Module 3

Irrigation Engineering Principles

Lesson
3
Estimating Irrigation Demand

Instructional objectives

On completion of this lesson, the student shall learn the following:

1. How much water is required for the proper growth of important crops
2. How to estimate the water demand of crops
3. What are the different seasons of crop growth
4. What are the usual cropping patterns
5. On what variables does the crop water requirement vary?

3.3.0 Introduction

A plot of land growing a certain crop or a combination of crops has to be supplied with water from time to time. Primarily, the plot or field is expected to receive water from rain falling on the land surface. But, as we know, the distribution of rain is rather uncertain both in time and space. Also some of the rain as in a light shower does not reach the ground as it may be intercepted by the leaves of the plant during a heavy downpour; much of the water might flow away as surface runoff. Hence, only a certain amount of falling rain may be effective in raising the soil moisture that is actually useful for plant growth. Hence, for proper crop growth, the effective rain has to be supplemented by artificially applying water to the field by irrigation.

If the area of the field is small, water may be supplied from the local ground water source. If the field is large, supplemented irrigation water may be obtained from a local surface water source, like a river, if one is available nearby. The work of a water resources engineer therefore would be to design a suitable source for irrigation after knowing the demand of water from field data. In this lesson, we proceed on to find out the methods by which estimation may be made for irrigation water demand.

3.3.1 Crop water requirement

It is essential to know the water requirement of a crop which is the total quantity of water required from its sowing time up to harvest. Naturally different crops may have different water requirements at different places of the same country, depending upon the climate, type of soil, method of cultivation, effective rain etc.

The total water required for crop growth is not uniformly distributed over its entire life span which is also called crop period. Actually, the watering stops same time before harvest and the time duration from the first irrigation during sowing up to the last before harvest is called base period. Though crop period is slightly more than the base period, they do not differ from practical purposes. Figure 1 indicates the relative usage of water for a typical crop during its entire growth period.

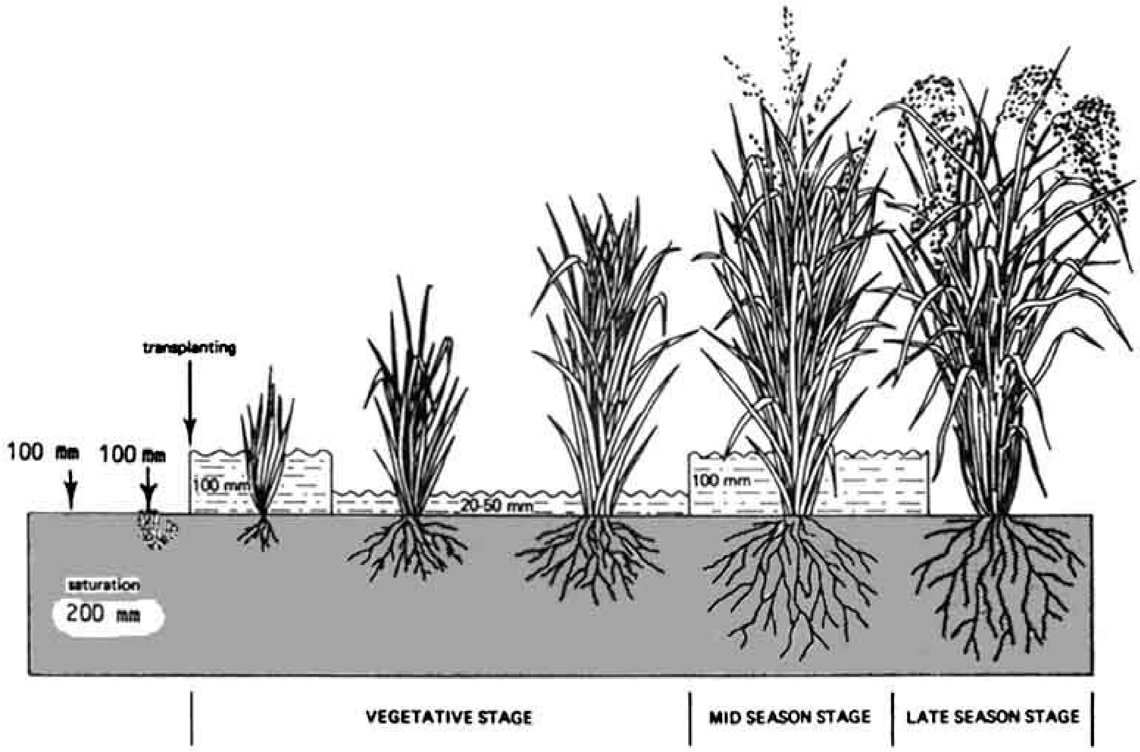

FIGURE 1. Variation in the requirement of water for paddy with stage of growth
(Image courtesy: Food and Agriculture Organisation, FAO)

Sometimes, in the initial stages before the crop is sown, the land is very dry. In such cases, the soil is moistened with water as t helps in sowing the crops. This is known as ***paleo*** irrigation. A term ***kor*** watering is used to describe the watering given to a crop when the plants are still young. It is usually the maximum single watering required, and other waterings are done at usual intervals.

The total depth of water required to raise a crop over a unit area of land is usually called ***delta***. Some typical values of delta for common crops in some regions of India are as follows:

Rice

- 1000mm to 1500mm for heavy soils or high water table
- 1500mm to 2000mm for medium soils
- 2000 to 2500 for light soils or deep water table
- 1600mm for upland conditions

Wheat

- 250mm to 400mm in northern India

- 500mm to 600mm in Central India
- Barley: 450mm

Maize

- 100mm during rainy season
- 500mm during winter season
- 900mm during summer season
- Cotton: 400 – 500mm

Sugarcane

- 1400mm to 1500mm in Bihar
- 1600mm to 1700mm in Andhra Pradesh
- 1700mm to 1800mm in Punjab
- 2200mm to 2400mm in Madhya Pradesh
- 2800mm to 3000mm in Maharashtra

This information has been gathered from the ***Handbook of Agriculture*** (fifth edition, 2000) published by the Indian Council of Agricultural Research.

3.3.2 Duty of water

The term ***duty*** means the area of land that can be irrigated with unit volume of irrigation water. Quantitatively, duty is defined as the area of land expressed in hectares that can be irrigated with unit discharge, that is, 1 cumec flowing throughout the base period, expressed in days.

Imagine a field growing a single crop having a base period B days and a Delta Δ mm which is being supplied by a source located at the head (uppermost point) of the field, as shown in Figures 2 and 3.

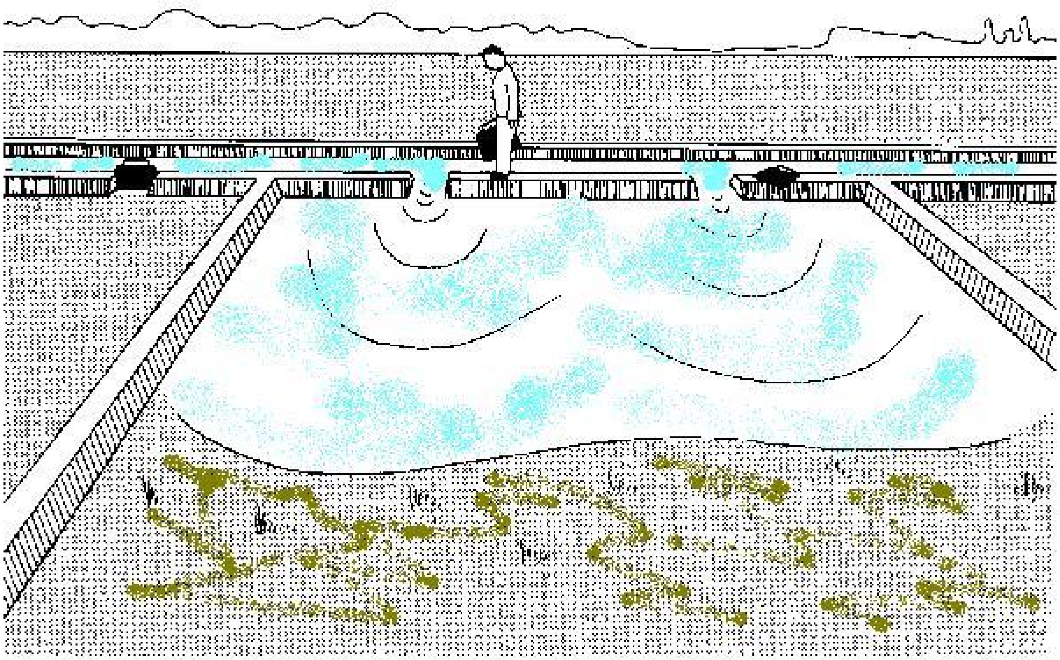

FIGURE 2. Border irrigation method of applying water at the head of a field
(Image courtesy: Food and Agriculture Organisation, FAO)

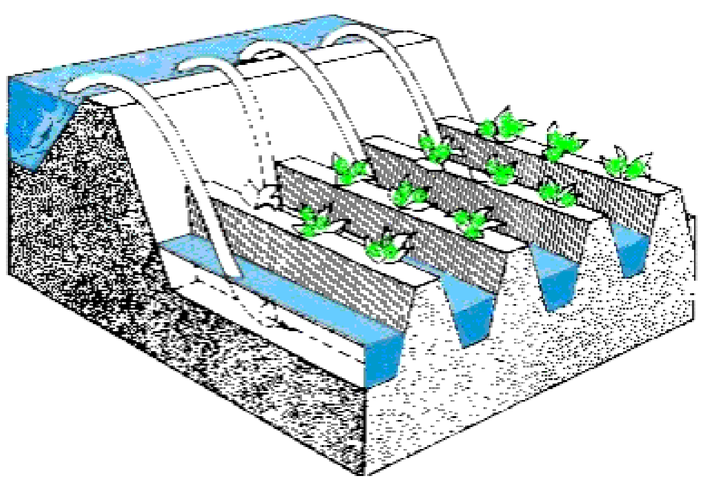

FIGURE 3. Furow irrigation method of applying water to a field

(Image courtesy: Food and Agriculture Organisation, FAO)

The water being supplied may be through the diversion of river water through a canal, or it could be using ground water by pumping (Figure 4).

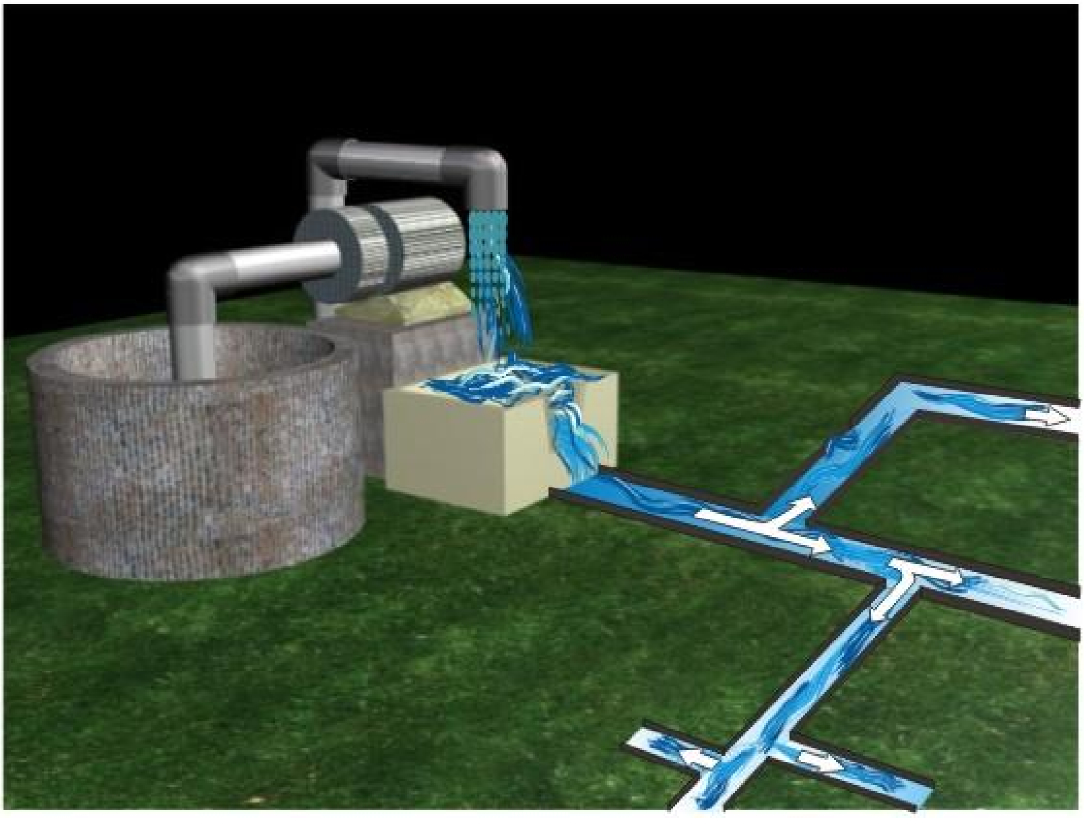

FIGURE 4. Water applied to field by pumping ground water

If the water supplied is just enough to raise the crop within D hectares of the field, then a relationship may be found out amongst all the variables as:

Volume of water supplied = B*60*60*24 m^3
Area of crop irrigated = D*10^4 m^2
Volume of water supplied per unit area = $\frac{86400}{10000D} = \frac{8.64B}{D}$

Hence, knowing two of the three variables B, D and Δ the third party may be found out.

The duty of irrigation water depends upon a number of factors; some of the important ones are as follows:

- **Type of crop:** As different crops require different amount of water for maturity, duties are also required. The duty would vary inversely as the water requirement of crop.

- **Climate season and type of soil:** Some water applied to the field is expected to be lost through evaporation and deep percolation.

Evaporation loss has a direct bearing on the prevalent climate and percolation may be during drier seasons when the water table is low and soil is also dry. Percolation loss would be more for sandy soils than silty or clayey soils.

- **Efficiency of cultivation methods:** If the tillage and methods of water application are faulty and less efficient, then the amount of water actually reaching the plant roots would be less. Hence, for proper crop growth more water would be required than an equivalent efficient system. Also, if the water is conveyed over long distances through field channels before being finally applied to the field, then also the duty will rise due to the losses taking place in the channels.

3.3.3 Crop growing seasons in India

Each crop has its own sowing and harvesting seasons and it is important to have a knowledge of this which may help to decide the total water demand in a field having mixed crops.

In India, the northern and north eastern regions have two distinct cropping seasons. The first coinciding mostly with the South western monsoon is called ***kharif*** , which spans mostly from July to October. The other, called ***rabi***, spans generally over October to March. The summer season crops are planted sometime between April and June. In southern part of India, there is no such distinct season, but each region has its own classification of seasons.

Generally, the kharif is characterized by a gradual fall in temperature, more numerous cloudy days, low intensity, high relative humidity and cyclonic weather. During Rabi, there is a gradual rise in temperature, bright sunshine, near absence of cloud days, and a lower relative humidity.

The following table indicates some the regional cropping calendars in India.

State	Season	Local name	Growing month
Andhra Pradesh	Kharif	Serva or Abi	July – December
	Rabi	Dalwa or Tabi	December – April
	Summer	In limited areas	March/April – June
Assam	Pre-monsoon	Ahu	Mar/April–June/july
	-	Sali	June/July-Nov/Dec
	-	Boro	Nov - May
Bihar	Summer	-	March – July/Aug
	Autumn	-	May/June–

			Sept/Oct
	Winter	-	June – Nov/Dec
Gujarat	Kharif	Chomasu Dangar	June/July-Oct/Nov
	-	Unala Dangar	Dec – June
Haryana	Kharif	-	May/June–Sept/Oct
Himachal Pradesh	Kharif	-	June/July-Sept/Oct
Jammu & Kashmir	-	-	Jammu: June-Nov Kashmir: Last week of April - October
Karnataka	Kharif	-	June – Dec
	Summer	-	Jan-May/June
Kerala	first crop	Virippu	April-May/Sept-Oct
	Second crop	Mundakan	Sept-Oct/Dec-Jan
	Third crop	Punja	Dec/Jan-Mar/April
Madhya Pradesh	Kharif	-	June/July-Dec
Maharashtra	Kharif	-	June/July-Dec
Manipur	Kharif	-	Mar/June-Sept/Oct
Meghalaya	Kharif	-	May/June-Aug/Sept
	Rabi	-	----------------
Nagaland	Kharif	-	May/June-Nov/Dec
	Rabi	-	Feb - May
Orissa	-	Sarad	June-Dec
	-	Dalua	Dec-April
	-	Beali (short Duration)	April/May –Sept (Only in uplands)
Punjab	Kharif	-	May – Nov
Rajasthan	Kharif	-	June/July-Sept/oct
Tamil Nadu	-	Navarai	Jan-April
	-	Sornavari	April – July
	-	Kar or Kuruvai	June – August
	-	Samba	June/July-Nov/Dec
	-	Thaladi or Pishanam	Sept/Oct-Feb/March
Uttar Pradesh	Kharif	-	June – Oct
West Bengal	Pre-Kharif	Aus	April-Sept
	Kharif	Aman	June-Dec
	Summer	Boro	End Nov-Mid June

3.3.4 Variations in the country's irrigation demands

It may be appreciated that in India there is a large variation of rainfall, which is the primary source of irrigation in most parts of the country. In fact, the crops grown in various regions have been adapted according to the local rainfall availability. Water resources engineers are therefore concerned with arranging supplementary water to support the crops for seasonal variations of rainfall in order to ensure an assured crop harvest.

Further, due to variation in the type of soil over different regions of the country, the types of crop grown also varies- thus dictating the water requirement at different regions during different times. Hence, the country has been broadly classified into eight agro climatic zones, a list of which is given.

3.3.5 Cropping patterns

Planning of an irrigation project requires estimation of water demand of a cultivated area. Naturally, this would depend upon the type of crop grown. Since irrigation water may have to be supplied to one field growing a combination of crops or to many fields growing different crops, it is important to understand certain cropping practices which would be helpful in estimating the irrigation demand. Some of the prevalent practices are as follows:

- Crops grown solely or mixed: Mixed cropping
- Crops grown in a definite sequence: Rotational cropping
- Land occupied by one crop during one season: Mono cropping
- Land occupied by two crops: double cropping
- Land sowed with more than one crop in a year: multiple cropping

3.3.6 Irrigation water need

For raising a field crop effectively, it is essential to supply water through artificial irrigation supplementing the rain falling over the plot of land and raising the soil moisture. Irrigation requirement for a typical crop and an assumed rainfall pattern may be illustrated as in Figure 5.

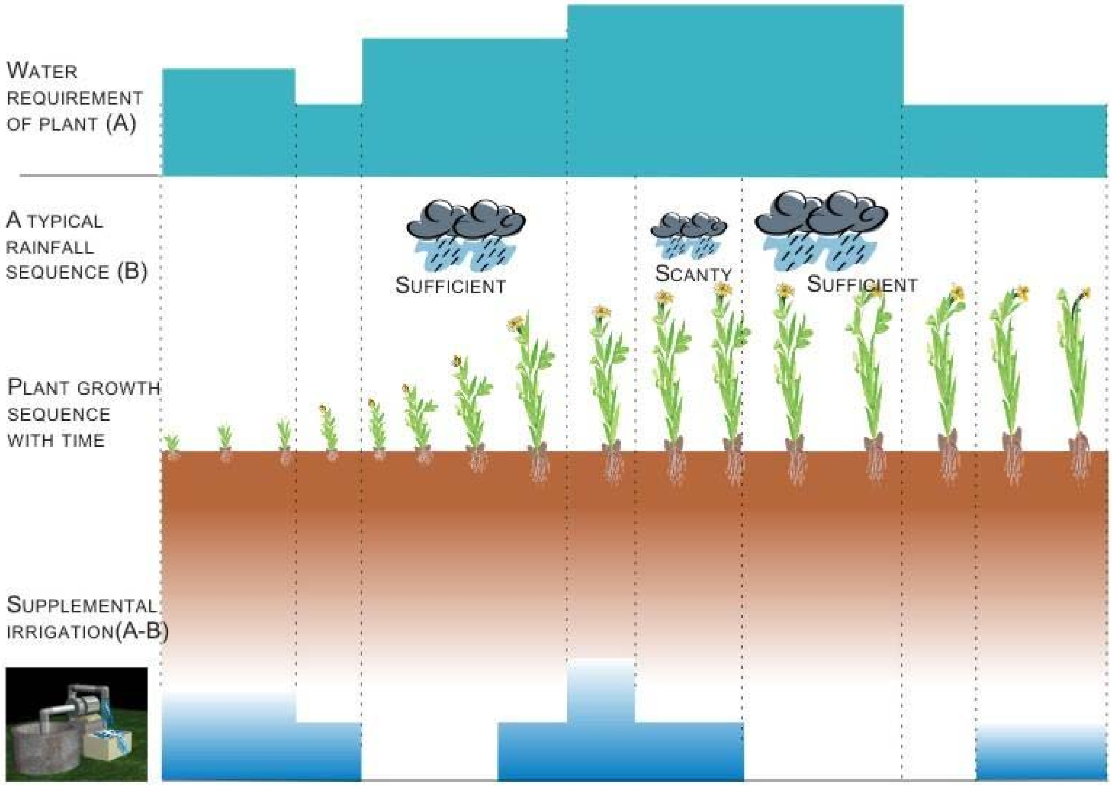

FIGURE 5 . Typical irrigation requirement of a crop and water provided naturally by rain or artificially by pumping

Hence, it may be seen that irrigation water requirement is rather a dynamic one. Also, the crop water requirement is shown with slight variation, it actually shows more variation, depending on the type of crop and the prevalent climate. Though farmers may be tempted to allow more water to the plants through supplemental irrigation, it must be remembered that there is an optimum water requirement schedule of each crop depending upon its stage of growth. It has been proved that at times application of more water may cause reduction in yield.

3.3.7 Variation of crop water requirement

The total water need for various plants, known as delta, has been discussed earlier. However, in planning the supply of irrigation water to a field crop, it is essential to estimate the water requirement of each plot of land growing a crop or crops at any point of time. This may be done by studying the dynamic interaction between a crop and the prevalent climate and the consequent water requirement. The demand would, naturally be also dependant on the type of crop and its stage of growth.

Plant roots extract water from the soil. Most of this water doesn’t remain in the plant, but escapes to the atmosphere as vapour through the plants leaves and stems, a process which is called ***transpiration*** and occurs mostly during daytime. The water on the soil surface as well as the water attaching to the leaves and stem of a plant during a rainfall also is lost to the atmosphere by evaporation. Hence, the water need of a crop consists of transpiration plus evaporation, together called ***evapotranspiration***.

The effect of the major climatic factors on crop water needs may be summarized as follows:

- Sunshine
- Temperature
- Humidity
- Wind speed

The variation of evapotranspiration upon these factors is illustrated in Figure 6.

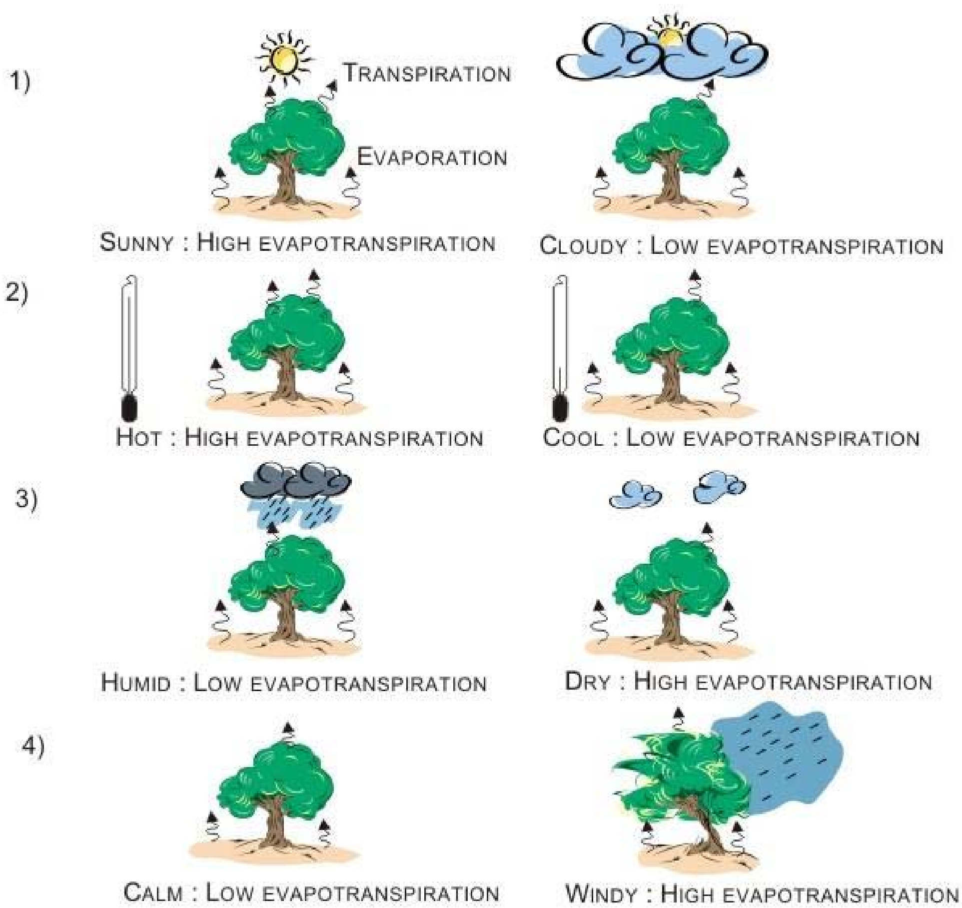

FIGURE 6. Dependence of evapotranspiration upon different climatological factors

Since the same crop grown in different climatic variations have different water needs, it has been accepted to evaluate the evapotranspiration rate for a standard or reference crop and find out that of all other crops in terms of this reference. Grass has been chosen as standard reference for this purpose. The evapotranspiration rate of this standard grass is, therefore, called the ***reference crop evapotranspiration*** and is denoted as ET_O, which is of course, the function of the climatic variables. Training Manual 3: Irrigation Water Needs published by the Food and Agricultural Organisation, (FAO) and available on-line through the under-mentioned web-site gives an idea about the variation of ET_O under different climatic conditions and is reproduced in the table below.

http://www.fao.org/ag/agL/public.stm#iwmtm

Table showing the daily variation of water needs of standard grass (in mm) under different climatic patterns (ET_O)

Climatic Zone	Mean daily Temperature		
	Low (<15^{0}C)	Medium (15^0-25^{0}C)	High (>25^{0}C)
Desert/Arid	4-6	7-8	9-10
Semi-arid	4-5	6-7	8-9
Sub-humid	3-4	5-6	7-8
humid	1-2	3-4	5-6

Other methods have been devised to calculate ET_O for given values of climatic parameters. These are discussed in the next section. In this section, we proceed on to discuss, how to find crop water need, if ET_O is known.

Agricultural scientists have evaluated a factor called ***crop factor*** and denoted it by K_C, to evaluate specific crop water needs. Naturally, Kc would be different for different crops and would not be the same throughout the growth season of one type of crop. Thus, the crop evapotranspiration, denoted by ET_C is to be evaluated as under:

$$ET_O = K_C * ET_C \qquad (1)$$

Both ET_O and ET_C should be in the same units and generally, mm/day is used as a standard all over the world.

In order to simply the calculations, the factor K_C has been evaluated for 4 stages of a crop growth usually denoted as

1. Initial stage
2. Crop development stage
3. Mid-season stage
4. Late season stage

The FAO Training Manual 3 gives the growth stage periods and the corresponding K_C values for some typical crops. In the table below, that for rice is presented.

Rice	Climate			
	Little wind		Strong wind	
Growth stage	Dry	Humid	Dry	Humid
0-60 days	1.1	1.1	1.1	1.1
Mid season	1.2	1.05	1.35	1.3
Last 30 days before harvest	1.0	1.0	1.0	1.0

It may be mentioned that any crop doesn't have a fixed total growth period, which is the summation of growth stage periods given above. There is usually a range, depending upon the variety of the crop and the condition in which it is cultivated.

The values of K_C also depend upon the climate and particularly on humidity and wind speed, as shown for rice in the above table. In general, the values of K_C should be reduced by 0.05 if the relative humidity is high (>80%) and the wind speed is low (<2m/s). Likewise, the values should be increased by 0.05 if the relative humidity is low (<50%) and the wind speed is high (>5m/s).

For full details, the FAO training manual 3 may be consulted as K_C values for other crops are evaluated in different manners. For some of the crops, the following table provides information:

Crop	Variety	Crop growth stage				Total growth period
Cabbage/Carrot	Short duration	20 days	25 days	60 days	15 days	120 days
	Long duration	25 days	30 days	65 days	20 days	140 days
	K_C	0.45	0.75	1.05	0.9	
Cotton/Fiax	Short duration	30 days	50 days	55 days	45 days	180
	Long duration	30 days	50 days	65 days	50 days	195
	Kc	0.45	0.75	1.15	0.75	
Lentil/Pulses	Short duration	20 days	30 days	60 days	40 days	150
	Long duration	25 days	35 days	70 days	40 days	170
	K_C	0.45	0.75	1.1	0.5	
	Short	20	25	25	10	80

Maize	duration					
	Long duration	20	30	50	10	110
	K_C	0.4	0.8	1.15	1.0	
Onion (dry)	Short duration	15	25	70	40	150
	Long duration	20	35	110	45	210
	K_C	0.5	0.75	1.05	0.85	
Potato	Short duration	25	30	30	20	105
	Long duration	30	35	50	30	145
	K_C	0.45	0.75	1.15	0.85	

3.3.8 Estimation of reference crop ET_O

Of the many methods available, the commonly used ones are two:

i. Experimental methods, using the experimentation data from evaporation pan.
ii. Theoretical methods using empirical formulae, that take into account, climatic parameters.

3.3.8.1 *Experimental method*

Estimation of ET_0 can be made using the formula

$$ET_O = Kpan \times Epan \quad (2)$$

Where ET_O is the ***reference crop evapotranspiration*** in mm/day, Kpan is a coefficient called ***pan coefficient*** and Epan is the ***evaporation*** in mm/day from the pan.

The factor Kpan varies with the position of the equipment (say, whether placed in a fallow area or a cropped area), humidity and wind speed. Generally, the details are supplied by the manufacturers of the pan. For the ***US Class A evaporation pan***, which is also used in India, Kpan varies between 0.35 and 0.85, with an average value of 0.7.

It may be noticed that finding out ET_C would involve the following expression

$$ET_C = Kcrop \times ET_O = Kc \times Epan \times Kpan \quad (3)$$

K_C has been discussed in the previous section. If instead, Kcrop x Kpan is taken as a single factor, say K, then ET_C may directly be found from Epan as under:

ET_C =K x Epan, where K may be called the crop factor (4)

The water management division of the Department of Agriculture, Government of India has published a list of factors for common crops and depending upon the stage of growth, which have to be multiplied with the evaporation values of the USWB Class A evaporation pan.

3.3.8.2 *Theoretical methods*

The important methods that have been proposed over the years take into account, various climatic parameters. Of these, only the following would be discussed, as they are the most commonly used.

3.3.8.2.1 Blanney-Criddle formula:

This formula gives an estimate of the mean monthly values of ET_O, which is stated as

$$ET_O = p\,(0.46\,T_{mean} + 8.13) \qquad (5)$$

Where p is the mean daily percentage of annual day time hours and has been estimated according to latitude; Tmean is the mean monthly temperature in degrees Centigrade and may be taken as ½ x (Tmax + Tmin) for a particular month. Thus using the Equation (1), one may evaluate ET_C for each month of the growing season, from which the total water need for the full growing season of the crop may be found out.

3.3.8.2.2 Penman-Monteith method:

This method suggests that the value of ET_O may be evaluated by the following formula:

$$ET_O = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (6)$$

Where the variables have the following meanings:

ET_o reference evapotranspiration [mm day^{-1}],
R_n net radiation at the crop surface [MJ m^{-2} day^{-1}],
G soil heat flux density [MJ m^{-2} day^{-1}],
T mean daily air temperature at 2 m height [°C],
u_2 wind speed at 2 m height [m s^{-1}],
e_s saturation vapour pressure [kPa],
e_a actual vapour pressure [kPa],
$e_s - e_a$ saturation vapour pressure deficit [kPa],
Δ slope vapour pressure curve [kPa $°C^{-1}$],
g psychrometric constant [kPa $°C^{-1}$].

3.3.9 Application interval of irrigation water

The water need of a crop is usually expressed as mm/day, mm/month or mm/season, where season means the crop growing period. Whatever be the water need, it need not be applied each day. A larger amount of water may be applied once in a few days and it gets stored in the crop root zone, from where the plant keeps on extracting water.

Soon after irrigation, when the soil is saturated, up to the field capacity, the extraction of water from the soil by the plants is at the peak. This rate of water withdrawal decreases as the soil moisture depletes (Figure 7).

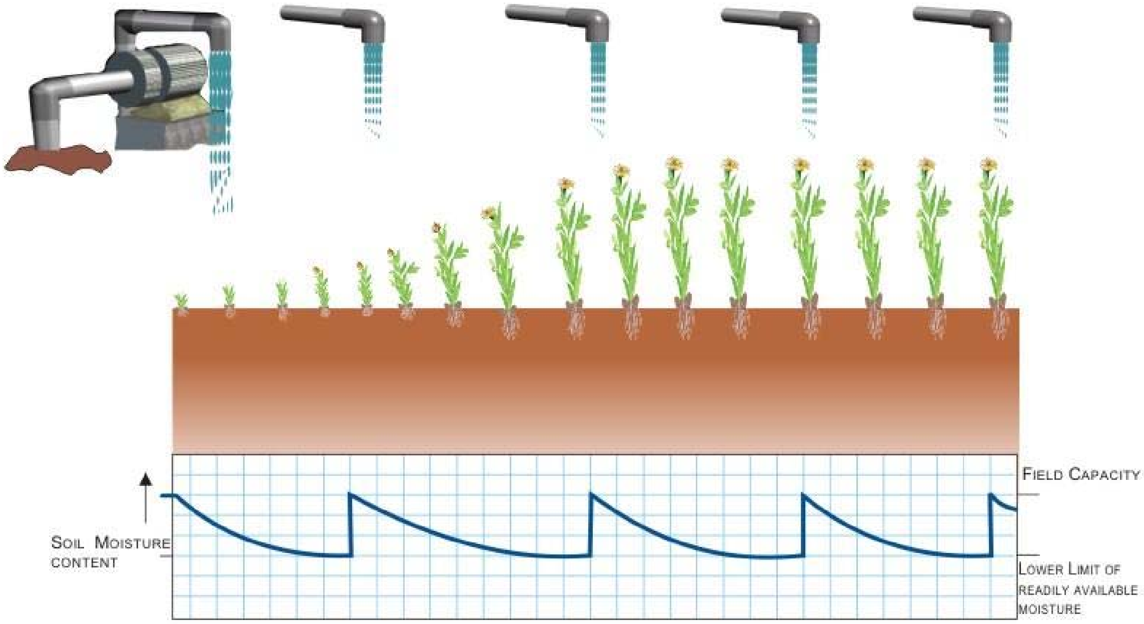

FIGURE 7. Rise and fall of soil moisture content due to irrigation and evapotranspiration

A stage is reached, in the moisture content of the soil, below which the plant is stressed to extract and unless the soil moisture is increased by application of water, the plant production would decrease. The difference of moisture content between field capacity (the maximum content of available water) and the lowest allowable moisture content is called the optimum soil water.

The optimum soil moisture range for some common crops is required from which the interval period of irrigation water may be estimated as follows:

$$\text{Irrigation period (days)} = \frac{\text{Net depth of soil depletion in the crop area just before irrigation (mm)}}{\text{ETc (mm/day)}} \qquad \ldots\ldots\ldots \quad (7)$$

Where the crop evapotranspiration rate (ET_C) may be determined according to the crop type, growth stage and prevailing climate as mentioned in the previous sections.

The irrigation period, as calculated above, has not taken the soil retention characteristics. Naturally, a soil with greater water retentive capacity serves as a bigger water reservoir for crops and supply of irrigation can be delayed. Consequently, frequency of irrigation is lower and interval of irrigation is longer in heavier soils and in soils with good organic content and low content of soluble salts.

Further, the calculation of ET_C as presented earlier and employed in the equation above to calculate irrigation period, what is called, the ***potential evapotranspiration*** (PET). This is the highest rate of water with drawl by an actively growing crop with abundant water supply. However as the soil moisture depletes, the ***actual evapotranspiration*** (AET) also decreases, as evident from the decrease in the gradient of the soil moisture curve with time in Figure 7. The AET would also be different from the PET if the climatic conditions like humidity temperature etc vary from the ones assumed when calculating PET. Nevertheless since PET is easier to estimate and since it would also be higher than AET, it is rational to consider PET, while designing the water requirement for a field of crop.

3.3.10 Total water requirement in growing a crop

The water that is required to irrigate a field or plot of land growing the particular crop not only has to satisfy the evapotranspiration needs for growing the crop, but would also include the following:

- Losses in the form of deep percolation while conveying water from the inlet of the field upto its last or tail end as the water gets distributed within the field

- Water requirement for special operations like land preparation, transplanting, leaching of salts, etc.

Further, the evapotranspiration requirement of crops (ET) really doesn't include the water required by crops for building up plant tissues, which is rather negligible compared to the evaporation needs. Hence ET_C is often equivalently taken as the ***consumptive irrigation requirement*** (CIR).

The ***net irrigation requirement*** (NIR) is defined as the amount of irrigation water required to be delivered in the field to meet the consumptive requirement of crop as well as other needs such as leaching, ***pre-sowing*** and ***nursery water requirement*** (if any). Thus,

$$NIR = CIR + LR + PSR + NWR \qquad (8)$$

Where

LR = Leaching requirement
PSR = Pre-sowing requirement
NWR = Nursery water requirement

Field Irrigation Requirement (FIR) is defined as the amount of water required to meet the net irrigation requirements plus the amount of water lost as surface runoff and through deep percolation. Considering a factor η_a called the water application efficiency or the field application efficiency which accounts for the loss of irrigation water during its application over the field, we have

$$\text{FIR} = \frac{\text{NIR}}{\eta_a} \tag{9}$$

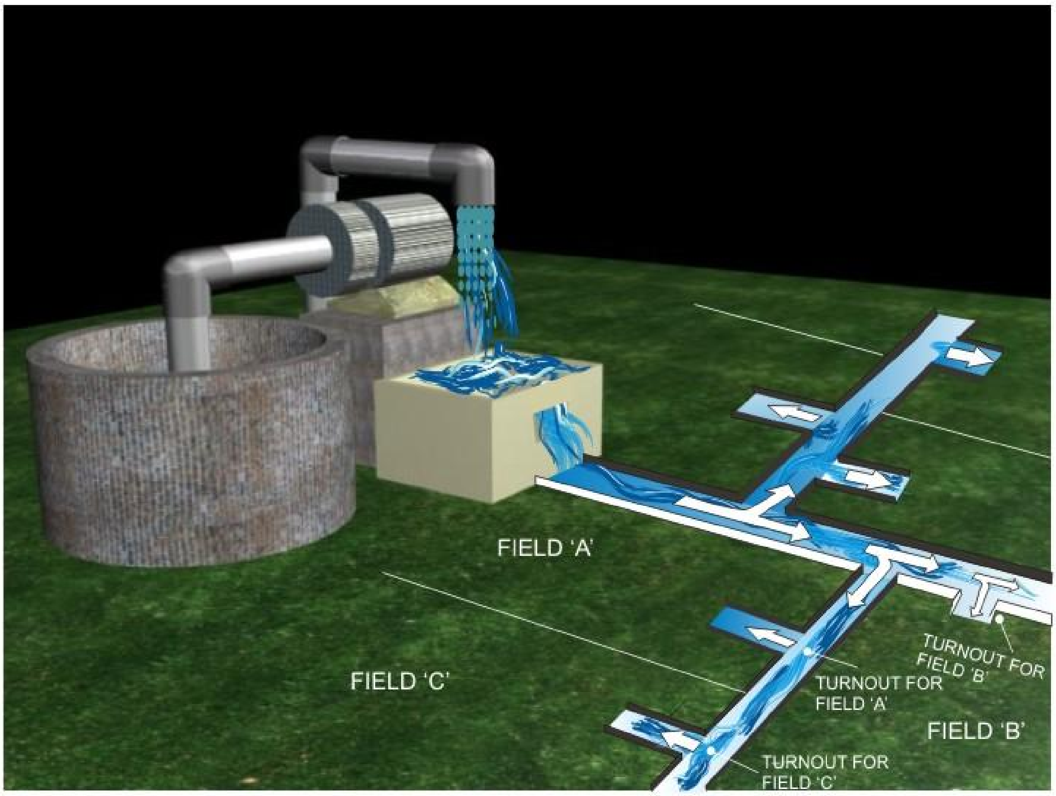

FIGURE 8. A typical ground water source irrigating a number of fields

Now, consider an irrigated area where there is a single source of water (say, a ground water pump) is supplying water to a number of fields and water is applied to each field by rotation (Figure 8). Naturally, some water is lost through the respective turnouts. Hence, the source must supply a larger amount of water than that required at any point of time by adding up the flows to the fields turnouts that are open at that point of time. Thus, the capacity of the water supply source may be termed as the ***gross irrigation requirement*** (GIR), defined as:

$$\text{GIR} = \frac{\text{FIR}}{\eta_C} \tag{10}$$

In the above equation, η_c is the ***water conveyance efficiency***.

Figure 9 shows the factors that decide the overall irrigation efficiency.

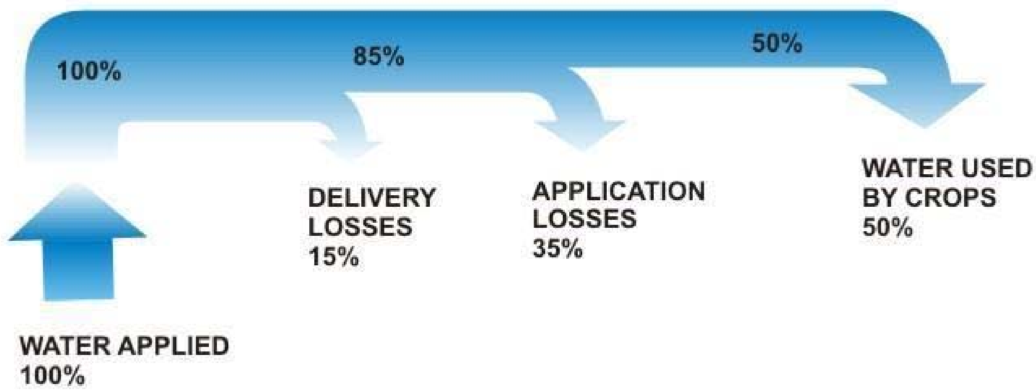

FIGURE 9. Typical values of losses in an irrigation system: factors affecting irrigation efficiency

3.3.11 Important terms related to crop water requirements and irrigation

Paleo irrigation

Sometimes, in the initial stages before the crop is sown, the land is very dry. This happens usually at the time of sowing Rabi crops because of hot September, when the soil may be too dry to be sown easily. In such a case, the soil is first moistured with water to help to sowing of seeds, and the water application for this purpose is known as Paleo Irrigation.

Kor watering

The total quality of water required by a crop is applied through a number of waterings at certain intervals throughout the base period of the crop. However, the quantity of water required to be applied during each of these waterings is not the same. In general, for all crops during the first watering after the plants have grown a few centimeters high, the quantity of water required is more than that during subsequent waterings. The first watering after the plants have grown a few centimeters high is known as Kor watering and the depth of water applied during watering is known as Kor depth. The watering must be done in a limited period which is known as the Kor period.

Outlet factor

The duty of water at the outlet that is at the turnout leading from the water courses and field channels on the field is known as the outlet factor.

Overlap allowance

It might happen that the crop of one season may sometimes overlap the next crop season for some period. During such a period of overlapping, irrigation water is required to be supplied simultaneously to the crops of both the seasons. Thus there is extra demand of water during this period and thus the water supply must be increased by some amount. The extra discharge that has to be supplied for this purpose is known as Overlap allowance.

The Evaporation Pan

A shallow edged container used to hold water during observations for the determination of the quantity of evaporation at a given location. The U.S. Weather Bureau Class A pan is 4 feet in diameter, 10 inches deep, set up on a timber grillage so that the top rim is about 16 inches from the ground. The water level in the pan during the course of observation is maintained between 2 and 3 inches below the rim.