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A GUIDE
for
ESTIMATING IRRIGATION WATER REQUIREMENTS

GOVERNMENT OF INDIA
MINISTRY OF IRRIGATION
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FOREWORD

With about 30 percent of our cultivated area under irrigation and with very definite limits to the additional areas which can be brought under irrigation, it is clear that the most critical input for Indian agriculture today is water. It is accordingly a matter of the highest importance that all available supplies of water should be used to the best possible advantage. Recent experiments and demonstrations have shown that the productivity of a given quantity of water can be increased upto 200 percent in certain situations if the fields are properly levelled, the water requirements of the crops as well as the irrigability characteristics of the soil are known and the best possible cropping pattern and correct methods of irrigation are followed. Very significant gains can also be made if cropping patterns are changed so as to minimise storage during the hot summer months when evaporation losses are the highest, if losses by seepage during conveyance are reduced and if water is applied at the critical times when it is most useful for plant growth.

Water management thus involves a knowledge of plant-soil-water relationships under any given climatic conditions as well as of the various engineering aspects of irrigation from the storage down to the field, and calls for inter-disciplinary studies by specialists in irrigation engineering and practices, agronomy and soil science. To illustrate, unregulated irrigation of paddy has been found to be not only wasteful of water to the extent of as much as two-thirds of the quantity applied but also results in unfavourable environment for plant growth due to drainage congestion and development of saline-alkali conditions when drainage is inadequate. Again, in the case of Mexican wheat, it has been found that four irrigations given at critical points of time are almost as productive as six or more irrigations given at regular intervals. In certain situations, when soils are sandy, the lining of field channels or the use of the sprinkler system can mean a saving upto 30 percent of the water used. The lining of canals and distributaries is also called for when seepage losses are unduly heavy and water is scarce. The use of even limited quantities of groundwater to grow paddy nurseries in the command of Nagarjunasagar Project has permitted the utilisation of surface water for an earlier rabi crop and enabled two crops to be grown instead of one.

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CONVERSION FACTORS

Length

1 foot	=30.48 cm
1 foot	= 0.305 m
1 inch	= 2.54 cm
1 yard	=91.44 cm
1 statute mile	= 1.61 km
1 US naut. mile	= 1.85 km
1 Int. naut. mile	= 1.85 km

Area

1 in^2	= 6.45 cm^2
1 ft^2	=929.03 cm^2
1 yd^2	= 0.835 m^2
1 acre	= 0.405 ha
1 sq. stat. mile	= 2.59 km^2

Volume

1 in^3	= 16.39 cm^3
1 ft^3	=28316.8 cm^3
1 ft^3	= 28.32 litre (l)
1 gallon (US)	= 3.79 l
1 gallon (Imp.)	= 4.55 l
1 acre foot	=1233.5 m^3

Temperature

°F	=1.8°C+32
°C	=(°F−32)5/9

Velocity

1 knot	= 0.515 m/sec
	= 1.85 km/hr
1 foot/sec	= 0.305 m/sec
	= 1.095 km/hr
1 foot/min	= 0.51 cm/sec
	= 0.18 km/hr
1 mile/min	= 2682 cm/sec
	= 1.61 km/min
1 m/sec (24 hr)	=86.4 km/day
1 foot/sec (24 hr)	=26.33 km/day
1 mile/hour(24 hr)	=38.6 km/day
1 knot (24 hr)	=44.5 km/day

Pressure

1 atmosphere	= 76 cm Hg
1 atm	= 1.013 bar
1 inch Hg	= 0.0334 atm
1 inch H_2O	= 2.49 mbar
1 mbar	= 0.75 mm Hg
1 lb/in^2	=51.72 mm Hg

Radiation to Equivalent of Evaporation

1 cal/cm^2	=1/59 mm
1 cal/cm^2 min	=1 mm/hr
1 mW/cm^2	=1/70 mm/hr
1 mW/cm^2 (24 hr)	= 0.344 mm/day
1 cal/cm^2 min (24 hr)	=24 mm/day
1 Joule/cm^2 min (24 hr)	=5.73 mm/day

CHAPTER I

Introduction

Crop Water requirements are defined as under :

> "The depth of water needed to meet the water loss through evapotranspiration (ET Crop) of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment".

The work on water requirements of crops was started as early as 1850 at Rothamsted. But the term was actually defined by Hellregal, who conducted investigations in pots to determine the water requirements of the crops in 1883.

Simultaneously in the first decade of the century very systematic investigations were undertaken in the Great Plains area in the United States of America and the Indo-Gangetic Plains of India. The water requirement studies in the later years had been more extensively conducted in regions where water was a limiting factor in crop production ; it was then considered that there existed a relationship between the ability of a plant to withstand drought and its water requirements. Investigations in the Great Plains area, in the year 1910 and 1911, proved that drought resistance and water requirements were two distinct features of the crop plants.

1.11 Initial investigations on water requirements of crops were conducted in pots. It was soon realised that the information thus made available, was not in toto applicable to field conditions, as the water requirements, worked out in pots had a limited applicability. Besides the effect of pot-bound root system, water distribution, excessive evaporation and transpiration in pot studies, usually conducted in the green house, produced results far from comparable to the field crops grown under natural environments. Therefore, the investigations soon began to relay more on and gave importance to experiments conducted in the field, with a view to arriving at a more scientific basis of irrigation. At first, the techniques were not much refined as information on the movement of soil moisture, the physiology or water absorption and the transpiration (evaporation of water from the surface of the plant) was limited. At present, we are in a better position to assess the water needs of the crops in relation to weather conditions, the nature of soil, the status of soil fertility and the source of water supply.

1.12 In India, already about 63 million hectares of gross sown area against a total of 180 M ha lias been covered under irrigation. Annually, an additional irrigation potential of about 2.5 M ha is being added.

1.13 Besides the rapidly increasing potential of irrigation, the measures to conserve soil and water are being adopted on a wide scale in different states.

1.14 With the all-round development activity and planned use of resources, the cropping pattern is under-going a gradual yet perceptible change. The use of fertilizers and water has made it possible for the farmer to grow two crops where one was raised a few years back. In addition, there has developed an urge to take to commercial crops and vegetable production. However, all this change underlines the need for economical use of water.

D.I. 5.20 Gl/sec/Ha.
= 1 cusec/Ha

CHAPTER II

Definition of Terms

Some of the terms related to estimating water requirement of crops are defined as follows :

2.10 Consumptive Use

Consumptive use, commonly known as evapo-transpiration, is the amount of water used by growing plant in transpiration and building of plant tissues and that evaporated from adjacent soil or from intercepted precipitation on the plant foliage in any specified time. Consumptive use is usually expressed in metre cube per hectare or centimetres per hectare or in depth in millimetres or centimetres.

2.11 Consumptive Water Requirement

The amount of water potentially required to meet the evapo-transpiration needs of the plant so that the plant does not suffer in its growth through short supply of water.

2.12 Consumptive Irrigation Requirement

The depth of irrigation water, exclusive of precipitation, stored soil moisture, or ground water (capillary) contribution that is required to meet evapo-transpiration and other physiological need of plants during crop production.

2.13 Net Irrigation Requirement

The depth of irrigation water, exclusive of precipitation, stored soil moisture, or ground water (capillary) contribution that is required consumptively for crop production and for other purposes such as leaching and percolation losses inevitable in case of some crops. In other words in normal soils (without leaching requirement) and for crops other than paddy (where standing water results in percolation loss) it is the amount or the depth of water required to bring the soil moisture level in the effective root zone to field capacity from the soil moisture content before applying irrigation water.

2.14 Field Irrigation Requirement

The field irrigation requirement is net irrigation requirement plus losses in water application. The losses in water application depend on the type of soil, grade (slope) of the field, method of irrigation, etc.

2.15 Gross Irrigation Reqirement

It is net irrigation requirement plus water application losses plus losses in the conveyance system due to seepage, evaporation, etc. This can be determined at outlet head or canal head depending on the purpose of determination.

2.16 Effective Rainfall

It is that portion of the rainfall falling during the growing period of the crop which is available to meet the consumptive water need or the evapo-transpiration requirement of the crop. It does not include precipitation lost through deep percolation below the root zone or through surface runoff.

2.17. Peak Period Consumptive Use

Peak period consumptive use is the average daily evapo-transpiration rate of a crop at its maximum during the period between normal irrigations.

2.18 Irrigation Efficiency

It is the percentage of applied irrigation water stored in the soil and available for consumptive use by the crop. When the applied water is measured at its entry to a farm, it is called farm-irrigation efficiency ; when measured at the field, it is known as field-irrigation efficiency ; and when measured at the point of diversion, it is termed project-efficiency (see Chapter XII).

2.19 Field Capacity

The moisture percentage, on dry weight basis, of a soil after rapid drainage of gravitational water

has taken place following rainfall or an application of water, provided there is no water-table within capillary reach of the root zone. This moisture percentage is usually reached within one to three days after the soil has been thoroughly wetted by rain or irrigation, depending upon the soil type.

2.20 Wilting Point

Wilting point, also known as wilting coefficient, is the soil moisture content at which plants can no longer obtain enough moisture to meet their transpiration requirements and remain wilted unless water is added to the soil. At the wilting point the film of water along the soil particles are held so tightly that roots, which are in the contact of soil, are unable to remove water at a required rate, resulting in wilting of the plant. The wilting point varies with kind of plant and kind of soil.

2.21 Carryover Soil Moisture

Moisture stored within the root zone soil between cropping seasons or before crop is planted. This moisture is available to help in meeting the consumptive water needs of the crop.

2.22 Crop Coefficient

Crop coefficient relates reference evapo-transpiration to crop evapotranspiration or consumptive use. It accounts for the effect of crop characteristics on crop water requirements. Crop coefficient value takes into account the sowing time, crop development stages, crop characteristics and climate.

2.23 Reference Evapotranspiration

The effect of climate on crop water requirement is given by the reference evapotranspiration. It is defined as the rate of evapotranspiration from an extensive surface of 8 to 15 centimetres tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water.

2.24 Potential Evapotranspiration

The concept of potential evapotranspiration was suggested by Thorthwaite who defined it as the evapotranspiration from a large vegetation covered land surface with adequate moisture at all times.

2.25 Evaporation

It is the diffusion of water as a vapour from a surface into the atmosphere. The factors that affect the rate of evaporation are the nature of the evaporating surface and the difference in vapour pressure as determined by temperature, wind and atmospheric pressure. In determining consumptive use, evaporation includes both evaporation from the ground surface and evaporation of water intercepted by vegetation.

2.26 Transpiration

It is the process by which water vapour leaves the living plant body and enters the atmosphere. Both plant and environmental factors affect the rate of transpiration.

2.27 Infiltration

The movement of water from the surface into the soil is called infiltration.

2.28 Percolation

Percolation is the downward movement of water through saturated or nearly saturated soil in response to the force of gravity. Percolation rate is synonymous with infiltration rate with the qualitative provision of saturated or nearly saturated conditions.

2.29 Leaching

Removal of excess soluble salts beyond the root zone through water is termed leaching.

CHAPTER III

Influence of Various Factors on Water Use

3.10 Many factors operate singly or in combination in influencing the amount of irrigation water required by plants. Their effects may differ with locality and fluctuate from time to time. The more important factors which influence water use are climate, water supply, type of crop and plant growth characteristics.

3.11 Precipitation

The amount frequency and intensity of precipitation has an effect on the amount of irrigation water consumptively used during any season. Sometimes precipitation may come in frequent, light showers. Such showers may add little or nothing to the soil moisture for use by the plants through transpiration but do decrease the withdrawal from the stored moisture. The precipitation may be largely lost by evaporation directly from the surface of the plant foliage and from the land surface. Some of the precipitation from heavy storms may be lost by surface runoff. Where storms occur within a relatively short period after completion of an irrigation, a high percentage of percipitation is lost due to surface runoff, deep percolation or both. Other storms may be of such intensity and amount that a large percentage of their precipitation will enter the soil and become available for plant consumptive use. Such a condition materially reduces the amount of irrigation water needed.

3.12 Temperature

The rate of consumptive use of water by crops in any particular locality is probably affected more by temperature, which for long time periods is a good measure of solar radiation, than by any other factor. Abnormally low temperatures may retard plant growth and unusually high temperatures may produce dormancy. Consumptive use may vary even in years of equal accumulated temperatures because of deviations from the normal seasonal distribution. Transpiration is influenced not only by temperature but also by the area of leaf surface and the physiological needs of the plant, both of which are related to stage of maturity.

3.13 Growing Season

The growing season, has a mojor effect on the seasonal use of water by plants. Actual dates of planting and crop maturity are important in determining the consumptive irrigation requirements of the crops.

3.14 Latitude and Sunlight

Because of the earth's movement and axial inclination, the hours of day-light during the summer are much greater in the higher latitudes than at the Equator. Since the sun is the source of all energy used in crop growth and evaporation of water, the longer day may allow plant transpiration to continue for a longer period each day and to produce an effect similar to that of lengthening the growing season.

3.15 Clouds or dust in the atmosphere can reduce the amount of sunlight (solar energy) that reaches the plant. Elevation may also affect the amount of energy received since at higher elevations, there is less absorption of energy by the atmosphere.

3.16 Other Climatic Factors

Other climatic factors that have an effect on the amount of irrigation water consumed by plants are as follows :

3.17 Humidity

Evaporation and transpiration are accelerated on days of low humidity and slowed during periods of high humidity. If the average relative humidity percentage is low during the growing season, a greater use of water by vegetation may be expected.

3.18 Wind Movements

Evaporation of water from land and plant surface takes place more rapidly when there is moving air than under calm air eonditions. Hot, dry winds and other

unusual wind conditions during the growing period will affect the amount of water consumptively used. However, there is a limit in the amount of water that can be utilised. As soon as the land surface is dry, evaporation practically stops and transpiration is limited by the ability of the plants to extract and convey the soil moisture through the plants.

3.19 Advection

Crops grown in irrigated areas surrounded by large arid or semi-arid areas can receive additional energy for vaporisation of water by advection. A high percentage of net solar radiation received in arid areas is used in heating the atmosphere. As this warm air mass moves over irrigated areas that are generally cooler, energy contained in the air as sensible heat can be used to evaporate water by vertical turbulent transfer. Thus an "oaisis" effect is created. This evaporation of water by vertical turbulent transfer may cause a considerable increase in normal consumptive use in arid areas. It is not believed to be of significance in humid areas.

3.20 Type of Crop

The type of crop grown in an area has a considerable effect on the consumptive use rate. The wide variations between major groups of crops are largely due to the resistance to transpiration of different plants such as closed stomata during the day (pine apple) and waxy leaves (citrus). The difference in the critical stages of growth, ground cover, crop height, crop roughness, size of leaves, root system, etc., have the effect on the water use by different crops.

3.21 Stage of Plant Growth

Other factors being equal, the stage of a crop's growth has a very considerable influence on its consumptive use rate. This is particularly true for annual crops which generally have three rather distinct stages of growth. These are (1) emergence and development of complete vegetative cover during which time the consumptive-use rate increases rapidly from a low value and approaches its maximum ; (2) the period of maximum vegetative cover during which time the consumptive-use rate may near or at its maximum if abundant soil moisture is available and (3) crop maturation where, for most crops, the consumptive-use rate begins to decrease.

3.22 Available Irrigation Water Supply

All the above mentioned factors influence the amount of water that potentially can be consumed in a given area. However, there are other factors that also cause important differences in the consumptive-use rates. Naturally, unless water is available from some source (precipitation, high water-table or irrigation) there can be no consumptive use. In those areas where the major source of soil moisture is irrigation, both the quantity and seasonal distribution of the available supply will affect consumptive-use. Where water is plentiful and cheap there is tendency for farmers to over-irrigate. If the soil surface is frequently wet and the resulting evaporation is high, the combined evaporation and transpiration or consumptive use may likewise increase. Also, under more optimum soil moisture conditions, yields of crops may be higher than average and more water consumed. When water is in short supply and the requirements of plant cannot be fully met, plant defence mechanisms become operative reducing the consumptive use and usually the production.

3.23 Quality of Water

Investigations have shown that, besides the quantity and seasonal distribution of the water supply, the quality of the water also has a minor effect on the consumtive use. Whether or not plants require more or less water, if the supply is highly saline, may be debatable. The leaching requirement may, however, be affected by water quality. Similarly the drainage conditions available and soil type limit the use of saline water considerably.

3.24 Soil Fertility

If a soil is made more fertile through the application of manure or by some other means, the yields may be expected to increase with an accompanying increase in water use. However, this increase is so small that it is seldom considered when estimating consumptive use.

CHAPTER IV

Estimating Consumptive Use (Evapotranspiration)

4.10 In planning and designing the irrigation systems, an estimate of water requirement of crops is required. Since the beginning of this century, considerable amount of work has been done on soil-water-plant relationship and on computation and determination of evapotranspiration for different crops. The objective of this work was to obtained practical answer to the main problem of knowing the quantity of irrigation water that is needed for growing certain crops in an area. The emphasis was given in these studies to the need of developing useful concepts and different methods which could be reliably used, based, on the knowledge gained in one climatic zone to another climatic zone.

4.11 Blaney and Criddle developed a formula for estimating the consumptive use of agricultural crops :

$$u = k.\frac{p.t}{100} = kf$$

Where,

u = monthly consumptive use during the period in inches.

k = crop factor

t = mean monthly temperature in °F

p = monthly day light hours expressed as percent of day light hours of the year,

and,

$$f = \frac{t.p}{100}$$

4·12 This formula has been extensively used throughout the world for estimating seasonal water requirements. However, it was found that the volues of 'k' used based on seasonal determination were too low for the short periods between irrigations. This led to further attempts to develop formulae for estimating evaporation and evapo-transpiration that would depend less on the judgement of the users. The further expressed the seasonal consumptive use by formula :

$$U = k\Sigma f$$

4.13 Where the season was considered to be the period of plant growth. Phelan proposed an empirical modification of the Blaney-Criddle formula for use for the Western United States as given by Quackenbush and Phelan where the product of k_c and k equalled k in the original Blaney-Criddle formula. The term k_c, a crop growth stage co-efficient, was determined experimentally. Values of k_t, the temperature coefficient were given by equation :

$$kt = 0{\cdot}0173.\ t - 0{\cdot}314$$

4.14 The Blaney-Criddle formula involves the use of k (crop factor) which has to be developed for each crop under the environmental conditions of the particular areas and is generally considered to give good results in humid areas. This formula does not take into consideration such factors as humidity, wind velocity, elevation and the like. These aspects, therefore make it necessary to try other methods which can give reasonaly accurate estimation of irrigation water requirement. The formula attains following shape in metric system with t expressed in O_c and U in millimetres.

$$U = 0{\cdot}254\ (1{\cdot}8t + 32)\ pk.$$

Since many climatic factors influence evapotranspiration and the Blaney-Criddle approach considers only two of them, it should be only rarely used.

4.15 Penman developed a formula for estimating evaporation and potential evapo-transpiration along theoretical lines. This formula is generally considered to give good results in humid areas. Later, on the basis of the intensive studies of the relevant climatic and grass evaporation data, Doorenbos and Pruitt (1975) proposed a modified Penman method f

estimating fairly accurate crop water requirement. The details of this method with relevant tables are given in Chapter VII.

4.16 Another method for calculating evapotranspiration has been developed by Hargreaves. The basis for this method is the high degree of correlation found by various technicians between class A pan evaporation and evapo-transpiration. Hargreaves has developed a series of k factors by major crop groupings. Hargreaves has also introduced several modifying coefficients into his pan evaporation formula.

4.17 Many other formulae for calculating evapotranspiration on climatological approach are in existence. Some of them are those given by Thornthwaite, Alpatyev, Ture, Sharov and Shaumyan. Their use, however, has been limited because of the limited number of factors considered and the particular set of environment in which they were developed.

CHAPTER V

Computing Pan Evaporation

5.10 In recent years, much work has been done on correlating evapo-transpiration with evaporation as measured in a n Evaporimeter. The ratio between evapo-transpiration (E_t) and pan evaporation (E_p) is usually termed K.

5.11 Christiansen *et al* (1966) provided an empirical formula to permit the estimation of pan evaporation from climatic data when reliable measured pan evaporation is not available. Hargreaves (1956) has developed a similar formula for estimating pan evaporation.

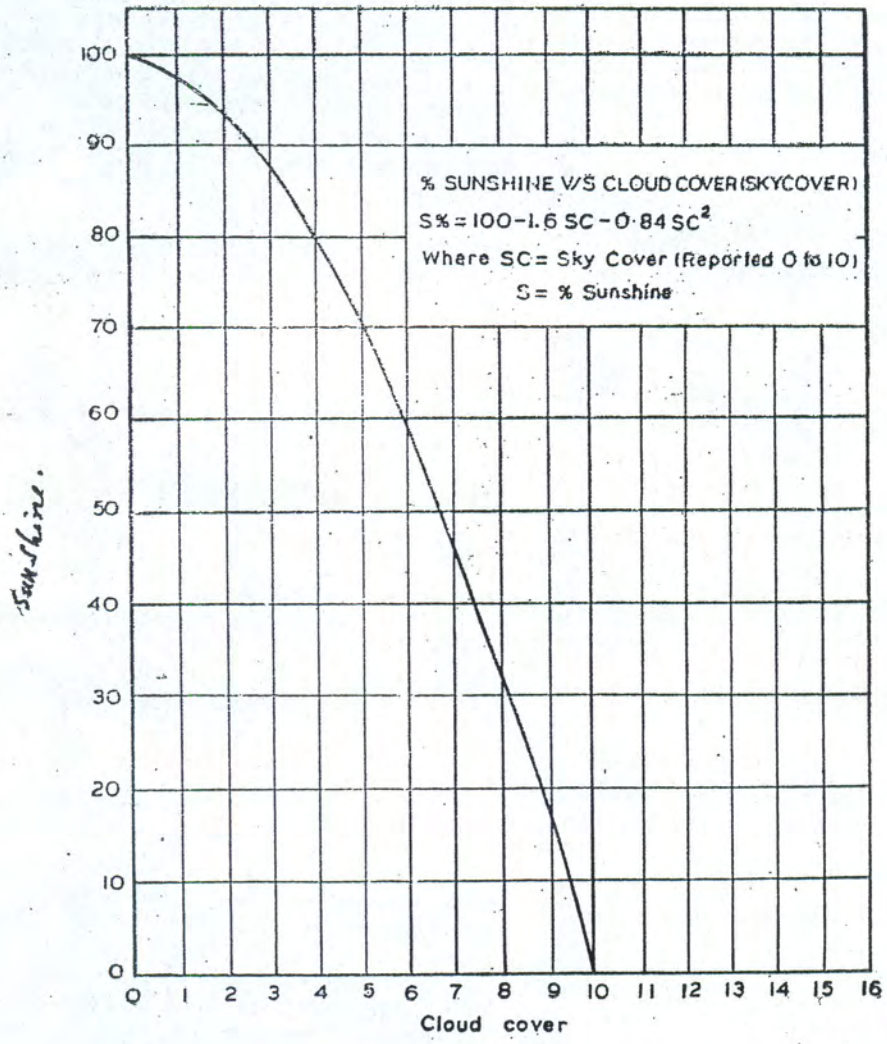


FIGURE 1

5.12 Unfortunately, class A pan evaporation is not available in many places where estimates of evapo-transpiration are needed. Also because of variations in the size and shape of pans, the exposure, the presence or absence of algae, the specific methods of measuring the loss of water from the pans, and the protection against use of the water by birds and animals, available pan evaporation data may need to be standardised before it could be used to obtain reliable estimates of evapo-transpiration. Pan evaporation estimated by means of a reliable formula may give more reliable results than reported pan evaporation.

The Christiansen Method

5.13 Christiansen and co-workers have developed the following pan evaporation equation.

$$E_p = 0{\cdot}459\ R\ .\ C_t\ .\ C_w\ .\ C_h\ .\ C_s\ .\ C_e$$

in which E_p is computed pan evaporation equivalent to class A pan evaporation, R is extra-terrestrial radiation in the same evaporation units as E_p and C_t, C_w, C_h, C_s and C_e are coefficients for temperature, wind velocity, relative humidity, percent of possible sunshine, and elevation. Equations for these coefficients are as follows :

$$C_t = 0{\cdot}393 + 0{\cdot}02796\ T_c + 0{\cdot}0001189\ T_c^2$$ (Table 2)

where, T_c is expressed in degrees centigrade.

$$C_w = 0{\cdot}708 + 0{\cdot}0034\ W - 0{\cdot}0000038\ W^2$$ (Table 3)

where, W is the mean wind velocity at 0·5 metre above the ground in kilometres per day.

$$C_h = 1{\cdot}250 - 0{\cdot}0087\ H + 0{\cdot}75 \times 10^{4}\ H^2 - 0{\cdot}85 \times 10^{-8}\ H^4$$

(Table 4) where H is the mean relative humidity at noon, or average relative humidity for 11 and 18 hours.

$$C_s = 0{\cdot}542 + 0{\cdot}0080\ S - 0{\cdot}78 \times 10^{-4}\ S^2 + 0{\cdot}62 \times 10^{-6}\ S^3$$

(Table 5) where S is the mean sunshine percentage (when cloud cover is reported in tenths, use Figure 1 to convert to percent sunshine.

$C_e = 0{\cdot}970 \times 0{\cdot}00984\ E$ (Table 6) where E is expressed in hundred of metres.

R = Extra-terrestrial radiation (Table 1) may be expressed in millimetres (or inches).

5·14 Sample Calculation

Given

—Location : Bellary, Karnataka State.
Latitude : 15° 09′ N Elevation : +449 metres.

—Month : April

—Mean Temperature : 31·8°C

—Wind Velocity at 0·5 m above the ground—
Surface : 183 kilometres per day.

—Mean relative humidity : 40 percent.

—Sunshine percent : 89

Solution: (See Appendix A for Graphical Solution)

R (Table 1) for April ; Lat. 15° 09′ N = 473 millimetres.

C_t (Table 2) for 31·8°C = 1.403

C_w (Table 3) for 183 kilometres per day = 1.200

C_h (Table 4) for 40 percent = 1.000

C_s (Table 5) for 89 percent = 1.073

C_e (Table 6) for 449 metre = 1.014

$E_p = 0.459\ R\ .\ C_t\ .\ C_w\ .\ C_h\ .\ C_s\ .\ C_e.$

$= 0.459(473)\ (1{\cdot}403)\ (1{\cdot}2000)\ (1{\cdot}000)\ (1{\cdot}073)\ (1{\cdot}014)$

$= 398$ millimetres.

CHAPTER VI

Computing Evapotranspiration from Pan Evaporation

6.10 The relationship of evapotranspiration to pan evaporation has long been used in the computation of irrigation requirements. Many research stations are now reporting consumptive use data by relating evapotranspiration (consumptive use) to pan evaporation. This relationship is available for some crops from many diverse parts of the world such as Israel, Philippines, United States and India. Table 7 shows evapotranspiration coefficients for vegetative cycle percentages for various crops.

6.11 Where specific data are not available, average values can be used as recommended by Hargreaves. Table 8 shows consumptive use coefficients k, for computing evapotranspiration (E_t) from either computed or measured pan evaporation (E_t). These coefficients are suggested as representative in average conditions and are proposed for use in the formula $E_t = KE_p$. The eight crop groups are as follows :

6.12 Crop Group A

These crops fit a fairly even bell type curve and have a modal grouping of maximum E_t/E_p ratios in the range of 0.80 to 1.10. An average value of 1.00 is used. The more important crops include beans, maize, cotton, potato, sugar beet, jowar and pea.

6.13 Crop Group B

This group consists of the deciduous fruits and some field crops. Some group A crops that fail to produce maximum vegetal cover and maximum growth ratios will best fit in this group. It includes date, olive, plums, walnut, tomato and hybrid jowar.

6.14 Crop Group C

The crops include melon, onion, carrot, hop and grape with a maximum E_t/E_p ratio of about 0.60. The general pattern is again that of a bell type curve.

6.15 Crop Group D

The maximum E_t/E_p ratio is about 0.90 and usually occurs at about 75 to 80 percent completion of the crop vegetative cycle. The crops included are barley, celery, flax, wheat and other small grains.

6.16 Crop Group E

These crops have fairly flat curves. Ratios E_t/E_p range from 0.70 to 1.10. The usual or modal group ratio is about 0.90. The crops include pasture, orchard with cover crop and plantain.

6.17 Crop Group F

This group includes the citrus crops : orange, grape fruit. The E_t/E_p ratios are fairly constant throughout the year and average about 0.60.

6.18 Crop Group G

This group includes sugarcane and alfalfa. E_t/E_p values generally vary from 0.66 to 1.00.

6.19 Rice

The E_t/E_p ratios present a fairly flat curve. A maximum value of 1.30 and a minimum of 0.80 is representative of average conditions.

6.20 Since these coefficients are average values, some care must be taken in their use. Frequently for a given crop, considerable variations in E_t/E_p ratios may exist. Sugar beets are shown as fitting a typical bell curve with maximum ratios at 50 to 55 percent completion of the crop growing season. This is frequently the true relationship. However, in highly productive fields, growth and evapotranspiration have been maintained until shortly before harvest.

6.21 Other factors may cause the evapotranspiration to be greater or lesser than the average value. 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 rates of absorption of solar energy and hence the rate of evapotranspiration will be higher than that for light green vegetation. Plant diseases that produce yellowing of the leaves of the plants greatly reduce evapotranspiration. Assuming

that factors for crop roughness and crop colour are comparable, then evapo-transpiration is roughly a function of crop cover.

6.22 Under similar climatic conditions, there is little difference in the rate of evapotranspiration by various crops or types of vegetative cover provided equal densities, roughness and colour of vegetation are compared and the crop is in an active stage of growth.

Evapotranspiration (Consumptive Use)

6.23 The Sample Calculation given in Table 6·1 show the computation of consumptive use and net irrigation requirement for jowar at Bellary, Karnataka State. These estimates are made on a monthly basis. The various columns of the table are explained below :

Column 1—months and fractions of month.

Column 2—number of days from planting to mid-point of each monthly period.

Column 3—percentage of the growing season to the mid-point of the monthly period, i.e., column 2 divided by number of days required for crop.

Column 4—E_t/E_p ratio for jowar at specific growth periods as shown in Table 7.

Columan 5—pan evaporation, E_p, as computed by Christiansen Method (for Bellary), millimetres.

Column 6—consumptive use (evapotranspiration) of jowar by monthly periods (Column 4 × Column 5), millimetres.

Column 7—percolation losses, millimetres.

Column 8—effective rainfall (see Chapter 7 and Table 10) millimetres.

Column 9—net irrigation requirement (determined by substracting effective rainfall from consumptive use), millimetres.

Some more sample calculations for working out gross irrigation requirement based on this approach are presented in Table 13 through 15. Also see Tables 28 and 29.

TABLE 6.1

Sample calculation—computation of evapotranspiration and net irrigation requirement from pan evaporation data for Jowar Crop at Bellary, Karnataka

Dates	*Mid Point*	*% G.S.*	E_t/E_p *(k)*	*PE or* E_p	*CU*	*Perc. L*	*Re*	*NIR*
1	2	3	4	5.	6	7	8	9
Oct.	16—31	8	7	.44	84.9	37.4	—	34·2	3.2
Nov.	1—30	31	28	.54	155.7	84.1	—	21·9	62.2
Dec.	1—31	62	56	.94	165.9	155.9	—	5.4	150.5
Jan.	1—31	93	85	.99	191.0	189.1	—	1·5	187.6
Feb.	1—2	109	99	.73	15.4	11.2	—	0·2	11.0

Energy component is related to the energy available for latent evaporation. While Second an Aerodynamic Component. Has to do with transport mechanism available to remove the water vapour from the soil and crop surfaces.

E_a = Aerodynamic Component

Penman $E_{TO} = WR_n + (1-W) \cdot E_a$

Energy component

CHAPTER VII

Modified Penman Method

7.10 Based on studies of the climatic and measured grass evapotranspiration data from various research stations in the world. Doorenbos and Pruitt (1977) proposed a modified Penman's method for estimating reference crop evapotranspiration (*ETo*) and gave tables to facilitate the necessary computations. The prediction equation and its terms are defined below :

$$ETo = c[W \cdot Rn + (1-W) \cdot f(u) \cdot (ea-ed)]$$

radiation term — aerodynamic term

where, *ETo* = reference crop evapotranspiration, mm/day

c = adjustment factor to compensate for the effect of day and night weather conditions

W = temperature and elevation related weighing factor for the effect of radiation on *ETo* (obtained from Table 21 with the altitude of the place and the mean temperature known)

and *Rn* = net radiation, *mm*/day

$= Rns - Rnl$

where, *Rns* = the net incoming shortwave solar radiation

$$= I \ (1-\alpha)\left(0.25+0.50\ \frac{n}{N}\right)$$

in which, *Ra* = extra terrestrial radiation, mm/day

α = reflection coefficient = 0.25 for most of the crops

$\frac{n}{N}$ = ratio of actual sunshine hours to maximum possible sunshine hours. The value of actual sunshine hours may be obtained for the station in vicinity of the command area. The value of maximum possible sunchine hour can be obtained from the Table 16.

and *Rnl* = net long wave radiation

$= f(t), f(ed), f\left(\frac{n}{N}\right)$; values may be obtained from Tables 23, 24, and 25 respectively.

$(1-W)$ = temperature and elevation related weighing factor for the effect of wind and humidity on *ETo*

ea = mean saturation vapour pressure in m bar (m bar) at mean air temperature

ed = mean actual vapour pressure of air in m bar

$f(u)$ = wind related function.

The Procedure to Adopt Different Terms

(A) Aerodynamic Term

7.11 (*i*) *ea* is saturation vapour pressure in m bar at the mean air temperature. The mean air temperature should be the average of maximum temperature and minimum temperature for the station under consideration. With mean temperature in °C known, the value can be taken from the Table 18.

7.12 (*ii*) *ed* is mean actual vapour pressure of the air in m bar and is given by : $\left(\frac{ea \times RH \text{ mean}}{100}\right)$ in bar ; where, *RH* mean is the mean relative humidity and is equal to the average of maximum relative humidity and minimum relative humidity which can be obtained from the climatological data. It can also be computed from dry and wet bulb temperatures.

7.13 (*iii*) $f(u)$ is wind related function and is equal to

$$0.27\left(1+\frac{u}{100}\right)$$

where, u is the wind velocity in 24 hours in kilometre/day at 2 metres height from ground level. In case where anemometer is fixed at different level, the wind speed (u) should be adjusted for 2 metres height, before it is used for the calculation of $f(u)$. These correction factors are given in Table 19. The $f(u)$ can be taken from the Table 19.

7.14 (*iv*) $1\text{-}W$ is a temperature and elevation related weighing factor for the effect of wind and humidity and can be obtained from Table 20 having known the altitude of the places and mean temperature.

(B) Radiation Term

7.15 (*i*) W is a temperature and elevation related factor for the effect of radiation. This can be taken from the Table 21 knowing the altitude and mean temperature.

7.16 (*ii*) Rn is net radiation in mm/day and can be obtained from the following relation :

$$Rn = Rns - Rnl$$

where, $Rns = (1 - 0.25)\, Rs$

and, $$Rs = \left(0.25 + \frac{0{\cdot}5\, n}{N} \right) Ra$$

Ra is radiation received at the top of the atmosphere and is dependent on latitude and time of the year. It can be obtained from Table 17 for the latitude of the place and month of the year.

7.17 (*iii*) $\frac{n}{N}$ is the ratio of actual sunshine hours to the maximum possible sun shine hours. The value of n can be obtained from the nearest meteorological station. Conversion factors from cloudiness is expressed in oktas (0—8) or tenths (0—10), to $\frac{n}{N}$ ratio can be obtained from the Table 7.1.

TABLE 7.1

Conversion on cloudiness to n/N ratio

Cloudiness (tenths)	*0*	*.2*	*.4*	*.6*	*.8*	*Cloudiness (oktas)**	*0.*	*.2.*	*.4.*	*.6.*	*.8.*
0	.95	.9	.9	.9	.9	0	.9	.9	.9	.85	.85
1	.85	.85	.85	.85	.8	1.	.85	.85	.8*	.8	.8
2	.8	.8	.8	.75	.75	2	.75	.75	.75	.7	.7
3	.75	.7	.7	.7	.65	3	.65	.65	.65	.6	.6
4	.65	.65	.6	.6	.6	4	.55	.55	.5	.5	.45
5	.55	.55	.5	.5	.5	5	.45	.4	.4	.35	.35
6	.5	.45	.45	.4	.4	6	.3	.3	.25	.25	.2
7	.4	.35	.35	.3	.3	7	.15	.15	—	—	—
8	.3	.25	.25	.2	.2						
9	.15	.15	.15	—	—						
10	—	—	—								

*Oktas a scale where 0.0 is full cloudiness.

(Source : FAO Irrigation and Drainage Paper No. 24.)

7.18 The conversion factor for extra terrestrial radiation (*Ra*) to net solar radiation (*Rns*) for a given reflection (α) of 25 percent and different ratios of actual to maximum sun shine hours can be obtained from the Table 22.

7.19 (*iv*) Net long wave radiation $(Rnl) = f(t)\, f(ed)\, f\left(\frac{n}{N}\right)$ where $f(t)$, $f(ed)$ and $f\left(\frac{n}{N}\right)$ can be obtained from the Tables 23, 24 and 25 knowing mean temperature, vapour pressure, and ratio of actual to maximum bright sun shine hours respectively.

(C) Adjustment Factor (C)

7.20 *c* is the adjustment factor to compensate the day and night weather conditions. To arrive at correction factor (*c*), the following information are required :

(1) Solar radiation (*Rs*)

(2) Maximum relative humidity (*RH* max.)

(3) Average wind speed during day (*U* day in m/sec)

(4) Average wind speed during night (*U* night in m/sec).

7.21 With the above information the adjustment factor can be obtained from the Table 26. The values are available for three different maximum relative humidity and to arrive at appropriate adjustment factor, the table should be judiciously used.

Selection of Crop Coefficient

7.22 The crop evapotranspiration (*Et* crop) is computed by multiplying the crop coefficient (*Kc*) with the reference evapotranspiration (*ETo*) as given below :

$$Et \text{ crop} = Kc \times ETo$$

7.23 The *Kc* values relates 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 procedures for appropriate *Kc* values takes into account the crop characteristics, time of planting or sowing, stages of crop development and general climatic condition.

7.24 The *Kc* values should be adopted from the research station of ICAR/Agricultural Universities in the locality. However, in the absence of such data the values of crop co-efficient (*Kc*) may be judiciously taken from the Table 27 (adapted from FAO Publication 33) for different crop development stages.

Effective Rainfall

7.25 The effecive rainfall may be taken as described under Chapter IX.

Percolation Losses

7.26 The deep percolation losses vary from soil to soil in the command areas. For the paddy crop, constant ponded level of water is required throughout the crop period. Therefore, the deep percolation losses should be considered for the entire crop period based on observation in the command areas.

Requirement of Water for Nursery and Land Preparation

7.27 The requirement for nursery and land preparation are in addition to the normal water requirement of the crops and as such an account of these should also be made, especially for paddy for which the requirement may be approximately as below :

(*a*) Nursery –30-50 mm for entire area of 300-500 mm for 1/10 of the area.

(*b*) Land preparation (puddling and transplanting) 150 to 300 mm.

7.28 Sample Calculation

Given

Crop	Wheat
Station	Agra
Location	Lat. 27° 10 'N
	Long. 78° 02 'E

Height above mean sea level : 169 metre

Period of observation : 1931 to 1960

For the above location, the average data in respect of temperature, humidity, cloud cover and wind speed for the month of January are as below :

1.	Temperature	14.8°C
2.	Humidity	59 percent
3.	Cloud cover	2.95 oktas or 3.00 oktas
4.	Wind speed	3.6 kilometre/hour
		86.4 kilometre/day.

Solution

I. COMPUTATION OF ETo

7.29 **A. Solving Aerodynamic Term**

$$(1-W) \cdot f(u) \cdot (ea - ed)$$

(*i*) *ea* from Table (18) at mean air temperature 14.8°C=16.80 m bar

(*ii*) $ed = \frac{ea \times Rh \text{ mean}}{100}$ m bar

$=16.8 \times 0.59 = 9.91$ m bar

(*iii*) $(ea-ed) = 16.8 - 9.91 = 6.89$ m bar

(*iv*) $f(u)$ from Table (19) at wind velocity (86.4 km/day)=0.5028

(*v*) $(1-W)$ from Table (20) at 14.8°C and at altitude 169 metre above sea level=0.378

Therefore, Aerodynamic term
$=0.378 \times 0.5028 \times 6.89 = 1.3095$

or $=1.31$

7.30 **B. Solving Radiation Term**

$$W \cdot Rn = W (Rns - Rnl)$$

(*vi*) Value of $\frac{n}{N}$ for cloudiness equal to 3.0 oktas=0·65

(*vii*) *Ra* from Table (17) at lat. 27° 10′ *N* =9·55

(*viii*) Conversion factor for extra-terrestrial Radiation (*Ra*) to net solar radiation *Rns* for a given reflection of $X=0.25$ and at

$\frac{n}{N} = 0{\cdot}65$

i.e., $(1-X)\left(0.25+0.5 \frac{n}{N}\right) = 0.43$

(*ix*) $Rns = Ra\,(1-X)\left(0.25+0.50 \frac{n}{N}\right)$

$=9.55 \times 0.43$

$=4.1065$

(*x*) $Rnl = f(t) \cdot f(ed) \cdot f(n)$ from Tables (23, 24 and 25).

$=13.62 \times 0.20 \times 0.69$

$=1.87956$

(*xi*) *W*=temperature and elevation related weighing factor for effect of radiation from Table (21)=0·622

Therefore,

(*xii*) $=W\,(Rns-Rnl)$

$=0.622\ (4.1065-1.8795)$

$=1.385$

(*xiii*) The aerodynamic plus radiation term

$=1.31+1.385=2.695$

or say=2.70.

7.31 **C. Adjustment Factor**

For $Rs=\left(0.25+0.50 \frac{n}{N}\right) Ra = 5.49$

or say=5.5 mm/day, and

assumed *U* day=9.00 m/sec, *RH* Max=90 percent and *U* day/*U* night=4.00, the adjustment factor (*c*) would be 1.26 (from Table 26).

7.32 **D. Reference Evapotranspiration**

$ETo = 2.70 \times 1.26 = 3.4$ mm/day

(see also the format for calculation of *ETo* by modified Penman method).

II. COMPUTATION OF ET CROP

7.33 **Crop Period**

(*i*)	Initial Stage	15th Nov. to 30th Nov. (16 days).
(*ii*)	Crop Development Stage	1st Dec. to 31st Dec. (31 days).
(*iii*)	Mid Season	1st Jan. to 15th Feb. (45 days)
(*iv*)	Late Stage	15th Feb. to 15th March (30 days)
(*v*)	Last Stage	16th March to 31st March (16 days).
	Total	138 days.

7.34 F- Crop Co-e[illegible]ent (Kc)

—from Table (27)

(*i*) Ini[illegible]age 0.30

(*ii*) [illegible] Dev. stage 0.70

[illegible]id season 1.05

Late stage 0.65

(*v*) Last stage (Harvest stage) 0.20

7.35 G. *ETo* for the month of January as calculated and for other months are assumed as below :

Month	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*March*
ETo (mm/day)	3.2	3.1	3.4	3.8	4.1

7.36 H. Ground water (Capillary) Contribution : Nil

7.37 I. Percolation losses (*P*) : Nil

7.38 J. Effective rainfall (*Re*) : Table 7.2

7.39 K. **Irrigation Water Requirement**

— Net Irrigation Requirement (*NIR*)

=Consumptive Use or *ET* crop (*ETo*×*Kc*) +Nursery and land preparation requirement +Percolation loss (*P*)—Effective Rainfall (*Ro*)— Ground water (capillary) contribution, if any

— Field Irrigation Requirement = *NIR* ÷ Farm Irrigation efficiency.

— Gross Irrigation Requirement=*FIR*÷Conveyance Efficiency.

— Table 7.3 gives the crop evapotranspiration and irrigation water requirement as computed on modified Penman approach with assumed farm irrigation and conveyance efficiencies of 60 percent and 75 percent respectively.

Computer Programme for Crop Water Requirement

7.40 A computer programme has been developed by *FAO* to facilitate computation of crop water requirements from climatic data. The programme is based on calculation procedure for the Modified Penman Method as laid down in *FAO* Irrigation and Drainage Paper 24. The method of computer programme for computing crop water requirement developed by *FAO* is given at Appendix *B*. This could also be used wherever computer facility is available. A list of location of Agro-Meteorological station in India is given at Appendix *C*. The climatological data should be collected from nearest station for use.

TABLE 7.2

Calculation of Effective Rainfall

Months	*Average monthly ETo (mm)*	*Monthly mean rainfall (mm)*	*Normal effective rainfall (mm)*	*Average annual rainfall (mm)*	*Percent chance of occurrence*			*Effective rainfall (Re) (mm)*
Nov.	96	2.1	2.1	765	0·8	1.68	or	1.5
Dec.	96.1	3.7	3.7	765	0.8	2.96	or	3.0
Jan.	105.4	16.2	16.2	765	0·8	12.96	or	13.0
Feb. (29 days)	110.2	8.8	8.8	765	0.8	7.04	or	7.0
March	127.1	10.9	10.9	765	0.8	8.72	or	8.5

Note : Since the rainfall is less than values given in Table 10, the amount of rainfall had been taken as effective rainfall.

FORMAT FOR CALCULATION OF E_{To}

BY PENMAN METHOD

Penman Reference Crop $E_{Tb} = C[WR_n + (1-W)f(u)(ea-ed)]$

Country : India Place : Agra. Latitude : 27°10'N Altitude : 169 m
Period : January Longitude : 78°02'N

Data		
an 14.8°C	ea mbar (18)[1]	16.8
an 59%	$R_H/100$ data	0.59
etbulb depression	ed mbar calc	9.91
dew point	(ea-ed) mbar calc	6.89
36.4 Km/day	f(u) (19)	0.5028
an 14.8°C	(1-w) (20)	0.378
itude 169 m	(1-w) f(u) (ea-ed) mm/day calc	1.31
th January	R_a mm/day (17)	9.55
itude 78°02'N	n hr/day data	6.86
th January	N hr/day	10.56
itude 78°02'N	n/N calc	0.65
	(0.25+0.5n/N) calc	0.575
	Rs mm/day calc	5.491
0.25	Rns mm/day (1-α)Rs calc	4.106
an 14.8°C	f(t) (23)	13.62
9.91 mbar	f(ed) (24)	0.20
0.65	f(n/N) (25)	0.69
	$R_{nl}=f(t)f(ed)f(\frac{n}{N})$ mm/day calc	1.879
an 14.8°C	$R_n = R_{ns} - R_{nl}$ calc	2.227
itude 169 m	W (21)	0.622
	$W.R_n$ calc	1.385
y/U night 4.00	C (26)	1.26
ax 90%		
5.491		

$E_{To} = C\,[WR_n + (1-W)f(u)(ea-ed)]$ mm/day

1) Numbers in brackets indicate Table of reference.
2) When Rs data are available Rns=0.75 Rs.

TABLE 7.3

Sample calculation—computation of crop evapotranspiration and irrigation water requirement by modified Penman method

Crop : Wheat

Sl. No.	Crop period	ETo (mm)	Kc	ET crop (mm) = ETo × kc	P (m)	Re* (mm)	NIR (ET crop +P—Re) (mm)	FIR (NIR/0.6) (mm)	GIR (FIR/0.75)
	Nov. 1—30	51.2	0.30	15.36	—	0.75	14.61	24.35	32.46
	Dec. 1—15	46·5	0.70	32.55	—	1.5	31.05	51.75	69.00
	16—31	49.6	0.70	34.72	—	1.5	33.22	55.36	73.81
	Jan. 1—15	51.0	1.05	53.55	—	6.5	47.05	78.42	104 56
	16—31	54.4	1.05	57.12	—	6.5	50.62	84.36	112.48
	Feb. 1—15	57.0	1.05	59.85	—	3.5	56.35	93.92	125.23
	16—29	53.2	0.65	34.58	—	3.5	31.08	51.80	69.06
	March 1—15	61.5	0.65	39.98	—	4.0	39.98	66.63	88.84
	16—31	65.6	0.20	13.12	—	4.25	8.87	14.78	19.70

*The monthly effective rainfall is considered evenly distributed in 1st and 2nd fortnight of the respective months for the sake of illustration.

Note : Provide for pre-sowing irrigation, as needed.

10 cms. in case of cotton
20 cms in Paddy,
15 cm of Sugarcane

CHAPTER VIII

Peak Period Consumptive Use

8.10 Information on peak period rates of consumptive use is needed to properly design irrigation systems. It is used to determine the minimum capacity requirements of main and lateral canals, pipelines, and other water conveyances or control structures. The peak period rates of water use by crops also influence the operation of streams and reservoirs from which irrigation water supplies are obtained.

8.11 In irrigation project design, the peak period is the period during which the average daily rate of consumptive use of the various crops grown in the project area is at maximum. Different crops may have their peak rates of use at different times. Therefore, some crops may not be using water at their maximum rate during the project peak period.

8.12 Variations in planting dates may also cause variation in the times individual fields reach their peak use rate. Some may be reaching the maximum when other fields are at a reduced rate. For this reason, the peak consumptive use of project area may be somewhat less than that of an individual field.

Factors Influencing peak period use ratea

8.13 In this publication besides modified Penman approach, the evapo-transpiration (consumptive use) is also computed using pan evaporation and vegetative cycle percentages for group of crops. Ratios of evapotranspiration to pan evaporation for vegetative cycle percentage and group of crops are given in another portion of this publication. The remaining factors that have an influence on the peak period consumptive use rate pan evaporation and net irrigation application.

Pan Evaporation

8.14 An analysis of pan evaporation records shows that at a given location the mean daily pan evaporation for the greatest consecutive 5-day period will be greater than that for the greatest consecutive 10-day period, the mean daily value for the 10-day period will exceed the mean daily value for the 15-day period, and so on. All will be greater than the mean daily pan evaporation for a period of one month. Since consumptive use is directly related pan evaporation, the shorter the peak period days, the greater will be the mean daily pan evapo tion and therefore, the greater will be the consumpt use rate.

Net Irrigation Application

8.15 The length of the peak period is that num of days in which the normal net irrigation applicati will last under the peak rate of use for the peri Thus smaller net irrigation applications will last smaller periods of time and, as shown above, result in greater peak period-use rates. Converse higher net irrigation applications will result in lo peak period use rates.

8.16 Table 9 shows peak-period average daily c sumptive-use rates as related to estimated monthly and net irrigation application. As an illustration the use of this table, take a case where the pe month of an irrigation season has a monthly consu ptive use (*Um*) of 250 mm. The water extracti depth of the crop and the soil on the field are su that net irrigation application (*I*) will be 100 m Using Table 9, it is seen that the peak period Da Use Rate (*UP*) works out to 9.0 mm.

8.17 A suggested procedure for using Table 9 estimate project peak period consumptive-use requi ments is as follows :

1. Determine the net irrigation application required for the crops and soils in the project area.

2. Determine the monthly consumptive use rat (*Um*) for each crop in the project area for the mo of greatest overall water use.

(Note that if some crop is using water for only portion of the month, its rate of use must be compu ted by dividing the estimated requirement by th fraction of the month when water is used).

3. From Table 9, using appropriate values of (*I*) and (*Um*), determine the peak period consumpti use-rate (*UP*) for each of the crops.

CHAPTER IX

Effective Rainfall

9.0 Effective rainfall supplies a portion of the consumptive use by crops. It may be a nearly insignificant portion in arid areas or it may be a major portion in humid areas. The technician engaged in estimating irrigation water requirements of a crop is confronted with the problem of determining what portion of total consumptive use will be met by effective rainfall and what portion will have to be supplied by irrigation. Since there are no records of effective rainfall available, it is necessary to estimate the portion of total rainfall that can be effective. An approximate procedure for arriving at effective rainfall is described in succeeding paragraphs.

Factors Influencing Rainfall Effectiveness

Total Rainfall

9.11 In arid areas where total crop season precipitation is light, the moisture level in the soil profile at the time the precipitation occurs is usually such that almost all of it enters the soil profile and becomes available for consumptive use. Losses due to surface runoff or through percolation below the crop root zone are usually negligible. Thus the effectiveness of rainfall in these areas will be relatively high.

9.12 In humid areas, storms of large magnitude and high intensity occur frequently during the crop season. These storms often bring down water in excess of that which can be stored in the soil profile for consumptive use. This excess water is lost either as surface runoff or as percolation below the root zone. When such storms occur soon after an application of irrigation water almost all of the rainfall may be lost as runoff. Thus in areas of high total rainfall during crop season the effectiveness of rainfall is low by comparison.

Topography of Land

9.13 The entry of rain water into the soil greatly depends on time it gets on the land surface for infiltration and this would be influenced by the undulation characteristics, slope of land etc. If the land is levelled water will have a longer infiltration opportunity time than land otherwise slopy, undulating and this consequently influence the effective rainfall fraction.

Soil Characteristics

9.14 Characteristics of soil influence the rate of infiltration, moisture holding capacity and moisture movement in the soil body ; this ultimately affects the extent of effective rainfall. The infiltration, permeability and the moisture retention capacity of a soil are influenced by the soil depth, texture, structure and organic matter content of the soil. A higher infiltration rate reduces the surface run-off. Similarly, the soil with good physical condition with finer soil particles will hold more water for longer duration and increase the effective rainfall fraction.

Initial Soil Moisture Content

9.15 The effective rainfall is affected by the moisture content available in the soil at the time of rainfall. The lower the moisture content, the higher the infiltration rate and lower the surface run-off which increases the effective rainfall. The degree of effective rainfall is higher in rainfed areas than in areas having irrigation facilities.

Management Practices

9.16 All the soil management practices which affect the physical characteristics of the soil like infiltration, permeability, water retention capacity, etc. also influence the extent of effective rainfall. Similarly the water conservation practices like bunding, terracing ridging, mulching contour cultivation balanced cropping etc. increase the effectiveness of rainfall.

Ground Water Characteristics

9.17 The moisture when depleted in the upper layer of the soils exerts suction in the capillary tubes. If ground water is within the reach of the suction, water moves upward through capillary tubes and meets

the crop water requirement. Hence the degree of effective rainfall is higher when the ground water is deep compared to when it is shallow.

Consumptive Use Rate

9.18 Where the consumptive use rate of a crop is high, available moisture in the soil profile gets depleted rapidly, thus providing storage capacity at a relatively rapid rate for subsequent rainfall. Should a substantial storm occur, the amount of water required to bring the moisture in the profile back to the field capacity level would be relatively large and the losses due to runoff and/or deep percolation would be relatively small.

9.19 Conversely, where the consumptive use rate is low, storage capacity of the soil for rainfall is provided at a slower rate. When a storm occurs, there is less capacity in the profile available to receive water and thus the water loss will be relatively large. Thus the higher the rate of consumptive use, the greater will be the rainfall effectiveness. Conversely, the lower the rate of consumptive use, the lower will be the effectiveness of rainfall.

Net Irrigation Application

9.20 The net irrigation application is dependent upon the capacity of the soil profile at root zone depth to store readily available moisture for plant use. When this capacity is low and a storm of considerable magnitude occurs, only a small percentage of the precipitation may be sufficient to fill the soil profile to field capacity and the effectiveness of resulting rainfall will be low. If the capacity is high, all or most of the rainfall resulting from such a storm might be stored in the profile before the field capacity level is reached. In this case, the effectiveness of the rainfall would be relatively high.

Monthly Effective Rainfall

9.21. The relationship between effective rainfall and the variable factors discussed previously can be well illustrated in Table 10.

9.22 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 millimetre net irrigation application. Factors for converting to other net depths of application are presented. For example, a crop of maize grown on a sandy soil has a net depth of application of 50 millimetre. Its average consumptive use for a given month is 200 millimetre and the normal monthly rainfall is 150 millimetres. From Table 10, the normal effective rainfall for this month is 120 (0·93) or 112 millimetre.

Seasonal Effective Rainfall

9.23 Normal effective rainfall during the gr season is determined by adding the values of effective rainfall for each month and fractions t of the total growing season of the crop in ques

9.24 The effective rainfall chart is from conducted in the United States of America. studies were made by using the daily soil balance procedure whereby a soil moisture bal computed for each day by subtracting cons use and adding effective rainfall and/or irriga the previous days balance. This procedure nec fails to consider two factors soil intake ra rainfall intensity which in some instances, ma a bearing on the effectiveness or rainfall factors, soil intake rates and rainfall intensiti not considered for two reasons :

(*i*) sufficient data are not available ; an

(*ii*) the complexity involved in their co tion would make such a study impractical. areas where soil intake rates are low and intensities are consistently high, large perce rainfall may be lost to surface runoff with moisture level in the soil profile being rai reciably. In such cases, Table 10 may nee modified.

Frequency Distribution of Effective Rainf

9.25 It can safely be assumed that for a crop at a particular location, monthly and consumptive use will vary only slightly from year provided the crop is planted at about time each year. On the other hand, mont seasonal effective rainfall can be expect widely from year to year as rainfall varies.

9.26 In view of this wide variation in ne gation requirements from year to year, it i that the development of a dependable wate cannot be based on normal requirements, s would provide an adequate supply about half It is common practice, therefore, to estimate rainfall and irrigation water requirements o bability basis, the percent chance of occurren being an economic consideration. For ex might be economical to provide a water sup is adequate in nine out of ten year for a h crop while for a low value crop, it may not b mical to provide an adequate supply more t years out of ten.

9.27 The procedure for determining the distribution of effective rainfall is based assumption that for any fixed period of time location, other factors being equal, effective will vary from year to year in direct pro

the variance in total rainfall. Thus the frequency distribution of effective rainfall will approximate that of total rainfall. The procedure is as follows :

9.28 From Table 11, find the factor that represents the percent chance of occurrence and the average annual rainfall. Multiply this factor by the normal effective rainfall during growing season to arrive at the percent chance growing season effective rainfall. For example, it is desired to find the effective rainfall during growing season that will be equalled or exceeded in 8 out of 10 years at a location where the average total rainfall is 1000 millimetres and for a growing season where the normal effective rainfall is 300 millimetre. From the table, the applicable ratio is found to be 0.83. Thus, the 80 percent chance growing season effective rainfall is

$$0.83 \times 300 = 249 \text{ millimetre.}$$

CHAPTER X

Irrigation Water Requirements

10.10 Consumptive use data are used in estimating the irrigation water requirements of existing or proposed projects and for crop production on individual farms. The consumptive irrigation water requirement is dependent not only on total consumptive need, but also on the amount of moisture contributed from such natural sources as effective growing season rainfall, carry over soil moisture from pre-sowing rain or prior crops and any contribution from ground water. Effective rainfall has been discussed in preceding paragraphs. The other natural sources are discussed below.

Soil Water

10.11 There is such data on depth over which the crop extracts most of its water show great difference. With salt free water in ample supply, water uptake for most field crops has been expressed as 40 percent of total water uptake over the first one fourth of total rooting depth, 30 percent over the second one fourth, 20 percent over the third and 10 percent over the last. However, movement of soil water will take place inside and to the root zone when portions become dry. Also water can be supplied to the roots from shallow ground water. If plants are sufficiently anchored and there are proper growing conditions, including available water and nutrients, soil aeration, soil temperature and soil structure, *ET* crop is not affected even when rooting depth is severly restricted. Water Management practices should be adjusted accordingly.

Available Soil Water

10.12 The methods of working ET crop assume soil water in ample supply. After irrigation or rain the soil water content will be reduced primarily by evapo-transpiration. As the soil dries, the rate of soil water movement will reduce. When at some stage the rate of flow falls below the rate needed to meet ET Crop, ET Crop will fall below its predicted level. The effect of soil water content on evapotranspiration varies with crop and is conditioned primarily by type of soils and water holding characteristics, cr rooting characteristics and the meteorological facto determing the level of transpiration. With modera evaporative conditions whereby ET crop does n exceed 5 mm/day, for most field crops ET cr is likely to be little affected at soil water te sions up to one atmosphere (corresponding appr ximately to 30 volume percentage of availab soil water for clay, 40 for loam, 50 for sandy loa and 60 for loamy sand). When evaporative conditio are lower the crop may transpire at the predicted E rate even though available soil water depletion greater ; when higher, ET crop will be reduced if t rate of water supply to the roots is unable to co with transpiration losses. This will be more pronounce in heavy textured than in light textured soils.

10.13 Since reduction in evapotranspiration affects cr growth and/or crop yields, timing and magnitude of r duction in ET crop are important criteria for irrigatio practices. Following an irrigation the crop will transpir at the predicted rate during the days immediately follow ing irrigation. With time the soils become drier and th rate will decrease, more so under high as compared t low evaporative conditions. Whether or not th reduction in ET crop is permissible during part o whole growing season can be determined only whe the effect of soil water stress on yield during variou stages of growth is known.

10.14 In planning and design, the predicted ET crop values should be applied unless specific objectives are pursued such as assuring that the greatest numbe of farmers benefit from irrigation or maximising yield per unit of water when available water supply is the limiting factor.

Carryover Soil Moisture

10.15 The contribution of carryover soil moisture resulting from pre-sowing rains or residual moisture from the prior crop is difficult to estimate. In some areas, and during some seasons, pre-sowing precipitation is sufficient to bring the soil moisture in the root zone depth of the profile up to field capacity. The

ontribution from residual moisture from prior crops may be significant particularly when the prior crop was paddy.

Ground Water Contribution

10.16 In areas of high natural ground water, the irrigation requirement may be materially less than if ground water were not available. For some deep rooted crops, as much as one third of the seasonal consumptive use requirement may be contributed by ground water.

Net Field Irrigation Requirement

10.17 Net field irrigation water requirements for any period of time are estimated by subtracting, from consumptive use and other uses, that moisture that is supplied by one or more of the three natural sources previously mentioned.

10.18 Calculation at the end of this chapter illustrates the procedure for estimating both average net irrigation requirements and those net irrigation requirements that can be expected to be equalled or exceeded in five out of ten years using a crop of jowar grown after paddy near Ballary, Karnataka State. In this case, it has been assumed that residual moisture is 50 mm above the 50 percent level available of water holding capacity. The net irrigation requirement is 75 mm. It has been assumed that each farmer in a project starts irrigating when the soil moisture reaches the 50 percent level and applies enough water to bring the moisture level up to field capacity. Then at any given time the average soil moisture level over the entire project area will approximate 75 percent. The amount of moisture between the 50 and 75 percent levels (equivalent to one-half the net application or 37·5 mm in this case) has been carried over from month to month and finally consumed at the end of the growing season as shown in the calculation. This leaves the moisture in the soil profile at approximately 50 percent level at that time. The procedure for estimating gross irrigation requirement is also illustrated.

Field Application Efficiencies

10.19 Due to unavoidable losses, no field application of irrigation water can ever be 100 percent efficient. Thus, more water than is needed to satisfy net irrigation requirements must be applied. A reasonable accurate estimate of field application efficiencies must therefore be made in order to estimate gross field irrigation requirements.

10.20 Application losses include evaporation deep percolation, and surface runoff. The extent of such losses will depend on a number of different factors. The principal ones are discussed in succeeding paragraphs.

10.21 Probably the most important influence on application efficiencies is the skill and attention given by the irrigator. A field can be over-irrigated with considerable waste of water if the irrigator does not know how to move the water to another area or is careless in his work. Irrigation at night is frequently at a low efficiency level because of the inadequate attention that is given to proper water distribution (infiltration).

Intake Characteristics of Soils

10.22 In general, considerable loss of water due to deep percolation may be expected when coarse-textured soils with high intake rates are irrigated by surface methods. On the other hand when fine-textured soils with very low intake rates are irrigated by these methods, considerable losses will occur in the form of excess surface runoff. In either case, field application efficiencies are affected.

10.23 Variations in soil intake rates are also a factor in lowering application efficiencies. The intake rate of most soil on which a rotation of crops is grown, will vary both throughout the growing season and from year to year within the rotation period. Unless considerable flexibility is designed into the irrigation system and the irrigator has the skill required to adjust stream sizes to these changing intake rates, field application efficiencies will be materially lowered.

Topography

10.24 It is more difficult to control the flow of water on sloping land than it is on level or near level land. When relatively steep slopes are irrigated by either of the furrow, corrugation, border or contour ditch method, excessive surface runoff can be expected where enough water is applied to meet crop requirements. Highest application efficiencies are attained where the land is nearly level and all irregularities are removed by land levelling.

10.25 Where fields are sub-irrigated, the difficulty in maintaining a water-table approximately parallel to the land surface increases as slopes increase.

Climate

10.26 In arid and semi-arid areas where air temperatures and wind velocities are high, appreciable losses may be expected from the resulting evaporation. These tend to lower application efficiencies of all methods of irrigation except sub-irrigation. Sprinkler irrigation is particularly affected. High wind velocities may distort the distribution pattern that high application efficiencies are not attainable.

Net Depth of Irrigation

10.27 The amount of water applied at one irrigation and stored in the soil profile for plant use will affect

the application efficiency with some methods of irrigation. In the case of sprinklers, for example, the water retained on the ground foliage and that evaporated from the ground surface while sprinkling is in process will be approximately the same regardless of the depth of application. Thus, these losses will be greater percentage-wise for light applications. In the case of graded furrows or corrugations, the amount of water lost to deep percolation will be approximately equal for both light and heavy applications. Generally speaking, than, with these methods, lighter application will be made at lower efficiencies than will heavier applications. It follows that it is desirable to apply less frequent heavy application as permitted by the water holding capacity of the soil profile.

Irrigation Method

10.28 Relatively high application efficiencies can be attained by most methods of irrigation where the soils, topographic and climatic conditions are favourable. However, for any given set of conditions, usually a higher application efficiency can be attained with one method that can be attained with another. For example, a close-growing crop on a near-level field of deep medium textured soils where normal wind velocities exceed 24 kilometres per hour could be irrigated by the border method with a high application efficiency. Under the same conditions a sprinkler system would have a much lower application efficiency. If the same crop were to be irrigated on a sloping field with relatively calm wind conditions, the sprinkler system would prove to be more efficient. Thus in order to attain a high application efficiency, it is important that the most adaptable method of irrigation be selected.

Adequacy of System Design and Installation

10.29 In order to attain a high application efficiency, any irrigation system, regardless of method, must be adequately designed and properly installed. The system must include all structures and other devices necessary for controlling the irrigation stream. The extent to which this is accomplished will, in large measure, determine the application efficiency that can be reached.

Tailwater Recovery System

10.30 In some instances where the graded furrow and border methods of irrigation are used relatively large percentages of surface runoff cannot be avoided due to low soil intake rates. In such cases, field application efficiencies are low. Approximately 50 to 65 percent of these losses can be recovered, however, for re-use where tailwater recovery systems are installed. These are systems whereby the runoff from graded furrow and border systems is collected and either pumped back for re-use on the same field or allowed to flow by gravity into other fields of elevation. The use of such a system will materially increase the overall application efficiency on the farm.

Estimating Field Application Efficiencies

10.31 After all of the afore-mentioned influential factors have been given due consideration, field application efficiencies may best be estimated. Table 12 may be used as a guide for this purpose.

Water Requirements of Principal Crops

10.32 Water plays a vital role in crop production. With the introduction of the high yielding crop varieties and other advanced technology available at the farm, an essential aspect in agricultural production, needs to be tackled, is the efficient soil and water management. In the efficient irrigation water management programme, time of irrigation, amount of water to be applied through each irrigation and the best way of irrigation would need careful consideration. The amount of application of water during irrigation depends mainly on the soil type, the effective root zone, the carryover moisture in the soil before irrigation and the salt content in the soil.

10.33 A lot of work has been done on water requirement of field crops. For principal crops like Paddy, Wheat, Maize, Bajra, Barley, Groundnut, Mustard, Linseed, Cotton and Sugarcane, the suggested values for different parts of country are given in Tables 30-39.

TABLE 10.1

Sample Calculation—Estimating net field Irrigation requirements, cm.

Period	*CU*	Re_{50}	Carry-over	NIR_{50}	App. eff.	FIR_{50}	Re_{80}	Carry over	NIR_{80}	FIR_{80}
October 16	37.4	34.2	50.0	None	75	—	25.7	50.0	None	—
November	84.1	21.9	46.8	52.9	75	70.5	16.4	38.3	66.9	89.2
December	132.0	5.4	37.5	126.6	75	168.8	—	37.5	132.0	176.0
January	189.1	1.5	47.5	161.3	75	215 1	—	37.5	162.8	217.1
February 1-2	11.2	2	11.2	None	75	—	—	11.2	None	—
	453.8	63.2		340.8		454.4	42.1		361.7	482.3

Cols. 3, 5 and 7 Rainfall level 50 percent chance recurrence.

Cols. 8, 10 and 11 Rainfall level 80 percent chance recurrence.

CU consumptive use (Evapotranspiration)

Re_{50}—Effective rainfall—50 percent chance of occurrence.

Re_{80}—Effective rainfall—80 percent chance of occurrence.

NIR—Net irrigation requirement.

FIR—Field irrigation requirement.

CHAPTER XI

Requirements for Related Purposes

11.10 In order to maintain the sustained high crop production the removal of harmful soluble salts from the crop root zone is essential in irrigated soils. Salts accumulations are affected mainly by irrigation water quality, irrigation methods and practices, soil conditions and rainfall. The concentration of the salts in the soil solution results from the extraction of the moisture from the soil by the processes of evaporation and transpiration. Salinity levels in the soil increase as the growing season of crops advances. Such salt concentrations can be removed by passing enough water through the soil profile to dissolve the harmful soluble salts and transport them by the downward movement of water out of or beyond the crop root zone. This process is known as leaching.

11.11 To make the leaching process successful, the drainage should be adequate otherwise it may cause the water-table to rise and the soluble salts will quickly return to the root zone. In humid and sub-humid areas (mean annual rainfall exceeding 30 inches) salt free water is usually passed through the soil profile naturally in sufficient quantities to dissolve and remove salt accumulations and thus leaching is seldom required. In arid and semi-arid areas, rainfall may be insufficient to accomplish this purpose and water in excess of crop needs must be applied annually to maintain the salt content at a level that will assure sustained crop production.

Effect of Irrigation Water Quality

11.12 The salt content of irrigation water is obtained from the chemical analysis in which the amounts of the various salts present are usually expressed in parts per million. Some salts of low solubility such as Magnesium carbonate, Calcium carbonate, Calcium bicarbonate and Calcium sulphate are not considered to be harmful. Thus the amounts of these salts should not be considered in arriving at the total harmful salts content of the water. For use in computing leaching requirements the harmful salt contents of irrigation water is expressed in terms of electrical conductivity (*ECw*) in millimhos per centimetre. To convert to millimhos per centimetre, parts per million are divided by 640.

11.13 Table 11.1 can be used to evaluat effect of quality of irrigation water on soil sa permeability and toxicity.

TABLE 11.1

Effect of Irrigation Water Quality on Soil Salinity, Permeability and Toxicity

	None	Moderate	Sev
Salinity			
ECw (mmhos/cm)	<0.75	0.75—3.0	>3
Permeability			
ECw (mmhos/cm) adj. *SAR*	>0.5	0.5—0.2	<0
Montmorillonite	<6	6—9	>9
Illite	<8	8— 6	>1
Kaolinite	<16	16—24	>2
Toxicity (Most tree crops)			
Sodium (adj. *SAR*)*	<3	3—9	>9
Chloride (meq/l)**	<4	4—10	>1
Boran (mg/l)	<0·75	0.75—2	>2

* For most field crops use following table of this cl

** Sprinkler irrigation may cause leaf burn wh meq/l.

Source : FAO Irrigation and Drainage Paper No. 2

Leaching Requirement

11.14 Leaching requirement (*LR*) is the minimum amount of irrigation water supplied that must be drained through the root zone to control soil salinity at the given specific level. The following table 11.2 showing crop tolerance levels can be used to determine the leaching requirements for a given quality of irrigation water. The tolerance levels of crops are given as electrical conductivity of the soil saturation extract (*ECe*) for a crop appropriate to the tolerable degree of yield reduction. With poor quality irrigation water, frequent irrigation and excessive leaching water may be required to obtain acceptable yields. In the table the values of *ECw* (Electrical Conductivity of Irrigation Water) and *ECe* (Electrical Conductivity of the soil Saturation Extract) are given which could be used for the estimating leaching requirement. For sandy loam to clay loam soils with good drainage and where rainfall is low the leaching requirement can be obtained from :

TABLE 11.2

Crop Salt Tolerance Levels for Different Crops (Ayers and Westcot 1976)

Crop	Yield Potential								Max. ECe
	100%		90%		75%		50%		
	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	
Field/Crops									
Barley (1)	8.0	5.3	10.0	6.7	13.0	8.7	18.0	12.0	28
Beans (field)	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	7
Broad beans	1.6	1.1	2.6	1.8	4.2	2.0	6.8	4.5	12
Corn	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10
Cotton	7.7	5.1	9.6	6.4	13.0	8.4	11.0	11.0	27
Cowpeas	1.3	0.9	2.0	1.3	3.1	2.1	4.9	3.2	9
Flax	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10
Groundnut	3.2	2.1	3.5	2.4	4.1	2.7	4.9	3.3	7
Rice (Paddy)	3.0	2.0	3.8	2.6	5.1	3.4	7.2	4.8	12
Safflower	5.3	3.5	6.2	4.1	7.6	5.0	9.9	6.6	15
Sesbania	2.3	1.5	3.7	2.5	5.9	3.9	9.4	6.3	17
Sorghum	4.0	2.7	1.5	3.4	7.2	4.8	11.0	2.2	18
Soyabean	5.0	3.3	5.5	3.7	6.2	4.2	7.5	5.0	10
Sugarbeet	7.0	4.7	8.7	5.8	11.0	7.5	15.0	10.0	24
Wheat(1)	6.0	4.0	7.4	4.9	9.5	6.4	13.0	8.7	20

TABLE 11.2 (*Contd.*)

Crop	Yield Potential							
	100%		90%		75%		50%	
	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw
Vegetable Crops								
Beans	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4
Beets(2)	4.0	2.7	5.1	3.4	6.8	4.5	9.6	6.4
Broccoli	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5
Cabbage	1.8	1.2	2.8	1.9	4.4	2 9	7.0	4.6
Cantaloupe	2.2	1.5	3.6	2.4	5.7	3.8	9.1	6.1
Carrot	1.0	0.7	1.7	1.1	2.8	1.9	4.6	3.1
Cucumber	2.5	1 7	3.3	2.2	4.4	2.9	6.3	4.2
Lettuce	1.3	0.9	2.1	1.4	3.2	2.1	5.2	3.4
Onion	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9
Pepper	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4
Potato	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9
Radish	1.2	0.8	2.0	1.3	3.1	2.1	5.0	3,4
Spinach	2.0	1.3	3.3	2.2	5.8	3.5	8.6	5.7
Sweet Corn	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9
Sweet Potato	1·5	1.0	2.4	1.6	3.8	2.5	6.0	4.0
Tomato	1.2	1.7	3.5	2.3	5.0	3.4	7.6	5.0
Forage crops								
Alfaalfa	2.0	1.3	3.4	2.2	5.4	3.6	8.8	5.9
Barley hay (1)	6.0	4.0	7.4	4.9	9.5	6.3	13.0	8.7
Bermuda grass	6.9	4.6	8.5	5.7	10·8	7.2	14.7	9.8
Clover, berseem	1.5	1.0	3.2	2.1	5.9	3.9	10·3	6.8
Corn (Forage)	1.8	1.2	3.2	2.1	5.2	3.5	8.6	5.7
Harding grass	4.6	3.1	5.9	3.9	7.9	5.4	11.1	7.4
Orchard grass	1.5	1.0	3.1	2.1	5.5	3.7	9.6	6.4
Perennial rye	5.6	3.7	6.9	4.6	8.9	5.9	12.2	8.1

TABLE 11.2 (*Contd.*)

Crop	Yield Potential								Max. ECe
	100%		90%		75%		50%		
	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	
Sudan grass	2.8	1.9	5.1	3.4	8.6	5.7	14.4	9.6	26
Tall fescue	3.9	2.6	5.8	3.9	8 6	5.7	13.3	8.9	23
Tall Wheat grass	7.5	5.7	9.9	6.6	13.3	9·0	19.4	13.0	32
Trefoil, big	2.3	1.5	2.8	1.9	3.6	2.4	4.9	3.3	8
Trefoil, small	5.0	3.3	6.0	4.0	7.5	5.0	10.0	6 7	15
Wheat grass	7.5	5.0	9.0	6.0	11.0	7.4	15.0	9.8	22
Fruit Crops									
Almond	1.5	1.0	2.0	1.4	2.8	1.9	4.1	2.7	7
Apple, Pear	1.7	1.0	2.3	1.6	3.3	2.2	4 8	3.2	8
Apricot	1.6	1.1	2.0	1.3	2.6	1.8	3.7	2.5	6
Avocado	1.3	0 9	1.8	1.2	2.5	1.7	3.7	2.4	5
Date Palm	4.0	2.7	6.8	4.5	10.9	7.3	17.9	12.0	32
Fig, Olive, Pomegranate	2.7	1.8	3.8	2.6	5.5	3.7	8.4	5.6	14
Grape	1.5	1.0	2.5	1.7	4.1	2.7	6.7	4.5	12
Grapefruit	1.8	1.2	2.4	1.6	3.4	2.2	4.9	3.3	8
Lemon	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8
Orange	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8
Peach	1.7	1.1	2.2	1.4	2.9	1.9	4.1	2.7	7
Plum	1.5	1.0	2.1	1.4	2.9	1.9	4.3	2.8	7
Strawberry	1.0	0.7	1.3	0.9	1.8	1.2	2.5	1.7	4
Walnut	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8

(1) During germination and seedling stage ECe should not exceed 4 or 5 mmhos/cm. Data may not apply to new semi-dwarf varieties of wheat.

(2) During germination ECe should not exceed 3 mmhos/cm.

Source : FAO Irrigation and Drainage Paper No. 24.

For surface irrigation methods (including sprinklers)

$$LR=\frac{ECw}{(5\ ECe-ECw)}\left(\frac{1}{Le}\right)$$

For drip and high frequency sprinkler

$$LR=\frac{ECw}{2\ \text{Max.}\ ECe}\left(\frac{1}{Le}\right)$$

where

ECw=electrical conductivity of the irrigation water, mmhos/cm.

ECe=electrical conductivity of the soil saturation extract for a given crop appropriate to the mmhos/cm tolerable degree of yield reduction.

Max. ECe=Maximum tolerable electrical conductivity of the soil saturation extract for a given crop, mmhos/cm.

Le=Leaching efficiency, decimals.

Examples

11.15 Given

(*i*) Et crop=1065 mm/season

(*ii*) Effective rainfall during growth season =160 mm

(*iii*) From water analysis (ECw)=7 mmhos/cm

(*iv*) Leaching efficiency (Le)=70 percent

(*v*) Irrigation method—Surface method

(*vi*) Soil is slightly layered and crop is cotto

Since

$$LR=\left(\frac{ECw}{5\ ECe-ECw}\right)\frac{1}{Le}$$

For cotton crop, (*a*) at 100 percent yield po tial and (*b*) at 75 percent yield po ntial the value ECe from the salt tole nce levels detail Table are and 13.0 mmhos/cm respectively.

Therefore, for

(*a*) $LR=\left(\frac{7}{5\times7.7-7}\right)\times\frac{1}{0.7}=0.32$

and for (*b*) $LR=\left(\frac{7}{5\times13-7}\right)\frac{1}{0.7}=0.17$

Therefore to meet seaso l ET Crop an water required for case (*a*) a d (*b*) would below :

$$a=\frac{ET\ \text{Crop}-Pe}{1-LR}$$

$$=\frac{1065-160}{1-0.32}=1330\ \text{m}$$

$$b=\frac{1065-160}{1-0.17}=1090\ \text{mm}$$

CHAPTER XII

Water Losses and Irrigation Efficiency

12.10 Considerable amount of water is lost through evaporation and seepage in the Canal System from the head of the Canal upto the canal outlet where water is delivered to the farmer's water course. These losses are termed as the conveyance losses. According to a study of Central Water and Power Commission (1967) it is observed that in any unlined Canal System from Head Works down to the field the loss of water is to the extent of 71 percent (Canals 15 percent, Distributaries 7 percent, Water Courses or Field Channels 22 percent, Field losses 27 percent) and only 29 percent is effective for utilisation. The bulk of losses, however, take place in unlined water-conveyance system and field channels. It is, therefore, very necessary that these losses are accounted for at the time of design of Irrigation System.

Seepage and Evapotranspiration Losses

12.11 Slow to rapid seepage through the sides and bed of canal takes place depending on the type of soil or geological formation through which the Canals traverse, depth of flow, velocity of flow, level of the ground water table, silt load in the flowing water, wetted perimeter etc. Evapotranspiration losses take place from weeds and plants in the channel bed and sides of embankments.

Evaporation Losses

12.12 These losses take place from the exposed water surface area which would vary with temperatures, humidity, wind velocity, etc., and are thus related to the pan evaporation rate. In hot and dry summer months these losses are maximum but they may seldom exceed about 10 percent of the total conveyance losses.

Operational Losses

12.13 Operational water losses result during the delivery of water by sluicing, breaks in the conduits and diversions or deliveries in excess of demands. Canal operational losses are dependent on many conditions which may be quite different from project to project.

12.14 Water deliveries in excess of the scheduled rate of flow result in excess deliveries to turnouts and spills at wasteways. Also when the demand for water is abruptly decreased from wasteways before the flow in the system can be reduced. These losses are some times termed regulatory losses. They are often substantial even for the most efficiently constructed and managed system. On large objects, with normal management, regulatory losses have run from 5 to 30 percent of the diversion amount. On carefully managed projects these losses can usually be held below 10 per cent of the diversion.

12.15 Gate leakage on large canals is usually not significant, however, as the volume of flow decreases and the number of gates increase this loss may become more meaningful. Estimates of this value will vary widely depending on the type of gates, maintenance programme and the degree of enforcement of closing regulations.

12.16 Perhaps the largest quantum of operational losses occurs during night irrigations. This is particularly so in cases where the irrigation water delivery system is not in proper condition. When breakouts occur during the night, they are often not discovered and repaired early, thus resulting in a substantial increase in operational losses.

Other Losses

12.17 These losses are due to slippage by over topping of canal banks ; breaches-accidental or deliberate. It is important to make an allowance of 10 to 15 percent in fully lined system and somewhat higher percentages in unlined systems to provide for these losses.

12.18 Of the above losses, seepage losses from a significant component of the total losses and it is necessary to assess the same as accurately as possible. The design of a conveyance system takes into account the crop water requirement in the field plus assumed seepage losses.

12.19 The theoretical solution for estimating seepage losses would be very difficult. It is, therefore, the general practice to estimate the average losses over a

length of channel based on experimental data obtained from existing channels and is usually sufficient for design purposes. The observed value is usually the combined figure for evaporation and seepage losses expressed as cumecs per million square metre of wetted area perimeter or cubicmeters per square metre of wetted perimeter per 24 hours.

12.20 It is considered desirable to mention a few general points in respect of the Seepage losses that occur in unlined and lined channels :

1. Seepage losses rates increase with the increase in water depth (ordischarge) in a channel.

2. An analysis of typical unlined channel sections shows that wetted perimeter (sqm) per unit of discharge (cumec) decreases from 7·3 for 0.28 cumec channel to 0.2 only for a 300 cumec channel.

3. In absolute terms the total seepage loss as percentage of the head discharge is larger for smaller stages of flow than for higher stages of channel's running. Also, the loss as percentage of head discharge decreases as the channel size increases.

4. Seepage losses increase as the difference between the water level in the channel and ground water table increases subject to certain limitations on the ceiling of this difference. It is generally assumed that if this difference in the two water levels is larger than 5 times the water surface width for average soil conditions of the channel, seepage losses do not increases any further.

5. The distribution of seepage losses across the canal profile depends upon the location of the water table or relatively impervious layer of strata with respect to the bed of the Canal. If the water table is shallow and is lower than but in close proximity of the canal bed, the contribution of seepage losses from the sides per unit wetted area would be more form the sides as compared to that from the bed. On the other hand if the water table is deep the reverse order of the contribution may prevail.

6. Seepage losses depend upon the nature of soil forming the channel profile. The significant depth of soil which may affect the seepage rate from the canal is assumed to be 5 times the bed width of the channel.

12.21 The rate of seepage losses as being adopted for design of canal by various agencies are given below :

(i) The seepage loss values suggested by Etchevery and Harding are shown below (Table 12.1)

TABLE 12.1

Character of Material	Seepage Losses: Cubic metre per square metre of wetted perimeter per 24 hours	Cubic feet per square feet of wetted perimeter per 24 hours	Cumec per million square metres of wetted perimeter	Cu per mill squa feet wet peri me
1.	2.	3.	4.	5.
Impervious	0.076-0.11	0.25-0.35	0.92-1.20	3.0-
Medium Clay Loam underlaid with hard pan at depth of not over 0.6 to 1.0 m below bed	0.11-0.15	0.35-0.50	1.2-1.8	4.0-6.7
Ordinary clay loam, silt soil, or lava ash loam	0.15-0.23	0.50-0.75	1.8-2.7	6.0-9.0
Gravelly or sandy clay loam, cemented gravel, sand and clay	0.23-0.30	0.75-1.00	2.7-3.6	9.0-12.0
Sandy loam	0.30-0.46	1.00-1.50	3.6-5.2	12.0-17.0
Loose Sandy Soil	0.46-0.53	1.50-2.75	5.2-6.1	17.0-20
Gravelly Sandy Soil	0.61-0.76	2.00-2.50	7.0-8.8	23.0-29.0
Porous gravelly soil	0.76-0.91	2.50-3.00	8.8-10.6	29.0-35.0
Very gravelly soil	0.91-1.83	3.00-6.00	10.6-21.2	35.0-70

The values adopted by the United States Bureau of Reclamation are shown below : (Table 12.2)

TABLE 12.2

Material	Seepage Losses			
	Cubic metre of wetted perimeter in 24 hours	Cubic feet of wetted perimeter in 24 hours	Cumec per million square metre of wetted perimeter	Cusec per million square feet of wetted perimeter
1	2	3	4	5
Cemented gravel and boulders with sandy soil	0.10	0.34	1.19	3.9
Clay and clay loam	0.12	0.41	1.46	4.8
Sandy loam	0.20	0.66	2.35	7.7
Volcanic ash	0.21	0.68	2.40	7.9
Volcanic ash with some sand	0.30	0.98	3.47	11.4
Sand and volcanic ash or clay	0.36	1.20	4.23	13.9
Sandy soil with some rock	0.51	1.68	5.94	19.5
Sandy and gravelly soil	0.67	2.20	7.83	25.7
Concrete Lining	0.10	0.33	1.16	38

The method of calculating the conveyance losses can be illustrated as follows :

Data : Bed width = 10 m

Full supply depth = 1.5 m

Side Slopes = 1 : 1

K = 2 cumec/M.Sq.m.

Wetted perimeter = B + √2 D = 14·24 m

conveyance losses per kilometre =

$$14{\cdot}24 \times 1000 \times \frac{2}{10^6} = 0{\cdot}028 \text{ cumecs.}$$

(*iii*) The method of calculating seepage losses suggested by Davis and Wilson is as under :

$$SL = 0{\cdot}45 \times C \times \frac{P_w \times L}{4 \times 10^6 + 3650\sqrt{V}} \times Hw^{1/3}$$

Where

S = Seepage losses (m^3 per length of canal per day)

L = Length of canal (m)

Pw = Wetted perimeter (m)

Hw = Water depth in the canal (m)

V = Velocity of flow in canal (m per sec)

C = Constant value depending on lining.

Type of Lining	*Value of C*
Concrete (10 cm)	1
Mass clay (15 cm)	4
Light asphalt	5
Clay (7.6 cm)	8
Asphalt or cement mortar	10

(*iv*) Allowance for transit losses varies in different states according to type of soil and canal capacity. In some States, empirical formulae are used as in U.P. and Punjab while in others, allowance made is arbitrary. It normally varies from 1.83 to 3.96 cumecs per million sq. m of wetted perimeter for unlined and negligible to 1.52 cumecs per million sq. m. of wetted perimeter, in case of lined channels. The statewise transit losses allowed in canal design are given below : (Table 12.3)

TABLE 12.3

	Transit losses in cumecs per million sq. m. of wetted perimeter	
	Unlined	*Lined*
Andhra Pradesh (a)	1.83	—
Gujarat	2.44, 3.96 (b)	0.3(c)
Karnataka	2.44	1.52
Kerala	1.83 to 2.44	0.0
Maharashtra	3.05, 4.6 (f)	0.61
Punjab	$K=1.9\ Q\ 0.0625$	$K=0.47\ Q0.056$
Rajasthan	$K=1.9\ Q\ 0.0625$ or 1.83 to 3.05 (g)	0.61
Tamil Nadu	0.9 to 3.05 (d)	0.412, 0.717(e)
Uttar Pradesh	3.05 or $K=\frac{c*(b+d)^{0.67}}{8}$	0.0
C.W.P.C.	0.9 to 3.05	0.61

*Value of 'c' is generally taken 0.5047 for constantly running main and branch canals and 0.6740 for all other canals ; b=width ; d=depth.

(a) for channels upto 14 cumecs only.

(b) for alluvial soil only. 2.44 for mains and branches and 3.96 for distributaries.

(c) in main canal transit losses have been estimated 1/10th of the unlined canals.

(d) losses for rock section are 0.91, black cotton soil 1.52 alluvial or red soil 2.44 and decayed rock 3.05 cumecs.

(e) 0.72 is based on inflow outflow method and 0.41 on impounding method.

(f) 3.05 cumecs for canals upto 7 cumecs and 4.6 cumecs for canal capacity greater than 7 cumecs.

(g) 1.83 to 2.44 cumecs for ordinary soil and 3.05 cumecs for sandy soil.

12.22 Data on actual observations of canal loss limited, but even the limited data have shown actual losses are generally much higher than assumed in design calculations. In the appraisa the Chambal Project carried out by the World the values of conveyance efficiency assumed are in water courses and 75% in the rest of the system for the Rajasthan part of the system givin overall conveyance efficiency of 52.5% while co ponding figures for Madhya Pradesh part are 6 cent and 50% which work out to an overall conve efficiency of 32.5 percent. In the Periyar-Vaigai which has been in existence for about 80 years the all conveyance efficiency worked out by the Worl is 45 percent. As against these values, the system of the Jayakwadi Project in Maharashtra pected to give a conveyance efficiency of 65 pe with all canals carrying upto 1.4 cumecs (50 c being lined and smaller canals unlined.

12.23 In order to reduce conveyance losses, lining of either in limited to selected reaches or ring the entire system is adopted The resu experiments for finding seepage losses in the channels with different materials carried Haryana are as under (Table 12.4)

TABLE 12.4

Type of lining	Seepage losses cumecs/ m. sq. m.	S loss cu m.
1. Conventional single tile lining with two plasters underneath	0.298	0.9
2. LDPE film lining in bed covered with tile lining thick and sides with conventional tile lining with two plasters	0.19	0.
3. LDPE film lining in bed and sides covered with tile lining laid in 1 : 3 mortar 60 cm	0.13	0.
Type of soil		Sandy clay

12.24 The discharge in the channel goes on re along the length and so does the bed width water depth. The losses have thus to be work for each section separately as well as for the o laterals or distributaries. These are then added find the total loss in the system.

me canal systems, it becomes necessary design or operate the canals and their laterals or distributaries for higher discharge in Kharif season and during Rabi (winter) season these laterals have to be operated for 1/3rd or 1/4th of the full capacity. Unless the wetted perimeter practically remains the same, the losses need to be worked out carefully at the time of planning and necessary provisions made to avoid shortage of water for crops in the Rabi season.

Storage Losses

12.26 Storage of water in tanks or reservoirs may be necessary for several reasons. Where intermittant streams may be relied upon to provide irrigation water, flow in such streams is often very low or non-existant during the irrigation season. In such cases, run-off from the watershed during the rainy seasons must be stored for use during the irrigation seasons. Where water is received from a project, the delivery schedules to the cultivator's fields may be such that water is not always received when and in the amount needed to satisfy farm irrigation requirements. Water may be received at rates which are too small to provide an irrigation stream that is adequate to operate the farm irrigation system efficiently. It may also be desirable to store the water delivered at night for use the following day. In either case storage reservoirs should be provided. In the latter cases, the reservoirs are referred to as equalizing reservoirs.

When water is stored in a reservoir, either on a farm or in a project, certain unavoidable losses will be incurred. These losses must be considered when estimating either farm or project irrigation requirements.

Seepage Losses in Reservoirs

12.27 The principal factors influencing seepage losses in reservoirs are the permeability and thickness of the soil layers in the ponded area and the total head of water producing seepage.

Seepage rates in existing reservoirs can be measured by the ponding methods. The procedure is similar to that used for unlined canals except that, in the case of reservoirs, evaporation rates must be estimated and subtracted from the total rate of loss.

12.28 Predicting or estimating seepage loss rates in proposed reservoirs involves primarily a knowledge of the permeability rates of the soils over which water is to be impounded. Permeability rates can be determined by the well permeater method or the laboratory permeability method.

Evaporation Losses in Reservoirs

12.29 There are several sophisticated methods for estimating daily and monthly evaporation rates in reservoirs. They are beyond the scope of this bulletin. A good average rate for reservoir evaporation is 0·7 times class A pan evaporation.

Losses Due to Phreatophytes and Hydrophytes

12.30 Where these water-loving plants are allowed to grow around the banks or in the shallow waters of an irrigation reservoir, their consumptive use may cause a considerable loss of water. Where these plants cannot be eliminated economically, the water lost to their consumptive use should be considered.

Phreatophytes are plants that habitually grow where they can send their roots down to the water-table or the capillary fringe immediately overlying the water-tables. They range in size from small natural vegetation to trees. Hydrophytes are plants that live wholly or partly submerged in water, or with roots in saturated soil that is intermittently submerged.

The moisture requirements for these natural plants are usually satisfied before water becomes available for irrigation or other purposes. Measurements of consumptive use indicate that some water-loving natural vegetation uses from 50 to 100 percent more water than most field crop plants.

Irrigation Efficiency

12.31 To account for losses of water incurred during conveyance and application to the field, and efficiency factor should be included while calculating the project irrigation requirement. The project efficiency is normally divided into three stages each of which is affected by a different set of conditions.

Conveyance efficiency (*Ec*) : ratio between water received at inlet to a block of fields and that released at the project headworks.

Field canal efficiency (*Eb*) : ratio between water received at the field inlet and that received at the inlet of the block of fields.

Field application efficiency (*Ea*) : ratio between water directly available to the crop and that received at the field inlet.

Project efficiency (*Ep*) : ratio between water made directly available to the crop and that released at headworks, or $Ep = Ea \cdot Eb \cdot Ec$.

12.32 Conveyance and field canal efficiency are sometimes combined as distribution efficiency (*Ed*), where $Ed = Ec \cdot Eb$; field canal and application efficiency are sometimes combined as farm efficiency where $Ef = Eb \cdot Ea$.

12.33 Factors affecting conveyance efficiency (*Ec*), are, amongst others, size of the irrigated area, size of rotational unit, number and types of crops requiring adjustments in the supply, canal lining and the technical and managerial facilities of water control, The fielded canal efficiency (*Eb*) is affected primarily by the method and control of operation, the type of soils in respect of seepage losses, length of field canals, size of the irrigation block and the fields. As can be expected, the distribution efficiency (*Ed*) has been shown to be particularly sensitive to quality of technical as well as origanizational operation procedures ($Ed = Ec \cdot Eb$). Farm efficiency (*Ef*) is much dictated by the operation of the main supply system in meeting the actual field supply requirements as well as by the irrigation skill of the farmers.

12.34 According to the FAO publication paper 24 (1977), the conveyance (*Ec*), field canal (*Eb*), distribution (*Ed*) and field application efficiency (*Ea*) a sample case are as below :

Conveyance Efficiency (Ec)

Continuous supply with no substantial change in flow 0.9

Rotational supply in projects of 3000–7000 ha and rotation areas of 70–300 ha, with effective management 0.8

Rotational supply in large schemes (>10000 ha) and small schemes (<1000 ha) with respective problematic communication and less effective management :

Based on predetermined schedule 0.7

Based on advance request 0.65

Field Canal Efficiency (Eb)

Blocks larger than 20 ha : Unlined 0.8

0.9 Lined or piped

Blocks up to 20 ha. 0.7 Unlined

0.8 Lined or piped

TABLE 1

Mean Monthly Values of Extraterrestrial Radiation

Lat. Degrees	Expressed as equivalent evaporation in inches and millimetres per month.											
	January		February		March		April		May		June	
	Inches	mms.	Inches	mms.	Inches	mms.	Inches	mms.	Inches	mms.	Inches	mms.
North												
45	6.15	156.21	7.87	199.90	12.58	319.53	16.17	410.72	19.81	503.17	20.53	521.46
40	7.72	196.09	9.21	233.93	13.79	350.27	16.90	429.26	20.08	510.03	20.53	521.46
35	9.27	235.46	10.50	266.70	14.91	378.71	17.50	444.50	20.23	513.84	20.44	519.18
30	10.79	274.07	11.73	297.94	15.91	404.11	17.98	456.69	20.26	514.60	20.23	513.84
25	12.26	311.40	12.87	326.90	16.79	426.47	18 33	465.58	20.16	512.06	19.91	505.71
20	13.67	347.22	13.93	353.82	17.54	445.52	18.55	471.17	19.92	505.97	19.46	494.28
15	15.00	381.00	14.89	378.21	18.16	461.26	18.63	473.20	19.55	496.57	18.89	479.80
10	16.24	412.50	15.75	400.05	18.64	473.46	18.57	471.68	19.05	483.88	18.21	462.53
5	17.37	441.20	16.49	418.85	18.98	482.09	18.37	466.60	18 42	467.87	17.41	442.21
0	18.40	467.36	17.12	434.85	19.17	486.92	18.04	458.22	17.67	448.82	16.50	419.10

TABLES

TABLE I (*Contd.*)

Lat. Degrees	Expressed as equivalent evaporation in inches and millimetres per month.											
	July		August		September		October		November		December	
	Inches	mms.	Inches	mms.	Inches	mms.	Inches	mms.	Inches	mms.	Inches	mms.
North												
45	20.64	524.26	18.15	461.01	13.86	352.04	10.13	257.30	6.65	168.91	5.45	138.43
40	20.76	527.30	18.70	474.98	14.87	377.70	11.54	293.12	8.15	207.01	7.02	178.31
35	20.76	527.30	19.12	485.65	15.77	400.56	12.86	326.64	9.63	244.60	8·59	218.19
30	20.65	524.51	19.40	492.76	16.55	420.37	14.10	358.14	11.06	280.92	10.15	257.81
25	20 41	518.41	19.56	496.82	17.20	436.88	15.24	387.10	12.43	315.72	11.67	296.42
20	20.04	509.02	19.57	497.08	17.72	450.09	16.26	413.00	13.74	349.00	13.14	333.76
15	19.55	496.57	19.45	494.03	18.11	459.99	17.17	436.12	14.95	379.73	14.53	369.06
10	18.93	480.82	19.18	487.17	18.35	466.09	17.95	455.93	16.07	408.18	15.85	402.59
5	18.18	461.78	18.78	477.01	18.46	468.88	18.60	472.44	17.09	434.09	17.07	433.58
0	17.32	439.93	18.25	463.55	18.43	468.12	19.11	485.39	17.99	456.95	18.18	461.77

Scheme Water Requirement

Scheme Area 200.0 (ha.) Irrigation Eff. 45 (%) Operation Time 12 (h/d) 6 (d/week)

Crop	Area (%)	Net Irrigation Requirement Per Crop (mm/mo) Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Maize 1	40	0.0	0.0	0.0	109.7	239.0	264.3	196.0	0.0	0.0	0.0	0.0	0.0	808.9
Maize 2	40	0.0	0.0	0.0	0.0	56.0	165.2	259.9	265.4	89.1	0.0	0.0	0.0	835.5
Pulses	20	0.0	0.0	0.0	0.0	0.0	128.4	251.5	210.6	0.0	0.0	0.0	0.0	590.5
		Scheme Irrigation Requirement												
Net Irr. Req.	(mm/mo)	0.0	0.0	0.0	43.9	118.0	197.5	232.6	148.3	35.6	0.0	0.0	0.0	775.9
Net Irr. Req.	(mm/d)	0.0	0.0	0.0	1.5	4.7	6.6	7.8	4.9	2.5	0.0	0.0	0.0	2.3
Net Irr. Req.	(1/s. ha)	0.0	0.0	0.0	0.2	0.5	0.8	0.9	0.6	0.3	0.0	0.0	0.0	0.3
Gross Irr. Req.	(mm/d)	0.0	0.0	0.0	3.4	10.4	14.7	17.2	11.0	5.7	0.0	0.0	0.0	5.2
Oper. Supl. Req.	(1/s. ha.)	0.0	0.0	0.0	0.9	2.8	4.0	4.7	3.0	1.5	0.0	0.0	0.0	1.4
Oper. Supl. Req.	(qm/s)	0.00	0.00	0.00	0.18	0.56	0.79	0.93	0.59	0.31	0.00	0.00	0.00	0.28

TABLE 2

Mean Temperature, T and Tc, Coefficient of Temperature, CT, and Log CT

T	Tc	CT	Log CT	T	Tc	CT	Log CT	T	Tc	CT	Log CT
°F	°C	...	...	°F	°C	...	...	°F	°C	...	...
				56	13.33	.787	—.1040	81	27.22	1.243	.0944
32	0.00	.393	—.4060	57	13.89	.804	—.0946	82	27.78	1.262	.1010
33	0.56	.408	—.3891	58	14.44	.822	—0.853	83	28.33	1.281	.1076
34	1.11	.424	—.3727	59	15.00	.839	—.0761	84	28,89	1.300	.1141
35	1.67	.440	—.3569	60	15.56	.857	—.0671	85	29.44	1.320	.1205
36	2.22	.455	—.3415	61	16.11	.874	—.0583	86	30.00	1.339	.1269
37	2.76	.471	—.3267	62	16.67	.892	—.0495	87	30.56	1.359	.1332
38	3.33	.487	—.3122	63	17.22	.910	—.0410	88	31.11	1.379	.1394
39	3.89	.503	—.2982	64	17.78	.928	—.0325	89	31.67	1.398	.1456
40	4.44	.519	—.2845	65	18.33	.946	—.0242	90	32.22	1.418	.1517
41	5.00	.536	—.2712	66	18.89	.964	—.0160	91	32.78	1.438	.1577
42	5.56	.552	—.2582	67	19.44	.982	—.0080	92	33.33	1.458	.1637
43	6.11	.568	—.2455	68	20.00	1.000	—.0000	93	33.89	1.478	.1696
44	6.67	.585	—.2332	69	20.56	1.018	—.0078	94	34.44	1.498	.1754
						1.037	—.0156	95	35.00	1.518	.1812

46	7.78	.618	—.2095	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
47	8.33	.634	—.1978	72	20.00	1.073	.0317	97	36.11	1.559	.1930
48	8.89	.651	—.1865	73	22.78	1.092	.0382	98	36.67	1.579	.1983
49	9.44	.668	—.1755	74	23.33	1.110	.0455	99	37.22	1.599	.2039
50	10.00	.684	—.1647	75	23.89	1.129	.0527	100	37.78	1.620	.2094
51	10.56	.701	—.1541	76	24.44	1.148	.0599	101	38.33	1.640	.2149
52	11.11	.718	—.1437	77	25.00	1.167	.0670	102	38.89	1.661	.2203
53	11.67	.735	—.1335	78	25.56	1.186	.0739	103	38.44	1.682	.2257
54	12.22	.753	—.1235	79	26.11	1.205	.0808	104	40.00	1.702	.2311
55	12.78	.770	—.1137	80	26.67	1.224	.0876	105	40.56	1.723	.2364

$C_T = 0.0678 + 0.0132\ T + 0.0000367\ T^2$

$C_T = 0.393 + 0.02796\ Tc + 0.0001189\ Tc^2$

TABLE 3

Wind Velocity W and Wk, Coefficient of Wind, Cw, and Log Cw

W	Wk	Cw	Log Cw	W	Wk	Cw	Log Cw	W	Wk	Cw	Log Cw
mi/day	km/day	...	...	mi/day	km/day	...	...	mi/day	km/day	...	...
0	0	.708	—.1500	56	90	.982	—.0077	86	138	1.104	.0428
5	8	.735	—.1337	57	92	.987	—.0058	87	140	1.107	.0443
10	16	.762	—.1183	58	93	.991	—.0039	88	142	1.111	.0457
15	24	.788	—.1037	59	95	.995	—.0020	89	143	1.115	.0472
20	32	.813	—.0893	60	97	1.000	.0000	90	145	1.118	.0486
25	40	.838	—.0766	61	98	1.004	.0017	91	146	1.122	.0500
30	48	.863	—.0641	62	100	1.008	.0035	92	148	1.126	.0514
33	53	.877	—.0569	63	101	1.012	.0053	93	150	1.129	.0528
34	55	.882	—.0545	64	103	1.016	.0071	94	151	1.133	.0542
35	56	.887	—.0521	65	105	1.021	.0089	95	153	1.136	.0555
36	58	.892	—.0498	66	106	1.025	.0106	96	154	1.140	.0569
37	60	.896	—.0475	67	108	1.029	.0124	97	156	1.144	.0582
38	61	.901	—.0453	68	109	1.033	.0141	98	158	1.147	.0596
39	63	.906	—.0430	69	111	1.037	.0158	99	159	1.151	.0611
40	64	.910	—.0408	70	113	1.041	.0175	100	161	1.155	.0626
41	66	.915	—.0386	71	114	1.045	.0192	110	177	1.188	.0747
42	68	.920	—.0364	72	116	1.049	.0209	120	193	1.219	.0861

TABLE 4

Relative Humidity H, Coefficient of Humidity, C_H, and Log C_H.

H	C_H	Log C_H	H	C_H	Log C_H	H	C_H	Log C_H	H	C_H	Log C_H
%	...	...	%	...	...	%	...	...	%	...	...
0	1.250	.0969	26	1.071	.0296	51	.944	−.0251	76	.738	−.1317
2	1.233	.0909	27	1.065	.0275	52	.938	−.0277	77	.726	−.1391
3	1.225	.0880	28	1.060	.0253	53	.933	−.0303	78	.713	−.1469
4	1.216	.0851	29	1.055	.0232	54	.927	−.0331	79	.700	−.1551
5	1.208	.0822	30	1.050	.0210	55	.921	−.0359	80	.686	−.1638
6	1.200	.0794	31	1.045	.0189	56	.914	−.0389	81	.671	−.1730
7	1.193	.0766	32	1.039	.0168	57	.908	−.0419	82	.657	−.1827
8	1.185	.0738	33	1.034	.0147	58	.902	−.0450	83	.641	−.1930
9	1.178	.0710	34	1.030	.0126	59	.895	−.0483	84	.625	−.2040
10	1.170	.0683	35	1.025	.0106	60	.888	−.0517	85	.609	−.2156
11	1.163	.0657	36	1.020	.0085	61	.881	−.0552	86	.592	−.2280
12	1.156	.0630	37	1.015	.0064	62	.873	−.0588	87	.574	−.2412
13	1.149	.0604	38	1.010	.0043	63	.866	−.0626	88	.555	−.2553
14	1.143	.0579	39	1.005	.0022	64	.858	−.0666	89	.536	−.2705

42	68	.920	—.0363								
43	69	.924	—.0342	73	117	1.053	.0226	130	209	1.251	.1003
44	71	.929	—.0320	74	119	1.057	.0242	140	225	1.276	.1060
45	72	.933	—.0299	75	121	1.061	.0258	150	241	1.302	.1146
46	74	.938	—.0278	76	122	1.065	.0274	160	257	1.326	.1224
47	76	.943	—.0257	77	124	1.069	.0290	170	274	1.347	.1294
48	77	.947	—.0236	78	126	1.073	.0306	180	290	1.367	.1357
49	79	.952	—.0216	79	127	1.077	.0322	190	306	1.384	.1413
50	80	.956	—.0195	80	129	1.081	.0337	200	322	1.400	.1461
51	82	.960	—.0175	81	130	1.085	.0353	210	338	1.414	.1503
52	84	.965	—.0155	82	132	1.088	.0368	220	354	1.425	.1539
53	85	.969	—.0135	83	134	1.092	.0383	230	370	1.435	.1568
54	87	.974	—.0116	84	135	1.096	.0398	240	386	1.442	.1591
55	89	.978	—.0096	85	137	1.100	.0413	250	402	1.448	.1608

$Cw = 0.708 + 0.328\ (W/W_0) - 0.036\ (W/W_0)^2$

W_0 = 60 miles per day or 96.56 Kilometres per day

Ht. of Anemometer	Factor	Ht. of Anemometer	Factor
0.5 (in meters)	1.00	5.0	0.72
2.0	0.82	10.0	0.65

15	1.136	.0554	40	1.000	.0001	65	.850	—.0708	90	—.2367
16	1.129	.0529	41	.995	—.0020	66	.841	—.0751	91	—.3041
17	1.123	.0504	42	.990	—.0042	67	.832	—.0796	92	.475	—.3229
18	1.117	.0480	43	.986	—.0063	68	.823	—.0844	93	.454	—.3432
19	1.111	.0456	44	.981	—.0085	69	.814	—.0893	94	.431	—.3653
20	1.105	.0432	45	.976	—.0108	70	.804	—.0945	95	.408	—.3893
21	1.099	.0409	46	.970	—.0130	71	.794	—.1000	96	.384	—.4156
22	1.093	.0386	47	.965	—.0153	72	.784	—.1057	97	.359	—.4446
23	1.087	.0363	48	.960	—.0177	73	.773	—.1117	98	.334	—.4767
24	1.082	.0341	49	.955	—.0201	74	.762	—.1180	90	.307	—.5125
25	1.076	.0318	50	.949	—.0226	75	.750	—.1247	100	.280	—.5528

$C_H = 1.250 - 0.0087\ H + 0.75 \times 10^{-4} H^2 - 0.85 \times 10^{-8} H^4$

$H_n = 113\text{-}4.5\ \Delta\ t$, where $\Delta\ t$=T. Max—T. Min, where H_n=Mean Relative Humidity.

TABLE 5

Sunshine Percentage, S, Coefficient of Sunshine, Cs, and Log Cs.

S	Cs	Log Cs	S	Cs	Log Cs	S	Cs	Log Cs	S	Cs	Log Cs
%	...	...	%	...	...	%	...	...	%	...	...
0	.542	—.2660	26	.708	—.1499	51	.829	—.0813	76	.972	—.0125
2	.558	—.2536	27	.713	—.1467	52	.834	—.0787	77	.979	—.0094
3	.565	—.2477	28	.718	—.1436	53	.839	—.0761	78	.986	—.0063
4	.573	—.2420	29	.724	—.1405	54	.844	—.0736	79	.993	—.0031
5	.580	—.2365	30	.729	—.1375	55	.849	—.0710	80	1.000	.0000
6	.587	—.2311	31	.734	—.1346	56	.854	—.0684	81	1.008	.0033
7	.594	—.2259	32	.738	—.1317	57	.859	—.0658	82	1.015	.0066
8	.601	—.2209	33	.743	—.1288	58	.865	—.0632	83	1.023	.0099
9	.608	—.2160	34	.748	—.1260	59	.870	—.0606	84	1.031	.0133
10	.615	—.2112	35	.753	—.1232	60	.875	—.0579	85	1.039	.0167
11	.621	—.2066	36	.758	—.1204	61	.880	—.0553	86	1.047	.0201
12	.628	—.2021	37	.763	—.1177	62	.886	—.0526	87	1.056	.0236
13	.634	—.1978	38	.767	—.1150	63	.891	—.0499	88	1.064	.0271
14	.640	—.1935	39	.772	—.1123	64	.897	—.0472	89	1.073	.0307

15	.647	−.1894	40	.777	−.1096	65	.903	−.0444	90	1.082	.0343
16	.653	−.1854	41	.782	−.1070	66	.908	−.0417	91	1.091	.0379
17	.659	−.1814	42	.786	−.1044	67	.914	−.0389	92	1.101	.0416
18	.664	−.1776	43	.791	−.1018	68	.920	−.0361	93	1.110	.0454
19	.670	−.1739	44	.796	−.0992	69	.926	−.0332	94	1.120	.0491
20	.676	−.1702	45	.801	−.0996	70	.932	−.0304	95	1.130	.0529
21	.681	−.1666	46	.805	−.0940	71	.939	−.0275	96	1.140	.0568
22	.687	−.1631	47	.810	−.0915	72	.945	−.0245	97	1,150	.0607
23	.692	−.1597	48	.815	−.0889	73	.952	−.0216	98	1.160	.0646
24	.698	−.1564	49	.820	−.0864	74	.958	−.0186	99	1.171	.0686
25	.703	−.1531	50	.825	−.0838	75	.965	−.0156	100	1.181	.0725

$$Cs = 0.542 + 0.0080 - 0.000078\,S^2 + 0.0000062\,S^3$$

TABLE 6

Elevation E, Coefficient of Elevation, C_E, and Log C_E.

Elev. E	Elev.	C_E	Log C_E	Elev. E	Elev.	C_E	Log C_E	Elev. E	Elev.	C_E	Log C_E
1000 feet	meters			1000 feet	meters			1000 feet	meters		
.0	0	.970	−.0132	2.6	792	1.048	.0204	5.1	1554	1.123	.0504
.1	30	.973	−.0119	2.7	823	1.051	.0216	5.2	1585	1.126	.0515
.2	61	.976	−.0106	2.8	853	1.054	.0228	5.3	1615	1.129	.0527
.3	91	.979	−.0092	2.9	884	1.057	.0241	5.4	1646	1.132	.0538
.4	122	.982	−.0079	3.0	914	1.060	.0253	5.5	1676	1.135	.0550
.5	152	.985	−.0066	3.1	945	1.063	.0265	5.6	1707	1.138	.0561
.6	183	.988	−.0052	3.2	975	1.066	.0278	5.7	1737	1.141	.0573
.7	213	.991	−.0039	3.3	1006	1.069	.0290	5.8	1768	1.144	.0584
.8	244	.994	−.0026	3.4	1036	1.072	.0302	5.9	1798	1.147	.0596
.9	274	.997	−.0013	3.5	1067	1.075	.0314	6.0	1829	1.150	.0607
1.0	305	1.000	.0000	3.6	1097	1.078	.0326	6.5	1981	1.165	.0663
1.1	335	1.003	.0013	3.7	1128	1.081	.0338	7.0	2134	1.180	.0719
1.2	366	1.006	.0026	3.8	1158	1.084	.0350	7.5	2286	1.195	.0774
1.3	396	1.009	.0039	3.9	1189	1.087	.0362	8.0	2438	1.210	.0828

1.4	427	1.012	.0052	4.0	1219	1.090	.0374	8.5	2591	1.225	.0881
1.5	457	1.015	.0065	4.1	1250	1.093	.0386	9.0	2743	1.240	.0934
1.6	488	1.018	.0077	4.2	1280	1.096	.0398	9.5	2896	1.255	.0986
1.7	518	1.021	.0090	4.3	1311	1.099	.0410	10.0	3048	1.270	.1038
1.8	549	1.024	.0103	4.4	1341	1.102	.0422	10.5	3200	1.285	.1089
1.9	579	1.027	.0116	4.5	1372	1.105	.0434	11.0	3353	1.300	.1139
2.0	610	1.030	.0128	4.6	1402	1.108	.0445				
2.1	640	1.033	.0141	4.7	1433	1.111	.0457				
2.2	671	1.036	.0154	4.8	1463	1.114	.0469				
2.3	701	1.039	.0166	4.9	1494	1.117	.0481				
2.4	732	1.042	.0179	5.0	1524	1.120	.0492				
2.5	762	1.045	.0191								

$C_E = 0.970 + 0.030\ (E/E_0)$

E_0 = 1000 feet or 305 metres.

TABLE 7

CONSUMPTIVE USE (EVAPO-TRANSPIRATION) COEFFICIENTS K, TO BE MULTIPLIED BY ESTIMATED OR MEASURED CLASS A PAN EVAPORATION

% of Crop Growing Season	Wheat Ludhiana	Wheat Poona	Maize Ludhiana	Maize Albama U.S.A.	Jowar Albama U.S.A.	Cotton Poona	Soyabeans Hargreaves	Small Vegetable Hargreaves	Shallow rooted Vegetables Hargreaves
0	.14	.30	.40	.40	.42	.22	0.15	0.25	0.10
5	.17	.40	.42	.40	.44	.22	0.18	0.28	0.15
10	.23	.51	.47	.43	.46	.23	0.20	0.30	0.20
15	.33	.62	.54	.46	.48	.24	0.23	0.38	0.30
20	.45	.73	.63	.52	.50	.26	0.25	0.45	0.40
25	.60	.84	.75	.59	.52	.35	0,28	0.50	0.45
30	.72	.92	.85	.67	.56	.58	0.30	0.55	0.50
35	.81	.96	.96	.76	.59	.80	0.38	0.58	0.55
40	.88	1.10	1.04	.85	.64	.95	0.45	0.60	0.60
45	.90	1.10	1.07	.93	.71	1.03	0.50	0.63	0.60
50	.91	1.00	1.09	1.02	.79	1.08	0.55	0.65	0.60
55	.90	.91	1.10	1.09	.92	1.08	0.63	0.65	0.60
			1.11	1.14	1.01	1.07	0.70	0.65	0.60

60	.89	.80	1.11	1.14	1.01	1.07	0.70	0.65	0.60
70	.83	.51	1.07	1.21	1.09	1.00	0.80	0.60	0.55
75	.80	.40	1.04	1.23	1.09	.93	0.75	0.58	0.50
80	.76	.30	1.00	1.22	1.05	.85	0.70	0.55	0.45
85	.71	.20	.97	1.16	.99	.73	0.65	0.50	0.40
90	.65	.12	.89	1.06	.91	.62	0.60	0.45	0.35
95	.58	.10	.81	.95	.82	.50	0.55	0.38	0.33
100	.51	.10	.70	.75	.70	.40	0.50	0.30	0.30
seasonal k	.61	.61	.86	.86	.75	.68	0.48	0.50	0.44

TABLE 7 (*Cond.*)

CONSUMPTIVE USE (EVAPO-TRANSPIRATION) COEFFICIENTS k, TO BE MULTIPLIED BY ESTIMATED OR MEASURED CLASS A PAN EVAPORATION

% of Crop Growing Season	Sugarcane Hawaii	Rice Los Banos	Groundnut Israel	Castor Beans Hargreaves	Sugarc Hargre
0	·34	1·00	·30	·16	·48
5	·37	1·02	·30	·30	·50
10	·40	1·03	·32	·50	·52
15	·44	1·05	·35	·65	·5
20	·50	1·07	·40	·74	·6
25	·60	1·09	·49	·81	·6
30	·72	1·11	·60	·87	·7
35	·86	1·13	·69	·92	·8
40	·93	1·16	·78	·96	·85
45	·98	1·18	·85	·98	·87
50	1·02	1·20	·90	1·00	·89
55	1·05	1·21	·94	1·00	·90
60	1·07	1·22	·96	·99	·90
65	1·10	1·22	·95	·97	·85
70	1·13	1·21	·94	·93	·7
75	1·16	1·19	·91	·89	·7
80	1·19	1·16	·86	·82	·68
85	1·20	1·10	·79	·72	·5
90	1·20	1·03	·72	·58	·5
95	1·19	·96	·64	·37	·50
100	·19	·86	·55	·22	·5
seasonal k	·89	1·10	·68	·73	·69

(1) Based on a 13 months crop length.

For Groups
Ref. P-1D

TABLE 8

CROP CONSUMPTIVE USE COEFFICIENTS

Percent of Crop Growing Season	Consumptive use (Evapo-transpiration) coefficients, k, to be Multiplied by Class A Pan Evaporation or Calculated E_p							
	Group A	Group B	Group C	Group D	Group E	Group F	Group G	Rice
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	0·86	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	0·20	0·90	0·60	0·50	0·20

TABLE 9

Net Irrigation Application (I) (mm)	Computed Peak Monthly Consumptive Use Rate (U_m) in mm.										
	100	125	150	175	200	225	250	275	300	325	350
	Peak Period Daily Use Rate (U_p) in Millimeters Per Day										
25	3·9	5·1	6·2	7·4	8·5	9·6	10·8	11·9	13·1	14·2	15·4
38	3·6	4·8	5·9	7·0	8·1	9·2	10·3	11·5	12·5	13·5	14·5
50	3·5	4·6	5·7	6·7	7·8	8·8	9·9	11·0	12.0	13·0	14·0
63	3·5	4·5	5.5	6·5	7·5	8·5	9·5	10·5	11·5	12·5	13·5
75	3·4	4·4	5·3	6·3	7·2	8·3	9·3	10·3	11·2	12·2	13·2
88	3·4	4·3	5·2	6·2	7·1	8·2	9·1	10·1	11·0	12·0	13·0
100	3·3	4·3	5·2	6·1	7·1	8·1	9·0	10·0	10·9	11·9	12·8
113	3·3	4·3	5·1	6·0	7·0	7·9	8·8	9·7	10·6	11·6	12·6
125	3·3	4·2	5·1	5·9	6·8	7·7	8·6	9·5	10·5	11·4	12·4
138	3·3	4·2	5·1	5·9	6·7	7·6	8·5	9·4	10·3	11·3	12·2
150	3·3	4·2	5·0	5·8	6·7	7·6	8·5	9·4	10·3	11·2	12·1

SW Monsoon

NE Monsoon.

TABLE 10

NORMAL MONTHLY EFFECTIVE RAINFALL(1) AS RELATED TO NORMAL MONTHLY RAINFALL AND AVERAGE MONTHLY CONSUMPTIVE USE

Monthly Normal Rainfall (Rt) (mm).	Average Monthly Consumptive use in mm.													
	25	50	75	100	125	150	175	200	225	250	275	300	325	350
	Normal Monthly Effective Rainfall (mm) Re													
25	15	17	18	18	19	20	21	22	25	25	25	25	25	25
50	25	33	35	36	37	40	41	44	48	50	50	50	50	50
	42													
75		47	51	54	56	58	61	65	69	74	75	75	75	75
100		50	65	69	73	75	79	83	88	95	100	100	100	100
		81												
125			75	83	89	91	96	102	108	116	123	125	125	125
			124											
150				97	104	106	113	120	127	136	144	150	150	150
175				100	117	120	128	136	143	154	166	172	175	175
				162										
200					125	131	140	148	158	169	184	191	197	200
					200									
225						142	152	162	175	189	200	210	220	225
250						148	164	175	192	206	216	226	236	245
275						150	173	188	205	223	233	242	255	265
						260								
300							175	195	215	235	246	258	273	288
							290							
325								199	220	242	258	275	290	304
350								200	224	245	265	285	303	320
								330						
375									225	248	270	292	310	328
									360					
400										250	273	296	317	335
										390				
425											275	298	320	340
											420			
450												300	322	343
												450		
475													324	346
500													325	349
													485	350
														520
525	25	50	75	100	125	150	175	200	225	250	275	300	325	

(1) Based on 75 millimeters net depth of application, for other net depths of application, multiply by the factors shown below.

Net depth of Application	25	38	50	63	75	100	125	150	175
Factor	0·77	0·86	0·93	0·99	1·00	1·02	1·04	1·06	1·07

for Paddy

TABLE 11

AVERAGE RATIOS APPLICABLE TO EFFECTIVE RAINFALL

Average Annual Rainfall (mm)	Percent Chance of Occurrence				
	50	60	70	80	90
100	0·84	0·72	0·61	0·50	0·38
200	0·90	0·81	0·71	0·62	0·51
300	0·93	0·85	0·78	0·69	0·58
400	0·95	0·88	0·81	0·73	0·63
500	0·96	0·90	0·83	0·75	0·67
600	0·97	0·91	0·84	0·78	0·70
700	0·97	0·92	0·86	0·80	0·72
800	0·98	0·93	0·87	0·81	0·74
900	0·98	0·93	0·88	0·82	0·75
1000	0·98	0·94	0·89	0·83	0·76
1200	0·98	0·94	0·90	0·85	0·78
1400	0·99	0·95	0·91	0·86	0·80
1600	0·99	0 95	0·91	0·87	0·82
1800	0·99	0·95	0·92	0·88	0·84
2000	0·99	0·95	0·92	0·89	0·85

TABLE 12

ATTAINABLE FIELD APPLICATION EFFICIENCIES

(Percent)

FURROW METHOD--Using cutback streams.

Soil	Slopes (Percent)	NET APPLICATION DEPTH (Cm)				
		5.0	7.5	10.0	12.5	15.0
Clay[1]	0.1 — 0.2	75	70	70	70	70
	0.4 — 0.75	70	70	70	65	60
	1.25 — 2.00	65	65	65	60	60
Loam	0.1 — 0.2	75	75	75	75	75
	0.4 — 0.75	70	70	70	70	70
	1.25 — 2.00	65	65	70	70	70
Sand	0.1 — 0.2	70	75	80	80	80
	0.4 — 0.75	65	70	75	75	75
CHECK OR BASIN METHOD						
Clay[2]		80	80	85	85	85
Loam		80	80	85	85	85
Sand		65	70	75	80	80
BORDER STRIP METHOD						
Clay[1]	0.1 — 0.2	65	65	65	65	65
	0.4 — 0.75	55	*	*	*	*
Loam	0.1 — 0.2	65	65	70	70	70
	0.4 — 0.75	60	65	65	70	70
Sand	0.1 — 0.2	65	65	70	70	70
	0.4 — 0.75	55	60	60	65	65

1 On expanding types of clays—that crack when dry and swell when wet—use 80% efficiency.

2 On expanding types of clays—that crack when dry and swell when wet—use 90% efficiency.

* Not recommended.

TABLE 12 (Contd.)

ATTAINABLE FIELD APPLICATION EFFICIENCIES

(Percent)

SPRINKLER METHOD

Depth of Water Applied Per Irrigation (centimeters)	Application Rate Centimeters Per Hr.	
	Under 1.25 percent.	More than 1.25 percent.
AVERAGE WIND MOVEMENT 0—6 Km Per Hr.		
Under 5.0	65	70
More than 5.0	70	75
AVERAGE WIND MOVEMENT 6.16 Km Per Hr.		
Under 5.0	60	65
More than 5.0	65	70
AVERAGE WIND MOVEMENT 16.25 Km Per Hr.		
Under 5.0	55	60
More than 5.0	60	65

TABLE 13

SAMPLE CALCULATION

Water Requirement (in Centimetres)

RICE (Loam Soil)

Dates	Mid. point	%G.S.	Pan Evap.	K	CU	Perc. Losses (.0254 cms. per hour. 6 mm/day)	Re_1	NIR	FIR	GIR
June 1-30	15	8.5	28.83	1.03	29.69	—	10.31	19.38	19.38	25.84
July 1-12	36	20.3	8.18	1.07	8.76	—	6.99	1.79	1.79	2.39
July 13-31	52	29.4	12.95	1.11	14.38	11.58	15.80	10.16	10.16	13.55
Aug. 1-31	77	43.5	19.43	1.17	22.73	18.90	24.79	16.84	16.84	22.45
Sept. 1-30	107	60.5	17.45	1.22	21.29	18.29	22.63	16.94	16.94	22.59
Oct. 1-31	138	78.0	21.79	1.17	25.50	18.90	5.08	39.32	39.32	52.43
Nov. 1-24	165	93.2	15.06	1.00	15.06	14.63	1.75	27.94	27.94	37.25

177 days

Effective Rainfall — Nursery period 70% average ; Cropping period 100% average.

%G. S. — Percent Growing Season.

K — Et/E=Growth period Evapo-transpiration ratio.

Perc. Losses. — Percolation losses (at .0254 ~~cum.~~ cms. per hour). × 24 = 0.6 cms/day.

GIR —Gross Irrigation Requirement.

FIR — include percolation losses in the field water courses, field channels and in field application.

GIR — FIR+Conveyance Losses in Canal, distributaries upto the field=FIR÷0.75.

Pan Evap. —Pan Evaporation (in cms.)

CU—Consumptive Use (in cms.)

FIR—Field Irrigation Requirement (in cms.)

Re—Effective Rainfall (in cms.)

NIR—Net Irrigation Requirement (Cu+Perc. Losses−Re)

TABLE 16

Mean Daily Maximum Duration of Bright Sunshine Hours (N) for Different Months and Latitudes

Northern Lats / Southern Lats.	Jan. / July	Feb. / Aug.	March / Sept.	April / Oct.	May / Nov.	June / Dec.	July / Jan.	Aug. / Feb.	Sept. / Mar.	Oct. / Apr.	Nov. / May	Dec. / June
50	8·5	10·1	11·8	13·8	15·4	16.3	15·9	14·5	12·7	10 8	9·1	8·1
48	8·8	10·2	11·8	13·6	15·2	16·0	15·6	14·3	12·6	10·9	9·3	8·3
46	9·1	10·4	11·9	13·5	14·9	15·7	15·4	14·2	12·6	10·9	9·5	8·7
44	9·3	10·5	11·9	13·4	14·7	15·4	15·2	14·0	12·6	11.0	9·7	8·9
42	9·4	10·6	11·9	13·4	14·6	15·2	14·9	13·9	12·6	11·1	9·8	9·1
40	9·6	10·7	11·9	13·3	14·4	15·0	14·7	13·7	12·5	11·2	10·0	9·3
35	10·1	11·0	11·9	13·1	14·0	14·5	14·3	13·5	12·4	11.3	10·3	9·8
30	10·4	11·1	12·0	12·9	13 6	14·0	13·9	13·2	12·4	11·5	10·6	10·2
25	10·7	11·3	12·0	12·7	13·3	13·7	13·5	13·0	12·3	11·6	10·9	10·6
20	11·0	11·5	12·0	12·6	13·1	13·3	13·2	12·8	12·3	11·7	11·2	10·9
15	11·3	11·6	12·0	12·5	12·8	13·0	12·9	12·6	12·2	11·8	11·4	11·2
10	11·6	11·8	12·0	12·3	12·6	12·7	12 6	12·4	12·1	11·8	11·6	11·5
5	11·8	11·9	12·0	12·2	12·3	12·4	12·3	12·3	12 1	12·0	11·9	11·8
0	12·1	12·1	12·1	12·1	12·1	12·1	12·1	1 · 1	12·1	12·1	12 1	12·1

TABLE 17

Extra-Terrestrial Radiation Ra Expressed in Equivalent Evaporation in mm/Day

Northern Hemisphere

Lat	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
50	3.8	6.1	9.4	12.7	15.8	17.1	16.4	14.1	10.9	7.4	4.5	3.2
48	4.3	6.6	9.8	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7
46	4.9	7.1	10.2	13.3	16.0	17.2	16.6	14.5	11.5	8.3	5.5	4.3
44	5.3	7.6	10.6	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7
42	5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2
40	9.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7
38	6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1
36	7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	14.1	10.6	8.0	6.6
34	7.9	9.8	12.4	14.8	16.5	17.1	16 8	15.5	13.4	10.8	8.5	7.2
32	8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8
30	8.8	10.7	13.1	15.2	16.5	17.0	16.8	15.7	13.9	11.6	9.5	8.3
28	9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8
26	9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3
24	10.2 10.5	11.9 12.1	13.9 14.1	15.4 15.45	16.4 16.35	16.5 16.45	16.5 16.45	15.8	14.5 14.55	12.6 12.8	10.7 10.9	9.7 9.95
22	10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2
25												
20	11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7
18	11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1
16	12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6
14	12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0
12	12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	13.4	13.3	12.5
10	13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9
8	13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3
6	13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7
4	14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1
2	14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4
0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

TABLE 17 (*Contd.*)

Ex tra-Terrestrial Radiation Ra Expressed in Equivalent Evaporation in mm/Day

Southern Hemisphere

Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July.	Aug.	Sept.	Oct.	Nov.	Dec
50	17.5	14.7	10.9	7.0	4.2	3.1	3.5	5.5	8.9	12.9	16.5	18.7
48	17.6	14.9	11.2	7.5	4.7	3.5	4.0	6.0	9 3	13.2	16.6	18.2
46	17.7	15.1	11.5	7.9	5.2	4.0	4.4	6.5	9.7	13.4	16.7	18.3
44	17.8	15.3	11.9	8.4	5.7	4.4	4.9	6.9	10.2	13.7	16.7	18.3
42	17.8	15.5	12.2	8.8	6.1	4.9	5.4	7.4	10.6	14.0	16.8	18.3
40	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	18.3
38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	18.3
36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.7	17.0	18.2
34	17.8	16.1	13.5	10.5	8.0	6.8	7.2	9.2	12.0	14.9	17.1	18.0
32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.1
30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	12.2	15.5	17.2	17.8
24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
18	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1
16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.3	16.7	16.8
14	16.7	16.4	15.3	13.7	12.1	11.2	12.9	12.9	14.5	15.8	16.5	16.6
12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.1	14.7	15.8	16.4	16.5
10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
6	15.8	16.0	15.6	15.6	14.7	13.4	13.1	13.1	15.0	15.7	15.8	15.7
4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.0	15.6	15.5	15.4
2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.3	15.1
0	15.0	15 5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

TABLE 18

Saturation Vapour Pressure ea in mbar as Function of Mean Air Temperature t in O°C

Temperature °C	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
ea mbar	6.1	6.6	7.1	7.6	8.1	8.7	9.4	10.0	10.7	11.5	12.3	13.1	14.0	15.0	16.1	17.0	18.2	19.4	20.6	22.0

Temperature °C	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	39	37	38	39
ea mbar	23.4	24.9	26.4	28.1	29.8	31.7	33.6	35.7	37.8	40.1	42.4	44.9	47.6	50.3	53.2	56.2	59.4	62.8	66.3	69.9

TABLE 19

Values of Wind Function, $f(u)=0.27\left(1+\frac{U_2}{100}\right)$ for Wind run at a 2 m Height* in km/Day

Wind in km/day	0	10	20	30	40	50	60	70	80	90
0–9		.30	.32	.35	.38	.41	.43	.49	.49	.51
100	.54	.57	.59	.62	.65	.67	.70	.73	.76	.78
200	.81	.84	.86	.89*	.92	.94	.97	1.00	1.03	1.05
300	1.08	1.11	1.13	1.16	1.19	1.21	1.24	1.27	1.30	1.32
400	1.36	1.38	1.40	1.43	1.46	1.49	1.51	1.54	1.57	1.59
500	1.62	1.65	1.67	1.70	1.73	1.76	1.78	1.81	1.84	1.90
600	1.89	1.92	1.94	1.97	2.00	2.02	2.05	2.08	2.11	2.15
700	2.16	2.19	2.21	2.24	2.27	2.29	2.32	2.35	2.38	2.40
800	2.43	2.46	2.84	2.51	2.54	2.56	2.59	2.62	2.64	2.65
900	2.70									

*Where wind data are not collected at 2m height the appropriate corrections for wind measurements taken at different heights are given below :

Measurement height, m	0.5	1.0	1.5	2.0	3.0	4.0	5.0	6.0	10.0
Correction factor	1.35	1.15	1.06	1.00	0.93*	0.88	0.85	0.83	0.77

TABLE 20

Values of Weighting Factor (1-W) for the Effect of Wind and Humidity on ETO at different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
(1-W) at altitude m																				
0	0·57	·54	·51	·48	·45	·42	·39	·36	·34	·32	·29	·27	·25	·23	·22	·20	0·19	·17	·16	·15
500	·56	·52	·49	·46	·43	·40	·38	·35	·33	·30	·28	·26	·24	·22	·21	·19	·18	·16	·15	·14
1000	·54	·51	·48	·45	·42	·39	·36	·34	·31	·29	·27	·25	·23	·21	·20	·18	·17	·15	·14	·13
2000	·51	·48	·45	·42	·39	·36	·34	·31	·29	·27	·25	·23	·21	·19	·18	·16	·15	·14	·13	·12
3000	·48	·45	·42	·39	·36	·34	·31	·29	·27	·25	·23	·21	·19	·18	·16	·15	·14	·13	·12	·11
4000	·46	·42	·39	·36	·34	·31	·29	·27	·25	·23	·21	·19	·18	·16	·15	·14	·13	·12	·11	·10

TABLE 21

Values of Weighting Factor W for the Effect of Radiation on ETO at different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
W at altitude m																				
0	0·43	·46	·49	·52	·55	·58	·61	·64	·66	·68	·71	·73	·75	·77	·78	·80	·82	·83	·84	·85
500	·44	·48	·51	·54	·57	·60	·62	·65	·67	·70	·72	·74	·76	·78	·79	·81	·82	·84	·85	·86
1000	·46	49	·52	·55	·58	·61	·64	·66	·69	·71	·73	·75	·77	·79	·80	·82	·83	·85	·86	·87
2000	·49	·52	·55	·58	·61	·64	·66	·69	·71	·73	·75	·77	·79	·81	·82	·84	·85	·86	·87	·88
3000	·52	·55	·58	·61	·64	·66	·69	·71	·73	·75	·77	·79	·81	·82	·84	·85	·86	·87	·88	·89
4000	·54	·58	·61	·64	·66	·69	·71	·73	·75	·77	·79	·81	·82	·84	·85	·86	·87	·88	·90	·90

TABLE 22

Conversion Factor for Extra-terrestrial Radiation RA to Net Solar Radiation Rns for a given Reflection α of 0·25 and Different Ratios of Actual to Maximum Sunshine Hours

$(1-\alpha)(0{\cdot}25+0{\cdot}50\ n/N)$

n/N	0·0	·05	·10	·15	·20	·25	·30	·35	·40	·45	·50	·55	·60	·65	·70	·75	·80	1·5	·90	·95	1·00
$(1-\alpha)(0{\cdot}25+0{\cdot}50\ n/N)$	0·19	·21	·22	·24	·26	·28	·30	·32	·34	·36	·37	·39	·41	·43	·45	·47*	·49	·51	0·52	·54	·56

TABLE 23

Correction for Temperature f(t) on Longwave Radiation Rnl

t°C	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
$f(t)=6\ Tk^4$	11·0	11·4	11·7	12·0	12·4	12·7	13·1	13·5	13·8	14·2	14·6	15·0	15·4	15·9	16·3*	16·7	17·2	17·7	18·1

TABLE 24

Correction for vapour pressure f(ed) on Longwave Radiation Rnl

ed mbar	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
$f(ed)=0{\cdot}34-0{\cdot}44\sqrt{ed}$	·23	·22	·20	·19	·18	·16	·15	·14*	·13	·12	·12	·11	·10	·09	·08	·08	·07	·06

TABLE 25

Correction for the Ratio Actual and Maximum Bright Sunshine Hours F(n/N) on Longwave Radiation Rnl

n/N	0	·05	·1	·15	·2	·25	·3	·35	·4	·45	·5	·55	·6	·65	·7	·75	·8	·85	·9	·95	1·0
$f(n/N)=0{\cdot}1+0{\cdot}9\ n/N$	·10	·15	·19	·24	·28	·33	·37	·42	·46	·51	·55	·60	·64	·69	·73	·78	·82	·87	·91	·96	1·0

TABLE 26

Adjustment Factor (C) in Presented Penman Equation

Rs mm/day / Uday m/sec	RHmax=30%				RHmax=60%				RHmax=90%			
	3	6	9	12	3	6	9	12	3	6	9	12
	1	2	3	4	5	6	7	8	9	10	11	12	13
Uday/Unight=4·0												
0	·86	·90	1·00	1·00	·96	·98	1·05	1·05	1·02	1·06	1·10	1·10
3	·79	·84	·92	·97	·92	1·00	1·11	1·19	·99	1·10	1·27	1·32
6	·68	·77	·87	·93	·85	·96	1·11	1·19	·94	1·10	1·26	1·33
9	·55	·65	·78	·90	·76	·88	1·02	1·14	·88	1·01	1·16	1·27
Uday/Unight=3·0												
0	·86	·90	1·00	1·00	·96	·98	1·05	1·05	1·02	1·06	1·10	1·10
3	·76	·81	·88	·94	·87	·96	1·06	1·12	·94	1·04	1·18	1·28
6	·61	·68	·81	·88	·77	·88	1·02	1·10	·86	1 01	1·15	1·22
9	·46	·56	72	·82	·67	·79	·88	1·05	·78	·92	1·06	1·18

TABLE 26 (*Contd.*)

1	2	3	4	5	6	7	8	9	10	11	12	13
						Uday/Unight=2·0						
0	·86	·90	1·00	1·00	·96	·98	1·05	1·05	1·02	1·06	1·10	1·10
3	·69	·76	·85	·92	·83	·91	·99	1·05	·89	·98	1·10	1·14
6	·53	·61	·74	·84	·70	·80	·94	1·02	·79	·92	1·05	1·12
9	·37	·48	·65	·76	·59	·70	·84	·95	·71	·81	·96	1·06
						Uday/Unight=1·0						
0	·86	·90	1·00	1·00	·96	·98	1·05	1·05	1·02	1·06	1·10	1·10
3	·64	·71	·82	·89	·78	·86	·94	·99	·85	·92	1·01	1·05
6	·43	·53	·68	·79	·62	·70	·84	·93	·72	·82	·95	1·00
9	·27	·41	·59	·70	·50	·60	·75	·87	·62	·72	·87	·96

TABLE 27

Crop Coefficients (Kc)

CROP	Crop Development Stages					Total growing period
	Initial	Crop Development	Mid Season	Late Season	At harvest	
1	2	3	4	5	6	7
Banana						
tropical	0.4 -0.5	0.7 -0.85	1.0 -1.1	0 9 -1.0	0.75-0.85	0.7-0.8
subtropical	0.5 -0.65	0.8 -0-9	1.0 -1.2	1.0 -1.15	1.0 -1.15	0.85-0.95
Bean						
green	0.3 -0.4	0.65-0.75	0.95-1.05	0.9 -0.95	0.85-0.95	0.85-0.9
dry	0·3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.25-0.3	0.7 -0.8
Cabbage	0.4 -0.5	0.7 -0.8	0.95-1.1	0.9 -1.0	0.8 -0.95	0.7 -0.8
Cotton	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.9	0.65-0.7	0.8 -0.9
Grape	0.35-0.55	0.6 -0.8	0.7 -0.9	0.6 -0.8	0.55-0.7	0.55-0.75
Groundnut	0.4 -0.5	0.7 -0.8	0.95-1.1	0.75 0.85	0.55-0.6	0.75-0.8
Maize						
sweet	0.3 -0.5	0.7 -0.9	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
grain	0·3 -0.5*	0.7 -0.85*	1.05-1.2*	0.8 -0.95	0.55-0.6*	0.75-0.9*
Onion						
dry	0.4 -0.6	0.7 -0.8	0.95-1.1	0.85-0.9	0.75-0.85	0.8 -0.9
green	0.4 -0.6	0.6 -0.75	0.95-1.05	0.95-1.05	0.95-1.05	0.65-0.8
Pea, fresh	0.4 -0.5	0.7 -0.85	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0·95
Pepper, fresh	0.3 -0.4	0.6 -0.75	0.95-1.1	0.85-1.0	0.8 -0.9	0.7 -0.8
Potato	0.4 -0.5	0.7 -0.8	1.05-1.2	0.85-0.95	0.7 -0.75	0.75-0.9
Rice	1.1 -1.15	1.1 -1.5	1.1 -1.3	0.95-1.05	0.95-1.05	1.05-1.2
Safflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.7	0.2 -0.25	0.65-0.7
Sorghum	0.3 -0.4	0.7 -0.75	1.0 -1.15	0.75-0.8	0.5 -0.55	0.75-0.85
Soyabean	0.3 -0.4	0.7 -0.8	1.0 -1.15	0.7 -0.8	0.4 -0.5	0.75-0.9
Sugarbeet	0.4 0.5	0.75-0.85	1.05-1.2	0.9 -1.0	0.6 -1.7	0.8 -0.9
	20 d	35 d	40 d	30 d		

TABLE 27 (Contd.)

1	2	3	4	5	6	7
Sugarcane	0.4 -0.5	0.7 -1.0	1.0 -1.3	0.75-0.8	0.5 -0.6	0.85-1.05
Sunflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.7 -0.8	0.35-0.45	0.75-0.85
Tobacco	0.3 -0.4	0.7 -0.8	1.0 -0.8	1.0 -1.2	0.9 -1.0	0.75-0.85
Tomato	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.95	0.6 -0.65	0.75-0.9
Watermelon	0.4 -0.5	0.7 -0.8	0.95-1.05	0.8 -0.9	0.65-0.75	0.75-0.85
Wheat	0.3 -0.4	0.7 -0.8	1.05-1.2	0.85-0.75	0.2 -0.25	0.8 - 0.
Alfalfa	0.3 -0.4				1.05-1.2	0.85-1.0
Citrus						0.65-0.7
clean weeding						0.85-0.9
no weed control						0.4 -0.
Olive						

First figure: Under high humidity (RHmin >70%) and low wind (U<5m/sec).

Second figure : Under low humidity (RHmin<20%) and strong wind (>5m/sec).

Source : FAO Irrigation and Drainage Paper No.33.

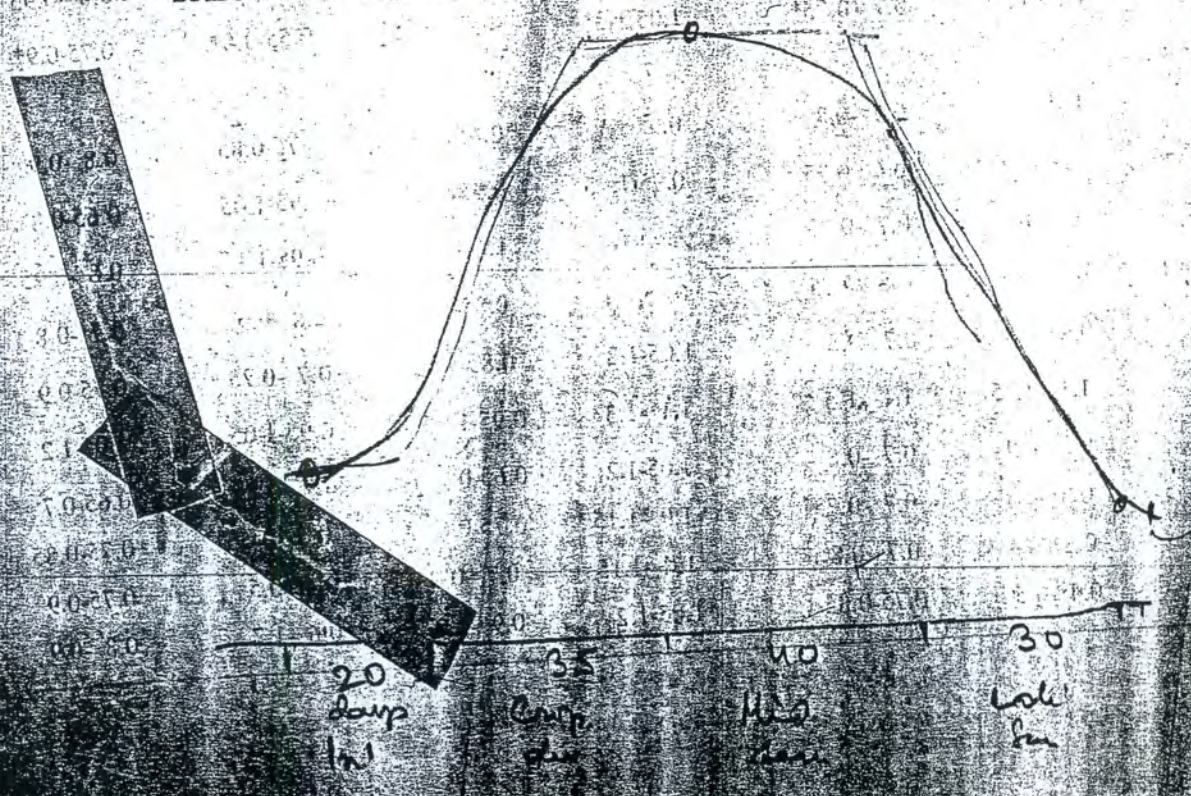


TABLE 28

Water Requirement (Month and Crop-wise)

(in cms.)

Months	Paddy nursery	Paddy (loam)	Paddy (clay)	Groundnut	Maize Jowar	Cotton	Sugarcane	Chillies
June	19·38	—	—	—	—	—	25·86	—
July	1·78	10·16	4·37	—	—	—	7·59	—
August	—	16·84	7·39	—	—	—	6·78	—
September	—	16·94	7·80	—	—	—	5·97	1·68
October	—	39·32	29·87	—	3·40	3·96	34·67	23·50
November	—	27·94	20·62	6·27	15·09	7·98	42·32	22·38
December	—	—	—	16·13	23·83	20·70	18·01	16·56
January	—	—	—	21·69	20·47	22·86	21·92	10·82
February	—	—	—	13·39	—	14·30	25·04	—
March	—	—	—	—	—	—	36·45	—
April	—	—	—	—	—	—	40·72	—
May	—	—	—	—	—	—	49·86	—

TABLE 29

DEMAND TABLE AT CANAL HEAD

Monhts	9000 Ac.	120000 Ac.	60000 Ac.	100000 Ac.	230000 Ac.	20000 Ac.	10000 Ac.	30000 Ac.	FIR Monthly Total	GIR[1] Monthly Total	Irrigation Water Demand	
	Paddy Nursery	Paddy (Loam)	Paddy (Clay)	Ground-nut	Maize Jowar	Cotton	Sugar-cane	Chillies			Calcu-lated	As per Project
	Ac. ft.	Ac. ft.	Ac. ft.	Ac. ft.	Ac. ft.	Ac. ft.	Ac. ft.	Ac. ft.	Ac. ft.	Ac. ft.	TMC	TMC
June	5,723	...	...	...	...	...	8,483	...	14,206	18,941	.82	2.47
July	525	40,000	8,600	...	...	...	2,492	...	51,617	68,821	2.99	4.69
Aug.	...	66,300	14,550	...	...	...	2,225	...	83,075	110,767	4.81	5.53
Sep.	...	66,700	15,350	...	...	...	1,958	1,650	85,658	114,208	4.97	7.24
Oct.	...	154,800	58,800	...	25,683	2,600	11,375	23,125	276,383	368,501	16.05	12.83
Nov.	...	110,000	40,600	20,583	113,520	5,233	13,883	22,025	325,844	434,447	18.92	12.78
Dec.	...	...	...	52,918	179,786	13,583	5,908	16,300	268,495	357,984	15.59	9.26
Jan.	...	...	...	71,167	154,486	15,000	7,191	10,650	258,495	344,650	15.01	8.30
Feb.	...	...	...	43,917	...	9,383	8,216	...	61,516	82,019	3.57	5.54
Mar.	...	...	...	...	...	...	11,958	...	11,958	15,944	.69	1.90
Apr.	...	...	...	...	...	...	13,358	...	13,358	17,810	.77	1.46
May	...	...	...	...	...	...	16,358	...	16,358	21,811	.95	...
Total	6,428	437,800	137,200	188,585	437,475	45,799	103,405	73,750	14,66,962	19,55,903	85.14	72.00

[1]GIR calculated using 75 per cent conveyance efficiency.

TABLE 30

Water requirement of rice in different parts of the Country as measured near the field head

State/ Place	Season	Water requirement (mm)	Irrigation requirement (mm)	Reference
West Bengal :				
Kharagpur	*Aus* (Mar./April-June/July	1850	N.A.	Pande and Mitra (1972)
	Aman (July/Aug-Nov. Dec.)	189)	N.A.	
	Boro (Dec./Jan.-Mar./April)	2150	N.A.	
Orissa :				
Cuttack	*Kharif* (June-Sept)	1300	790	Chaudhry and
	Boro (Jan.-April)	1190	980	Pandey (1968)
Bhubaneswar	*Kharif* (June-Sept.)	1440	780	Sahu (1967)
	Rabi (Sept.-Dec.)	1650	1630	—do—
Uttar Pradesh :				
Roorkee	*Kharif* (June-Oct.)	1620	750	Gupta and Bhattacharya (1963)
Dhanauri	*Kharif* (June-Oct.)	1630	910	Bhattacharya (1972)
Karnataka :				
Siruguppa	*Kharif* (June-Oct.)	N.A.	1344	Yadav (1972)
	Kharif (June-Oct.)	1520	1170	Patil (1963)
Tamil Nadu :				
Coimbatore	*Samba* (July/Aug.-Dec./Jan.)	1680	N.A.	Chandramohan (1965, 1967)
Puttukottai	*Samba* (July/Aug.-Dec./Jan.)	2650	N.A.	—do—
	Kuruvai (June-Sept.)	2000	N.A.	—do—
Delhi :	*Kharif* (June-Oct.)	2400	1640	Hukkeri and Sharma (1974)

N.A.=data not available

CGIR calculated using 75 per cent conveyance efficiency.

TABLE 31

Scheduling of different Irrigation to wheat at selected locations

(I.C.A.R., 1972)

S. No.	Centre	Soil type	Date of sowing	First irrigation		Other Irrigations (*Days after sowing)								Depth of each irrigation from 2nd onwards	Total depth of irrigation water (cm)	Yield (q. ha.)
				Days after sowing	Depth (cm)	2nd	3rd	4th	5th	6th	7th	8th	9th			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Jobner (Rajasthan)	Loamy	Nov. Ist half	20	4.5	40	60	80	98	112	124	134	142	4.5	40.5	28.0
		Sand to Sandy	Nov. 2nd half	20	4.5	40	58	75	89	102	114	124	132	4.5	40.5	30.0
2	Hissar (Haryana)	Sandy loam	Nov. 1st week	26	6.0	42	67	94	111	125	133	—	—	6.0	42.0	38.6
3	Ludhiana (Punjab)	Sandy loam	Nov. 1st week	25	6	57	95	118	140	—	—	—	—	7.5	36	41.7
			Nov. 2nd week	25	6	61	95	119	136	—	—	—	—	7.5	36	
			Nov. 3rd week	25	6	61	94	116	131	—	—	—	—	7.5	36	
			Nov. 4th week	25	6	64	91	113	128	—	—	—	—	7.5	36	
			Dec. 1st week	25	6	64	88	101	115	—	—	—	—	7.5	36	
4	Roorkee (Uttar	Sandy loam	Mid. Nov.	25	6	65	100	—	—	—	—	—	—	8	22	40.0

TABLE 31 *(Contd.)*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
5	Siruguppa (Karnataka)	Heavy black Clay	Nov. 1st week	0	5	4 (2.5)	23 (6.0)	42 (8.0)	63 (8.0)	83 (8.0)	100 (8.0)				37.5	35.0
6	Navasari (Gujarat)	Black Clay	Nov. 2nd half	1	7.5	7 (7.5)	18 (7.5)	35 (7.5)	55 (10.0)	75 (10.0)	90 (10.0)				60	29.0

*For each cm of rain, increase the number of days by 5 upto the end of January and 3 thereafter (Figures in brackets indicate the depth of water used at each irrigation).

TABLE 32

Irrigation requirements of maize in different parts of India

Station	Soil type	Season	Irrigation requirement		Reference
			No.	Amount (mm)	
Delhi	Sandy loam	*Kharif*	2-3	100-150	Badhe (1968)
Hissar (Haryana)	Sandy loam	*Kharif*	5-6	300-360	Malik (1973) Sharma et. al. (1974)
Pantnagar (Uttar Pradesh)	Sandy loam	*Kharif*	4	225-275	Sharma and Upadhyay (1973)
Udaipur (Rajasthan)	Sandy loam	*Kharif*	4	300	Singh and Sharma (1968)
Arbhavi (Karnataka)	Sandy loam	*Kharif*	3	150	Anonymous (1956)
		Rabi	5	330	Anonymous (1956)
Siruguppa (Karnataka)	Clay loam	Summer	10	510	Patil et al. (1969)
Bhubaneshwar (Orissa)	Loam	*Kharif*	2	100-150	Sahu (1967)
		Rabi	11	500-600	Sahu (1967)
		Summer	18	900	Sahu (1967)
Bhavanisagar (Tamil Nadu	Loamy sand	Summer	25	1250	Ali et al. (1970)

TABLE 33

Irrigation requirement of *bajra* in different parts of India

Place	Soil Type	Season	Irrigation requirement		Reference
			No.	Amount (mm)	
Siruguppa (Karnataka)	Clay	*Kharif*	2	150	Patil *et al.* (1969)
Hissar (Haryana)	Sandy loam	*Kharif*	3	200	D.A.R.E. (1975)
Delhi	,,	*Kharif*	3	150	Pal (1975)
Anand (Gujarat)	,,	Summer	10	600	Joshi (1969)

TABLE 34

Irrigation requirement of barley in different parts of India

Place	Soil type	Season	Irrigation requirement		Reference
			No.	Amount	
Bikramganj (Bihar)	Sandy loam	*Rabi*	2	180	Pandey and Mukherji (1966)
Kanpur (Uttar Pradesh)	,,	*Rabi*	2-3	150 180	Bhan (1975) Warsi (1973)
Ludhiana (Punjab)	,,	*Rabi*	1	75	Singh (1975)
Hissar (Haryana)	,,	*Rabi*	4	250	Malik (1971)
Jobner (Rajasthan)	,,	*Rabi*	5-6	300 360	Bajpai and Singh (1972) Yadav (1972)
Bhind (Madhya Pradesh)	,,	*Rabi*	3	200	Garg and Saraswati (9175)
Delhi	,,	*Rabi*	2	150	Singh (1975)

TABLE 35

Irrigation requirement of groundnut in different parts of India

Place	Soil type	Season	Irrigation requirement		Reference
			No.	Amount (mm)	
Bhavanisagar (Tamil Nadu)	Red sandy loam	*Rabi*	9-13	500-700	Ali et al. (1974)
Hyderabad (Andhra Pradesh)	-do-	*Rabi*	8	655	Yadav (1972)
Yemmiganur (Karnataka)	-do-	Spring	6-7	300-350	Rao (1966)
Parbhani (Maharashtra)	Clay loam	Summer	8	550	Khuspe (1975)
Kanpur (Uttar Pradesh)	Sandy loam	*Kharif*	2	150	Bhan (1975)
Hissar (Haryana)	Fine Sandy loam	*Kharif*	5	350	Singh et al. (1968)
Ludhiana (Punjab)	Sandy loam	*Kharif*	2	140	Singh and Sandhu (1968a)
"	Loamy sand	*Kharif*	6	300	Saini et al. (1973)
Chakuli (Orissa)	Loamy sand	*Rabi*	10	690	Lenka and Misra (1973

TABLE 36

Irrigation requirement of mustard at different places in the country

Location	Soil Type	Irrigation requirement		Reference
		No.	Amount (mm)	
Roorkee (Uttar Pradesh)	Sandy loam	1	60	Yadav (1972)
Kanpur (Uttar Pradesh)	Sandy loam	2	140	Bhan (1975)
Karnal (Haryana)	Sandy loam	1	120	Yadav (1972)
Hissar (Haryana)	Sandy loam	1	70	Singh and Moolani (1972)
Ludhiana (Punjab)	Sandy loam	1	75	Yadav (1975)
Kota (Rajasthan)	Clay loam	2	150	Singh *et al.* (1974)
Delhi	Sandy loam	3	180	Yusuf (1973)

TABLE 37

Irrigation requirement of linseed in different parts of India

Location	Soil type	Irrigation requirement		Reference
		No.	Amount (mm)	
Kanpur (Uttar Pradesh)	Sandy loam	2	140	Bhan (1975)
Pantnagar (Uttar Pradesh)	Loam	2	150	I.C.A.R. (1973)
Hissar (Haryana)	Sandy loam	1	75	Prashar and Sach (1967)
Delhi	Sandy loam	3—4	150-200	Yusuf (1973)
Jabalpur (Madhya (Pradesh)	Clay loam	1	75	I.C.A.R. (1973)
Kota (Rajasthan)	Clay loam	2	150	Singh *et al.* (197

TABLE 38

Irrigation requirements of cotton in different parts of India

Place	Soil type	Season	Irrigation requirement		Reference
			No.	Amount (mm)	
Delhi	Sandy loam	*Kharif*	2	140	Rajput (1965)
Ludhiana (Punjab)	Sandy loam	*Kharif*	5	300	Singh and Sandhu (1968 b)
Hissar (Haryana)	Sandy loam	*Kharif*	4	240	Yadav (1972)
Bhavanisagar (Tamil Nadu)	Red sandy loam	*Rabi*	9-13	675-770	Ali *et al.* (1974)
Coimbatore (Tamil Nadu)	Clay loam	*Rabi*	6	837	Yadav (1972)
Siruguppa (Karnataka)	Clay	*Rabi*	8	730	Yadav (1972)
Akola (Maharashtra)	Clay	*Kharif*	2	200	Bathkal *et al.* (1975)

TABLE 35

Irrigation requirement of sugarcane in different parts of India

Location	Soil type	Irrigation requirement	
		No.	Amount (mm)
Delhi	Sandy loam	8	500
Ludhiana (Punjab)	Sandy loam	8	620
Roorkee (Uttar Pradesh)	Sandy loam	11	660
Bikramganj (Bihar)	Loam	7	450
Padegaon (Maharashtra)	Clay loam	25	*1960
Anakapalle (Andhra Pradesh)	Clay loam	20	680

*Irrigation requirement per annum and the requirement for a *adsali* (18 months) crop will be more. The crop duration in other places is 10-12 months only.

Appendix A

The method for calculating pan evaporation using Christiansen's equation is given in Chapter 5 of this bulletin. Calculations are lengthy and leave chances for errors. Whenever made, they should be thoroughly checked for accuracy.

Christiansen's equation for computing pan evaporation can also be solved graphically. The resulting answer from a graphic solution will not be as accurate as that from mathematical calculations. The graphic solution takes less time however and should be within a 10 percent error.

Following are the steps required for this solution.

Step 1—Find value of solar radiation from Table 1 for the appropriate latitude.

Step 2—Tabulate values of mean temperature, mean wind velocity at 0·5 metres above ground level in kilometers per day, mean relative humidity at noon, mean sunshine percentage, and elevation of the weather station. Most of these values are available for the weather observation stations in India. Where mean relative humidity at noon is not available, it may be calculated using the following equation :

$$H = 113\text{-}4{\cdot}5\ \Delta Tc$$

where H is the relative humidity at noon and ΔTc is the difference between the mean monthly maximum and minimum temperature in °C.

Step 3—Enter Figure 2 in the upper left-hand corner with the solar radiation value in millimeter per day found in Step 1. Project a line horizontally to the right and intercept the constant line.

Step 4—Project a line vertically downward from the constant line intercept to the appropriate value for mean temperature.

Step 5—Project a line horizontally to the right from the temperature intercept to the appropriate value for mean wind velocity.

Step 6—Project a line vertically upward from the wind velocity intercept to the appropriate value for mean relative humidity.

Step 7—Project a line horizontally to the right from the humidity intercept to the appropriate value for percent sunshine.

Step 8—Project a line vertically downward from the percent sunshine intercept to the appropriate value for elevation.

Step 9—Project a line horizontally to the right from the elevation intercept and read the estimated pan evaporation in millimeters per day.

Example : Station : New Delhi—Latitude 28°35'N

Step 1—From Table 1-R=15·3 millemetres per day

Step 2—For month of April

Tc=28.6°

W=10.9 Kilometres per hour at 12 metres height.

W=10.9×24 (0.6262)=164 Kilometres per day at 0.5 metre height.

H=41%

S=94% (1.9 tenths cloud cover converted to percent sunshine using Figure 1)

E=218 metres.

Step 3—9: Shown on Figure 2—Read Answer Ep= 11.6 millimetres per day.

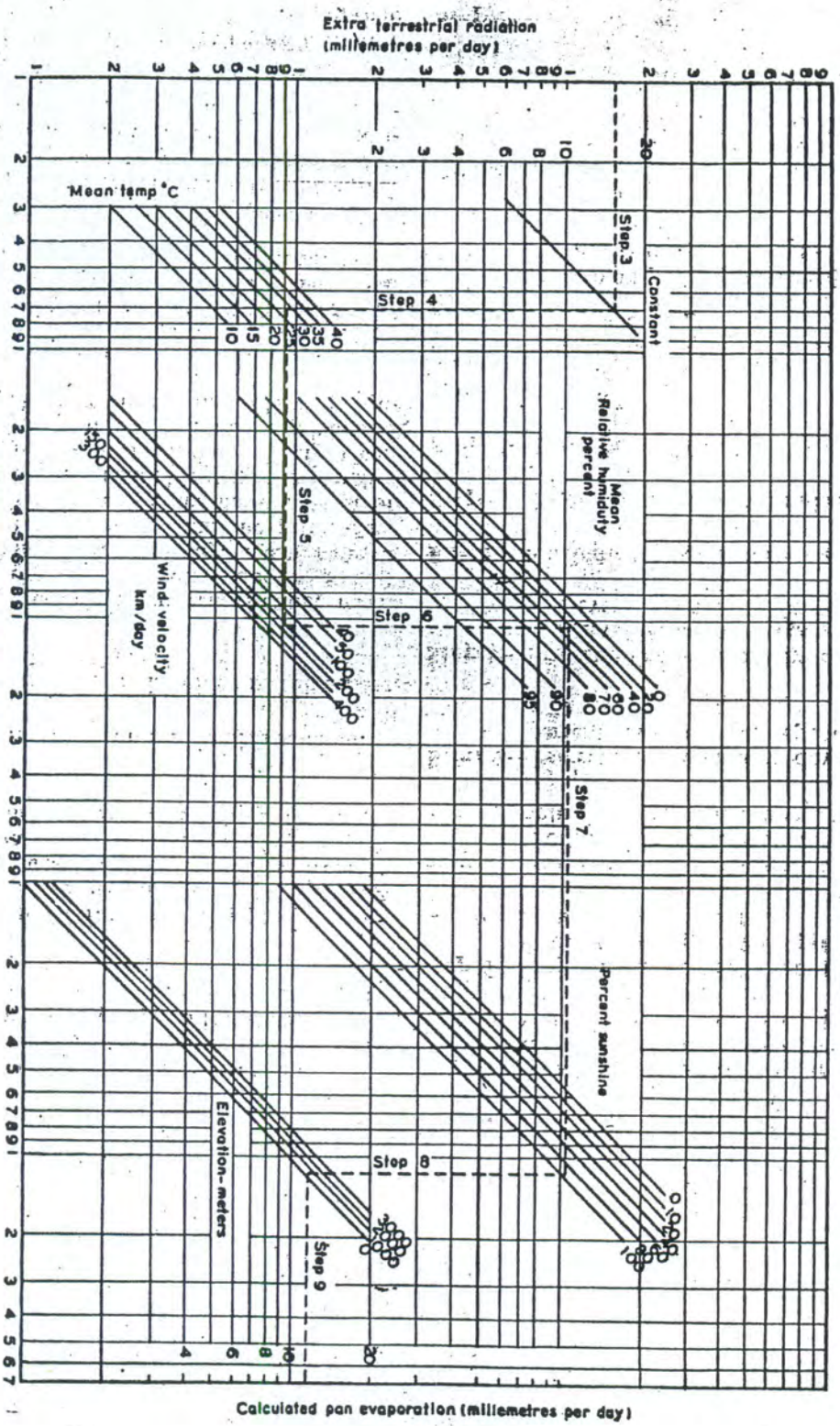


FIGURE 2 : Pan Evaporation Nomograph.

Appendix B

COMPUTER PROGRAMME
CROP WATER REQUIREMENTS

[Issued by the International Support Programme for Farm Water Management
Water Resources, Development and Management Service, Land
and Water Development Division, Food and Agri-
culture Organization of the United
Nations, Rome, 1981.]

Assistance to Field Projects in Calculation of Crop Water Requirements

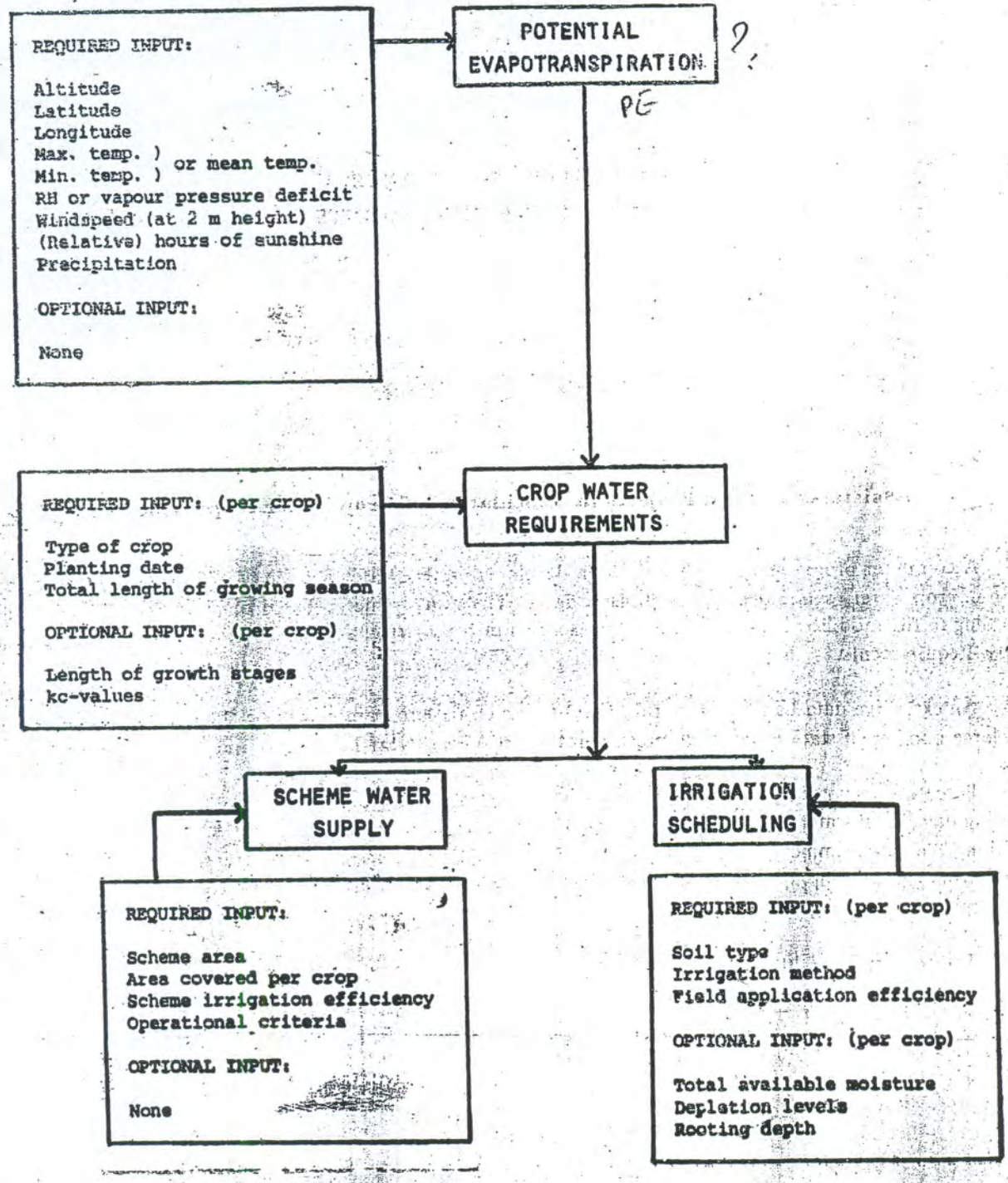
A computer programme has recently been developed in the Water Service of AGL to facilitate computation of crop water requirements from climatic data. The programme is based on the calculation procedure according to the modified Penman method as described in FAO Irrigation and Drainage Paper 24 on Crop Water Requirements.

An extensive data bank exists within FAO to which the programme can be linked with climatic data of a large number of stations covering most countries in Africa, Near East, Asia and Latin America.

Potential evapotranspiration is calculated from average monthly climatic data; for a given crop and planting date, crop water requirements for each 10-day period over the growing season are calculated. In addition, the programme provides the possibility to determine irrigation requirements and scheme water supply from given cropping pattern and operational criteria, as well as the irrigation scheduling (frequency and depth) for each crop.

The computer facilities are readily available for field projects, and on request assistance can be offered in the calculation of crop water requirements, irrigation scheduling and scheme water supply. Requests for such help can be directed to the Chief of the Water Resources, Development and Management Service. The request needs to be accompanied by specific input data, for which a form is attached. This form allows the inclusion of four crops; if more crops are grown, please submit similar data input sheets.

SEQUENCE OF CALCULATION



INPUT DATA

INPUT DATA TO CALCULATE POTENTIAL EVAPOTRANSPIRATION

1. Site specifications which should include country, station, latitude, longitude and altitude.

2. Average monthly climatic data on maximum and minimum (or mean) temperature (°C), relative humidity (%) (or vapour deficit, ea-ed, in mbar), windspeed (km/day or m/s), sunshine (hours/day or %) and precipitation (mm).

   If no climatic data are readily available, specifications on the station might be sufficient to locate a representative climatic data set from the data bank.

INPUT DATA TO CALCULATE CROP WATER REQUIREMENTS

3. A list of main crops for which calculations are requested.

4. For each crop, planting date and approximate length of growing season.

   If the same crop is planted in different seasons, a separate data set is required (see example maize 1, maize 2).

5. *OPTIONAL** : Length of the different growth stages (initial, vegetative, mid-season and late season stage) and values of the crop factor (kc) during the different stages.

   Irrigation requirements are computed from crop water requirements and effective rainfall, by inclusion of a simple linear relationship between total and effective rainfall.

INPUT DATA TO CALCULATE IRRIGATION SCHEDULING

6. Soil type (light, medium or heavy) and an estimation of the available moisture between field capacity and wilting point (mm/m).

7. Irrigation method and estimation of the field application efficiency.

8. *Optional* :* Depletion level (fraction of soil moisture at which stage evapotranspiration of the crop is reduced) during growth stages and rooting depth (initial and maximum rooting depth).

INPUT DATA TO CALCULATE SCHEME WATER SUPPLY

9. Total area (ha) of a irrigation scheme.

10. Area covered by the different crops (%) for each growing season over the total scheme.

11. Estimation of scheme irrigation efficiency.

12. Operational criteria : number of hours per day and number of days per week during which irrigation water is supplied.

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* *For optional data : please not thai if no optional data are supplied, worldwide average data stored in the computer will be used. Better results can be obtained if actual data are provided.*

INPUT DATA FORM

Name of Expert ..... Project .....

POTENTIAL EVAPOTRANSPIRATION

1. Country ..... Station ..... Altitude ..... m

   Latitude ..... North/South Longitude ..... East/West

2. Climatic Data:

	J	F	M	A	M	J	J	A	S	O	N	D
Max. temp. °C												
Min. temp. °C												
or mean °C												
RH % or ea-ed mbar												
Wind km/day or m/s												
Sun. hrs n (h) or n/N %												
Precip. mm												

CROP WATER REQUIREMENTS

		CROP 1	CROP 2	CROP 3	CROP 4
3.	Type of crop				
4.	Planting date (day/month)				
	Total growing season (days)				

5. *OPTIONAL:* length of growth stages (in days)

initial stage				
vegetative st.				
mid-season st.				
late season st.				
	OPTIONAL: kc values			
initial stage				
mid-season st.				
at harvest				

INPUT DATA FORM

Name of Expert ..T. Davis..... Project ...KEN/78/015

POTENTIAL EVAPOTRANSPIRATION

1. Country .Kenya..... Station ..Lodwar..... Altitude 506 m
   Latitude 3.08.. North/South Longitude .3.05. East/West

2. Climatic Data:

	J	F	M	A	M	J	J	A	S	O	N	D
Max. temp. °C	35.5	36.5	36.0	35.0	34.8	34.1	33.0	33.3	34.8	35.2	34.6	34.5
Min. temp. °C	22.2	23.1	24.3	24.3	24.6	24.0	23.5	23.5	23.8	24.5	23.5	22.6
or mean °C												
RH % or ed mbar	17.0	17.0	19.3	22.0	22.0	20.3	19.5	19.5	18.7	18.7	19.0	19.0
Wind km/day or m/s	2.5	2.7	3.0	2.7	2.7	2.5	2.3	2.7	3.0	3.1	2.7	2.3
Sun. hrs n (h) or n/N %	84	81	75	78	83	83	76	83	88	84	76	81
Precip. mm	8	5	20	41	27	8	13	9	3	8	10	13

CROP WATER REQUIREMENTS

		CROP 1	CROP 2	CROP 3	CROP 4
3.	Type of crop	maize 1	maize 2	PULSES	—
4.	Planting date (day/month)	1 april	15 may	1 jun	—
	Total growing season (days)	120	120	90	—

5. *OPTIONAL:* length of growth stages (in days)

initial stage				
vegetative st.				
mid-season st.				
late season st.				
OPTIONAL: kc values				
initial stage				
mid-season st.				
at harvest				

IRRIGATION SCHEDULING

6.

	CROP 1	CROP 2	CROP 3	CROP 4
Soil type (light/medium/heavy)				
7. Irrigation method				
Field application efficiency				
8. *OPTIONAL:* Total available moisture (mm/m)				

OPTIONAL: maximum allowable depletion (%)

initial stage				
mid-season stage				
at harvest				

OPTIONAL: rooting depth (m)

at planting				
mid-season stage				

SCHEME WATER SUPPLY

9. Scheme area ..... ha

10.

	CROP 1	CROP 2	CROP 3	CROP 4
Area covered as % total area				

11. Scheme irrigation efficiency ..... %

12. Operation period ..... hours/day ..... days/week

13. Remarks

IRRIGATION SCHEDULING

6.

	CROP 1	CROP 2	CROP 3	CROP 4
Soil type (light/medium/heavy)	medium	medium	heavy	
7. Irrigation method	furrow	furrow	graded border	
Field application efficiency	60	60	75	
8. *OPTIONAL:* Total available moisture (mm/m)	140	140	200	

OPTIONAL: maximum allowable depletion (%)

initial stage				
mid-season stage				
at harvest				

OPTIONAL: rooting depth (m)

at planting				
mid-season stage				

SCHEME WATER SUPPLY

9. Scheme area ....200.... ha

10.

	CROP 1	CROP 2	CROP 3	CROP 4
Area covered as % total area	40	40	20	—

11. Scheme irrigation efficiency ..45.. %

12. Operation period ....12.... hours/day ....6.... days/week

13. Remarks

Irrigation is only possible during 6 months per year, starting approx 1 april.

Climatological Data

Stat. Name : Lodwar Latitude 3.08 North Altitude 506 m

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Max. Temp. [dC]	35.5	36.5	36.8	35.0	34.8	34.1	33.0	33.3	34.8	35.2	34.6	34.5	
Min. Temp. [dC]	22.2	23.1	24.3	24.3	24.6	24.0	23.5	23.5	23.8	24.5	23.5	22.6	
Mean Temp. dC]	28.8	29.8	30.2	29.6	29.7	29.0	28.2	28.5	29.3	29.8	29.0	28.6	
Ed [mb]	17.0	17.0	19.3	22.0	22.0	20.3	19.5	19.5	18.7	18.7	19.0	19.0	
Wind [m/s]	2.5	2.7	3.0	2.7	2.7	2.5	2.3	2.7	3.0	3.1	2.7	2.3	
Sunshine [%]	84	81	75	78	83	83	76	83	88	84	76	81	
Daylength [h]	11.9	12.0	12.1	12.2	12.2	12.3	12.3	12.2	12.1	12.0	12.0	11.9	
Pet. Daily [mm]	8.1	8.8	8.9	8.1	8.0	7.6	7.2	8.1	9.0	9.1	8.0	7.4	
Pet. Month [mm]	250	246	277	242	248	229	222	249	271	283	238	228	2988
Rain [mm]	8	5	20	41	27	8	13	9	3	8	10	13	165
Eff. Rain [mm]	0	0	0	7	0	0	0	0	0	0	0	0	7

Explanation of Abbreviations :

D. Cet = Average Daily Evapotranspiration
Tot. Cet = Sum of Average Daily Crop Evapotranspiration
Period A = Initial Period
Period B = Crop Development Period
Period C = Mid Season Period
Period D = Late Season Period
Rain-Eff. = Effective Rainfall D. Ir. Req. = Average Daily Irrigation Requirement
Tot. Ir. Req. = Sum of Average Daily Irrigation Requirement
Depl. P. = Fraction of Total Available Moisture which is Readily Available = Max. Allowable Depletion
Root D = Average Root-Depth
Depl. D = Max. allowable Depletion over the Rootzone at last day of decade.
Irr. No. = Irrigation Number Int = Interval
N. Gift = Net Gift G. Gift = G. Gift

Crop Water Requirement

Crop : Maize 1 Plant-Date : 1. 4.

Day	Month	Crop Coef.	D. Cet. [mm]	Tot. Cet. [mm]	Period	Length [days]	Rain-Eff. [mm]	D. Ir. Req. [mm]	Tot. Ir. Req. [mm]
10	4	0.45	3.8	38.0	A	20	0.4	3.4	34.5
20	4	0.45	3.7	74.6	A	20	0.5	3.2	66.4
30	4	0.58	4.7	121.7	B	30	0.4	4.3	109.7
10	5	0.81	6.7	188.3	B	30	0.3	6.4	173.4
20	5	1.04	8.6	274.4	B	30	0.2	8.4	257.4
30	5	1.15	9.3	367.0	C	40	0.1	9.1	348.6
10	6	1.15	9.0	457.1	C	40	0.1	8.9	438.1
20	6	1.15	8.8	545.1	C	40	0.0	8.8	526.0
30	6	1.15	8.7	632 0	C	40	0.0	8.7	612.9
10	7	1.05	7.9	710.5	D	30	0.0	7.9	691.5
20	7	0.87	6.5	775 2	D	30	0.0	6.5	756.1
30	7	0.68	5.3	827.9	D	30	0.0	5.3	808.9

Irrigation Scheduling

Soil Type : Medium

Tot. Avail. Moisture [mm/m] : .140

Kind of Irrigation : Furrow

Application Efficiency [%] 60

Day-Per	Day-Cum	Month	D. Ir. Req.	Period	Depl. P	Root D [mm]	Depl. D [mm]	Tot. Irr. Req. [mm]	Irr. No.	Day	N. Gift [mm]	G. Gift [mm]	Int [days]
1-10	10	4	3.45	A	0.40	0.38	24.6	34.5	1	7	24.5	40.8	7
11-20	20	4	3.20	A	0.40	0.52	32.5	66.4	2	17	32.4	54.0	10
21-30	30	4	4.32	B	0.40	0.66	40.3	109.7	3	28	42.5	70.9	11
1-10	40	5	6.37	B	0.40	0.80	48.2	173.4	4	36	46.0	76.7	8
11-20	50	5	8.40	B	0.40	0.94	56.0	257.4	5	43	51.1	85.2	7
									6	50	60.8	101.4	7
21-30	60	5	9.12	C	0.40	1.00	56.0	348.6	7	57	64.1	106.8	7
1-10	70	6	8.95	C	0.40	1.00	56.0	438.1	8	64	64.2	105.3	7
11-20	80	6	8.79	C	0.40	1.00	56.0	526.0	9	71	62.3	103.9	7
									10	78	61.5	102.5	7
21-30	90	6	8.69	C	0.40	1.00	56.0	612.9	11	85	61.1	101.8	7
1-10	100	7	7.86	D	0.48	1.00	77.0	691.5	12	92	60.2	100.4	7
11-20	110	7	6.47	D	0.63	1.00	98.0	756.1	13	104	89.1	148.5	12
21-30	120	7	5.27	D	0.78	1.00	11.90	808.9					

It is assumed that the entire Rootzone is at field capacity at planting date.

Crop Water Requirement

Crop Pulses Plant-Date : 1. 6

Day	Month	Crop Coef.	D. Cet. (mm)	Tot. Cet. (mm)	Period	Length (days)	Rain-Eff. (mm)	D. Ir. Req. (mm)	Tot. Ir. Req (mm)
10	6	0.45	3.5	35.3	A	15	0.1	3.5	34.6
20	6	0.49	3.8	72.9	B	25	0.0	3.8	72.1
30	6	0.74	5.6	129.1	B	25	0 0	5.6	128.4
10	7	1.02	7.7	205.7	B	25	0.0	7.7	205.0
20	7	1.15	8.6	291.7	C	30	0.0	8.6	290.9
30	7	1.15	8.9	380.6	C	30	0.0	8.9	379.9
10	8	1.15	9.2	473.0	C	30	0.0	9.2	472.3
20	8	0.92	7.6	549.2	D	20	0.0	7.6	548.5
30	8	0.49	4.2	591.2	D	20	0.0	4.2	590.5

Irrigation Scheduling

Soil Type : Heavy
Tot. Avail. Moisture (mm/m) 200
Kind of Irrigation : Graded Border
Application Efficiency [%] 75

Day-Per	Day-Cum	Month	D. Ir. Req.	Period	Depl. P.	Root D (mm)	Depl. D (mm)	Tot. Irr. Req. (mm)	Irr. No.	Day	N. Gift (mm)	G. Gift (mm)	Int (days)
1-10	10	6	3.46	A	0.30	0.40	28.5	34.6	1	8	27.7	37.0	8
11-20	20	6	3.75	B	0.31	0.57	41.6	72.1	2	20	44.4	59.2	12
21-30	30	6	5.62	B	0.34	0.75	59.4	128.4					
1-10	40	7	7.66	B	0.38	0.92	80.0	205.0	3	31	63.0	84.0	11
11-20	50	7	8.59	C	0.40	1.00	80.0	290.9	4	42	87.0	116.0	11
21-30	60	7	8.89	C	0.40	1.00	80.0	379.9	5	52	86.3	115.1	10
1-10	70	8	9.24	C	0.40	1.00	80.0	472.3	6	61	80.5	107.4	9
									7	70	83.3	111.1	9
11-20	80	8	7.62	D	0.52	1.00	125.0	548.5					
21-30	90	8	4.20	D	0.75	1.00	170.0	590.5					

It is assumed that the Entire Root zone is at Field Capacity at Planting Date

Crop Water Requirement*

Crop : Maize 2 Plant-Date : 15. 5

Day	Month	Crop Coef.	D. Cet. (mm)	Tot. Cet (mm)	Period	Length (days)	Rain-Eff. (mm)	D. Ir. Req. (mm)	Tot. Ir. Req. (mm)
20	5	0.45	3.7	22.2	A	20	0.2	3.5	21.1
30	5	0.45	3.6	58.4	A	20	0.1	3.5	56.0
10	6	0.50	3.9	97.5	B	30	0.1	3.8	94.4
20	6	0.72	5.5	152.4	B	30	0.0	5.5	149.2
30	6	0.95	7.2	224.3	B	30	0.0	7.2	221.1
10	7	1.14	8.5	309.4	C	40	0.0	8.5	306.2
20	7	1.15	8.6	395.3	C	40	0.0	8.6	392.1
30	7	1.15	8.9	484.2	C	40	0.0	8.9	481.0
10	8	1.15	9.2	576.6	C	40	0.0	9.2	573 4
20	8	1.11	9.3	669.2	D	30	0.0	9.3	666.0
30	8	0.94	8.0	749.6	D	30	0.0	8.0	746.4
10	9	0.76	6.7	816.2	D	30	0.0	6.7	813.0
14	9	0.63	5.6	838.7	D	30	0.0	5.6	835.5

* The irrigation schedule printout for maize 2 is not included.

APPENDICES

Appendix C

Location of Agro-Meteorological Stations

Station	District	Category
ANDHRA PRADESH		
1. Tirupati	Chittoor	b(iii)
2. Rajamundry	East Godavari	b(iv)
3. Samalkot	Do	b(i)
4. Amravati	Guntur	b(iv)
5. Ibrahimpettam	Hyderabad	b(ii)
6. Rajendranagar	Hyderabad	b(i)
7. Pattan Cheru	Hyderabad	b(iv)
8. Garikapadu	Krishna	b(iv)
9. Yemmiganur	Kurnool	b(iv)
10. Vellore	Nellore	b(iii)
11. Rudrun	Nizamabad	b(i)
12. Anakapalle	Vishakapatnam	b(iv)
13. Anakapalle	Vishakapatnam	e
14. Warangal	Warangal	b(i)
ASSAM		
1. Karimganj	Cachar	b(i)
2. Silguri	Cachar	b(iv)
3. Delgaon	Darang	b(i)
4. Titabar	Sibsagar	b(i)
5. Tocklai	Sibsagar	b(iv)
6. Diphu	United District of Mikir & North Kachar Hills.	b(iv)
BIHAR		
1. Sabam	Bhagalpur	b(i)
2. Pusa	Darbhanga	b(i)
3. Patna	Patna	b(i)
4. Ranchi (Kanke)	Ranchi	b(i)
5. Madhipura	Saharsa	b(iv)
6. Bikramganj	Sahabad	b(i)
GUJARAT		
1. Ahmedabad	Ahmedabad	c(i)
2. Virangam	Ahmedabad	b(i)
3. Dhari	Amreli	b(iv)
4. Deesa	Banaskantha	b(iv)
5. Deesa	Banaskantha	d
6. Bhuj	Kutch	c(i)
7. Jamnagar	Jamnagar	b(i)
8. Junagarh	Junagarh	b(i)
9. Vasad	Karia	b(ii)
10. Dohad	Panch Mahal	c(ii)
11. Dohad	Panch Mahal	c(iii)
12. Surat	Surat	b(i)
13. Bardoli	Surat	b(iv)
14. Halvad	Surendranagar	b(i)
HARYANA		
1. Hissar	Hissar	b(iii)
2. Hissar	Sirsa	b(iv)
HIMACHAL PRADESH		
1. Raghunathpura	Bilaspur	b(ii)
2. Mashobra	Simla	b(iv)
3. Dhaulakuan	Sirmur	b(iv)
KARNATAKA		
1. Hebbal	Bangalore	b(iii)
2. Sambre	Belgaum	c(i)
3. Sankeshwar	Do	b(i)
4. Bellary	Bellary	b(iv)
5. Bellary	Bellary	b(ii)
6. Dharwar	Dharwar	e
7. Dharwar	Dharwar	b(iii)

Station	District	Category
8. Gadag	Dharwar	c(iii)
9. Mangalore	South Canara	c(iii)
10. Vittal	South Canara	b(iv)
11. Hunsur	Mysore	b(iv)
12. Raichur	Raichur	b(iv)
13. Thirthahalli	Shimoga	b(iv)
KERALA		
1. Kasargod	Kannanore	b(iv)
2. Kollayam	Kottayam	b(iv)
3. Pattambi	Palghat	b(i)
4. Kayangulan	Quilon	b(iv)
5. Konni	Quilon	b(iv)
6. Ollukara	Trichur	b(i)
7. Vellayani	Trivandrum	b(iii)
MADHYA PRADESH		
1. Pendra	Bilaspur	c(i)
2. Gwalior	Gwalior	b(iii)
3. Gwalior	Gwalior	c(i)
4. Adhartal	Jabalpur	c(ii)
5. Labhandi	Raipur	b(i)
6. Kuthulia	Rewa	b(i)
7. Bhopal	Sahore	b(iv)
MAHARASHTRA		
1. Akola	Akola	b(i)
2. Akola	Akola	b(iii)
3. Akola	Akola	e
4. Sindhewahi	Chanda	b(i)
5. Dhulia	Dhulia	b(iii)
6. Jalgaon	Jalgaon	b(iii)
7. Karat	Kolaba	b(i)
8. Kolhapur	Kolhapur	b(iii)
9. Kolhapur	Kolhapur	c(i)
10. Nagpur	Nagpur	b(i)
11. Niphad	Nasik	b(i)
12. Golegaon	Parbhani	b(iv)
13. Parbhani	Parbhani	b(i)
14. Khed	Poona	b(iv)
15. Poona	Poona	a
16. Poona	Poona	e
17. Depoli	Ratnagiri	b(iii)
18. Padegaon	Satara	b(i)
19. Sholapur	Sholapur	b(i)
MEGHALAYA		
1. Upper Shillong	United Khasi & Jantia Hills	b(iv)
NEW DELHI		
1. New Delhi		b(i)
2. New Delhi		e
ORISSA		
1. Cuttack	Cuttack	b(i)
2. Ganjam	Bhabanpur	b(iv)
3. Mayurbhanj	Samkhunta	b(i)
4. Puri	Bhubaneshwar	b(i)
5. Sambalpur	Bamra	b(iv)
6. Sambalpur	Chakuli	b(iv)
PUNJAB		
1. Amritsar	Amritsar	d
2. Ambala	Chandigarh	b(ii)
3. Gurdaspur	Gurdaspur	b(iv)
4. Jullundur	Jullundur	b(i)
5. Ludhiana	Ludhiana	b(iii)
RAJASTHAN		
1. Bikaner	Bikaner	b(iv)
2. Bikaner	Bikaner	c(i)
3. Ganganagar	Berore	b(iv)
4. Ganganagar	Hanumangarh	b(iv)
5. Ganganagar	Ganganagar	b(iv)
6. Ganganagar	Ganganagar	d
7. Jaipur	Dingapur	b(i)
8. Jaipur	Jobner	b(iii)
9. Jaisalmer	Jaisalmer	d

Station	District	Category
10. Jodhpur	Jodhpur	b(iv)
11. Jodhpur	Jodhpur	e
12. Kota	Kota	b(ii)
13. Kota	Kota	d
14. Kota	Rawatbhata	b(iv)
15. Pali	Pali	b(iv)
16. Udaipur	Udaipur	b(i)
17. Udaipur	Vallabhnagar	b(iv)
TAMIL NADU		
1. Coimbatore	Coimbatore	b(i)
2. Coimbatore	Coimbatore	e
3. Medasundur	Madurai	b(iv)
4. Ottacamund	Nilgiris	b(ii)
5. Annamalainagar	South Arcot	b(iii)
6. Aduthurai	Tanjore	b(i)
7. Kovilpatti	Tirunelveli	b(i)
UTTAR PRADESH		
1. Agra	Agra	b(ii)
2. Chaubattia	Almora	b(iv)
3. Basti	Basti	b(iv)
4. Bullandshahar	Bulandshahar	c(iii)
5. Dehradun	Dehradun	b(iv)
6. Dehradun	Dehradun	b(ii)
7. Ri h	Dehradun	b(iv)
8. Fai	Faizabad	b(iv)
9. Gorakh	Gorakhpur	c(iii)
10. Orai	Jalaun	c(i)
11. Jhansi	Jhansi	b(iv)
12. Lakhimpur	Kheri	c(i)
13. Lucknow	Lucknow	b(iv)
14. Rahmankhera	Lucknow	b(ii)
15. Pantnagar	Nainital	b(iii)
16. Roorkee	Saharanpur	b(iv)
17. Saharanpur	Saharanpur	b(iv)
WEST BENGAL		
1. Dinhata	Coochbehar	b(iv)
2. Nagri	Darjeeling	b(iv)
3. Chinsurah	Hooghly	b(iv)
4. Nagarkata	Jalpaiguri	b(iv)
5. Haringhata	Nadia	b(iv)
6. Barrackpore	24-Pargana	b(iv)
7. Canning	Do	b(iv)

Description of Categories

Category a—Provides detailed meteorological—and biological information and carries out research in Agricultural meteorology.

Category b—Provides on a routine basis meteorological and biological information. The meteorological elements observed at these stations include rainfall, air temperature and humidity, soil temperature and moisture, wind evaporation, sunshine and the occurrence of weather phenomenon like thunderstorms, hailstorms frost, high wind etc. The above are recorded at 07·00 and 14·00 LMT except rainfall and evaporation which are recorded at 08·30 IST and 14·00 LMT.

(*i*) Agro meteorological station which record simple observations on the growth and yield of standard crops according to a common standard plan.

(*ii*) Agrometeorological station maintained by Soil Conservation Research, Demonstration and Training Centre.

(*iii*) Agrometeorological station maintained by Agricultural schools, colleges and Universities.

(*iv*) Agrometeorological station maintained by Agricultural research farms and allied centres for meeting the data requirement of their research programme.

Category c—Air temperature and humidity, rain-

fall and may record some of the other meteorological parameters.

(*i*) Surface observations (IMD) recording phenological observations.

(*ii*) Phenological stations for which meteorological data are also recorded by some other agencies.

(*iii*) Pest and disease reporting stations for which meteorological data are also recorded by some other agency.

Category d—(*Pilot balloons-cum-micromet station*)—were started under desert locust meteorology scheme. Used for recording low level wind data for anti locust operations.

Category e—At these stations, measurement of evapotranspiration is made using gravimetric lysimeters in order to assess the water requirement of important crops.

Appendix D

GLOSSARY OF TERMS IN COMMON USE

ACTUAL CROP EVAPOTRANSPIRATION, ETa (Crop) : rate of evapotranspiration equal to or smaller than predicted ET crop as affected by the level of available soil water, salinity, field size, or other causes ; mm/day

ACTUAL VAPOUR PRESSURE, ed: pressure exerted by water vapour contained in the air; millibar

ADVECTION, horizontal transport of sensible heat by air movement as for instance from large, dry fallow surrounds into irrigated areas

ALLOWABLE SOIL WATER DEPLETION, p.Sa: depth of sotl water in the root zone readily available to the crop for given soil and climate allowing unrestricted evapotranspiration as the fraction p of total available soil water between field capacity (Sfc) and wilting point (Sw) ; mm/m soil depth

AVAILABLE SOIL WATER, Sa : depth of water stored in the root zone between field capacity (Sfc) and wiltingpoint (Sw) ; mm/m soil depth

AVERAGE INTAKE RATE : rate of infiltration of water into the soil obtained by dividing the total depth of water infiltrated by the total time from start to finish of water application; mm/hour

BA rate at which water will enter th ... initial wetting of the soil the rate becom... ...ntially constant ; mm/hour

CANOPY INTERCEPTION : depth of precipitation caught and held by plant foilage and lost be evaporation without reaching the ground surface ; mm or sometimes percentage of rainfall

CLOTHESLINE EFFECT : horizontal heat transfer (advection) from warm and dry upwind area to a relatively cooler crop field resulting in increased ET crop ; particularly refers to the field horder effects, or to patchwork of small interspersed fields

CLOUDINESS : degree of cloud cover, usually-mean of several observations per day ; expressed in oktas (in eights) of sky covered, or in tenths of sky covered

CONTINUOUS SUPPLY : method of water delivery with continuous but often variable discharge in water distribution system up to inlet of individual farm or field

CONVEYANCE EFFICIENCY, Ec : ratio between water received at the inlet to a block of fields and that released at the projects headworks ; fraction

CRITICAL PERIOD : periods during crop growth when soil water stress will have a lasting effect on crop growth and yields.

CROP COEFFICIENT, kc : ratio between crop evapotranspiration (ET crop) and the reference crop evpotranspiration (ETo) when crop is grown in large fields under optimum growing conditions, or ET crop =kc. ETo ; fraction

CROP EVAPOTRANSPIRATION, ET crop : rate of evapotranspiration of a disease-free crop growing in a large field (one or more ha) under optimal soil conditions, including sufficient water and fertilizer and achieving full production potential of that crop under the given growing environment ; includes water loss through tanspiration by the vegetation, and evaporation from the soil surface and wet leaves ; mm/day

CROPPING INTENSITY : for a given period the percentage of the total scheme area which is under a (irrigated) crop ; percentage

CROPPING PATTERN : sequence of different crops grown in regular order on any particular field or fields.

CROP WATER REQUIREMENTS : depth of water required by a crop or a diversified pattern of crops for evapotranspiration (ET crop) during a given period ; mm/day as average for given period

DAY LENGTH FACTOR, p : percentage p of total annual daylight hours occurring during the period being considered ; percentage

DESIGN FACTOR, £ : ratio between canal capacity or maxmum discharge in m^3/sec and the maximum daily supply requirements during the peak water use period in m^3/day or $\alpha = 86400\ Q\ max/V_{max}$; fraction

DEPTH OF IRRIGATION ; d : depth of irrigation, including application losses, applied to the soil in

Intensity of irrigation

one irrigation application and which is needed to bring the soil water content of root zone to field capacity;mm

DEVELOPMENT STAGE : for a given crop the period between end of initial (emergence) stage and full ground cover or when ground cover is between 10 and 80 percent; days.

DEWPOINT TEMPERATURE, T dewpoint : temperature to which the air needs to be cooled in order to become saturated and at which water vapour starts to condense ; degree celsius

DISTRIBUTION EFFICIENCY, Ed ; ratio of water made directly available to the crop and that released at the inlet of a block of fields ; Fd =Eb. Ea; fraction

EFFECTIVE FULL GROUNDCOVER ; percentage of groundcover by the crop when FT crop is approaching maximum - generally 70 to 80 per cent of surface area ; percentage

EFFECTIVE RAINFALL, Pe : rainfall useful for meeting crop water requirements ; it excludes deep percolation, surface runoff and interception; mm/period

EFFECTIVE ROOTING DEPTH, D : Soil depth from which the full grown crop extracts most of the water needed for evapotranspiration ; m

ELECTRICAL CONDUCTIVITY, EC : the property of a substance to transfer an electrical charge (reciprocal of resistance). It is measured in ohms of a conductor which is 1 cm long and 1 cm^2 electrical conductivity is expressed as the reciprocal of ohms/cm (mhos/cm) ; 1 mhos/cm =1000 mmhos/cm ; 1 mmhos/cm=1000 mmhos/cm

ELECTRICAL CONDUCTIVITY, IRRIGATION WATER, ECw : is used as a measure of the salt content of the irrigation water ; mmhos/cm

ELECTRICAL CONDUCTIVITY, SATURATION EXTRACTS, ECe : is used as a measure of the salt content of an extract from a soil when saturated with water ; under avarage conditions ECe=1·5 ECdw and also is approximately half the salinity of the soil water to which the crop is actually exposed in the soil, mmhos/cm

EVAPORATION E : rate of water loss from liquid to vapour phase from an open water or wet soil surface by physical processes; mm/day

EVAPOTRANSPIRATION : rate of water loss through transpiration from vegetation plus evaporation from the soil ; mm/day

EXTRA TERRESTRIAL RADIATION, Ra : amount of solar radiation received on a horizontal at the top of the atmosphere ; equivalent evaporation mm/day

FIELD APPLICATION EFFICIENCY, Ea : ratio of water made directly available to the crop and the water received at the field inlet

FIELD CANAL EFFICIENCY, Eb : ratio between water received at the field inlet and that at the inlet of a block of fields ; fraction

ELECTRICAL CONDUCTIVITY, MAXIMUM, EC_{max} : is used as a limit of the salt concentration of the soil saturation paste (ECe) beyond which growth would stop (zero yield) ; mmhos/cm.

FIELD CAPACITY, Sfc : depth of water held in the soil after ample irrigation or heavy rain when the rate of downward movement has substantially decreased, usually 1 to 3 days after irrigation or rain ; soil water content at soil water tension of 0·2 to 0·3 atmosphere ; mm/m soil depth

FIELD SUPPLY SCHEDULE : stream size, duration and interval of water supply to the individual field or farm

FIELD WATER BALANCE : sum of all gains and losses of water over a given period of time; mm/period

FLEXIBILITY FACTOR, C : coeffcient greater than one to account for fluctuations in water supply in excess of those determined for an assumed cropping pattern and cropping intentisy

FULL GROUND COVER : soil covered by crops approaching 100 percent when looking downwards

GROUND COVER : percentage of soil surface shaded by the crop if the sun were directly overhead ; percentage

GROUNDWATER TABLE : upper boundary of groundwater where water pressure is equal to atmosphere, i e. depth of water level in borehole when groundwater can freely enter the borehole ; cm below soil surface

GROWING SEASON : for a given crop the time between planting or sowing and harvest ; days

INITIAL DEVELOPMFNT STAGE : for a given crop the time during germination or early growth when ground cover is less than 10 percent; days

INITIAL INTAKE RATE : rate at which water will enter the soil when water is first applied ; mm/hour

IRRIGATION INTERVAL, i : time between the start of successive field irrigation applications on the same field ; days

IRRIGATION REQUIREMENTS : depth of water required for meeting evapotranspiration minus contribution by effective precipitation, groundwater, stored soil water, required for normal crop production

plus leaching requirement and water losses and operational wastes, sometimes called gross irrigation requirements ; mm/period

; LATE-SEASON STATE : time between the end of the mid-season stage and harvest or maturity ; days

LEACHING EFFICIENCY ,Le : fraction of the irrigation water applied for salt control (leaching) which was effective

LEACHING REQUIREMENTS, LR : fraction of the irrigation water entering the soil that effectively must flow through and beyond the root zone in order to prevent salinity build-up. This value is the minimum amount of water necessary to control salts ; fraction

LEVEL OF SUPPLY : selected water supply on the basis of probability to meet crop irrigation requirements

MAXIMUM NUMBER OF BRIGHT SUNSHINE HOURS ; N : number of bright sunshine hours for a 24-hour day with no cloud cover ; hours

METHOD OF SUPPLY : method of operating an irrigation system to convey water from the source of supply and to distribute it according to crop requirements to each field served by the system

MID-SEASON STAGE : for a given crop the period between effective full ground cover and the onset of maturity (i.e. leaves start to discolour or fall off) ; days

NET IRRIGATION REQUIREMENT, In : depth of water required for meeting evapotranspiration minus contribution by precipitation, groundwater, stored soil water ; does not include operation losses and leaching requirements ; mm/period

NET LONGWAVE RADIATION, Rnl : balance between all out going and incoming longwave radiation ; almost always a negative value, equivalent evaporation mm/day

NET RADIATION Rn : balance between all incoming and outgoing and longwave Radiation; Rn = Rns+Rnl; equivalent evaporation mm/day

NET SOLAR RADIATION, Rns : difference between shortwave radiation received on the earth's surface and that reflected by the soil crop or water surface; equivalent evaporation mm/day

OASIS EFFECT : effect of dry fallow surrounds on the microclimate of a relatively small acreage of land where an air mass moving into an irrigated area will give up sensible heat. For small fields this may result in a higher ET crop as compared to predicted ET crop using climatic data collected inside the irrigated area; conversely ET crop predictions based on weather data collected outside the irrigated fields may over-predict actual evapotranspiration losses

OSMOTIC PRESSURE : equivalent negative pressure to which water must be subject to bring the saline soil water through a semi-permeable membrane into static equilibrium with pure water; atmosphere

PAN COEFFICIENT, kp : ratio between reference evapotranspiration ETo and water loss by evaporation from an open water surface of a pan or ETo+Hp × Epan; fraction

PAN EVAPORATION, Epan : rate of water loss by evaporation from an open water surface of apan; mm/day

PEAK OR MAXIMUM SUPPLY, V_{max} : average daily supply requrement during the peak water use period for given crop or cropping pattern and climate : m/day

PEAK SUPPLY PERIOD : water use period for a given crop or cropping pattern during the month or period thereof of highest water requirements; mm/day

PLANT POPULATION : number of plants per unit of crop area.

PRECIPITATION : total amount of precipitation (rain, drizzle, snow, hail, fog, condensation, hoar, frost and rime) expressed in depth of water which would cover a horizontal plane if there is no runoff, infiltration or evapotranspiration; mm/day

PROJECT EFFICIENCY, Ep: ratio between water made directly available to the crop and that released at project head work : Ep+Ea. Eb. Ec ; fraction

PSYCHROMETER : device to measure air humidity, normally consisting of two standard thermometers, one of whose bulb is surrounded by a wet muslin bag and is called wet-bulb thermometer; both should normally be force ventilated and shielded against radiation (assmann type)

READILY AVAILABLE SOIL WATER; P. Sa : depth of soil water available for given crop, soil and climate allowing unrestricted evapotranspiration and crop growth; equals allowable soil water depletion; mm/m soil depth

REFERENCE CROP EVAPOTRANSPIRATION, ETo : rate of evapotranspiration from an extended surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water; mm/day

REFLECTION COEFFICIENT, also called albedo, x: ratio between the amount of shortwave radiation received at the earth's surface and that reflected back

RELATIVE HUMIDITY, RH, RHmaz, RH_{min} : actual amount of water vapour in the air relative to the amount of water vapour the air would hold when saturated at the some temperature;

RH_{max} : mean of maximum RH of each day over the period considered ; RH, min ; mean of minimum RH of each day over the period considered ;percentage

ROTATIONAL SUPPLY : supply of water rotated amongst laterals sub-laterals or field inlets at varied intervals

SATURATION VAPOUR PRESSURE, ea: upper limit of vapour pressure at or when air is saturated at given air temperature; millibar

SEASONAL IRRIGATION REQUIREMENTS : total depth of water, minus contribution by precipitation, groundwater, stored soil water, surface runoff required for normal crop growth during the crop growing season; mm and period

SOIL HYDRAULIC CONDUCTIVITY, k : rate of water flow through a unit cross-section of the soil under a unit hydroulic gradient also called permeability or transmission; mm/day

SOIL INTAKE (INFILTRATION) RATE : instantaneous rate at which water will enter the soil

SOIL SPECIFIC GRAVITY, As : ratio of the weight of water free soil to its volume; also called bulk density; g/cm^3

SOIL STRUCTURE : arrangement of soil particles into aggregates which occur in a variety of recognized shapes, sizes and strengths

SOIL TEXTURE : characterization of soil in respect of its particle size and distribution

SOIL WATER CONTENT : depth of water held in the soil ; mm/m soil depth

SOIL WATER DEPLETION FRACTION, p : fraction of available soil water (Sfc-Sw) that can be taken by the crop permitting unrestricted evapotranspiration and crop growth; fraction

SOIL WATER STRESS : sum of soil water tension and osmotic pressure to which water must be subjected to be in equilibrium with soil water; also called soil water potential; atmosphere

SOIL WATER TENSION : force at which water is held by the soil or negative pressure or suction that must be applied to bring the water in a porous cup into static equilibrium with the water in the soil; soil water tension does not include osmotic pressure; also called matric potential; atmosphere

SOLAR RADIATION, Rs : amount of shortwave radiation received on a horizontal plane at the earth's surface; equivalent evaporation mm/day.

STORED SOIL WATER, Wb : depth of wa the root zone from earlier rains, snow or irri applications which partly or fully meets crop requirements in following periods; mm.

STREAM SIZE, q : flow selected for supply t inlet or irrigation block; l/sec or m^3/sec.

SUNSHINE HOURS, n : number of ho bright sunshine per day, also sometimes defined duration of traces or burns made on a chart by C bell stokes recorder; hours.

SUPPLY DURATION, to or T : length of during which a given stream size is delivered t field or farm (t) or irrigation block (T) during an of the irrigation season; hour or day.

SUPPLY DURATION FACTOR, ft : is T/ for a fixed or constant canal discharge the ratio ween supply duration in days and the supply int in days during any part of the irrigation se fraction.

SUPPLY FACTOR. fs : is Q/Q_{max} or ratio ween actual and maximum possible supply in m^3 fraction.

SUPPLY INTERVAL, i or 1 : time interval ween the start of successive irrigation supplies at or farm (*i*) irrigation block or sector (1); days

SUPPLY ON DEMAND : irrigation water su to satisfy need for irrigation water at any stream duration and interval during the growing season.

SUPPLY REQUIREMENT FACTOR, fi: is V/V max or ratio between average daily supply requirm over a given period and maximum daily supply requ ment during the period of peak water use in m 3/d fraction.

SUPPLY SCHEDULE : stream size, supply du tion and supply interval of irrigation water supply field or irrigation block during the growing season.

TENSIOMETER : a device for measuring t tension of soil water in the soil consisting of a poro permeable ceramic cup connected through a tube to manometer or vacuum gauge

TOTAL AVAILABLE SOIL WATER, Sa=(Sfc Sw) : depth of soil water available in the root zone the crop; difference between field capacity and wiltin point; mm/m soil depth

TRANSPIRATION : rate of water loss thr ug the plant which is regulated by physical and physiolo gical processes; mm/day

LB TEMPERATURE, T-wet-bulb : tem-
rded on a thermometer whose bulb is sur-
wet muslin bag, thus lowering the tem-
oss of latent heat through evaporation ;
s

JLB DEPRESSION : difference between
s readings of wet and dry bulb thermo-
ee Calsius

WILTING POINT, Sw : depth of soil water below which the plant cannot effectively obtain water from the soil; soil water content at 15 atmosphers soil water tension; mm/m soil depth

WINDSPEED, U_2 : speed of air movement at 2m above ground surface in unobstructed surroundings mean in m/sec over the period considered, or total widd run in km/day

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