Existing Practice of Assessment of Irrigation Water Demand for Water Resources Projects

V. K. Chawla
Chief Engineer (POMIO), Central Water Commission, New Delhi
Chawlavk54@yahoo.co.in
B. C. Vishwakarma
Director (IP-S), Central Water Commission, New Delhi
P. K. Thakur
Dy. Director (IP-S), Central Water Commission, New Delhi

KEYWORDS

Irrigation water demand, Evapo-transpiration, Consumptive Use, Potential Evapo-transpiration (PET), Crop Coefficients (Kc)

ABSTRACT

Most of the water resources projects in the country are either planned for irrigation purpose only or irrigation is the major benefit from these projects. Matter of fact is, more than 80% of the developed water resources are used in irrigation sector. Computation of the water requirement of crops is the first step in planning of such projects which ultimately forms the basis for deciding storage requirements, type of structures required, canal networks etc. With availability of water for irrigation sector on decline due to increased demand from other sectors, optimum scenario would be to work out actual field requirements for particular crop in a similar climatic region by measuring water use using Lysimeter. It is however, not always viable, particularly in Indian scenario. The process is very costly, time consuming and not possible to be followed everywhere due to constraints of time, money and manpower. Crop water demands are normally assessed as function of crop type and climatological factors. Many methods have been developed for assessment of the crop water requirement for various crops. Some of the methods like Blaney - Criddle method relied only on temperature and sunshine hours and was considered too simplistic in approach. Christiansen method correlates the Pan Evaporation values with the evapo-transpiration and consumptive use of crops. Later on, a correlation between consumptive use of a standard crop (short green grass) and various climatological factors affecting the evapo-transpiration was attempted and Modified Penman equation and Monteith Penman equation were developed.

The methods and present practices being followed in estimation of the water requirements for the water resources projects are proposed to be discussed in the paper. Suitability of applying various methods and constraints etc. are also discussed in the paper.

1.0 INTRODUCTION

Water resources development projects serve many purposes and some of the main benefits from these projects are irrigation; hydropower generation; domestic & industrial water supply; flood mitigation etc. Irrigation is one of the important functions directly linked to food security of the country. Though irrigation sector uses more than 80% of the developed water resources, the scope of reducing it is limited as it may hamper the efforts being made by the country to enhance food grain production and achieve food security. Judicious assessment of irrigation water demand, therefore, assumes significance. Correct assessment of evapotranspiration is thus fundamental in deciding the water requirements of irrigation project. Various methods for proper assessment of irrigation water demand for crops have been developed last century to facilitate the planning of irrigation projects.

2.0 CROP WATER DEMAND

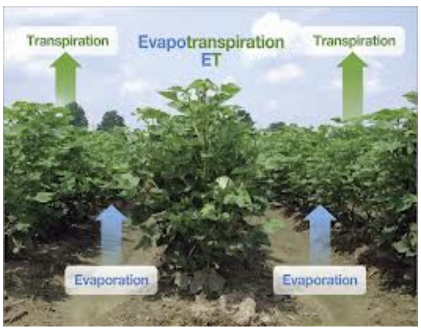
In plant metabolism, soluble nutrition & salts are transported by water from roots to body of plant and upto leaves where the photosynthesis takes place. The water is lost by evaporation from stomata in plant leaves and the process is called transpiration, an element of water consumption required for growth of plants and vegetation. The water requirement of crop / vegetation is sum of transpiration and inevitable evaporation losses from soils in vicinity, collectively called crop evapotranspiration. In true sense, water used by plant in building up plant tissues also contributes to consumptive use. However, it is insignificant as compared to evapotranspiration component. Therefore the consumptive use is practically considered same as crop evapotranspiration. Consumptive use is usually expressed in term of depth of water and reflects quantum of water required by plant to meet its evapo-transpiration needs for its full growth. The aim of planners is to provide optimum quantity of water to the crops in the command so that plants achieve full growth and benefits are maximised.

2.1 Potential Evapotranspiration

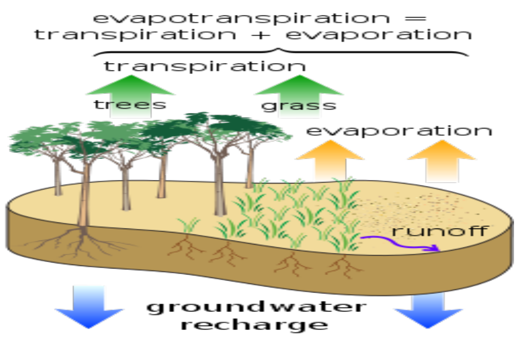
Potential Evapotranspiration (PET) is maximum water demand of a crop in given climatic conditions and it depends upon type of crop and climatological factors i.e. mean temperature, relative humidity, wind velocity, sunshine hours etc. Actual Evapotranspiration (AET) depends on water supplies and will be less than PET if water supplied is less. Actual evapotranspiration is said to equal potential evapotranspiration when there is ample water.

2.2 Reference Evapotranspiration

The term Reference Evapotranspiration denotes the water demand for standard crop in given climatological conditions. FAO defines the Reference Evapotranspiration, denoted by ETo, as evapotranspiration from a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m-1 and an albedo of 0.23. The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground. The fixed surface resistance of 70 s m^{-1} implies a moderately dry soil surface resulting from about a weekly irrigation frequency. The consumptive use of a crop at various stages is expressed in terms of crop coefficient (Kc), which is ratio of water demand of that crop at that stage to Reference Evapotranspiration (ETo).



Evapotranspiration in field



Evapotranspiration from a land mass

3.0 IRRIGATION WATER DEMAND

3.1 Net Irrigation Requirement

Apart from the water demand of plants for growth, some other demands arise depending upon soil conditions, water application method etc. Besides, in case of paddy the field is normally kept submerged with standing water in the field which leads to continuous percolation. Such water demands as well as transplantation & Nursery water requirements have also to be accounted for while computing water demands of farm.

The field also receive water from rainfall in the command and sometimes groundwater table also rises above root zone. A part of this water is stored in root zone and is available for use by plants. Contribution from such natural processes like precipitation, groundwater flow (generally ignored) etc. is estimated. Net Irrigation Requirement (NIR) for field is the difference of total water demand and that met by such sources in the corresponding period.

3.2 Field Irrigation Requirement

Field Irrigation Requirement (FIR) is net irrigation requirement plus losses in water application. The losses in water application depend on type of soils, extent of lining in field channels and water courses, grade of the field, method of irrigation etc.

3.3 Gross Irrigation Requirement

Gross Irrigation Requirement (GIR) is summation of field irrigation requirement and losses in the conveyance system due to evaporation and seepage, primarily depending on type and extent of lining.

4.0 ASSESSMENT OF IRRIGATION WATER DEMAND

4.1 Actual measurement

Amount of actual evapo-transpiration which is released by plants can be measured by lysimeter. The soil moisture in the land mass is measured by electronic meter (potentiometer) and evapotranspiration is measured by water balance equation. However, installation and operation of Lysimeters is very costly, time consuming and not possible to be followed everywhere due to constraints of time, money and manpower. Therefore efforts were made to assess the crop water demands as function of crop type and climatological factors. This method is used by research institutions for computing water demands for new variety of crops, correlating the water demands through other methods with actual water demands etc.

4.2 Empirical Formulae

- **Blaney Criddle formula**

The Blaney–Criddle equation is a relatively simple method for computing evapo-transpiration and is dependant only on temperature.

$u = k.\ p.t\ /\ 100\ = kf$

Where u = monthly consumptive use (inches), k = crop factor, t = mean monthly temperature in degree Fahrenheit (°F).

- **Christiansen Formula**

Evaporation from water surface is affected by several climate elements: temperature, humidity, solar radiation, and wind. The Class A Evaporation Pan is considered a standard measure of evaporation. A Class A Evaporation Pan is cylindrical with a diameter of 1.2065 metres and a depth of 254 mm. The pan should rest on a carefully levelled, wooden base. Evaporation is measured daily as the depth of water evaporates from the pan. Christiansen (1966) provided empirical formula to estimate evaporation from climatic data where reliable measurement of pan evaporation is not available.

$Ep = 0.459.\ R.\ Ct.\ Cw.\ Ch.\ Cs.\ Ce$

Ep = computed pan evaporation equivalent to class A pan evaporation,

R = is extra Terrestrial radiation in save evaporation unit as EP

Ct, Cw, Ch, Cs, Ce = coefficients for temperature, wind velocity, relative humidity, percentage of possible sunshine and elevation.

Evapo-transpiration for various crops is crop coefficient multiplied with Class A pan evaporation.

- **Thornthwaite method**

Thornthwaite's method calculates potential evapotranspiration using observed air temperature and duration of sunlight data. The rationale is that air temperature, to a considerable extent, serves as a parameter of the net radiation. This is a shortcut of replacing a comprehensive atmospheric model, as well as some interactions by prescribing observed temperature and precipitation (Huang et al., 1996). This method for estimating PET requires only two variables; mean monthly temperature values, and the average monthly number of daylight hours.

- **Modified Penman Method**

Doorenbos and Pruitt (1977) proposed a modified Penman's method for estimating reference crop evapo-transpiration (ETo). The prediction equation and its terms are defined below:

ETo = c[W.Rn + (1-W). f(u).(ea –ed)]

Radiation term Aerodynamic term

Where ETo	=	reference crop evapo-transpiration (mm/day)
c	=	adjustment factor to compensate for the effect of day and night whether conditions
W	=	temperature and elevation related weighing factor for the effect of radiation on ETo (W is obtained from Table 21 with the altitude of the place and the mean temperature known)
Rn	=	net radiation mm/day
Rns	=	the net incoming shortwave solar radiation
	=	Ra (1-α) (0.25 +0.50 n /N)
(1-W)	=	temperature and elevation related weighing factor for the effect of wind and humidity on ETo
ea	=	mean saturation vapour pressure in milli bar (m bar) at mean air temperature
ed	=	mean actual vapour pressure in milli bar (m bar) at mean air temperature
f(u)	=	wind related function.

Detailed procedure and tables are given in Technical Series-2, "A Guide for Estimating Irrigation Water Requirements" a publication of Water Management Division of erstwhile Ministry of Irrigation, Govt. of India.

- **FAO Penman-Monteith equation**

The FAO Penman-Monteith method is recommended as the sole ETo method for determining reference evapotranspiration by Food and Agriculture Organisation (FAO). The method overcomes shortcomings of the previous FAO Penman method and provides values more consistent with actual crop water use data worldwide.

FAO Penman-Monteith method

:

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

where

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],
D	slope vapour pressure curve [kPa °C^{-1}],
g	psychrometric constant [kPa °C^{-1}].

The reference evapotranspiration, ETo, provides a standard to which:

- evapotranspiration at different periods of the year or in other regions can be compared
- evapotranspiration of other crops can be related.

4.3 Merits and Demerits of various methods

Given the limited data input to the equation for computing evapo-transpiration, Blaney-Criddle method and Thornthwaite method can be regarded as only broadly accurate rather than a precise measure of evapo-transpiration. The inaccuracy of the equation is exacerbated by extreme variants of weather. Pan Evaporaton method was used earlier before adoption of Modified Penman method and is useful where either the Class A evaporation data is available or accurate climatic data is available.

Modified Penman method is useful where accurate climatic data is available. However the database is limited and availability of accurate data is necessary. Also it may be more useful to develop local crop coefficients for region instead of the adopting those developed by FAO. Due to development of various types of crop varieties, the choice of the crop growth period and crop coefficients becomes crucial in accurate assessment of the crop water demands.

The modified Penman method is considered to offer the best results with minimum possible error in relation to a living grass reference crop. However, as per FAO, it overestimates ETo, especially for low evaporative conditions. The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climates has been indicated in both the ASCE and European studies. The FAO recommends Penman-Monteith method as the standard method with strong likelihood of correctly predicting ETo in a wide range of locations and climates and has provision for application in data-short situations.

5.0 EXISTING PRACTICE OF ASSESSMENT OF IRRIGATION WATER DEMAND

Water Management Division of erstwhile Ministry of Irrigation, Govt. of India published Technical Series-2, "A Guide for Estimating Irrigation Water Requirements" in May 1984 incorporating method and parameters for estimating the water requirements for various crops. The methodology given in the above publication is followed for project planning with due consideration to all factors i.e. crop evapotranspiration, crop coefficient (Kc), effective rainfall, percolation losses, type and stage of crop etc. and method of water application, type of conveyance system etc. for adoption of irrigation efficiency.

The methodology in brief is given as under:

- **Reference Evapotranspiration (Eto)**

The estimation of Eto (mm/day) is made by Modified Penman method as given in Technical series No. 2. This involves collection of detailed climatological data as discussed above which at times is difficult to get. The values of Et_0 can be obtained directly from the IMD publication which gives Et_0 values of different stations, by selecting value of the station near to the project location.

- **Crop co- efficient (Kc)**

The Kc value relate to evapotranspiration of disease free crop grown in large field under optimum soil, water and fertility conditions and achieving full production potential under the growing environment. The selection criteria for appropriate Kc values takes into account the crop characteristics, time of planting or sowing, stages of crop development and general climatic condition. The Kc values should be adopted from the research station of ICAR/Agricultural Universities in the locality. However, in the absence of such data, Kc may be judiciously taken from the Table 27 of Technical series No. 2. (adopted from FAO's Publication 33) for different crop development stages.

- **Effective Rainfall**

The effective rainfall is that component of rainfall which meets part requirement of consumptive use of crops. The relationship between effective rainfall and the variable factors like total rainfall, consumptive use, net irrigation application is illustrated in Table 10 of Tech. Series No. 2. This table shows the relationship between normal monthly effective rainfall (Re), normal monthly rainfall (Rt) and average monthly consumptive use. The values of (Re) are based on a 75 mm net irrigation application. Factors to be adopted for estimating Re for other net depth of application are to be obtained from the table provided in Technical Series- 2.

- **Percolation Losses**

For crops such as paddy, a constant ponded level of water is required throughout the crop period. This will result in some portion of water percolating deep down and joining the ground water, Therefore, the deep percolation losses should be considered for the entire crop period based on observation in the command area. The rate of percolation loss will depend upon the type of soil in the command area. The percolation loss varies from 2 mm/day in case of clay soil to 6 mm/day in case of sandy soils.

5.1 Net Irrigation Requirement

The Net Irrigation Requirements (NIR) of the various crops considered in the cropping pattern is estimated by using the above mentioned method. The relation to compute the NIR for a crop is as under:

NIR (mm) = Et_{crop} (crop evapotranspiration) + Percolation Losses - R_e (effective rainfall)

Provision for nursery as indicated in sample calculation is also kept.

5.2 Irrigation Efficiencies

Irrigation efficiency can be defined as the ratio of volume of water required for consumptive use by the crop for its growth to the volume of water delivered from the source.

All the water released at canal head does not reach root zone of the plant for consumptive use of the plant. Part of the water released is evaporated or joins groundwater through seepage / percolation in conveyance, distribution and application in the field. Irrigation efficiency accounts for such losses of surface water. Various irrigation efficiencies to be considered depend upon where the losses are taking place and generally comprise of conveyance efficiency, distribution efficiency and field application efficiency.

For planning purposes, following **field application efficiency** for ponded and non-ponded crop may be adopted:

i) Ponded 80 to 85%
ii) Other non-ponded crops 65%

Further, taking into account the type of distribution system, i.e. lined/partially lined or unlined, the following values of **conveyance efficiency** may be adopted to work out, gross irrigation requirements of the project.

i) For fully lined system 70 to 75%
ii) For partially lined system 65 to 70%
iii) For unlined canal system 55 to 60%

5.3 Field Irrigation and Gross Irrigation Requirement

Field Irrigation Requirement (FIR) at the canal outlet and Gross Irrigation Requirement (GIR) at the Head works of the project are to be computed considering field application efficiency and conveyance efficiency of the canal distribution system of the project as above.

5.4 Sample Computation

A sample crop water computation table for crop of Paddy (Kharif Season) and Wheat (Rabi season) are given below.

Crop Water Requirement

Crop **Paddy** **(Kharif)**
Area 10000 Ha

Crop Stages
Ini- Initial Stage
Dev- Development Stage
Mid-Mid Season
Late - Late Season
Harv- Harvest Season

No of days	Period / Ten-Daily	Stage	Ref. Evapo-transpiration Eto (mm /day)	Crop Coefficient (Kc)	ET crop (mm/day)	Total ET crop (mm)	Pre-sowing & transplantation	Percolation	Effective Rainfall Re	**Net Irrigation Requirements NIR (mm)**	**FIR (mm) = NIR / 0.85**	**GIR (mm) = FIR / 0.75**	**GIR (ham)**
10	Jun (11-20)	Nursury (Demand in 10% area only					25		14.5	10.50	12.35	16.47	164.7
10	Jun (21-30)	Nursury (Demand in 10% area only)					25		14.5	10.50	12.35	16.47	164.7

10	Jul (1-10)	Tran	4.26	1	4.26	42.6	75	30	72.7	74.90	88.12	117.49	1174.9
10	Jul (11-20)	Tran	4.26	1	4.26	42.6	75	30	72.7	74.90	88.12	117.49	1174.9
11	Jul(21-31)	Dev	4.26	1.05	4.47	49.2		33	72.7	9.50	11.18	14.91	149.1
10	Aug (1-10)	Dev	3.96	1.05	4.16	41.6		30	55.8	15.78	18.56	24.75	247.5
10	Aug (11-20)	Dev	3.96	1.10	4.36	43.6		30	55.8	17.76	20.89	27.85	278.5
11	Aug (21-31)	Dev	3.96	1.15	4.55	50.1		33	55.8	27.29	32.11	42.81	428.1
10	Sep (1-10)	Mid	4.15	1.20	4.98	49.8		30	40	39.80	46.82	62.43	624.3
10	Sep (11-20)	Mid	4.15	1.20	4.98	49.8		30	40	39.80	46.82	62.43	624.3
10	Sep (21-30)	Mid	4.15	1.15	4.77	47.7		30	40	37.73	44.39	59.19	591.9
10	Oct (1-10)	Late	3.80	1.05	3.99	39.9		30	10	59.90	70.47	93.96	939.6
10	Oct (11-20)	Harv	3.80	1.05	3.99	39.9			10	29.90	35.18	46.91	469.1
	Total Water Requirement											**527.36**	**703.16**

Crop Water Requirement

Crop **Wheat** **(early)**

Area 2700 Ha

Crop Stages

Ini- Initial Stage

Dev- Development Stage

Mid-Mid Season

Late - Late Season

Har- Harvest Season

No of days	Period / Ten- Daily	Stage	Ref . Evapo-transpiration Eto (mm /day)	Crop Cofficient (Kc)	ET crop (mm/day)	Total ET crop (mm)	Pres-owing & transplantation	Effective Rainfall Re	Net Irrigation Requirements NIR (mm) Etc+P - Re	FIR (mm) = NIR / 0.85	GIR (mm) = FIR / 0.75	GIR (ham)
11	Oct(21-31)	Ini	3.66	0.45	1.65	18.12	50	9.1	59.0	90.8	139.6	377.1
10	Nov (1-10)	Ini	2.33	0.55	1.28	12.82		0.2	12.6	19.4	29.8	80.4
10	Nov (11-20)	Ini	2.33	0.65	1.52	15.15		0.2	14.9	22.9	35.3	95.3
10	Nov (21-30)	Ini	2.33	0.75	1.75	17.48		0.2	17.2	26.5	40.8	110.2
10	Dec (1-10)	Dev	1.55	0.75	1.16	11.64		1.1	10.6	16.3	25.0	67.6
10	Dec(11-20)	Dev	1.55	0.95	1.47	14.74		1.1	13.7	21	32.3	87.3
11	Dec (21-31)	Dev	1.55	1.05	1.63	17.93		1.1	16.9	25.9	39.9	107.7
10	Jan (1-10)	Dev	1.91	1.05	2.01	20.06		3.4	16.7	25.6	39.4	106.5
10	Jan (11-20)	Mid	1.91	1.10	2.10	21.01		3.4	17.6	27.1	41.7	112.5
11	Jan (21-31)	Mid	1.91	1.05	2.01	22.07		3.4	18.7	28.7	44.2	119.3
10	Feb (1-10)	Late	2.78	0.85	2.36	23.62		2.3	21.3	32.8	50.5	136.3
10	Feb (11-20)	Late	2.78	0.55	1.53	15.28		2.3	13.0	20	30.8	83
8	Feb (21-28)	Late	2.78	0.45	1.25	10.01		2.3	7.7	11.9	18.3	49.4
10	Mar(1-10)	Har	4.31	0.35	1.51	15.09		0.9	14.2	21.9	33.7	90.9
	Total Water Requirement										**601**	**1623**

6.0 DISCUSSION

The crop coefficient for various crops has been developed by the FAO. However only a single value has been provided which may not truly reflect the value to be adopted for computing the water demands for crops for particular regions or country especially for countries like India. With continued research in the crop varieties and the agriculture technology, various high yield varieties and agriculture techniques have emerged. The crop coefficients for such crop are different than for normal crops. The reference evapo-transpiration for various agro-climatic zones of the country for long term climatic normals like temperature, sunshine hours, humidity, wind velocity etc. are not available.

Various better agricultural practices / technologies like SRI, mulching, dry farming, laser levelling etc. increase the water use efficiency. The effect of these developments needs to be standardised for incorporation of same at planning level.

Aqua Crop is a crop water productivity model developed by the Land and Water Division of FAO. It is a new version of CROPWAT and designed to simulate biomass and yield responses of field crops to various degrees of water availability. This is stated to be a tool for predicting crop production under different water management conditions (including rain-fed and supplementary, deficit and full irrigation) under present and future climate change conditions. This model helps in evaluating the effects of water deficits on crop yield or productivity. The model predicts crop productivity, water requirement and water use efficiency under water limiting conditions. The model can be accustomed with Indian climatic conditions.

Updating of Technical Series – 2 is being contemplated. While updating, latest developed formulae / software are suggested to be reviewed for incorporation.

REFERENCES

1. Technical Series Number 2 (revised) : A Guide for Estimating Irrigation Water Requirements, erstwhile Ministry of Irrigation, Govt. of India, May 1984.
2. Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56.