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CROP WATER REQUIREMENTS FOR KRISHNAI IRRIGATION PROJECT (MEDIUM) OF ASSAM

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PREFACE

The estimation of water requirements of crop is essential for irrigation planning and management and also it is the basis on which an irrigation project designed. The increasing demand and scarcity of water makes it important to use the available water in the most economic way. The key to effectiveness irrigation water management lies in proper estimation of crop water requirements, which are primarily based on cropping pattern, rainfall in the area and other climatic factors.

The main aim of this report is to provide a framework for calculating crop water requirements for Krishnai irrigation project. In this report crop water requirements for the crops under Krishnai irrigation project have been estimated as per the guidelines of Food and Agricultural Organization (FAO-24). The krishnai irrigation project is a medium irrigation project situated under the Goalpara district of Assam. The object of the project is aimed to supply the controlled water to vast cultivated area and to improve the existing cropping pattern and also to ensure irrigation to the field against vagaries of rainfall. There is a proposal to construct a barrage across the river Krishnai to tap water for irrigation to the proposed command area. Hence it is necessary to estimate the actual crop water requirements in advance to manage the barrage water efficiently and economically.

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ABSTRACT

An attempt has been made to estimate the design mean monthly reference crop evapotranspiration (ETo) for Krishnai Irrigation Project of Assam. For this analysis the mean monthly climatological and physiographical data for the period of 1986 to 1994 have been collected from the Indian Meteorological Department, Borjhar. Since the ETo value depends on large number of climatological, physiographic and other data and manual estimation is highly tedious and time consuming, so use of computer software is very essential. A computer program given in FAO-24 developed by Doorenbos and Pruitt (1977) has been modified and used for estimation of ETo by seven different empirical methods viz. Blaney & Crridle, Radiation, Penman, Modified Penman, Pan Evaporation, Hargreave and Thornthwaite. Modified Penman Method of ETo estimation is the most elaborate and rational but requires a large number of data. Often such data is very scanty forcing the use of some other empirical methods. Therefore the study is further extended to evaluate regional relationships for Krishnai Irrigation Project relating the ETo values of Modified Penman and of six other climatological methods. The developed relationships are useful in determining the rational value of ETo which will correspond to the ETo value by Modified Penman method even in the situation of scanty data. Finally crop water requirements calculated on the basis of mean monthly ETo values received from Modified Penman method.

1.0 INTRODUCTION

Water is becoming precious and scarce with the increasing demand for it due to growth of population and rapid industrialization. Agriculture being the mainstay of population, exploitation of available water resources to meet the agricultural needs requires its scientific management. An important aspect of agricultural planning is to work out requirements of water for crops. The water requirements of crop vary widely from crop to crop and also during the entire crop period of individual crop. Thus estimation of crop water requirements considering the crop pattern has been an area which has attracted attention of water resources planners and engineers. The main parameter which is required to be determined for estimating the crop water requirements is crop evapotranspiration (ETo) which when multiplied with the crop factor gives the value of water required by the crop. The actual evapotranspiration can be measured in the field with the help of lysimeter or by actual moisture content measurement. But it is not always possible. Therefore some analytical methods are required for evaluating ETo values.

The estimation of water requirements of crop is essential for crop planning on a farm and also it is the basis on which an irrigation project is designed. The increasing demand and scarcity of water makes it important to use the available water in the most economic way. Management practices for conservation of water have been increasingly emphasized because of sparse natural precipitation, high evapotranspiration and excessive depletion of limited ground water resources. Higher crop productivity can only be attained by proper soil, water and crop management in the areas with assured irrigation.

Crop water requirements may be defined as the depth of water consumptively used by a crop plus unavoidable irrigation application losses. Also included in it are other aspects of beneficially used water i.e. the water required for land preparation, leaching of salts and toxic substances and for temperature control. Water requirements depend to an important degree upon potential demands and the factors that relate a standardized potential to crop or plant water used. Crops need water in certain quantities and at specific intervals. Improper scheduling, over irrigation, improper drainage, etc. often lead to reduction in crop yields, water logging and salt imbalance in soils. In some cases vast portion of agricultural land have been rendered unproductive due to these problems. The irrigation requirement depends on several factors like land grading and levelling, water conveyance and distribution, timely supply of water in right quantities, method of water application, adequate inputs and agronomic techniques, drainage etc. Therefore the knowledge of soil-water-plant-atmospheric relationships is required and an integrated approach is needed for economizing irrigation water use for optimum crop production.

The key to effective irrigation water management lies in proper estimation of crop water requirement, which are primarily based on cropping pattern, rainfall in the area and other climatological factors. A number of methods for estimation of crop water requirements are available which are mainly dependent on the value of reference crop evapotranspiration. However, no method is universal and regional factors always influences the value of crop water requirements.

Prediction methods for crop water requirements are used owing to the difficulty of obtaining accurate field measurements. FAO (1977) has given guidelines to calculate crop water requirements of crops under different climatic and agronomic conditions based on the recommendations received during its meeting held in Lebanon (1971) and Rome (1973). The methods often need to be applied for such climatic and agronomic conditions, which are different from those under which they were originally developed. Testing the accuracy of the methods under a new set of conditions is laborious, time consuming, therefore available computer software with appropriate modifications to suit the site conditions is very useful.

In Assam, the difference between the maximum and minimum values of temperature during the extreme weather conditions is very low. The humidity of the region is very high with a very high rate of rainfall concentrated during monsoon only with an occasional dry spell, as a result of which the crops of the area suffer. The fertility of the soil of this region is good and if timely supply of water can assured to the crops as per requirement, the yield may appreciably increase.

The present study deals with the development of the regional relationships between the various available evapotranspiration determination methods and Modified Penman method and to estimate the crop water requirements for Krishnai basin under Goalpara district. However, meteorological data from 1986 to 1994 have been taken from nearby place Borjhar, Guwahati. Presently there is no method in use in this region, which could directly predict the optimum amount of water loss by crops due to evapotranspiration.

Taking the case of Krishnai Irrigation Project Area in lower Assam, three different types of relationships for crop water requirements have been developed by regression analysis technique. The first relationship is the overall yearly relationship where all the years data considered in the analysis. Monthly data has been considered in the second relationship. Seasonal data in respect of each crop have been used in the third relationship. From the developed relationships, corresponding evapotranspiration values of Modified Penman method have been worked out and the percentage deviation from the original values have been evaluated for comparison. By observing the deviation, it is seen that the equations of the second relationship i.e. Monthly relationships are most suitable to estimate the crop evapotranspiration when there is lack of data for Modified Penman method. Finally crop water and irrigation water requirements have been worked out with the help of a computer software.

2.0 REVIEW

Consumptive water use is the amount of water entering plant roots to build plant tissues, water retained by plant body, transpired by the leaves to the atmosphere and the amount evaporated from adjacent soil and water surfaces. Since the water used in the actual metabolic processes is insignificant, the term consumptive use is generally taken equivalent to evapotranspiration. Evapotranspiration is the evaporation of water from all surfaces of water, soil, snow, ice, vegetative and other surfaces plus transpiration.

The concept of evaporation and consumptive use of natural water available from rainfall has been of concern to the mankind from time immemorial. To categorize, the review is presented in the following heads:

(i) Concept of Potential Evapotranspiration and Reference crop Evapotranspiration

(ii) Measurement of Potential Evapotranspiration.

(iii) Measurement of Actual Evapotranspiration.

2.1 CONCEPT OF POTENTIAL EVAPOTRANSPIRATION & REFERENCE CROP EVAPOTRANSPIRATION

On the basis of experimental evidence available, it was earlier believed that the type and form of vegetation cover on the earth's surface had little effect on the rate of natural evaporation. Evaporation was limited by the heat supplied to the surface and not by the surface water. So a term potential evapotranspiration (PET) was conceived.

Thornthwaite (1948) suggested that soil moisture may have considerable effect on evapotranspiration and potential evapotranspiration was equal to actual evapotranspiration that would occur when there was an adequate supply of soil moisture at all the times. Penman(1956) defined potential evapotranspiration as the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water. Van Bavel (1966) defined potential evapotranspiration as the evapotranspiration that occurs when the vapour pressure at the evaporating surface is at the saturation point. Gangopadhyaya et. al. (1970) defined potential evapotranspiration as the maximum quantity of water capable of being lost as water vapour in a given climate by a continuous, extensive stretch of vegetation covering the whole ground when the soil is kept saturated. Jensen (1973) defined potential evapotranspiration as the rate at which water, if available, would be removed from the soil and plant surfaces, expressed as the latent heat transfer per unit area or its equivalent depth of water per unit area.

It has been found that evapotranspiration depends on the density of vegetation cover and its stages of development. Therefore, potential evapotranspiration needs to be defined with reference to a particular surface cover. Doorenbos and Pruitt (1977) stated that the climate was the most important factor to be taken into account and the effect of which on crop water requirements was given by the reference crop evapotranspiration (ETo) which is defined as "*the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water.*"

2.2 MEASUREMENT OF POTENTIAL EVAPOTRANSPIRATION

Various research workers defined and discussed many ways for measurement of potential evapotranspiration. There are mainly three approaches for measurement of potential evapotranspiration as follows :

(i) The transformation of measurements made from non- vegetated surfaces,

(ii) The direct measurement of water losses from moist vegetative surfaces, and

(iii) More or less empirical formulae.

In the first approach, use of evaporimeters and evaporation pans were suggested. Evaporimeters provide a measure of the drying power of the air. The consistency and accuracy of these evaporimeters are always doubtful as they are not able to provide a value, which closely approximates potential water loss. Experiments at IARI, New Delhi found best correlation of open pan evaporimeter values with consumptive use values as compared to any other formulae. The two main types of pans in use are the U.S. Weather Bureau class A pan and the British Meteorological office sunken pan. After reviewing evaporation pan and other measured data, Chang (1968) concluded that "*the evaporation pan is as accurate as any formula or field instrument for estimating PET in a humid climate and the potential maximum evapotranspiration in an arid climate when properly exposed*". Sharma and Dastane (1966) have designed sunken screen open pan evaporimeter for direct determination of consumptive use of water by an irrigated crop. Dastane and Patil (1967) prepared a broad map showing isolines of annual consumptive use based on the U.S. open pan evaporimeter data in India. Doorenbos & Pruitt (1977) have suggested evaporation pan method to estimate reference crop evapotranspiration as:

$$ETo = Kp \, . \, Epan \qquad \ldots(2.1)$$

Where,

ETo = reference crop evapotranspiration (mm/day)

Kp = pan coefficient

Epan = pan evaporation (mm/day)

The value of pan coefficient depends upon cover around the pan, mean relative humidity, wind velocity and type of pans.

The direct measurement of ET losses from moist vegetated surfaces involves the use of irrigated evapotranspirometers in which soil moisture content is maintained at a level which permits water losses to occur at the potential rate. The theory of operating irrigated evapotranspirometers has been fully discussed by Green (1959) and Ward (1975). The use of irrigated evapotranspirometer is more preferable to an evaporation pan.

Consumptive use of water by a crop , which is the main part of water requirements in most field crops, is governed primarily by meteorological parameters when plant canopy is adequate and moisture supply is sufficient. Many empirical relations have been developed by various researchers. Out of which Penman (1948), Thornthwaite (1948) and Blaney-Criddle (1950) formulae have been in use widely in India. Penman proposed an equation for evaporation estimation from a free water surface and evapotranspiration estimates for crops can be done by multiplying the estimated evaporation by the crop coefficient. Thornthwaite assumed that an exponential relationship exists between mean monthly temperature and mean monthly consumptive use. Blaney-Criddle developed an empirical equation, which correlates evapotranspiration values with monthly temperature, percent of day time hours and length of growing season. Attempts were made to refine the above mentioned empirical equations both by the authors themselves and by subsequent workers. One of the major improvement in the PET measurement technique by Penman method was the insertion of measured radiation value in place of the original radiation term . Hershfield (1957) pointed out that this would result in an improved estimate of PET only if the network of radiation instruments were sufficiently dense to enable a representative sampling of vegetation type having different albedo, and temperatures. Chang (1959), Pelton (1961) and Ward (1975) discussed Thornthwaite's temperature based formula for PET in those conditions in which air temperature and net radiation availability are closely related , where the formula works quite effectively. In other conditions it is more or less unsatisfactory but continues to be widely used because of its minimal input data requirements. Dastane and Singh (1964) found that climatological approach is simpler than the moisture deficit approach. Christiansen (1968) proposed a revised empirical formula, originally developed in 1966 to estimate pan evaporation from climatic data when reliable measured pan evaporation are not available for estimation of evapotranspiration. Thom and Oliver (1977) modified the Penman equation by introducing a generalized aerodynamic term. Hargreave et.al.(1985) presented an equation for PET that requires only maximum and minimum temperatures and extraterrestrial radiation. Hargreave and Samani (1985) compared the monthly PET values estimated by the Hargreave equation with those from the modified Penman method and with cool season grass lysimeter evapotranspiration. They concluded that temperature based equation provides a better fit with the measured monthly values in most cases.

2.3 MEASUREMENT OF ACTUAL EVAPOTRANSPIRATION

For estimating evapotranspiration from naturally wet or irrigated field one has to consider actual evapotranspiration and also the great difficulties of measuring this phenomenon. After removing the constriction of adequate water supply imposed by the concept of PET, it is necessary to consider all the factors relating to the soil and plant cover. Keeping in view the above mentioned facts Penman (1949) suggested that one could obtain reasonable results by simply calculating PET from one or more reliable formulae and then reducing the values obtained in proportion to the degrees of soil moisture depletion. This approach was also adopted by the U.K. meterological office (Grindlay, 1970) in their mapping of soil moisture deficit and actual evapotranspiration. To estimate actual ET for long periods of time, it has been found that formulae such as those of Turc (1954) and Budyko (1948) give comparatively satisfactory results. The situation in case of short term estimates of actual ET is far more complex. Three main approaches to estimate actual ET are:

(1) Combination of Energy Balance & Mass Transfer Formulae

The first approach is the theoretical modelling of entire evapotranspiration process from soil to atmosphere using combination of energy balance and mass transfer formulae and taking into account surface and other resistance of the evaporating vegetation surface. After suitable modification and improvement of Penman formula it becomes a successful means of estimation of not only PET but also ET if appropriate crop and soil factors are incorporated. Initially the combination formulae were based on the assumption of a vegetation surface, but in case if the vegetation is not wet, it will reduce the rate of evapotranspiration because of the diffusion resistance imposed by the soil pores and stomata. Penman & Schofield (1951) and subsequently Monteith and Sceiez (1961) modified the combination formulae taking into the account of the stomata and other surface resistance. Monteith and Sceiez (1961) showed that the effective surface resistance of field crops could be estimated from their radiative temperature. Monteith (1963) suggested that the effective surface resistance could also be calculated from temperature, vapour pressure and wind profiles over the vegetation surface.

(2) Water Balance Approach

The estimation of actual ET can be made through physical modelling of the ET system in the sense of water balance calculations. These water balance calculations are done for known areas or volumes of vegetation or vegetation covered ground surface in which evaporative loss is derived as the residual item in the water balance equation;

$$\text{Inflow} = \text{Outflow} + \text{Storage.} \qquad \ldots(2.2)$$

This approach of estimating evapotranspiration is based on the concept of balancing the continuity equation consisting measurable quantities i.e inflow, outflow and storage by the amount of water which represent evapotranspiration. This concept has been used for estimation of evapotranspiration at different scales including lysimeters, water table fluctuations, river basins and small experimental watersheds and moisture fluctuation within the profile.

Lysimeter studies involve the growing of crops in large lysimeters and measuring their water loss and gain.

The technique of estimating evapotranspiration from water table fluctuations is one of the simplest way of water balance approach and used by White (1932) and Meyboon (1965).

By measuring water balance of a river basin, long term evapotranspiration can be estimated assuming one year sub surface storage changes negligible.

The simplified water balance equation for estimating long term evapotranspiration will be

$$\text{Evapotranspiration} = \text{Precipitation - Runoff.} \qquad \ldots(2.3)$$

(3) Estimation of Actual Evapotranspiration (ET) Through Moisture Flux measurements

The correct estimates of actual ET can be made through the measurement of the flux of moisture above the evaporating vegetation surface. This water loss in the form of actual ET passes into the overlaying air layers where it is reflected in humidity and temperature gradient.

Different theories and experimental methods depending upon different situations have been investigated by a number of research workers for determination of actual evapotranspiration from measurement of flux of moisture above the evaporating surface. Thornthwaite and Holtzman (1939), Pasquill (1949,1950) and Rider (1954,1957) developed and modified an approach based upon the fact that evapotranspiration into the lower layer develops a moisture gradient from the evaporating surface into the overlying air. The turbulent motion of air will break the moisture gradient establishing uniform moisture conditions. The contribution of water vapour from evapotranspiration process can be determined by measuring moisture gradient and the turbulent motion of the air.

Direct measurement of flux can also be done by leaf chamber and eddy correlation method. The plant chamber for field measurements was developed by F.W. Went and described by Ashby (1957) and Stark (1967, 1968). Swinbank (1961) suggested eddy correlation method to overcome the drawbacks of leaf and plant chamber approach.

3.0 THEORETICAL BACKGROUND

Water requirement may be defined as the quantity of water, regardless of its source, required by a crop of a diversified pattern of crops in a given period of time for its normal growth under field conditions at a place. Water requirement includes the losses due to ET plus losses during the application of irrigation water and the quantity of water required for special operations such as land preparation, transplanting, leaching etc. It may be formulated as follows:

$$WR = ET + \text{application losses} + \text{special needs} \qquad \ldots(3.1)$$

The values of potential evapotranspiration (PET) estimated by using different methods based on climatological parameters need to be adjusted for actual crop ET. Since under natural field condition, PET rarely occurs in most of the irrigated field crops. For converting PET values into ET, suitable crop coefficient (Kc) should be evolved for different crops, soils and climatic conditions and also for different stages of growth for the same crop. Once the crop ET is determined, the value of water requirement of crops could be obtained by adding the application losses and the water required for special needs to ET.

There are three ways for determination of crop ET:

(i) Direct measurements ,

(ii) Using evaporation measurements as indices ,

(iii) Empirical climatic formulae.

3.1 DIRECT MEASUREMENT

Direct measurement are performed by the following techniques :

(i) tanks and lysimeters

(ii) field plots

(iii) soil moisture depletion

(iv) water balance

(v) energy balance

LYSIMETER MEASUREMENT

This method is commonly used to determine evapotrans-piration of individual crop and natural vegetation, by growing the plants in tank, or lysimeter and then measuring the losses of water, necessary to maintain the growth satisfactorily. The tanks used are generally about 60 to 90 mm in diameter and 1.8 m. deep, although large sizes upto 3 m. in diameter and 3 m. deep have been used.

FIELD PLOT METHOD

ET can also be estimated from selected test plots under actual field conditions. Water input to the plot is determined from measurements of precipitation and irrigation water, while water losses include surface runoff and deep percolation in addition to consumptive use. ET can be computed as the difference between total input and surface runoff, adjusted for changes in soil moisture. Systematic measurements of soil moisture must be taken for some distance below the root zone. This method provides reliable estimate of ET than the lysimeter because observations are made under the natural conditions.

SOIL MOISTURE DEPLETION METHOD

This method is usually employed to determine the consumptive use of irrigated field crops grown on fairly uniform soils when the depth to the ground water is such that it will not influence the soil moisture fluctuation within the root zone. Consumptive use is calculated from the change in soil water content in successive samples from the following relationship:

$$u = \sum_{i=1}^{n} ((M1i - M2I)/100).Ai\ Di \qquad ...(3.2)$$

Where u is the water use from the root zone for successive sampling periods or within one irrigation cycle in mm, n is the number of soil layers sampled in the root zone depth D, M1i and M2i are the moisture percentage at the time of the first and second sampling in the ith layer respectively, Ai is the apparent specific gravity of the ith layer of the soil and Di is the depth of ith layer of soil in mm.

WATER BALANCE METHOD

Where vegetation obtain its moisture from the capillary fringe or zone of saturation,the height of the water table is influenced by the amount of water absorbed by the plants and its fluctuation can be used as a basis for computing consumptive use. On the basis of studies of the diurnal fluctuation of shallow water table, White (1932) developed the formula:

$$Uc = r_s\,(24a+b) \qquad (3.3)$$

Where Uc is the consumptive use in inches per day, r_s is the specific yield of the soil, a is the rate of rise of the water table in inches per hour from midnight to 4 A. M., and b is the net change in water table elevation during the day in inches. The method is applicable only in areas where the water table is near the surface.

ENERGY BALANCE METHOD

The energy budget approach, like the water budget, employs a continuity equation required to maintain a balance. Although the continuity equation in this approach is one of energy, this method can be used to determine ET for short periods. Because the components of energy balance such as energy for heating the soil and the advective energy can be neglected for short duration.

3.2 ESTIMATION OF ET FROM PAN EVAPORATION DATA

It has been observed that a close relationship exists between ET and the rate of evaporation from a properly located evaporation pan. It is clear that the energy exchange of all pans will differ from that of a reference crop. This difference first of all lies in the energy storage. The energy stored in the evaporation pan is greater than that of vegetation so that the surface temperature of the water tends to be lower during the days when most evaporation occur, and higher at night. A lot of works already has been done to convert the evaporation pan data into actual ET through empirical relations and to assess the relative merits of pan types with respect to their energy exchange. The standard US Weather Bureau Class A open pan evaporimeter or the sunken screen open pan evaporimeter (Sharma and Dastane,1968) has now been selected as a world wide standard for use in all new applications.

3.3 EMPIRICAL CLIMATIC FORMULAE

Owing to the difficulty in obtaining accurate direct measurement of pan evaporation under field conditions, ET is often predicted on the basis of climatological data. The crop ET depends on number of climatological factors such as solar energy received, temperature, wind velocity, relative humidity, total sunshine hours and their actual duration etc. Many formulae have been developed and used from time to time. Such formulae have often to be used under agroclimatic conditions different from those for which they were originally developed. It is therefore necessary to test the adaptability of these formulae and they should modify suitably before using them under a new set of conditions.

The formulae most commonly used in estimating ET are as under:

(i) Blaney -Criddle method.

(ii) Radiation method.

(iii) Penman method.

(iv) Modified Penman method.

(v) Pan evaporation method.

(vi) Hargreave method.

(vii) Thornthwaite method.

BLANEY-CRIDDLE Method

Blaney & Criddle (1950) observed that the amount of water consumed by crops (actual ET) during their growing season was closely correlated with mean monthly temperatures and day light hours. The relationship developed by Blaney and Criddle in FPS units may be stated as follows:

$$U = KF = \Sigma kf = \Sigma u = \Sigma (kt.p/100) \quad \ldots(3.4)$$

where

U = seasonal consumptive use of water by the crop for a given period, inches

u = monthly consumptive use of water by the crop, inches

K = Empirical seasonal consumptive use co-efficient for the growing season.

F = sum of monthly consumptive use factors(f) for the growing season.

k = Empirical consumptive use crop coefficient for the month, u/f

f = (t.p)/100

t = mean monthly temperature, degreeF

p = Monthly daylight hours expressed as percent of daylight hours of the year.

The Blaney-Criddle formula has generally given sufficiently accurate estimates of seasonal consumptive use owing to the inclusion of locally developed crop co-efficient factor (k). Crop water requirements have been found to vary widely between climates having similar air temperature but different humidity and wind conditions. The consumptive use crop coefficient K will, therefore vary not only with crop but also with climatic conditions.

Limitations of Blaney-Criddle Method

The method has been evaluated by many investigators, and it has been generally found that whereas it is simple to use and widely applicable, it tends to be less reliable in the following areas:

(i) Equatorial regions where temperature and day lenght fluctuate over a very small range even though climatological factors may vary.

(ii) Small islands where the air temperature is greatly influenced by the sea temperature, as is the humidity.

(iii) High altitudes where cold nights bring down the mean temperature and day time radiation levels very high.

(iv) Climates with a great fluctuation in sunshine hours during spring and autumn, and monsoon seasons.

RADIATION Method

The Radiation method is essentially an adaptation of the Makkink formula (1957). This method is suggested for areas where available climatic data includes measured air temperature and sunshine, cloudiness or radiation, but not measured wind and humidity.

The relationship recommended (representing mean value over the given period) is expressed as :

$$ETo = C(W.Rs) \quad \text{mm/day} \tag{3.5}$$

Where,

ETo = Reference crop ET expressed in mm/day

W = Weighing factor depends on temperature and altitude

Rs = Solar radiation in equivalent evaporation in mm/day

C = Adjustment factor depending on humidity and wind velocity in day.

Knowledge of general levels of humidity and wind is required and they are to be estimated using published weather descriptions, extrapolation from nearby areas or from local sources. There are only three unknowns in the right hand side of the equation. W can be obtained from the table, if temperature and altitude are known data. The value of Rs is available either as measured value or can be computed. Normally, the measured value is not available and Rs has to be computed from

$$Rs = (0.25 + 0.50\ n/N)\ Ra \tag{3.6}$$

Ra depends only on latitude and period of the year and can be obtained from the standard table. If the measurements of n i.e. the sunshine hours are available, Rs can be computed. Values of N i.e. maximum possible sunshine hours depend on month and latitude.

This method is simple in application and can be conveniently used where radiation is the dominating factor in ET. It can be used near equatorial regions, in coastal areas and small islands or high altitude regions. It is somewhat inaccurate in plains of low altitude.

PENMAN's Method

Penman's equation is based on sound theoretical reasoning and is obtained by a combination of the energy-balance and mass transfer approach. Penman's equation, incorporating some of the modifications suggested by other investigators is

$$PET = (A.\ Hn + Ea.r)/(A + r) \qquad (3.7)$$

where,

PET = Daily potential ET in mm/day

A = Slope of the saturation vapour pressure vs. temperature curve at the mean air temperature, in mm of mercury per degreeC .

Hn = Net radiation in mm. of evaporable water per day.

Ea = Parameter including wind velocity and saturation deficit.

r = Psychometric constant =0.49 mm. of mercury for Zero degreeC

Hn is calculated from the following equation :

$$Hn = Ha(1-\alpha)(a+b(n/N))-\sigma Ta^4(0.56-0.092\sqrt{ea})-(0.10+0.90(n/N))$$

Ha = incident solar radiation outside the atmosphere on a horizontal surface expressed in mm of evaporable water per day (it is a function of the latitude and period of the year)

α = reflection co-efficient (albedo). The value of α for close ground crops is generally varies from 0.15-0.25

a	=	a constant depending upon the latitude ∅ and is given by a = 0.29 cos ∅
b	=	a constant with an average value of 0.52
n	=	actual duration of bright sunshine, hrs.
N	=	maximum possible hours of bright sunshine
σ	=	Stefan-Boltzman constant = 2.01×10^{-9} mm/day
Ta	=	mean air temperature in degreeK
e_a	=	actual mean vapour pressure in the air in mm of mercury.

The parameter Ea is estimated as :

$$Ea = 0.35\,(1 + (u_2 / 160))\,.\,(e_w - e_a)$$

in which,

u_2	=	mean wind speed at 2m above the ground in km/day.
e_w	=	saturation vapour pressure at mean air temperature in mm of mercury.
e_a	=	actual vapour pressure

For the computation of PET, data on n, e_a, u_2, mean air temperature and nature of surface (value of σ) are needed. These can be obtained from actual observations or through available meteorological data of the region.

MODIFIED PENMAN Method

Based on intensive studies of the climatic and measured grass ET data from various research stations in the world and the available literature on prediction of ET or PET, Doorenbos and Pruitt (1975) proposed a Modified Penman method, for estimating fairly accurately the reference crop ET as

$$ETo = C\,[(W.Rn) + (1-W)\,f(u)(e_a - e_d)] \qquad (3.8)$$

Where,

ETo = Reference crop ET (mm/day)

C = Adjustment factor for day and night wind velocities and different humidity levels.

W = Weighing factor for altitude and temperature effect radiation

Rn = Net radiation in equivalent evaporation in mm/day

$= (1-0.25)[0.25 + (n/N)\ 0.5]\ Ra - f(T).f(ed).f(n/N)$

where, f(ed), f(n/N) and f(T) is the function of saturated vapour pressure, actual possible sunshine and temperature hours and obtained from standard tables (FAO-24).

f(u) = Wind function or the effect of wind on ETo

$= 0.27(1+u_2/100)$

PAN EVAPORATION Method

Evaporation from a free water surface is an integrated effect of all the climatological factors, such as, radiation, wind velocity, temperature and humidity. The evapotranspiration of plant also depends on the same combination of factors. Of course several major factors may have significant differences in the loss of water in the two cases. These factors can be enlisted as:

(1) Reflection of solar radiation is 5% to 8% from water surface while it is 20% to 25% from vegetative surfaces.

(2) Storage of heat within the pan is appreciable and hence the evaporation during day and night is almost equal. In most crops the evapotranspiration during night is very low as compared to evapotranspiration during daytime.

(3) The effect of turbulence, temperature and humidity immediately above the surface

is different for water and cropped soil.

(4) Heat transfer from the sides of the pan is significant specially in the sunken pans.

(5) The colour of the pan and the screen affect the water loss.

(6) The placing of the pan, in cropped field or in fallow field affect the measurements.

Notwithstanding these differences, the pan evaporation measurements bear a certain relationship with ET crop as

$$ETo = Kp.\ Epan \qquad (3.9)$$

Where,

Epan = Pan evaporation in mm/day and represents the main daily value of the period considered.

Kp = Pan coefficient depends upon different humidity and wind conditions and pan environment.

HARGREAVE Method

George H. Hargreave and Zorab A Saman (1983) compared Lysimeter ET data in Haiti with the results obtained from several equations. They have concluded that the results predicted from climatological data, limited only to Radiation and Temperature closely approach the ETo given by lysimeter. The original relationship suggested by Hargreave (1975) related the ETo to Rs and Temperature as

$$ETo = 0.0075.Rs.T\ degreeF \qquad ...(3.10)$$

Where,

T degreeF is the mean air temperature in degrees Fahrenheit and Rs is the solar radiation reaching the earth expressed in equivalent evaporation in mm/day. ETo is also expressed in mm/day.

However, measured data for Rs is normally not available. Relationship between Rs (which is almost independent of the variations in climate) and Ra was developed as :

$$Rs = Kt \cdot Ra \cdot (TD)^{0.50} \qquad ..(3.11)$$

Where, Kt is a coefficient requiring some calibration and Ra is extra terrestrial radiation in mm/day, TD is the difference in mean maximum and mean minimum temperatures in degreeC. Combining the above two equations, the equation developed by Hargreave for universal application is

$$ETo = 0.0023 \cdot Ra(T+17.8)\,(TD)^{0.50} \qquad ..(3.12)$$

Where,

Ra = Extra terrestrial radiation in equivalent evaporation in mm/day.

T = Mean temperature in degreeC.

The equation is comparatively very simple and requires only the temperature data apart from the latitude. The temperature data is normally available. The equation claims to be superior to many other equations at least for interior locations with plain topography where the growing season of the crops is frost free.

THORNTHWAITE Method

Thornthwaite (1948) assumed that an exponential relationship exists between mean monthly temperature and mean monthly consumptive use. The relationship was based largely on experience in the central and eastern United States. No allowance was made for different crops on varying land uses. The formula was originally developed for the purpose of a rational classification of the broad climatic patterns of the world. Suitable coefficients should therefore be developed locally for reliable estimation of crop ET values. Thornthwaite proposed the following formula:

$$ET = 1.6\ La(10\ T/I)^{a} \quad ..(3.13)$$

Where,

ET = Monthly PET in cm.

La = Adjustment for the number of hours of daylight and days in the month, related to the latitude of the place.

T = Mean monthly air temperature in degree Celsius.

I = Total of 12 monthly values of heat index i

$$= \sum_{n=1}^{12} i_n$$

where,

$$I = (T/5)^{1.514}$$

a = an empirical constant = $6.75x10^{-7}\ I^3 - 7.71x10^{-5}\ I^2 + 1.792x10^{-2}\ I + 0.49239$

The Thornthwaite formula gives a reasonable estimate of PET in the temperate, continental climate of North America where the formula was originally derived, because there the temperature and radiation are strongly correlated. In other parts of the world this approach has been less successful.

3.4 CROP COEFFICIENT

The different methods described, predict the reference crop evapotranspiration (ETo). We can determine actual ET from standard evaporation rates by multiplying an additional factor, Kc (crop coefficient).

i.e. ETcrop = Kc . ETo ...(3.14)

where

ETcrop = actual ET

ETo = reference ET in mm/day

Factors affecting the value of the crop coefficient (Kc) are mainly the crop characteristics, crop planting or sowing data, rate of crop development length of growing season and climatic conditions.

The crop coefficients are dependent on the stage of growth and the rate of growth of crop. The growth period is therefore divided into four stages :

(1) Initial stage : Germination period and early growth of the crop when the soil cover by the crop is less than 10% .

(2) Crop development stage : The end of initial stage till the soil cover by the crop is about 70 to 80% .

(3) Mid season stage : From the end of crop development stage to the start of maturity, which is indicated by discolouring of leaves or falling off the leaves. For most crops this may extend well past the following stage.

(4) Late season stage : From end of mid season stage to the full maturity or harvesting.

The period of these stages depend not only on the crop characteristics and soil,but also on the sowing dates.The stage are therefore, to be determined by local observations.

3.5 EFFECTIVE RAINFALL

Not all rainfall is effective and a part may be lost by surface runoff, deep percolation or evaporation. Only the portion of rainfall, which contributes to the crop water needs, is the effective rainfall. A portion of heavy and high intensity rains can enter and be stored in the root zone and the effectiveness is consequently low. Frequent high rains intercepted by plant foliage with ground cover are close to 100 percent effective. With a dry soil surface and little or no vegetative cover, rainfall upto 8mm/day may all be lost by evaporation; rains of 25 to 30 mm may be only 60 percent effective with a low percentage of vegetative cover.

Effective rainfall can be estimated by the evapotranspiration/precipitation ratio method (USDA, 1969). The U.S. Department of Agriculture, Soil Conservation service has developed tables relating the effective rainfall of the mean monthly rainfall and mean monthly consumptive use of the crops. All the time of irrigation, the net depth of irrigation water that can be stored effectively over the root zone is assumed equal to 75 mm. Of course the effective rainfall cannot exceed the consumptive use. If it does, the lower value of the two is adopted as effective rainfall.

If the irrigation application is other than 75 mm, a correction factor is to be applied to the effective depth. The correction factor for different depth of application varies from 10mm to 170 mm.

3.6 CROP AND IRRIGATION WATER REQUIREMENT

Crop Water Requirements

The estimation of the water requirements of crops is one of the basic needs for crop planning on a farm and for the planning of any irrigation project.

Crop water requirements is met by irrigation water (IR), effective rainfall (ER) and soil profile contributions (S) including that from shallow water table. Numerically therefore, crop water requirements is given as:

$$WR = IR + ER + S \quad (3.15)$$

Irrigation Water Requirements

Irrigation water requirements includes the following:

(i) Evapotranspiration or consumptive use of water less effective rainfall.

(ii) Water required for special operations such as land preparation, leaching etc.

(iii)Losses during application of irrigation water.

(iv) Losses during conveyance and distribution.

The net irrigation requirements of a crop refers to the water requirements of crops, exclusive of effective rainfall and contribution from soil profile, and it may be given as:

$$NIR = WR - (ER + S) \quad (3.16)$$

A small amount of irrigated water is lost due to percolation through the soil voids. If P is the percolation loss, then the net irrigation requirements can be given as :

$$NIR = WR - (ER + S) + P \quad (3.17)$$

There are water losses in the application of irrigation water in the field. The losses have to be taken into account and its quantity is a measure of Field Application Efficiency. It is given as:

Field Irrigation Efficiency = (Water applied at field- Losses)/ Water applied at field

The field irrigation requirements (FIR) is the amount of water that will be required to supply at the field entrance and it is generally taken as, FIR = (NIR)/ 0.90

The percentage ratio of water that is available at the outlet canal to irrigation water supplied at the diversion point is termed as Conveyance Efficiency (CE). It is given as:

Irrigation Water at outlet of canal

CE = (Irrigation Water at outlet of canal)/ Irrigation Water at diversion point

And Project Efficiency (PE) is given by

PE = (Irrigation Water Transpired by crop Irrigation)/ Water at diversion point

So the gross irrigation requirement (GIR) is the total water available at the inlet of the main canal and it may be given as,

GIR = (NIR)/ 0.70

4.0 STUDY AREA AND DATA ACQUISITION

4.1 SALIENT FEATURES

The Krishnai irrigation project is aimed at harnessing the water of river Krishnai and its tributaries. This envisage construction of a barrage across river Krishnai at Beltraghat for diverging water into right and left main canal for providing irrigation facilities to its gross commanded area (GCA) of 5000 hectare. The culturable commanded area (CCA) is 4200 hect while net irrigable area (NIA) is 3500 hect. and annually irrigated area (AIA) is 6300 hect. The entire commanded area of the Krishnai Irrigation scheme has been falls under the Goalpara District

The study area of Krishnai river catchment is in the north-eastern frontier of the country comprising seven states. The Krishnai river catchment belongs to the states of Meghalya and Assam. The physiography of the entire region is mainly divided into two divisions, namely the Meghalya Plateau and the plains of river Brahmputra valley which falls into the state of Assam accounting for about 70% and 30% of the total area respectively. The Assam state mainly comprises of two main river valleys. The northern valley is called the Brahmaputra valley & the Southern valley is known as Surama and Barak valley. The Brahmaputra valley is an alluvial plain in between the foot hills of Bhutan range on the north and two other hill tracts of Naga, Mikir, Khasiya, Jaintia, Garo hills etc. on the south. The Brahmaputra valley is nearly 720-km. long and 80-km. wide covering about 56339 Sq km. of riverine area between both banks of the Brahmaputra starting from Sodiya in the East and Dhubri in the West. The river Brahamputra receives number of tributaries and sub-tributaries throughout its course. The river Dudhnoi is one of such major south bank tributaries. The river Krishnai is again a tributary of the river Dudhnoi. The river Krishnai originates in

Meghalya from Garo hills at an elevation of about 280 m above mean sea level and meets with river Dudhnoi near Domuni at about 12 km north from Dudhnoi at an elevation of about 150 m above mean sea level and finally flows towards river Brahmaputra. A good number of streams originating from Garo hills having elevation between 500m to 300 m above mean sea level fall to the Krishnai river in the Meghalya area which produces good discharges for Krishnai river. The geographical area of the catchment is about 953.88 Sq Km up to the proposed head work site for construction of a barrage at Beltraghat. The area with elevation ranging from 500 to 250 m above m.s.l. is narrow and steep, forming deep river valleys.

The population of the area are mainly Bodo, Rava, and other community in general. Agriculture is the only main source of their livelihood. The people of this locality are very active and laborious. The principal crop of this region is paddy.

CLIMATE

The general climate of the commanded area is similar to that of rest of Assam. The south-west monsoon reigns from the end of May to December, the early half being the general rainy season. but the distribution of rainfall is not uniform. About 90% of the rainfall occur during the monsoon period from May to October. The area is in the highest rainfall zone of the country. The rains are of long duration and occur mostly between March and October. During March and April the rainfall is sporadic, but it is steady and heavy or very heavy during May and October. Average annual rainfall in the Krishnai basin is about 4000 mm but the distribution of rainfall is not uniform.

LOCATION OF THE COMMAND AREA -

The proposed command area of the scheme extends on both the banks of the river Krishnai. The whole command area falls under Matia development block under Goalpara Civil Sub-Division in the district of Goalpara . The Krishnai river catchment lying between 25°45' to 26°0' north latitude and 90°30' to 90°45' east longitude is in Garo hill district of Meghalya, in the northern slope of the state adjoining Assam. The index map of the area is shown in figure 4.1.

SCOPE OF THE KRISHNAI IRRIGATION PROJECT

The Krishnai Irrigation project has been envisaged with a view to insure against the vagaries of natural rainfall. It will further serve as a projection against occasional draught and will also promote double cropping which hitherto could not be carried out for want of artificial irrigation. Due to the irregular and uneven distribution of rain-fall, the crops of the locality suffer from short fall of water. The irregular rainfall can't meet up the timely requirement of water for the crops. The soil in the command area is sandy loam and very fertile. If timely supply of water can be made available to the crops as per requirement by providing irrigation facilities, the yield of the different crops will sufficiently increase as well as uplift the economic condition of the locality. Hence the scheme to construct a Barrage on river Krishnai at Beltraghat is proposed to tap water for Irrigation to the proposed command area.

Thus the object of the project is aimed to supply the controlled water to a vast cultivable area in the Goalpara Civil Sub-Division under the district Goalpara and to improve the existing cropping pattern. This will promote practice of multiple cropping , which has not been practiced at present by the local people of the locality for want of ensured irrigation. The location of the Head work is situated within the revenue village Beltraghat under Matia Development Block. There will be a diversion barrage on river Krishani with two numbers of head regulator on both the banks.

4.2 DATA ACQUISITION FOR KRISHNAI IRRIGATION PROJECT

CROPPING PATTERN

The crop pattern as proposed by the project authorities and used in the present study is shown in Table-4.1 below :

Table 4.1 : Proposed cropping pattern for the Krishnai project

SEASON	CROP	Area to be irrigated	% Area of NIA
KHARIF	Ahu regular paddy (21 April-5 Aug.)	875-ha.	25%
	Sali paddy (26 June-Sep)	2275-ha	65%
	Early Ahu (21 Feb.- May)	525-ha.	15%
RABI	Oil Seed (Mustard) (Oct.-20 Jan.)	700-ha.	20%
	Potato (21 Oct.-20 Feb)	175-ha.	5%
	Wheat (21 Nov.-March)	1225-ha.	35%
	Pulses (Oct.-Jan.)	525-ha.	15%
PERENNIAL	NIL		

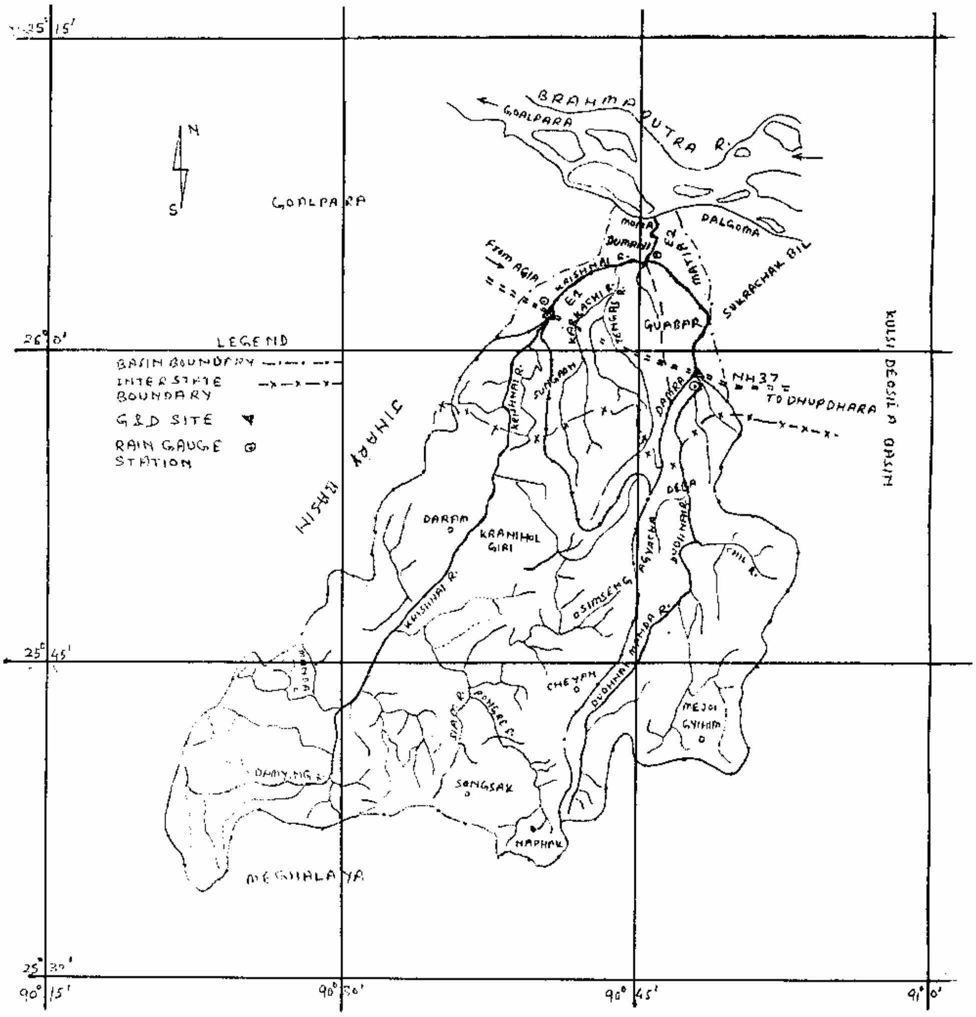

Fig. 4.1 : Map of Krishnai River Basin

METEOROLOGICAL DATA

The data collected from the nearest Meteorological centre, Borjhar are mean monthly rainfall, temperature, relative humidity, wind velocity, sunshine hours, pan evaporation, cloudiness and vapour pressure, which are available from 1986 to 1994.

5.0 METHODOLOGY

The water requirements of each crop are calculated on the basis of meeting the evapotranspiration rate of a fully growing crop. It depends mainly on climate, growing season, crop development, agricultural and irrigation practices. It involves large data handling in computational work which is highly tedious and time expensive if performed manually. This analysis could be very easily performed with the help of computer program. Considering this aspect, a computer software available in Doorenbos and Pruitt (1977) has been made workable first and then modified to work out the crop water requirements for the Krishnai irrigation project to develop the desired relationships as mentioned in objectives

The entire methodology adopted is described in the following steps :

(1) A computer program, originally developed by Doorenbos and Pruitt (1977), available in FAO -24, make workable in PC with suitable modifications.

(2) The main program was originally developed for five methods i.e. Blaney-Criddle, Radiation, Penman, Modified Penman and Pan Evaporation method. In this study, the program is extended for two other methods of ETo estimation i.e. Hargreaves and Thornthwaite method.

(3) The various climatological and physiographic data have been collected for the Krishnai Irrigation project from the Irrigation Department, Assam and IMD, Borjhar. The monthly climatological data have been collected from the year 1986 to 1994. The collected data have been arranged in the format as required by the program.

(4) Using the available monthly climatological data, the monthly reference

evapotranspiration (ETo) values have been estimated by all the seven methods i.e. Blaney- Criddle, Radiation, Penman, Modified Penman, Pan Evaporation, Hargreave and Thornthwaite's methods by using the computer program.

(5) After evaluating the ETo values, the crop factor of various crops at different growth stages have been selected from FAO, Irrigation and Drainage Paper No 33 and the list publisd by Ministry of Agriculture, India (Ann.-II). The evapotranspiration of crop (ETcrop) are determined in the second program. The crop water requirement for various crops can be estimated with the help of second program by all the seven methods.

(6) Using the estimated data of ETo values by various methods as mentioned above, relationships between the following have been developed:

(i) $ETo_{MP} = f(ETo_{BC})$
(ii) $ETo_{MP} = f(ETo_{R})$
(iii) $ETo_{MP} = f(ETo_{P})$
(iv) $ETo_{MP} = f(ETo_{PE})$
(v) $ETo_{MP} = f(ETo_{H})$
(vi) $ETo_{MP} = f(ETo_{TH})$

where,

ETo_{MP} = ETo value by Modified Penman method
ETo_{BC} = ETo value by Blaney - Criddle method.
ETo_{R} = ETo value by Radiation method
ETo_{P} = ETo value by Penman method
ETo_{PE} = ETo value by Pan Evaporation method
ETo_{H} = ETo value by Hargreave method
ETo_{TH} = ETo value by Thornthwaite method.

A linear relationship in the form $Y = a.X + b$ has been assumed and the Linear Regression technique has been used to evaluate the value of constants `a' and `b'.

(7) Having developed the equations as mentioned above methodology (5), the ETo_{MP} values have been estimated by using the developed equations.

(8) Further the crop water and irrigation requirements have been evaluated from the program. The effective rainfall data is taken 75% of the total rainfall (Anne-III) and percolation loss is 0.254 mm/hr. for evaluation of irrigation water requirements.

ANALYSIS FOR DEVELOPMENT OF RELATIOSHIPS

Lotus 123 software is used for development of the relationships. Modified-Penman method is adopted as a most rational method for the determination of evapotranspiration and relationships of other methods are found with this method. Three different relationships in this study. have been evaluated The first relationship i.e the evaluation of 'a' and 'b' in the equation Y = a.X + b are determined by considering whole the 9 years data. The second relationship is calculated by considering the seasonal values for different crops. In the third relationship, only the monthwise data is considered for 9 years. The calculated values of evapotranspiration from the relationships and percentage deviation from the original values of Modified-Penman method are evaluated.

6.0 RESULTS AND NALYSIS

6.1 RESULTS OF ETo VALUES

The reference crop evapotranspiration (ETo) values have been estimated by various methods viz. Blaney-Criddle, Radiation, Penman, Modified Penman, Pan Evaporation, Hargreave and Thornthwaite methods for monthly data of Krishnai Irrigation Project. The monthly data has been taken for 9 years from 1986 to 1994. The estimated monthly ETo values have been tabulated in Table 6.1.

6.2 RELATIONSHIPS OF DIFFERENT METHODS WITH MODIFIED PENMAN METHOD.

The Modified Penman method has been considered most rational and elaborate. It requires a very large number of data to determine the ETo value. In some situations, all the data may not be available which will be required to estimate ETo by Modified Penman method. Therefore, it is attempted to evolve regional relationships for Krishnai Irrigation project relating the ETo values of Modified Penman and of six other climatological methods. The developed relationships are useful in determining the rational value of ETo which will correspond to the ETo-value by Modified Penman even in the situation of scanty data.

Using the ETo values of Table 6.1 and assuming a linear relationship between the ETo value by Modified Penman method and the ETo value of other methods, the constants of the equations have been worked out.

The general equation of linear regression is

$$Y = a.X + b \quad (6.1)$$

Where,

Y = ETo value of Modified Penman method.

X = ETo value of other methods (Blaney-Criddle, Radiation, Penman, Hargreave, Pan evaporation and Thornthwaite method)

A = slope of the line,

b = constants of the equation.

The estimated parameters of the relationships have been shown in Table 6.2 to 6.4. The first type of relationship (i.e. overall yearly relationship) where all the 9 years data have been considered is shown in Table 6.2. In Table 6.3, the values of the equation where the monthwise data are considered for 9 years are tabulated. The values of the seasonal relationship are tabulated in Table 6.4 by considering the values of ETo for each crop

6.3 COMPARISON OF RESULTS

The variation of ETo values i.e. minimum and maximum values have been shown in Table 6.5 & 6.6. In Table 6.5, the variation of ETo values have been shown for the first two relationships i.e. overall yearly and monthly relationship. The cropwise variation of ETo values has been given for all the relationships in the Table 6.6.

Using the relationships of overall yearly & monthly and ETo values of various methods given in Table 6.1, the corresponding values of ETo_{MP} have been evaluated and tabulated in Table 6.7 for comparison with the actual Modified Penman value. The values of ETo corresponding to actual ETo_{MP} evaluated from the seasonal relationship have been shown in Table 6.8.

Table 6.1 : Estimated ETo value by different methods for Kriahnai irrigation project

Year	Month	Modified Penman	Blaney & Criddle	Radiation	Penman	Pan Evaporation	Hargreave	Thornthwaite
1986	Jan.	2.36	2.15	2.70	2.28	3.20	2.89	1.13
	Feb.	3.57	3.38	4.23	3.51	4.09	3.82	1.58
	Mar.	4.76	4.38	4.59	5.02	4.13	5.32	3.32
	Apr.	4.71	3.78	4.21	4.69	3.61	4.94	4.13
	May	5.55	4.57	5.28	5.42	4.54	5.07	5.16
	June	5.38	4.04	4.62	5.26	4.38	5.35	7.23
	July	4.50	3.41	3.83	4.45	3.51	4.60	6.87
	Aug.	4.62	3.54	4.09	4.48	3.96	4.82	6.89
	Sep.	3.39	2.29	2.56	3.38	3.15	3.94	5.79
	Oct.	3.46	2.56	3.19	3.36	2.97	3.64	3.98
	Nov.	2.75	2.35	3.03	2.66	2.28	2.95	2.27
	Dec.	2.12	1.96	2.50	2.05	2.28	2.62	1.20
1987	Jan.	2.57	2.41	3.09	2.48	2.35	2.98	1.17
	Feb.	3.00	2.54	3.06	3.00	2.50	3.55	1.69
	Mar.	3.82	3.22	3.94	3.75	3.17	4.30	2.78
	Apr.	5.51	4.13	4.99	5.37	5.05	5.25	4.51
	May	5.59	4.51	5.05	5.45	3.36	5.36	6.20
	June	3.77	3.14	3.31	3.82	3.17	5.05	5.87
	July	4.40	3.24	3.97	4.19	3.37	4.12	6.24
	Aug.	5.06	3.67	4.60	4.79	3.03	4.00	6.09
	Sep.	3.82	2.78	3.33	3.74	2.89	3.69	5.50
	Oct.	3.48	2.70	3.28	3.36	2.89	3.31	4.09
	Nov.	2.79	2.50	3.05	2.75	2.61	2.89	2.59
	Dec.	2.01	1.88	2.44	1.94	2.04	2.68	1.33
1988	Jan.	2.36	2.17	2.79	2.28	2.19	2.81	1.14
	Feb.	3.59	3.34	3.98	3.49	2.81	3.67	1.85
	Mar.	4.89	3.94	4.69	5.00	2.70	4.37	2.82
	Apr.	5.55	4.32	4.86	5.74	3.04	5.03	4.34
	May	4.69	3.36	3.98	4.80	3.05	4.58	5.04
	June	5.01	3.73	4.33	5.05	2.99	4.57	6.58
	July	5.08	3.44	3.77	5.10	2.88	4.39	6.87
	Aug.	4.09	2.68	2.91	4.13	2.26	3.86	6.17
	Sep.	4.55	3.15	3.61	4.53	3.08	3.85	5.60
	Oct.	4.15	2.90	3.57	4.15	2.99	3.43	4.16
	Nov.	2.93	2.50	2.98	2.96	2.34	3.04	2.40
	Dec.	2.21	2.02	2.57	2.14	1.78	2.53	1.53
1989	Jan.	2.26	2.14	2.98	2.20	1.68	2.65	0.99
	Feb.	2.73	3.01	3.60	2.80	2.03	3.38	1.39
	Mar.	3.83	4.04	4.66	3.85	2.83	4.73	2.83
	Apr.	5.00	4.47	5.66	4.90	4.11	4.74	3.74
	May	5.05	3.69	4.38	4.93	3.86	4.99	5.65
	June	5.02	3.54	3.94	4.89	4.26	4.58	6.34
	July	4.73	3.17	3.64	4.68	3.69	4.28	6.27
	Aug.	4.80	3.61	4.30	4.64	3.52	4.52	6.27
	Sep.	3.62	2.60	3.11	3.58	3.23	3.76	5.32
	Oct.	3.66	2.82	3.49	3.59	2.72	3.48	4.34
	Nov.	2.78	2.29	2.93	2.73	2.03	2.90	2.17
	Dec.	2.02	1.76	2.36	1.96	1.78	2.59	1.08
1990	Jan.	2.23	1.99	2.41	2.15	2.62	2.80	1.44
	Feb.	2.86	1.87	2.68	2.77	2.72	3.34	1.57
	Mar.	3.92	3.33	4.09	3.86	2.89	4.04	2.23
	Apr.	3.72	2.85	3.96	3.59	2.76	2.82	2.40
	May	5.38	4.00	5.01	5.11	4.25	4.84	5.69
	June	4.04	3.17	3.40	4.03	2.77	4.46	6.57
	July	4.02	3.04	4.00	3.00	3.05	4.37	6.66
	Aug.	4.52	3.51	4.04	4.39	3.46	4.46	6.53
	Sep.	3.82	2.83	3.37	3.75	3.40	3.92	5.63
	Oct.	3.08	2.27	2.82	3.02	2.63	3.21	3.82
	Nov.	2.99	2.55	3.27	2.88	2.79	3.20	2.77
	Dec.	2.14	1.85	2.45	2.07	1.95	2.78	1.38

Contd...

Contd...

Year	Month	Modified Penman	Blaney & Criddle	Radiation	Penman	Pan Evaporation	Hargreave	Thornthwaite
1991	Jan.	2.18	1.84	2.52	2.10	2.03	2.82	0.98
	Feb.	3.36	3.06	3.56	3.29	2.82	4.22	2.33
	Mar.	4.17	3.74	4.43	4.11	3.44	4.67	3.25
	Apr.	4.59	3.69	4.47	4.50	4.48	4.84	4.02
	May	3.70	2.70	3.28	3.61	3.56	3.98	4.34
	June	3.80	3.05	3.26	3.78	3.64	4.39	6.34
	July	4.38	3.37	3.76	4.27	4.06	4.40	6.98
	Aug.	3.87	2.98	3.40	3.83	4.41	3.87	6.21
	Sep.	3.45	2.68	2.97	3.39	3.39	3.83	5.61
	Oct.	3.54	2.76	3.39	3.43	2.71	3.48	4.21
	Nov.	2.58	2.17	2.85	2.48	2.54	3.11	2.15
	Dec.	1.95	1.66	2.16	1.88	2.38	2.51	1.06
1992	Jan.	2.07	2.48	2.60	1.99	2.90	2.67	1.01
	Feb.	2.47	2.41	3.08	2.41	2.25	3.20	1.20
	Mar.	4.17	3.70	4.13	4.24	4.65	4.46	2.91
	Apr.	5.48	4.59	5.17	5.46	4.84	5.32	4.80
	May	4.60	3.63	4.43	4.43	4.10	4.79	4.88
	June	4.42	3.53	3.92	4.23	3.88	4.94	6.56
	July	4.56	3.37	4.05	4.30	3.32	4.31	6.24
	Aug.	5.02	3.64	4.59	4.70	4.24	4.49	6.49
	Sep.	3.97	2.98	3.58	3.88	3.13	4.05	5.53
	Oct.	3.54	2.75	3.51	3.43	2.71	3.48	3.93
	Nov.	2.60	2.22	2.81	2.51	2.54	3.16	2.32
	Dec.	1.85	1.72	2.31	1.78	1.69	2.67	1.05
1993	Jan.	2.04	1.60	2.19	1.96	2.55	2.43	0.95
	Feb.	2.73	2.30	2.72	2.68	2.53	3.30	1.73
	Mar.	3.98	3.40	4.14	3.98	2.80	4.38	2.49
	Apr.	4.69	3.80	4.57	4.60	2.89	5.00	3.81
	May	4.63	3.34	4.26	4.44	2.78	4.45	4.84
	June	4.06	3.11	3.49	3.98	2.54	4.37	5.89
	July	4.23	3.14	3.61	4.16	2.88	4.48	6.71
	Aug.	4.16	2.77	3.26	4.11	3.22	4.22	6.44
	Sep.	3.98	2.80	3.35	3.90	3.49	3.84	5.45
	Oct.	3.86	3.09	3.85	3.70	3.71	3.59	4.32
	Nov.	2.81	2.49	3.06	2.72	2.95	3.14	2.57
	Dec.	2.16	2.12	2.47	2.09	1.85	2.83	1.51
1994	Jan.	2.27	2.08	2.43	2.21	2.36	2.95	1.20
	Feb.	3.05	2.77	3.29	2.99	2.49	3.47	1.42
	Mar.	4.20	3.57	4.26	4.11	2.65	4.26	2.66
	Apr.	4.87	3.87	4.73	4.75	2.81	4.97	4.16
	May	5.03	3.96	4.61	4.95	2.72	5.29	5.80
	June	4.59	3.42	3.99	4.45	3.36	4.67	6.54
	July	4.88	3.82	4.29	4.75	3.51	5.13	7.32
	Aug.	5.28	3.69	4.65	4.96	3.82	4.78	6.84
	Sep.	4.62	3.66	4.31	4.47	3.20	4.54	6.18
	Oct.	3.62	2.75	3.50	3.48	3.31	3.70	3.84
	Nov.	2.72	2.32	2.91	2.63	3.05	3.12	2.25
	Dec.	2.05	1.70	2.20	1.99	2.55	2.80	1.14

Table 6.2 : Values of the regression analysis for overall yearly relationships

X	a	b	r^2	Eq. No.
1. Blaney-Criddle	-0.201	1.318	0.863	6.2.1
2. Radiation	-0.501	1.183	0.821	6.2.2
3. Penman	0.089	0.999	0.986	6.2.3
4. Pan Evaporation	0.553	1.048	0.533	6.2.4
5. Hargreave	-0.809	1.168	0.854	6.2.5
6. Thornthwaite	2.160	0.405	0.629	6.2.6

Table 6.3 : Values of the regression analysis for monthly relationship

X	a	b	r^2	Eq. No.	Month
1. Blaney-Criddle	1.646	0.293	0.239	6.3.1	January
2. Radiation	1.135	0.427	0.578	6.3.2	
3. Penman	0.054	1.010	0.996	6.3.3	
4. Pan Evaporation	2.351	-0.037	0.011	6.3.4	
5. Hargreave	0.232	0.730	0.603	6.3.5	
6. Thornthwaite	1.793	0.420	0.160	6.3.6	
1. Blaney-Criddle	1.461	0.576	0.548	6.3.7	February
2. Radiation	1.151	0.562	0.583	6.3.8	
3. Penman	0.070	1.039	0.984	6.3.9	
4. Pan Evaporation	1.700	0.497	0.550	6.3.10	
5. Hargreave	-0.464	0.987	0.631	6.3.11	
6. Thornthwaite	1.848	0.727	0.360	6.3.12	
1. Blaney-Criddle	1.623	0.964	0.447	6.3.13	March
2. Radiation	0.401	0.877	0.389	6.3.14	
3. Penman	0.815	0.802	0.975	6.3.15	
4. Pan Evaporation	3.822	0.114	0.043	6.3.16	
5. Hargreave	2.090	0.467	0.199	6.3.17	
6. Thornthwaite	2.637	0.554	0.237	6.3.18	
1. Blaney-Criddle	0.896	1.016	0.831	6.3.19	April
2. Radiation	1.038	0.816	0.516	6.3.20	
3. Penman	0.519	0.905	0.980	6.3.21	
4. Pan Evaporation	3.683	0.327	0.262	6.3.22	
5. Hargreave	1.776	0.656	0.719	6.3.23	
6. Thornthwaite	1.833	0.769	0.812	6.3.24	

Contd..

Contd..

X	a	b	r^2	Eq. No.	Month
1. Blaney-Criddle	1.314	0.960	0.915	6.3.25	May
2. Radiation	0.770	0.926	0.918	6.3.26	
3. Penman	0.026	1.020	0.970	6.3.27	
4. Pan Evaporation	3.953	0.268	0.088	6.3.28	
5. Hargreave	-0.843	1.195	0.764	6.3.29	
6. Thornthwaite	0.472	0.840	0.684	6.3.30	
1. Blaney-Criddle	-1.245	1.669	0.899	6.3.31	June
2. Radiation	-0.025	1.177	0.919	6.3.32	
3. Penman	-0.115	1.041	0.980	6.3.33	
4. Pan Evaporation	2.651	0.524	0.335	6.3.34	
5. Hargreave	1.082	0.716	0.169	6.3.35	
6. Thornthwaite	-2.214	1.036	0.524	6.3.36	
1. Blaney-Criddle	1.248	0.985	0.471	6.3.37	July
2. Radiation	3.838	0.179	0.014	6.3.38	
3. Penman	2.324	0.511	0.830	6.3.39	
4. Pan Evaporation	4.406	0.037	0.002	6.3.40	
5. Hargreave	2.871	0.373	0.106	6.3.41	
6. Thornthwaite	3.104	0.214	0.060	6.3.42	
1. Blaney-Criddle	1.118	1.042	0.780	6.3.43	August
2. Radiation	1.793	0.705	0.878	6.3.44	
3. Penman	-1.227	1.311	0.986	6.3.45	
4. Pan Evaporation	4.179	0.119	0.027	6.3.46	
5. Hargreave	1.041	0.821	0.385	6.3.47	
6. Thornthwaite	0.588	0.624	0.134	6.3.48	

Contd..

Contd..

X	a	b	r^2	Eq. No.	Month
1. Blaney-Criddle	0.936	1.040	0.844	6.3.49	Sept.
2. Radiation	1.191	0.812	0.818	6.3.50	
3. Penman	-0.091	1.041	0.992	6.3.51	
4. Pan Evaporation	5.328	-0.440	0.035	6.3.52	
5. hargreave	-0.005	0.996	0.328	6.3.53	
6. Thornthwaite	-0.504	0.786	0.199	6.3.54	
1. Blaney-Criddle	0.552	1.115	0.742	6.3.55	October
2. Radiation	0.713	0.849	0.690	6.3.56	
3. Penman	0.290	0.945	0.977	6.3.57	
4. Pan Evaporation	2.355	0.420	0.253	6.3.58	
5. Hargreave	0.969	0.756	0.159	6.3.59	
6. Thornthwaite	0.053	0.870	0.338	6.3.60	
1. Blaney-Criddle	0.688	0.877	0.812	6.3.61	November
2. Radiation	0.315	0.823	0.708	6.3.62	
3. Penman	0.529	0.830	0.932	6.3.63	
4. Pan Evaporation	2.728	0.017	0.002	6.3.64	
5. Hargreave	2.812	-0.013	0.0	6.3.65	
6. Thornthwaite	1.709	0.445	0.499	6.3.66	
1. Blaney-Criddle	1.020	0.559	0.604	6.3.67	December
2. Radiation	0.671	0.581	0.503	6.3.68	
3. Penman	0.062	1.003	0.998	6.3.69	
4. Pan Evaporation	2.083	-0.013	0.001	6.3.70	
5. Hargreave	1.573	0.181	0.035	6.3.71	
6. Thornthwaite	1.439	0.493	0.682	6.3.72	

Table 6.4 : Values of the regression analysis for seasonal relationship

X	a	b	r^2	Eq. No.	Crop
1. Blaney-Criddle	0.037	1.195	0.788	6.4.1	Early Ahu (Feb-May)
2. Radiation	-0.535	1.136	0.794	6.4.2	
3. Penman	0.070	0.996	0.987	6.4.3	
4. Pan Evaporation	1.942	0.700	0.381	6.4.4	
5. Hargreave	-0.812	1.151	0.792	6.4.5	
6. Thornthwaite	2.396	0.544	0.760	6.4.6	
1. Blaney-Criddle	0.557	1.179	0.801	6.4.7	Sali (June-Sept)
2. Radiation	1.038	0.889	0.775	6.4.8	
3. Penman	0.385	0.939	0.886	6.4.9	
4. Pan Evaporation	3.176	0.353	0.115	6.4.10	
5. Hargreave	1.169	0.736	0.333	6.4.11	
6. Thornthwaite	0.257	0.654	0.646	6.4.12	
1. Blaney-Criddle	1.210	0.976	0.781	6.4.13	Ahu Paddy (April-Aug.)
2. Radiation	1.644	0.727	0.695	6.4.14	
3. Penman	0.587	0.898	0.909	6.4.15	
4. Pan Evaporation	3.518	0.329	0.161	6.4.16	
5. Hargreave	1.309	0.730	0.433	6.4.17	
6. Thornthwaite	4.725	-0.008	0.0	6.4.18	
1. Blaney-Criddle	-0.710	1.493	0.837	6.4.19	Oilseed & Pulses (Oct.-Jan.)
2. Radiation	-1.116	1.328	0.874	6.4.20	
3. Penman	0.052	1.010	0.997	6.4.21	
4. Pan Evaporation	0.504	0.868	0.443	6.4.22	
5. Hargreave	-2.379	1.686	0.856	6.4.23	
6. Thornthwaite	1.576	0.496	0.919	6.4.24	
1. Blaney-Criddle	0.170	1.055	0.900	6.4.25	Wheat (Nov.-March)
2. Radiation	-0.354	1.026	0.913	6.4.26	
3. Penman	0.187	0.951	0.996	6.4.27	
4. Pan Evaporation	0.608	0.869	0.453	6.4.28	
5. Hargreave	-0.652	1.062	0.898	6.4.29	
6. Thornthwaite	1.144	0.935	0.679	6.4.30	
1. Blaney-Criddle	0.033	1.149	0.730	6.4.31	Potato (Oct.-Feb.)
2. Radiation	-0.413	1.070	0.781	6.4.32	
3. Penman	0.057	1.006	0.996	6.4.33	
4. Pan Evaporation	0.709	0.802	0.447	6.4.34	
5. Hargreave	-1.274	1.294	0.748	6.4.35	
6. Thornthwaite	1.800	0.452	0.697	6.4.36	

Table 6.5 : Variation of ETo values of different relationships

S. No.	Method	Actual ETo Values		Observed From Overall Yearly		Observed From Monthly	
		Max.	Min.	Max.	Min.	Max.	Min.
1	Modified Penman	5.59	1.85	-	-	-	-
2	Blaney & Criddle	4.59	1.60	5.85	1.91	5.70	1.95
3	Radiation	4.59	2.16	6.19	2.05	5.66	1.93
4	Penman	5.74	1.78	5.82	1.87	5.71	1.85
5	Pan Evaporation	5.05	1.68	5.85	2.31	5.33	2.05
6	Hargreave	5.36	2.43	5.45	2.03	5.56	2.01
7	Thornthwaite	7.32	0.95	5.12	2.54	5.68	1.96

Table 6.6 : Variation of ETo values of different crops for different relationships

Crop	Methods	Observed From							
		Actual ETo		Seasonal ETo (Calculated)		Monthly ETo (Calculated)		Overall Yearly ETo (Calculated)	
		Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Early Ahu (Feb.-May)	Mod. Penman	5.59	2.47	-	-	-	-	-	-
	Bln. & Criddle	4.59	1.87	5.52	2.27	5.70	2.54	5.85	2.26
	Radiation	5.66	2.68	5.89	2.51	5.66	2.66	6.19	2.67
	Penman	5.74	2.41	5.78	2.47	5.71	2.43	5.82	2.50
	Pan Evapo.	5.05	2.03	5.48	3.36	5.33	2.71	5.85	2.68
	Hargreave	5.36	2.82	5.36	2.43	5.56	2.69	5.45	2.48
	Thornthwaite	6.20	1.20	5.77	3.05	5.68	2.72	4.67	2.65
Ahu Paddy (April-Aug.)	Mod. Penman	5.59	3.70	-	-	-	-	-	-
	Bln. & Criddle	4.59	2.68	5.69	3.82	5.70	3.79	5.85	3.36
	Radiation	5.66	2.91	5.76	3.76	5.66	3.81	6.19	3.36
	Penman	5.74	3.00	5.74	3.28	5.71	3.71	5.82	3.09
	Pan Evapo.	5.05	2.26	5.18	4.26	5.33	3.98	5.85	3.21
	Hargreave	5.36	2.82	5.22	3.37	5.56	3.63	5.45	2.48
	Thornthwaite	7.32	2.40	4.71	4.67	5.68	3.68	5.12	3.13
Sali Paddy (June-Sep.)	Mod. Penman	5.38	3.39	-	-	-	-	-	-
	Bln. & Criddle	4.04	2.29	5.32	3.26	5.50	3.32	5.12	2.82
	Radiation	4.65	2.56	5.17	3.31	5.41	3.27	5.00	2.53
	Penman	5.26	3.00	5.32	3.20	5.36	3.43	5.34	3.09
	Pan Evapo.	4.41	2.26	4.73	3.97	4.95	3.79	5.17	2.92
	Hargreave	5.35	3.69	5.10	3.88	5.00	3.67	5.44	3.50
	Thornthwaite	7.32	5.32	5.05	3.74	5.28	3.68	5.12	4.31
Oilseed & Pulses (Oct.-Jan.)	Mod. Penman	4.15	1.85	-	-	-	-	-	-
	Bln. & Criddle	3.09	1.60	3.90	1.68	4.00	1.95	3.87	1.91
	Radiation	3.85	2.16	4.00	1.75	3.98	1.93	4.05	2.05
	Penman	4.15	1.78	4.25	1.85	4.21	1.85	4.23	1.87
	Pan Evapo.	3.71	1.68	3.72	1.96	3.91	2.05	4.44	2.31
	Hargreave	3.70	2.43	3.86	1.72	3.77	2.01	3.51	2.03
	Thornthwaite	4.34	0.95	3.73	2.03	3.83	1.96	3.91	2.54
Potato (Oct.-Feb.)	Mod. Penman	4.15	1.85	-	-	-	-	-	-
	Bln. & Criddle	3.38	1.60	3.92	1.87	4.00	1.95	4.25	1.91
	Radiation	4.23	2.16	4.11	1.90	3.98	1.93	4.50	2.05
	Penman	4.15	1.78	4.23	1.85	4.21	1.85	4.23	1.87
	Pan Evapo.	4.09	1.68	3.99	2.06	3.91	2.05	4.84	2.31
	Hargreave	4.22	2.43	4.19	1.87	3.77	2.01	4.12	2.03
	Thornthwaite	4.34	0.95	3.76	2.23	3.83	1.96	3.92	2.54
Wheat (Nov.-March)	Mod. Penman	4.89	1.85	-	-	-	-	-	-
	Bln. & Criddle	4.38	1.60	4.79	1.86	4.66	1.95	5.57	1.91
	Radiation	4.69	2.16	4.46	1.86	4.51	1.93	5.05	2.05
	Penman	5.02	1.78	4.96	1.88	4.84	1.85	5.10	1.87
	Pan Evapo.	4.65	1.68	4.65	2.07	4.35	2.05	5.43	2.31
	Hargreave	5.32	2.43	5.00	1.93	4.57	2.01	5.40	2.03
	Thornthwaite	3.32	0.95	4.25	2.03	4.48	1.96	3.50	2.54

Table 6.7 : Calculated ETo values from overall yearly and monthly relationships

Year	Mon.	Actual ETo of Mod.Pen.	Calculated from Overall Yearly Equation						Calculated from Monthly Equation					
			Bla.	Rad.	Pen.	Etp.	Harg.	Thor.	Bla.	Rad.	Pen.	Etp.	Harg.	Thor.
1986	Jan.	2.36	2.63	2.69	2.37	3.91	2.57	2.62	2.28	2.29	2.36	2.23	2.34	2.27
	Feb.	3.57	4.25	4.50	3.59	4.84	3.65	2.80	3.41	3.53	3.58	3.73	3.31	3.00
	Mar.	4.76	5.57	4.93	5.10	4.88	5.40	3.50	4.66	4.43	4.84	4.29	4.57	4.48
	Apr.	4.71	4.78	4.48	4.77	4.34	4.96	3.83	4.74	4.47	4.76	4.86	5.02	5.01
	May	5.55	5.82	5.75	5.50	5.31	5.11	4.25	5.70	5.66	5.55	5.17	5.22	4.81
	June	5.38	5.12	4.96	5.34	5.14	5.44	5.09	5.50	5.41	5.36	4.95	4.91	5.28
	July	4.50	4.29	4.03	4.53	4.23	4.56	4.94	4.61	4.52	4.60	4.54	4.59	4.57
	Aug.	4.62	4.46	4.34	4.56	4.70	4.82	4.95	4.81	4.68	4.64	4.65	5.00	4.88
	Sep.	3.39	2.82	2.53	3.46	3.86	3.79	4.50	3.32	3.27	3.43	3.94	3.92	4.04
	Oct.	3.46	3.17	3.27	3.44	3.67	3.44	3.77	3.41	3.42	3.46	3.60	3.72	3.51
	Nov.	2.75	2.90	3.08	2.75	2.94	2.64	3.08	2.75	2.81	2.74	2.77	2.77	2.72
	Dec.	2.12	2.38	2.46	2.14	2.94	2.25	2.65	2.12	2.12	2.12	2.05	2.05	2.03
1987	Jan.	2.57	2.98	3.15	2.57	3.02	2.67	2.63	2.35	2.45	2.56	2.26	2.41	2.28
	Feb.	3.00	3.15	3.12	3.09	3.17	3.34	2.84	2.92	2.87	3.05	2.94	3.04	3.08
	Mar.	3.82	4.04	4.16	3.83	3.88	4.21	3.28	3.86	3.86	3.82	4.18	4.10	4.18
	Apr.	5.51	5.24	5.40	5.45	5.85	5.32	3.99	5.09	5.11	5.38	5.33	5.22	5.30
	May	5.59	5.74	5.47	5.53	4.08	5.45	4.67	5.64	5.45	5.58	4.85	5.56	5.68
	June	3.77	3.94	3.41	3.90	3.88	5.09	4.54	4.00	3.87	3.86	4.31	4.70	3.87
	July	4.40	4.07	4.20	4.27	4.09	4.00	4.69	4.44	4.55	4.46	4.53	4.41	4.44
	Aug.	5.06	4.64	4.94	4.87	3.73	3.86	4.62	4.94	5.04	5.05	4.54	4.33	4.39
	Sep.	3.82	3.46	3.44	3.82	3.58	3.50	4.39	3.83	3.89	3.80	4.06	3.67	3.82
	Oct.	3.48	3.36	3.38	3.44	3.58	3.06	3.82	3.56	3.50	3.46	3.57	3.47	3.61
	Nov.	2.79	3.09	3.11	2.84	3.29	2.57	3.21	2.88	2.82	2.81	2.77	2.77	2.86
	Dec.	2.01	2.28	2.39	2.03	2.69	2.32	2.70	2.07	2.09	2.01	2.06	2.06	2.09
1988	Jan.	2.36	2.66	2.80	2.37	2.85	2.47	2.62	2.28	2.33	2.36	2.27	2.28	2.27
	Feb.	3.59	4.20	4.21	3.57	3.50	3.48	2.91	3.38	3.39	3.56	3.10	3.16	3.19
	Mar.	4.89	4.99	5.05	5.08	3.38	4.29	3.30	4.36	4.51	4.82	4.13	4.13	4.20
	Apr.	5.55	5.49	5.25	5.82	3.74	5.06	3.92	5.28	5.00	5.71	4.68	5.07	5.17
	May	4.69	4.23	4.21	4.88	3.75	4.54	4.20	4.54	4.45	4.92	4.77	4.63	4.70
	June	5.01	4.72	4.62	5.13	3.69	4.53	4.82	4.98	5.07	5.14	4.22	4.35	4.60
	July	5.08	4.33	3.96	5.18	3.57	4.32	4.94	4.64	4.51	4.93	4.51	4.51	4.57
	Aug.	4.09	3.33	2.94	4.21	2.92	3.70	4.66	3.91	3.85	4.19	4.45	4.21	4.44
	Sep.	4.55	3.95	3.77	4.61	3.78	3.69	4.43	4.21	4.12	4.62	3.97	3.83	3.90
	Oct.	4.15	3.62	3.72	4.23	3.69	3.20	3.84	3.78	3.74	4.21	3.61	3.56	3.67
	Nov.	2.93	3.09	3.02	3.05	3.01	2.74	3.13	2.88	2.77	2.99	2.77	2.77	2.78
	Dec.	2.21	2.46	2.54	2.23	2.42	2.15	2.78	2.15	2.16	2.21	2.06	2.03	2.19
1989	Jan.	2.26	2.62	3.02	2.29	2.31	2.29	2.56	2.27	2.41	2.28	2.29	2.17	2.21
	Feb.	2.73	3.77	3.76	2.89	2.68	3.14	2.72	3.19	3.18	2.84	2.71	2.87	2.86
	Mar.	3.83	5.12	5.01	3.93	3.52	4.71	3.31	4.43	4.49	3.90	4.15	4.30	4.20
	Apr.	5.00	5.69	6.19	4.98	4.86	4.73	3.67	5.44	5.66	4.95	5.03	4.88	4.71
	May	5.05	4.66	4.68	5.01	4.60	5.02	4.45	4.85	4.82	5.05	4.99	5.12	5.22
	June	5.02	4.46	4.16	4.97	5.02	4.54	4.73	4.66	4.61	4.98	4.88	4.36	4.36
	July	4.73	3.98	3.81	4.76	4.42	4.19	4.70	4.37	4.49	4.71	4.54	4.47	4.44
	Aug.	4.80	4.56	4.59	4.72	4.24	4.47	4.70	4.88	4.83	4.85	4.60	4.75	4.50
	Sep.	3.62	3.23	3.18	3.66	3.94	3.58	4.31	3.64	3.71	3.64	3.91	3.74	3.68
	Oct.	3.66	3.52	3.63	3.67	3.40	3.25	3.92	3.70	3.68	3.68	3.50	3.60	3.83
	Nov.	2.78	2.82	2.97	2.82	2.68	2.58	3.04	2.70	2.72	2.80	2.76	2.77	2.68
	Dec.	2.02	2.12	2.29	2.05	2.42	2.22	2.60	2.01	2.04	2.03	2.06	2.04	1.97
1990	Jan.	2.23	2.42	2.35	2.24	3.30	2.46	2.74	2.23	2.16	2.23	2.25	2.28	2.40
	Feb.	2.86	2.26	2.67	2.86	3.40	3.09	2.80	2.54	2.66	2.81	3.05	2.83	2.99
	Mar.	3.92	4.19	4.34	3.94	3.58	3.91	3.06	3.93	3.99	3.91	4.15	3.98	3.87
	Apr.	3.72	3.56	4.18	3.67	3.45	2.48	3.13	3.79	4.27	3.77	4.58	3.63	3.68
	May	5.38	5.07	5.43	5.19	5.01	4.84	4.46	5.15	5.41	5.24	5.09	4.94	5.25
	June	4.04	3.98	3.52	4.11	3.46	4.40	4.82	4.05	3.98	4.08	4.10	4.28	4.59
	July	4.02	3.81	4.23	3.09	3.75	4.29	4.86	4.24	4.55	3.86	4.52	4.50	4.53
	Aug.	4.52	4.43	4.28	4.47	4.18	4.40	4.80	4.78	4.64	4.53	4.59	4.70	4.66
	Sep.	3.82	3.53	3.49	3.83	4.12	3.77	4.44	3.88	3.93	3.81	3.83	3.90	3.92
	Oct.	3.08	2.79	2.84	3.11	3.31	2.94	3.71	3.08	3.11	3.14	3.46	3.39	3.38
	Nov.	2.99	3.16	3.37	2.97	3.48	2.93	3.28	2.92	3.00	2.92	2.78	2.77	2.94
	Dec.	2.14	2.24	2.40	2.16	2.60	2.44	2.72	2.06	2.09	2.14	2.06	2.08	2.12

Contd...

Year	Mon.	Actual ETo of Mod.Pen.	Calculated from Overall Yearly Equation						Calculated from Monthly Equation					
			Bla.	Rad.	Pen.	Etp.	Harg.	Thor.	Bla.	Rad.	Pen.	Etp.	Harg.	Thor.
1991	Jan.	2.18	2.22	2.48	2.19	2.68	2.48	2.56	2.19	2.21	2.18	2.27	2.29	2.20
	Feb.	3.36	3.83	3.71	3.37	3.51	4.12	3.10	3.22	3.15	3.35	3.10	3.70	3.54
	Mar.	4.17	4.73	4.74	4.19	4.16	4.64	3.48	4.22	4.28	4.11	4.21	4.27	4.44
	Apr.	4.59	4.66	4.79	4.58	5.25	4.84	3.79	4.64	4.69	4.59	5.15	4.95	4.93
	May	3.70	3.36	3.38	3.69	4.29	3.84	3.92	3.90	3.81	3.71	4.91	3.91	4.12
	June	3.80	3.82	3.36	3.86	4.37	4.32	4.73	3.85	3.81	3.82	4.56	4.23	4.36
	July	4.38	4.24	3.95	4.35	4.81	4.33	4.98	4.57	4.51	4.50	4.56	4.51	4.59
	Aug.	3.87	3.73	3.52	3.91	5.18	3.71	4.67	4.22	4.19	3.79	4.71	4.22	4.46
	Sep.	3.45	3.33	3.01	3.47	4.11	3.66	4.43	3.72	3.60	3.44	3.84	3.81	3.90
	Oct.	3.54	3.44	3.51	3.51	3.39	3.25	3.86	3.63	3.59	3.53	3.49	3.60	3.71
	Nov.	2.58	2.66	2.87	2.57	3.22	2.82	3.03	2.59	2.66	2.59	2.77	2.77	2.67
	Dec.	1.95	1.99	2.05	1.97	3.05	2.12	2.59	1.95	1.93	1.95	2.05	2.03	1.96
1992	Jan.	2.07	3.07	2.57	2.08	3.59	2.31	2.57	2.37	2.25	2.06	2.24	2.18	2.22
	Feb.	2.47	2.98	3.14	2.50	2.91	2.93	2.65	2.85	2.89	2.43	2.82	2.69	2.72
	Mar.	4.17	4.68	4.38	4.32	5.43	4.40	3.34	4.19	4.02	4.21	4.35	4.17	4.25
	Apr.	5.48	5.85	5.61	5.54	5.63	5.40	4.10	5.56	5.26	5.46	5.26	5.26	5.53
	May	4.60	4.58	4.74	4.51	4.85	4.78	4.13	4.80	4.87	4.54	5.05	4.88	4.57
	June	4.42	4.45	4.14	4.31	4.62	4.96	4.81	4.65	4.59	4.29	4.68	4.62	4.58
	July	4.56	4.24	4.29	4.38	4.03	4.22	4.69	4.57	4.56	4.52	4.53	4.48	4.44
	Aug.	5.02	4.60	4.93	4.78	5.00	4.43	4.79	4.91	5.03	4.93	4.69	4.73	4.64
	Sep.	3.97	3.73	3.73	3.96	3.83	3.92	4.40	4.03	4.10	3.95	3.95	4.03	3.84
	Oct.	3.54	3.42	3.65	3.51	3.39	3.25	3.75	3.62	3.69	3.53	3.49	3.60	3.47
	Nov.	2.60	2.72	2.82	2.60	3.22	2.88	3.10	2.63	2.63	2.61	2.77	2.77	2.74
	Dec.	1.85	2.07	2.23	1.87	2.32	2.31	2.58	1.98	2.01	1.85	2.06	2.06	1.96
1993	Jan.	2.04	1.91	2.09	2.05	3.23	2.03	2.54	2.11	2.07	2.03	2.26	2.01	2.19
	Feb.	2.73	2.83	2.72	2.77	3.21	3.04	2.86	2.79	2.68	2.71	2.96	2.79	3.11
	Mar.	3.98	4.28	4.40	4.06	3.49	4.31	3.17	3.98	4.03	4.01	4.14	4.14	4.02
	Apr.	4.69	4.81	4.91	4.68	3.58	5.03	3.70	4.76	4.77	4.68	4.63	5.05	4.76
	May	4.63	4.20	4.54	4.52	3.47	4.39	4.12	4.52	4.71	4.55	4.70	4.48	4.54
	June	4.06	3.90	3.63	4.06	3.22	4.29	4.54	3.95	4.08	4.03	3.98	4.21	3.89
	July	4.23	3.94	3.77	4.24	3.57	4.42	4.88	4.34	4.48	4.45	4.51	4.54	4.54
	Aug.	4.16	3.45	3.36	4.19	3.93	4.12	4.77	4.00	4.09	4.16	4.56	4.51	4.60
	Sep.	3.98	3.49	3.46	3.98	4.21	3.68	4.37	3.85	3.91	3.97	3.79	3.82	3.78
	Oct.	3.86	3.87	4.05	3.78	4.44	3.38	3.91	4.00	3.98	3.79	3.91	3.68	3.81
	Nov.	2.81	3.08	3.12	2.81	3.65	2.86	3.20	2.87	2.83	2.79	2.78	2.77	2.85
	Dec.	2.16	2.59	2.42	2.18	2.49	2.50	2.77	2.21	2.11	2.16	2.06	2.09	2.18
1994	Jan.	2.27	2.54	2.37	2.30	3.03	2.64	2.65	2.26	2.17	2.29	2.26	2.39	2.30
	Feb.	3.05	3.45	3.39	3.08	3.16	3.24	2.73	3.06	3.00	3.04	2.94	2.96	2.88
	Mar.	4.20	4.50	4.54	4.19	3.33	4.17	3.24	4.10	4.14	4.11	4.12	4.08	4.11
	Apr.	4.87	4.90	5.09	4.83	3.50	4.99	3.84	4.83	4.90	4.82	4.60	5.03	5.03
	May	5.03	5.02	4.95	5.03	3.40	5.37	4.51	5.11	5.04	5.07	4.68	5.48	5.34
	June	4.59	4.31	4.22	4.53	4.08	4.64	4.81	4.46	4.67	4.52	4.41	4.43	4.56
	July	4.88	4.83	4.57	4.83	4.23	5.18	5.12	5.01	4.60	4.75	4.54	4.78	4.67
	Aug.	5.28	4.66	5.00	5.04	4.56	4.77	4.93	4.96	5.07	5.27	4.63	4.97	4.85
	Sep.	4.62	4.62	4.60	4.55	3.91	4.49	4.66	4.74	4.69	4.56	3.92	4.52	4.35
	Oct.	3.62	3.42	3.64	3.56	4.02	3.51	3.71	3.62	3.68	3.58	3.75	3.77	3.39
	Nov.	2.72	2.86	2.94	2.72	3.75	2.83	3.07	2.72	2.71	2.71	2.78	2.77	2.71
	Dec.	2.05	2.04	2.10	2.08	3.23	2.46	2.62	1.97	1.95	2.06	2.05	2.08	2.00

Table 6.8 : Calculated ETo values from seasonal relationship of different crops

Month	Year	Actual ETo of Mod. Pen.	Calculated From Crop's Seasonal Equation						Crop & Cropping Period
			Bln.	Rad.	Pen.	Etp.	Harg.	Thor.	
Feb.	1986	3.57	4.08	4.27	3.56	4.81	3.58	3.26	Early Ahu Paddy (Feb–May)
	87	3.00	3.07	2.94	3.06	3.69	3.27	3.31	
	88	3.59	4.03	3.99	3.54	3.91	3.41	3.40	
	89	2.73	3.63	3.55	2.86	3.36	3.08	3.15	
	90	2.86	2.27	2.51	2.83	3.85	3.03	3.25	
	91	3.36	3.69	3.51	3.35	3.92	4.04	3.66	
	92	2.47	2.92	2.96	2.47	3.52	2.87	3.05	
	93	2.73	2.79	2.55	2.74	3.71	2.99	3.34	
	94	3.05	3.35	3.20	3.05	3.69	3.18	3.17	
Mar.	1986	4.76	5.27	4.68	5.07	4.83	5.31	4.20	
	87	3.82	3.89	3.94	3.80	4.16	4.14	3.91	
	88	4.89	4.75	4.79	5.05	3.83	4.22	3.93	
	89	3.83	4.87	4.76	3.90	3.92	4.63	3.93	
	90	3.92	4.02	4.11	3.91	3.97	3.84	3.61	
	91	4.17	4.51	4.50	4.16	4.35	4.56	4.16	
	92	4.17	4.46	4.16	4.29	5.20	4.32	3.98	
	93	3.98	4.10	4.17	4.03	3.90	4.23	3.75	
	94	4.20	4.30	4.30	4.16	3.80	4.09	3.84	
April	1986	4.71	4.56	4.25	4.74	4.47	4.87	4.64	
	87	5.51	4.97	5.13	5.42	5.48	5.23	4.85	
	88	5.55	5.20	4.99	5.78	4.07	4.98	4.76	
	89	5.00	5.38	5.89	4.95	4.82	4.64	4.43	
	90	3.72	3.44	3.96	3.64	3.87	2.43	3.70	
	91	4.59	4.45	4.54	4.55	5.08	4.76	4.58	
	92	5.48	5.52	5.34	5.51	5.33	5.31	5.01	
	93	4.69	4.58	4.66	4.65	3.97	4.94	4.47	
	94	4.87	4.66	4.84	4.80	3.91	4.91	4.66	
May	1986	5.55	5.50	5.46	5.47	5.12	5.02	5.20	
	87	5.59	5.43	5.20	5.50	4.29	5.36	5.77	
	88	4.69	4.05	3.99	4.85	4.08	4.46	5.14	
	89	5.05	4.45	4.44	4.98	4.64	4.93	5.47	
	90	5.38	4.82	5.16	5.16	4.92	4.76	5.49	
	91	3.70	3.26	3.19	3.66	4.43	3.77	4.76	
	92	4.60	4.38	4.50	4.48	4.81	4.70	5.05	
	93	4.63	4.03	4.30	4.49	3.89	4.31	5.03	
	94	5.03	4.77	4.70	5.00	3.85	5.28	5.55	
April	1986	4.71	4.90	4.71	4.80	4.71	4.92	4.69	Ahu Paddy (Regular) (April-Aug)
	87	5.51	5.24	5.27	5.41	5.18	5.14	4.69	
	88	5.55	5.42	5.18	5.74	4.52	4.98	4.69	
	89	5.00	5.57	5.76	4.99	4.87	4.77	4.70	
	90	3.72	3.99	4.52	3.81	4.43	3.37	4.71	
	91	4.59	4.81	4.89	4.63	4.99	4.84	4.69	
	92	5.48	5.69	5.40	5.49	5.11	5.19	4.69	
	93	4.69	4.92	4.97	4.72	4.47	4.96	4.70	
	94	4.87	4.99	5.08	4.85	4.44	4.94	4.69	
May	1986	5.55	5.67	5.48	5.45	5.01	5.01	4.69	
	87	5.59	5.61	5.32	5.48	4.62	5.22	4.68	
	88	4.69	4.49	4.54	4.90	4.52	4.65	4.69	
	89	5.05	4.81	4.83	5.01	4.79	4.95	4.68	
	90	5.38	5.11	5.29	5.18	4.92	4.84	4.68	
	91	3.70	3.84	4.03	3.83	4.69	4.22	4.69	
	92	4.60	4.75	4.87	4.56	4.87	4.81	4.69	
	93	4.63	4.47	4.74	4.57	4.43	4.56	4.69	
	94	5.03	5.07	5.00	5.03	4.41	5.17	4.68	

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Month	Year	Actual ETo of Mod. Pen.	Calculated From Crop's Seasonal Equation Bln.	Rad.	Pen.	Etp.	Harg.	Thor.	Crop & Cropping Period
June	1986	5.38	5.15	5.00	5.31	4.96	5.22	4.67	Ahu Paddy (April-Aug)
	87	3.77	4.27	4.05	4.02	4.56	5.00	4.68	
	88	5.01	4.85	4.79	5.12	4.50	4.65	4.67	
	89	5.02	4.66	4.51	4.98	4.92	4.65	4.68	
	90	4.04	4.30	4.12	4.21	4.43	4.57	4.67	
	91	3.80	4.19	4.01	3.98	4.72	4.52	4.68	
	92	4.42	4.65	4.49	4.39	4.79	4.92	4.67	
	93	4.06	4.24	4.18	4.16	4.35	4.50	4.68	
	94	4.59	4.55	4.55	4.58	4.62	4.72	4.67	
July	1986	4.50	4.54	4.43	4.58	4.67	4.67	4.67	
	87	4.40	4.37	4.53	4.35	4.63	4.32	4.68	
	88	5.08	4.57	4.39	5.17	4.47	4.52	4.67	
	89	4.73	4.30	4.29	4.79	4.73	4.43	4.68	
	90	4.02	4.18	4.55	3.28	4.52	4.50	4.67	
	91	4.38	4.50	4.38	4.42	4.85	4.52	4.67	
	92	4.56	4.50	4.59	4.45	4.61	4.46	4.68	
	93	4.23	4.27	4.27	4.32	4.47	4.58	4.67	
	94	4.88	4.94	4.76	4.85	4.67	5.06	4.67	
Aug.	1986	4.62	4.66	4.62	4.61	4.82	4.83	4.67	
	87	5.06	4.79	4.99	4.89	4.52	4.23	4.68	
	88	4.09	3.82	3.76	4.30	4.26	4.13	4.68	
	89	4.80	4.73	4.77	4.75	4.68	4.61	4.68	
	90	4.52	4.63	4.58	4.53	4.66	4.57	4.67	
	91	3.87	4.12	4.12	4.03	4.97	4.14	4.68	
	92	5.02	4.76	4.98	4.81	4.91	4.59	4.68	
	93	4.16	3.91	4.01	4.28	4.58	4.39	4.68	
	94	5.28	4.81	5.03	5.04	4.78	4.80	4.67	
June	1986	5.38	5.32	5.14	5.32	4.72	5.10	4.99	Sali Paddy (June-Sep)
	87	3.77	4.26	3.98	3.97	4.30	4.88	4.10	
	88	5.01	4.95	4.89	5.13	4.23	4.53	4.56	
	89	5.02	4.73	4.54	4.97	4.68	4.54	4.40	
	90	4.04	4.29	4.06	4.17	4.16	4.45	4.56	
	91	3.80	4.15	3.93	3.93	4.46	4.40	4.40	
	92	4.42	4.72	4.52	4.36	4.55	4.80	4.55	
	93	4.06	4.22	4.14	4.12	4.07	4.38	4.11	
	94	4.59	4.59	4.58	4.56	4.36	4.60	4.54	
July	1986	4.50	4.58	4.44	4.56	4.42	4.55	4.75	
	87	4.40	4.38	4.57	4.32	4.37	4.20	4.34	
	88	5.08	4.61	4.39	5.17	4.19	4.40	4.75	
	89	4.73	4.29	4.27	4.78	4.48	4.32	4.36	
	90	4.02	4.14	4.59	3.20	4.25	4.38	4.61	
	91	4.38	4.53	4.38	4.39	4.61	4.41	4.82	
	92	4.56	4.53	4.64	4.42	4.35	4.34	4.34	
	93	4.23	4.26	4.25	4.29	4.19	4.46	4.65	
	94	4.88	5.06	4.85	4.84	4.42	4.94	5.05	
Aug.	1986	4.62	4.73	4.67	4.59	4.58	4.71	4.76	
	87	5.06	4.88	5.13	4.88	4.25	4.11	4.24	
	88	4.09	3.72	3.62	4.26	3.97	4.01	4.29	
	89	4.80	4.81	4.86	4.74	4.42	4.49	4.36	
	90	4.52	4.70	4.63	4.51	4.40	4.45	4.53	
	91	3.87	4.07	4.06	3.98	4.73	4.02	4.32	
	92	5.02	4.85	5.12	4.80	4.67	4.47	4.50	
	93	4.16	3.82	3.93	4.24	4.31	4.27	4.47	
	94	5.28	4.91	5.17	5.04	4.53	4.69	4.73	
Sep.	1986	3.39	3.26	3.31	3.56	4.29	4.07	4.04	
	87	3.82	3.83	4.00	3.90	4.20	3.88	3.86	
	88	4.55	4.27	4.25	4.64	4.26	4.00	3.92	
	89	3.62	3.62	3.80	3.75	4.32	3.94	3.74	
	90	3.82	3.89	4.03	3.90	4.38	4.05	3.94	
	91	3.45	3.72	3.68	3.57	4.37	3.99	3.93	
	92	3.97	4.07	4.22	4.03	4.28	4.15	3.87	
	93	3.98	3.86	4.01	4.05	4.41	3.99	3.82	
	94	4.62	4.87	4.87	4.58	4.31	4.51	4.30	

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Month	Year	Actual ETo of Mod. Pen.	Calculated From Crop's Seasonal Equation: Bln.	Rad.	Pen.	Etp.	Harg.	Thor.	Crop & Cropping Period
Oct.	1986	3.46	3.11	3.12	3.45	3.08	3.76	3.55	Oilseed & Pulses (Oct-Jan)
	87	3.48	3.32	3.24	3.45	3.01	3.20	3.61	
	88	4.15	3.62	3.63	4.24	3.10	3.40	3.64	
	89	3.66	3.50	3.52	3.68	2.86	3.49	3.73	
	90	3.08	2.68	2.63	3.10	2.79	3.03	3.47	
	91	3.54	3.41	3.39	3.52	2.86	3.49	3.67	
	92	3.54	3.40	3.55	3.52	2.86	3.49	3.53	
	93	3.86	3.90	4.00	3.79	3.72	3.67	3.72	
	94	3.62	3.40	3.53	3.57	3.38	3.86	3.48	
Nov.	1986	2.75	2.80	2.91	2.74	2.48	2.60	2.70	
	87	2.79	3.02	2.94	2.83	2.77	2.49	2.86	
	88	2.93	3.02	2.84	3.04	2.53	2.75	2.77	
	89	2.78	2.71	2.78	2.81	2.27	2.51	2.65	
	90	2.99	3.10	3.23	2.96	2.92	3.02	2.95	
	91	2.58	2.53	2.67	2.56	2.71	2.86	2.64	
	92	2.6	2.61	2.62	2.59	2.71	2.95	2.73	
	93	2.81	3.01	2.95	2.80	3.06	2.92	2.85	
	94	2.72	2.75	2.75	2.71	3.15	2.88	2.69	
Dec.	1986	2.12	2.22	2.20	2.12	2.48	2.04	2.17	
	87	2.01	2.10	2.13	2.01	2.27	2.14	2.24	
	88	2.21	2.31	2.30	2.21	2.05	1.89	2.34	
	89	2.02	1.92	2.02	2.03	2.05	1.99	2.11	
	90	2.14	2.05	2.14	2.14	2.20	2.31	2.26	
	91	1.95	1.77	1.75	1.95	2.57	1.85	2.10	
	92	1.85	1.86	1.95	1.85	1.97	2.12	2.10	
	93	2.16	2.46	2.16	2.16	2.11	2.39	2.33	
	94	2.05	1.83	1.81	2.06	2.72	2.34	2.14	
Jan	1986	2.36	2.50	2.47	2.35	3.28	2.49	2.14	
	87	2.57	2.89	2.99	2.56	2.54	2.65	2.16	
	88	2.36	2.53	2.59	2.35	2.40	2.36	2.14	
	89	2.26	2.49	2.84	2.27	1.96	2.09	2.07	
	90	2.23	2.26	2.09	2.22	2.78	2.34	2.29	
	91	2.18	2.04	2.23	2.17	2.27	2.38	2.06	
	92	2.07	2.99	2.34	2.06	3.02	2.12	2.08	
	93	2.04	1.68	1.79	2.03	2.72	1.72	2.05	
	94	2.27	2.40	2.11	2.28	2.55	2.60	2.17	
Oct.	1986	3.46	2.98	3.00	3.44	3.09	3.44	3.60	Potato (Oct-Feb)
	87	3.48	3.14	3.10	3.44	3.03	3.01	3.65	
	88	4.15	3.37	3.41	4.23	3.11	3.16	3.68	
	89	3.66	3.27	3.32	3.67	2.89	3.23	3.76	
	90	3.08	2.64	2.60	3.09	2.82	2.88	3.53	
	91	3.54	3.21	3.21	3.51	2.88	3.23	3.70	
	92	3.54	3.19	3.34	3.51	2.88	3.23	3.57	
	93	3.86	3.58	3.71	3.78	3.69	3.37	3.75	
	94	3.62	3.19	3.33	3.56	3.37	3.51	3.53	
Nov.	1986	2.75	2.73	2.83	2.73	2.54	2.54	2.83	
	87	2.79	2.91	2.85	2.82	2.80	2.47	2.97	
	88	2.93	2.91	2.78	3.03	2.59	2.66	2.88	
	89	2.78	2.67	2.72	2.80	2.34	2.48	2.78	
	90	2.99	2.96	3.09	2.95	2.95	2.87	3.05	
	91	2.58	2.53	2.64	2.55	2.75	2.75	2.77	
	92	2.60	2.58	2.59	2.58	2.75	2.81	2.85	
	93	2.81	2.89	2.86	2.79	3.08	2.79	2.96	
	94	2.72	2.70	2.70	2.70	3.16	2.76	2.82	
Dec.	1986	2.12	2.29	2.26	2.12	2.54	2.12	2.34	
	87	2.01	2.19	2.20	2.01	2.35	2.19	2.40	
	88	2.21	2.35	2.34	2.21	2.14	2.00	2.49	
	89	2.02	2.06	2.11	2.03	2.14	2.08	2.29	
	90	2.14	2.16	2.21	2.14	2.27	2.32	2.42	
	91	1.95	1.94	1.90	1.95	2.62	1.97	2.28	
	92	1.85	2.01	2.06	1.85	2.07	2.18	2.27	
	93	2.16	2.47	2.23	2.16	2.19	2.39	2.48	
	94	2.05	1.99	1.94	2.06	2.76	2.35	2.31	

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Month	Year	Actual ETo of Mod. Pen.	Calculated From Crop's Seasonal Equation Bln.	Rad.	Pen.	Etp.	Harg.	Thor.	Crop & Cropping Period
Jan.	1986	2.36	2.50	2.48	2.35	3.28	2.47	2.31	Potato (Oct-Feb)
	87	2.57	2.80	2.89	2.55	2.60	2.58	2.33	
	88	2.36	2.53	2.57	2.35	2.47	2.36	2.31	
	89	2.26	2.49	2.78	2.27	2.06	2.15	2.25	
	90	2.23	2.32	2.17	2.22	2.81	2.35	2.45	
	91	2.18	2.15	2.28	2.17	2.34	2.37	2.24	
	92	2.07	2.88	2.37	2.06	3.04	2.18	2.26	
	93	2.04	1.87	1.93	2.03	2.76	1.87	2.23	
	94	2.27	2.42	2.19	2.28	2.60	2.54	2.34	
Feb.	1986	3.57	3.92	4.11	3.59	3.99	3.67	2.51	
	87	3.00	2.95	2.86	3.07	2.72	3.32	2.56	
	88	3.59	3.87	3.84	3.57	2.96	3.47	2.64	
	89	2.73	3.49	3.44	2.87	2.34	3.10	2.43	
	90	2.86	2.18	2.45	2.84	2.89	3.05	2.51	
	91	3.36	3.55	3.40	3.36	2.97	4.19	2.85	
	92	2.47	2.80	2.88	2.48	2.51	2.87	2.34	
	93	2.73	2.68	2.50	2.75	2.74	3.00	2.58	
	94	3.05	3.22	3.11	3.06	2.71	3.22	2.44	
Nov.	1986	2.75	2.65	2.75	2.72	2.59	2.48	3.27	Wheat (Nov-March)
	87	2.79	2.81	2.77	2.80	2.88	2.42	3.56	
	88	2.93	2.81	2.70	3.00	2.64	2.58	3.39	
	89	2.78	2.59	2.65	2.78	2.37	2.43	3.17	
	90	2.99	2.86	3.00	2.93	3.03	2.75	3.73	
	91	2.58	2.46	2.57	2.54	2.82	2.65	3.15	
	92	2.60	2.51	2.53	2.57	2.82	2.70	3.31	
	93	2.81	2.80	2.78	2.77	3.17	2.68	3.55	
	94	2.72	2.62	2.63	2.69	3.26	2.66	3.25	
Dec.	1986	2.12	2.24	2.21	2.14	2.59	2.13	2.27	
	87	2.01	2.15	2.15	2.03	2.38	2.19	2.39	
	88	2.21	2.30	2.28	2.22	2.16	2.03	2.57	
	89	2.02	2.03	2.07	2.05	2.16	2.10	2.15	
	90	2.14	2.12	2.16	2.16	2.30	2.30	2.43	
	91	1.95	1.92	1.86	1.97	2.68	2.01	2.13	
	92	1.85	1.98	2.02	1.88	2.08	2.18	2.13	
	93	2.16	2.41	2.18	2.17	2.22	2.35	2.56	
	94	2.05	1.96	1.90	2.08	2.82	2.32	2.21	
Jan.	1986	2.36	2.44	2.42	2.35	3.39	2.42	2.20	
	87	2.57	2.71	2.82	2.54	2.65	2.51	2.24	
	88	2.36	2.46	2.51	2.35	2.51	2.33	2.21	
	89	2.26	2.43	2.70	2.28	2.07	2.16	2.07	
	90	2.23	2.27	2.12	2.23	2.89	2.32	2.49	
	91	2.18	2.11	2.23	2.18	2.37	2.34	2.06	
	92	2.07	2.79	2.31	2.08	3.13	2.18	2.09	
	93	2.04	1.86	1.89	2.05	2.82	1.93	2.03	
	94	2.27	2.36	2.14	2.29	2.66	2.48	2.27	
Feb.	1986	3.57	3.74	3.98	3.52	4.16	3.40	2.62	
	87	3.00	2.85	2.78	3.04	2.78	3.12	2.72	
	88	3.59	3.69	3.73	3.51	3.05	3.25	2.87	
	89	2.73	3.35	3.34	2.85	2.37	2.94	2.44	
	90	2.86	2.14	2.40	2.82	2.97	2.90	2.61	
	91	3.36	3.40	3.30	3.31	3.06	3.83	3.32	
	92	2.47	2.71	2.81	2.48	2.56	2.75	2.27	
	93	2.73	2.60	2.44	2.73	2.81	2.85	2.76	
	94	3.05	3.09	3.02	3.03	2.77	3.03	2.47	
Mar.	1986	4.76	4.79	4.35	4.96	4.20	5.00	4.25	
	87	3.82	3.57	3.69	3.75	3.36	3.91	3.74	
	88	4.89	4.33	4.46	4.94	2.96	3.99	3.78	
	89	3.83	4.43	4.43	3.85	3.07	4.37	3.79	
	90	3.92	3.68	3.84	3.86	3.12	3.64	3.23	
	91	4.17	4.12	4.19	4.09	3.60	4.31	4.18	
	92	4.17	4.07	3.88	4.22	4.65	4.08	3.86	
	93	3.98	3.76	3.89	3.97	3.04	4.00	3.47	
	94	4.20	3.94	4.02	4.09	2.91	3.87	3.63	

Table 6.9 : Yearwise % deviation of calculated ETo from the actual ETo of M. Penman

year		% deviation from overall yearly equation						% deviation from monthly equation					
		Bla.	Rad.	Pen.	Etp.	Harg.	Thor.	Bla.	Rad.	Pen.	Etp.	Harg.	Thor.
1986	MOE	19.16	26.13	7.20	65.58	13.52	32.84	4.05	2.07	2.14	16.32	15.57	19.30
(Jan-	MUE	-16.90	-25.44	-1.23	-7.91	-7.90	-26.40	-4.56	-7.03	-0.47	-9.79	-8.67	-16.07
Dec)	ave%	9.15	11.28	1.38	16.14	5.60	16.82	2.16	2.29	0.66	5.31	5.89	6.76
1987	MOE	15.77	22.74	3.56	33.91	34.97	34.22	6.00	3.93	2.47	14.36	24.63	9.34
(Jan-	MUE	-9.34	-9.99	-3.70	-27.10	-23.68	-27.68	-8.48	-7.26	-2.40	-13.16	-14.49	-13.32
Dec)	ave%	7.62	8.25	1.60	12.92	11.92	14.57	3.22	2.79	0.87	6.59	5.60	4.65
1988	MOE	17.03	18.63	4.90	20.72	4.75	25.74	-	1.20	4.91	8.77	2.97	8.46
(Jan-	MUE	-18.55	-28.08	-0.43	-32.61	-22.98	-32.49	-10.87	-11.19	-2.99	-15.83	-15.86	-14.40
Dec)	ave%	10.39	13.19	2.43	19.29	9.80	13.79	5.19	6.23	1.94	10.36	9.29	7.88
1989	MOE	37.96	37.65	5.70	19.76	23.09	28.55	17.00	17.14	4.00	8.23	12.25	9.78
(Jan-	MOE	-15.92	-19.55	-1.60	-11.60	-11.44	-26.53	-7.61	-8.14	-0.95	-4.42	-13.10	-13.24
Dec)	ave%	13.52	17.32	1.51	6.77	8.52	11.54	5.62	6.47	0.99	3.15	4.27	5.31
1990	MOE	8.60	12.62	1.83	47.97	13.89	27.02	5.66	14.77	2.06	23.24	11.94	13.71
(Jan-	MUE	-20.85	-12.84	-23.25	-14.43	-33.23	-21.88	-11.26	-6.98	-4.08	-7.16	-8.16	-2.41
Dec)	ave%	6.89	8.40	2.89	14.29	8.52	16.63	3.08	4.23	1.34	6.79	4.97	5.08
1991	MOE	14.05	13.77	1.69	56.31	22.59	32.75	9.14	8.31	2.84	32.65	11.21	15.27
(Jan-	MUE	-9.25	-12.68	-0.72	-4.12	-8.06	-17.50	-4.08	-6.10	-2.00	-7.65	-	-
Dec)	ave%	4.92	9.30	0.66	18.38	9.04	17.63	3.14	3.07	0.72	10.72	6.50	7.36
1992	MOE	48.20	27.23	3.68	73.58	24.79	39.71	15.33	16.81	1.07	14.15	11.19	10.13
(Jan-	MOE	-8.43	-6.42	-4.72	-11.55	-11.67	-25.14	-2.16	-4.07	-2.94	-6.67	-5.79	-7.66
Dec)	ave%	10.83	9.56	1.75	16.93	9.76	14.86	4.66	5.01	0.95	6.14	4.80	4.26
1993	MOE	20.05	12.09	2.11	58.15	15.53	28.28	3.67	5.98	5.16	10.57	8.35	13.75
(Jan-	MUE	-17.07	-19.34	-2.30	-25.11	-12.35	-21.07	-3.73	-2.48	-1.92	-4.68	-4.61	-5.10
Dec)	ave%	8.31	8.50	0.87	20.38	6.78	14.74	2.50	2.02	1.03	4.67	4.33	4.74
1994	MOE	13.11	11.18	1.29	57.38	20.02	27.85	2.67	1.76	0.86	3.48	8.93	6.21
(Jan-	MUE	-11.69	-8.08	-4.49	-32.32	-9.60	-22.95	-5.99	-5.65	-2.67	-15.13	-5.92	-8.07
Dec)	ave%	5.25	5.11	1.17	23.18	6.62	11.82	1.98	2.33	1.06	5.18	3.69	3.86
Overall average %deviation 1986-1994	ave%	8.54	10.1	1.58	16.47	8.51	14.71	3.51	3.83	1.06	6.55	5.48	5.54

Note : MOE : Maximum of Over Estimation
MUE : Maximum of Under Estimation

Table 6.10 : Cropwise % deviation of calculated ETo from the actual ETo of M. Penman

	% Deviation (Seasonal Relationship)						% Deviation (Monthly Relationship)						% Deviation (Overall Yearly Relationship)					
	Bla.	Rad.	Pen.	Etp.	Harg.	Thor.	Bla.	Rad.	Pen.	Etp.	Harg.	Thor.	Bla.	Rad.	Pen.	Etp.	Harg.	Thor.
Crop-->	Ahu-early (Feb.-May)						Ahu-early (Feb.-May)						Ahu-early (Feb.-May)					
MOE	33.14	30.20	6.46	42.40	20.92	28.54	17.00	17.14	4.91	32.65	12.25	13.75	37.96	37.65	7.23	35.56	23.12	7.08
MUE	-20.55	-15.01	-4.14	-26.66	-34.59	-19.65	-11.26	-9.84	-2.67	-15.75	-15.52	-16.07	-20.85	-10.29	-3.46	-32.63	-33.21	-32.53
avet	8.54	7.99	1.67	14.71	7.88	8.88	4.28	5.21	1.22	7.50	5.30	5.66	9.56	9.43	1.68	13.74	8.36	16.33
Crop-->	Ahu-regular (April-Aug.)												Ahu-regular (April-Aug.)					
MOE	11.78	17.76	6.15	22.12	24.56	21.14	9.14	14.77	5.16	32.65	24.63	15.27	13.81	23.90	4.92	33.71	35.00	24.25
MUE	-11.25	-15.84	-22.53	-22.83	-19.61	-19.51	-8.74	-11.19	-4.08	-15.83	-14.49	-13.42	-18.55	-28.08	-23.23	-32.63	-33.21	-29.49
avet	4.50	4.66	2.49	8.44	6.99	9.19	3.54	3.94	1.47	7.73	6.28	5.99	6.01	8.27	2.16	13.49	7.78	13.02
Crop-->	Sali paddy (June-Sep.)						Sali paddy (June-Sep.)						Sali paddy (June-Sep.)					
MOE	12.97	14.23	5.32	26.79	29.55	19.32	9.14	13.25	5.16	21.58	24.63	19.30	4.44	5.25	3.59	33.71	35.00	32.72
MUE	-9.21	-13.62	-20.38	-17.44	-18.74	-16.18	-8.74	-11.19	-4.08	-15.83	-15.86	-14.40	-18.55	-28.08	-23.23	-29.70	-23.66	-8.69
avet	4.27	4.19	2.70	9.30	7.68	7.68	3.59	3.46	1.39	7.63	7.00	7.13	7.32	10.39	2.22	12.01	8.13	11.11
Crop-->	Oilseed and Pulses (Oct.-Jan)						Oilseed and Pulses (Oct.-Jan)						Oilseed and Pulses (Oct.-Jan)					
MOE	44.63	25.77	3.80	45.90	14.76	13.37	14.62	8.83	2.06	12.35	11.19	9.60	48.20	33.82	3.96	73.54	24.84	39.69
MUE	-17.67	-14.61	-1.85	-25.34	-17.96	-16.07	-8.80	-9.80	-2.35	-12.98	-14.19	-11.53	-12.74	-10.31	-1.94	-11.17	-22.96	-7.45
avet	7.16	6.37	0.69	13.84	7.34	5.26	2.65	2.80	0.58	4.51	4.15	3.84	8.75	10.48	0.86	23.65	9.04	16.64
Crop-->	Potato (Oct.-Feb.)						Potato (Oct.-Feb.)						Potato (Oct.-Feb.)					
MOE	39.30	25.94	5.21	46.69	24.60	22.92	17.00	16.81	4.00	14.15	11.19	13.75	48.20	37.65	5.72	73.54	24.84	39.69
MUE	-23.69	-17.92	-2.14	-25.09	-23.75	-29.60	-11.26	-9.80	-2.35	-13.70	-14.19	-16.07	-20.85	-10.31	-1.94	-11.17	-22.96	-21.62
avet	8.11	7.60	0.85	13.28	8.15	9.14	3.51	3.58	0.71	4.97	4.46	4.71	10.36	11.52	0.99	21.32	9.43	15.06
Crop-->	Wheat (Nov.-March)						Wheat (Nov.-March)						Wheat (Nov.-March)					
MOE	34.62	22.30	4.36	51.16	18.03	27.77	17.00	17.14	4.00	14.15	12.25	13.75	48.20	37.65	7.23	73.54	24.84	39.69
MUE	-25.07	-16.25	-2.51	-39.57	-18.43	-26.59	-11.26	-7.71	-2.35	-15.54	-15.52	-16.07	-20.85	-6.66	-0.80	-30.83	-12.16	-32.53
avet	6.25	6.01	1.18	15.62	6.71	12.33	3.78	4.03	0.76	5.34	4.54	4.85	11.60	12.79	1.26	22.35	9.49	17.66

Note : MOE : Maximum of Over Estimation
MUE : Maximum of Under Estimation

Table 6.11 : Monthly % deviation of calculated ETo values from the actual ETo values

Month		% Deviation (Monthly Relationship)						% Deviation (Overall Yearly Relationship)					
		Bla.	Rad.	Pen.	Etp.	Harg.	Thor.	Bla.	Rad.	Pen.	Etp.	Harg.	Thor.
Jan	MOE	14.62	8.47	0.75	10.57	5.38	7.51	48.20	33.82	1.16	73.58	13.52	32.84
(1986-	MUE	-8.48	-4.50	-0.40	-11.94	-6.32	-11.12	-6.49	-	-0.16	-	-7.90	-26.40
1994)	ave±	3.90	3.79	0.33	5.23	0.17	0.37	14.79	15.54	0.47	38.01	6.26	17.35
Feb	MOE	17.00	16.81	4.00	14.15	10.16	13.75	37.96	37.65	5.70	35.59	34.97	20.31
(1986-	MUE	-11.26	-6.98	-1.82	-13.76	-12.02	-16.07	-20.85	-6.66	-0.43	-2.54	-23.68	-27.68
1994)	ave±	6.97	6.71	1.26	6.83	0.54	0.93	16.80	15.66	1.49	12.02	11.75	15.02
Mar	MOE	15.61	17.14	1.88	9.53	12.25	9.78	33.78	30.85	7.20	30.16	13.52	13.86
(1986-	MUE	-10.87	-7.71	-2.13	-15.54	-15.52	-14.13	-	-	-0.15	-30.81	-18.97	-32.49
1994)	ave±	3.78	4.85	1.17	6.70	0.57	0.54	11.77	10.50	2.37	12.78	11.24	15.10
Apr	MOE	8.72	14.77	2.93	23.24	7.83	7.30	13.82	23.89	4.90	14.37	5.30	19.14
(1986-	MUE	-7.61	-9.84	-2.40	-15.75	-8.57	-6.82	-4.85	-5.44	-1.22	-32.61	-11.44	-29.44
1994)	ave±	3.16	6.49	1.15	7.65	0.31	0.21	4.12	7.18	1.23	13.95	5.84	15.79
May	MOE	5.53	5.89	4.91	32.65	8.93	11.26	4.91	3.51	4.11	15.81	8.89	20.78
(1986-	MUE	-4.23	-5.02	-2.67	-13.16	-8.16	-13.42	-9.86	-10.29	-3.48	-32.32	-9.98	-23.46
1994)	ave±	3.20	2.81	1.30	8.80	0.33	0.46	5.56	4.37	1.62	16.22	4.88	15.77
June	MOE	6.00	3.80	2.68	19.93	24.63	14.62	4.45	-	3.56	14.97	34.97	28.41
(1986-	MUE	-7.09	-8.14	-2.94	-15.83	-13.10	-13.24	-11.06	-17.13	-2.41	-26.40	-9.63	-5.86
1994)	ave±	3.10	2.28	1.46	8.25	1.28	0.73	4.34	10.19	1.66	11.06	9.92	15.78
July	MOE	5.53	13.25	5.16	12.43	11.94	12.58	-	5.25	2.02	9.80	6.82	20.78
(1986-	MUE	-8.74	-11.19	-4.08	-11.16	-11.27	-10.02	-15.92	-22.07	-23.25	-29.68	-15.01	-4.65
1994)	ave±	3.87	5.33	2.51	5.53	0.41	0.44	7.34	10.55	3.93	11.80	7.24	8.05
Aug	MOE	9.14	8.31	2.34	21.58	9.04	15.27	-	-	3.03	33.75	4.32	20.75
(1986-	MUE	-5.99	-5.97	-2.00	-12.22	-14.49	-13.32	-18.55	-28.08	-4.72	-28.55	-23.68	-8.61
1994)	ave±	4.35	2.78	0.91	8.41	-0.30	0.24	8.70	9.09	2.42	14.36	7.95	9.74
Sep	MOE	7.90	4.39	1.64	16.32	15.57	19.30	0.07	-	2.20	19.04	11.85	32.84
(1986-	MUE	-7.44	-9.43	-1.25	-15.13	-15.86	-14.40	-16.90	-25.44	-1.44	-16.88	-18.97	-2.72
1994)	ave±	3.04	3.46	0.70	8.33	0.73	0.87	8.87	11.74	0.86	10.79	6.61	15.05
Oct	MOE	3.53	4.30	2.06	12.35	10.22	9.60	0.30	5.01	2.02	15.08	-	20.32
(1986-	MUE	-8.80	-9.80	-1.92	-12.98	-14.19	-11.53	-12.74	-10.31	-1.96	-11.14	-22.98	-7.39
1994)	ave±	2.45	2.59	0.92	4.88	0.48	0.38	5.53	4.11	1.07	7.66	9.20	8.03
Nov	MOE	3.24	3.06	1.92	7.43	7.42	5.46	10.90	12.62	3.93	37.88	10.81	19.18
(1986-	MUE	-3.01	-5.60	-2.35	-7.16	-7.35	-5.20	-	3.22	-	-3.56	-8.04	-
1994)	ave±	1.58	1.84	0.88	3.54	0.21	0.11	5.71	9.44	0.98	18.15	6.01	12.91
Dec	MOE	7.17	8.83	0.38	11.41	11.19	5.76	20.05	20.64	1.31	57.38	24.79	39.71
(1986-	MUE	-3.95	-4.90	-0.15	-6.79	-8.07	-4.23	-0.51	-	-	-	-2.93	-
1994)	ave±	2.65	2.98	0.17	4.38	0.27	0.09	8.95	12.84	0.91	30.90	13.03	29.88

Note : MOE : Maximum of Over Estimation
MUE : Maximum of Under Estimation

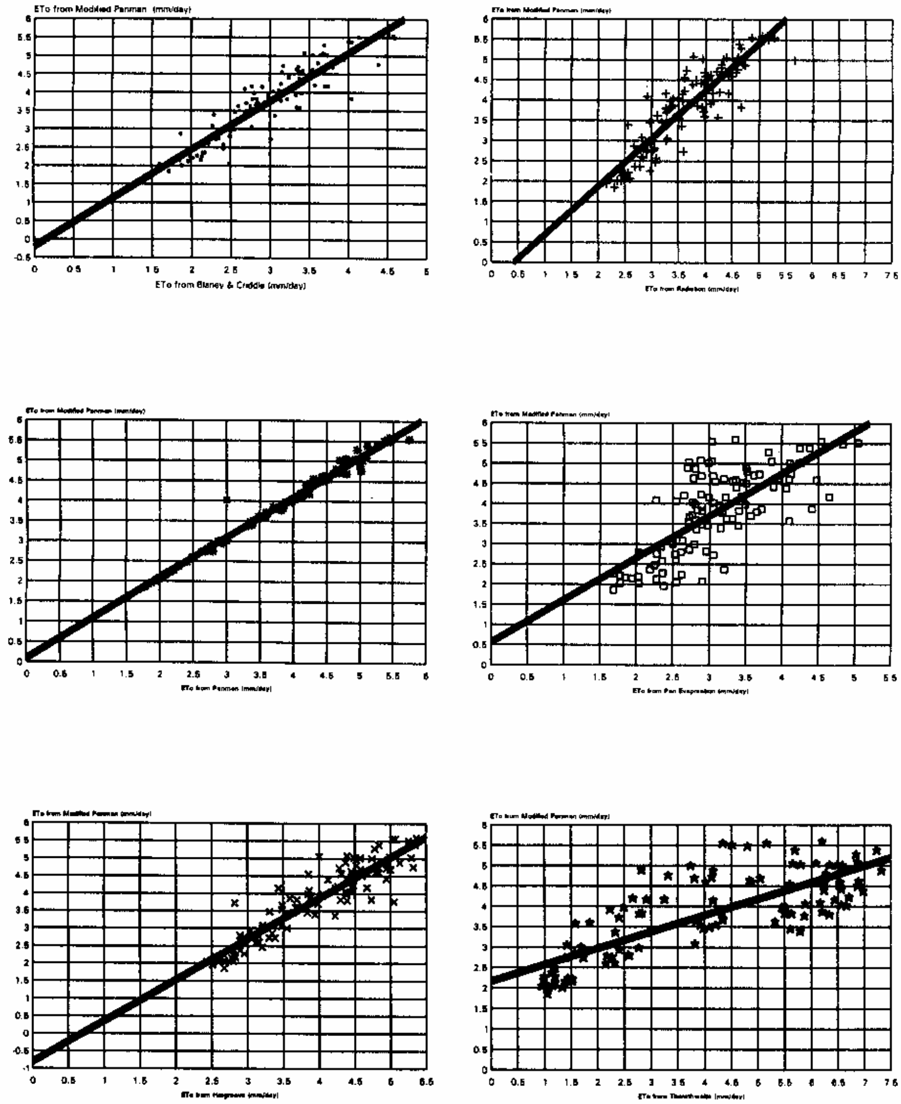


Fig. 6.1 : **Scatter plots between ETo of Modified Penman v/s other methods for overall yearly data (Jan-Dec) 1986-1994**

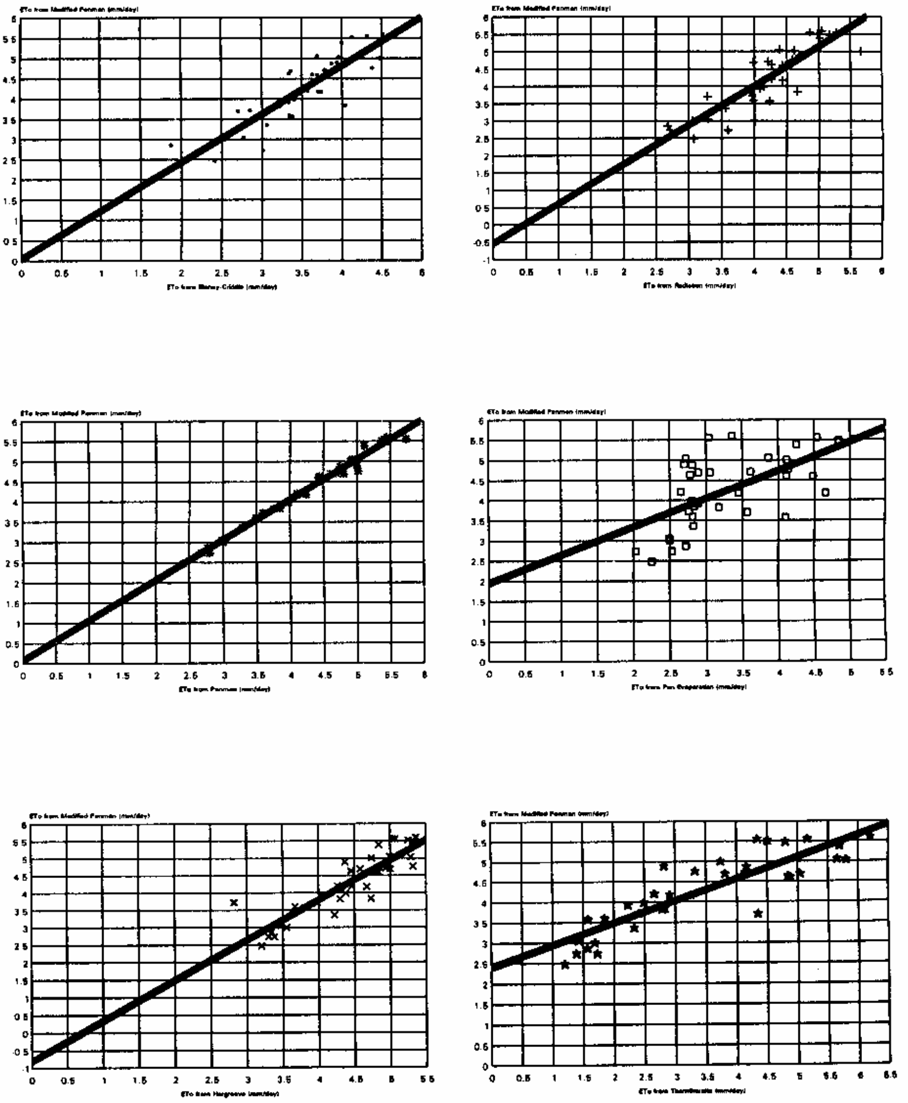
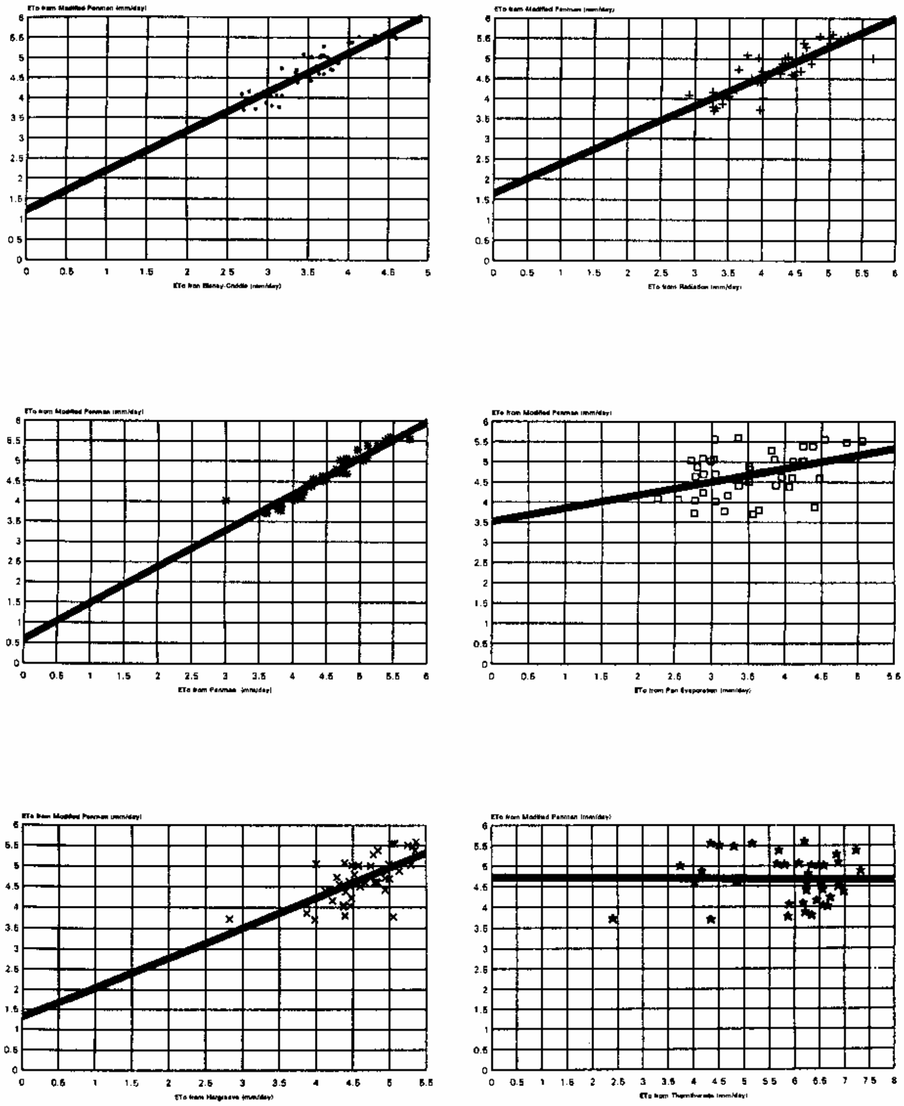


Fig. 6.2 : Scatter plots between ETo of Modified Penman v/s other methods by using seasonal data for Ahu regular paddy



6.3 : Scatter plots between ETo of Modified Penman v/s other methods by using seasonal data for Ahu early paddy

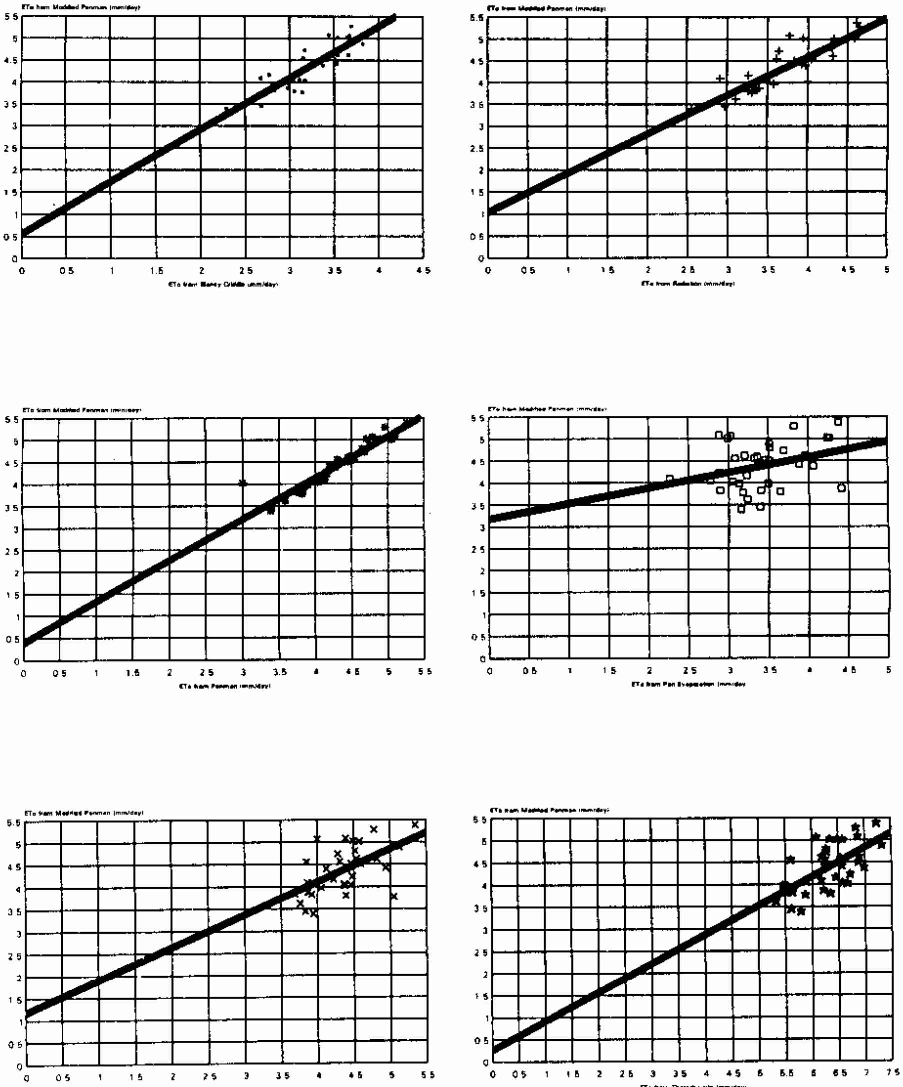


Fig. 6.4 : Scatter plots between ETo of Modified Penman v/s other methods by using seasonal data for Sali paddy

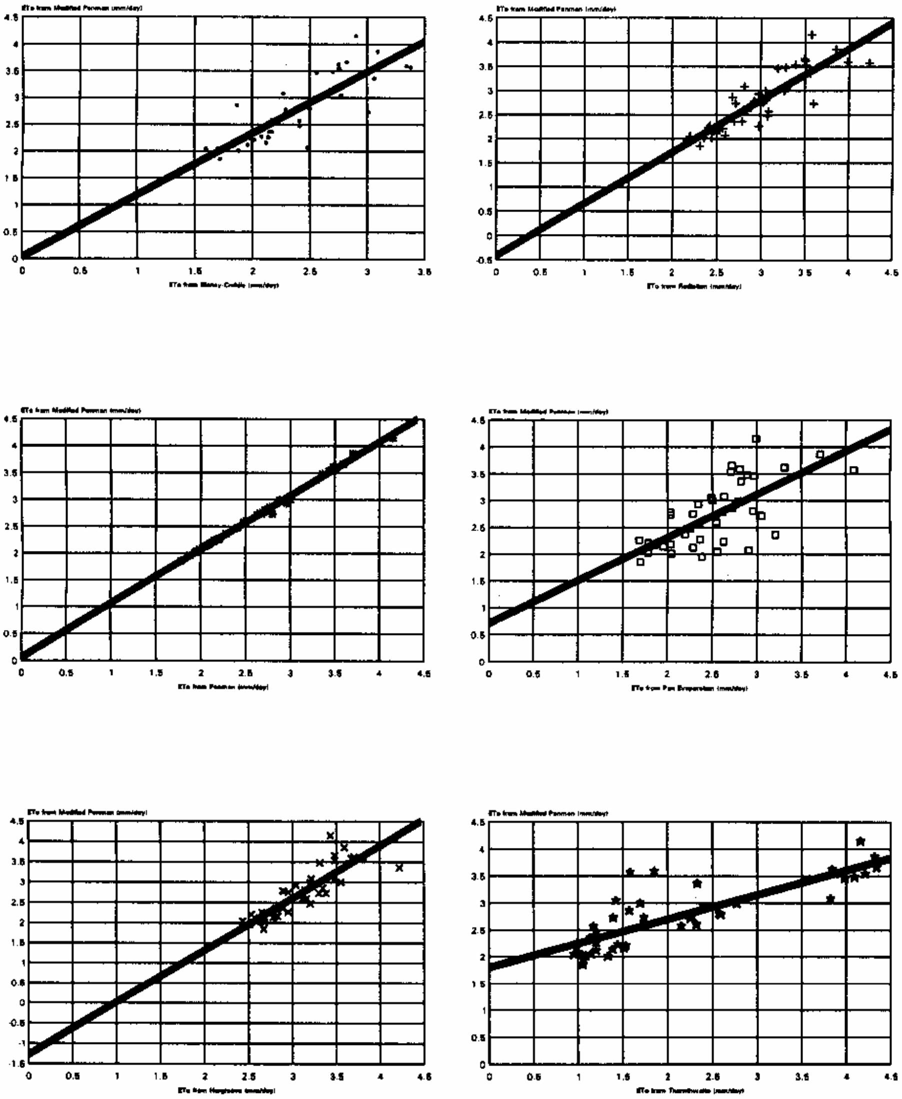


Fig. 6.5 : Scatter plots between ETo of Modified Penman v/s other methods by using seasonal data for Oilseed and pulses

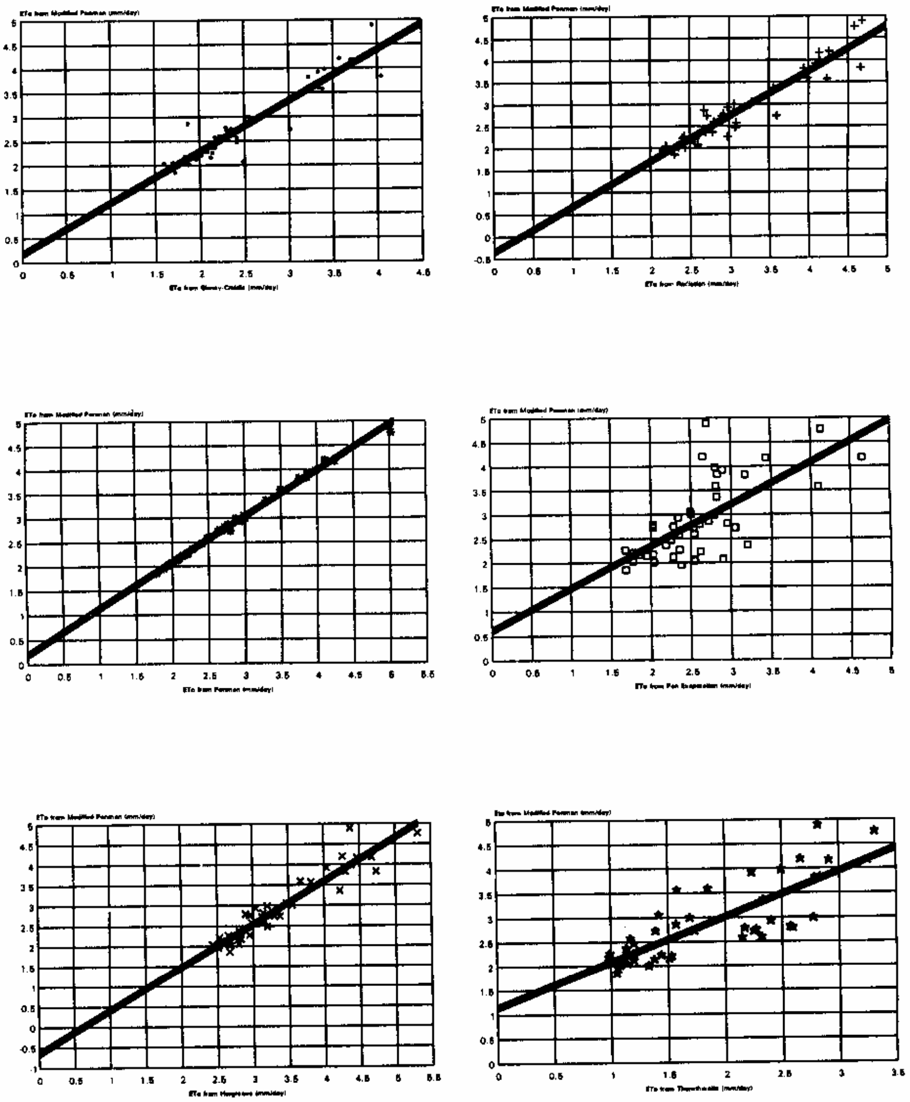


Fig. 6.6 : **Scatter plots between ETo of Modified Penman v/s other methods by using seasonal data for Potato**

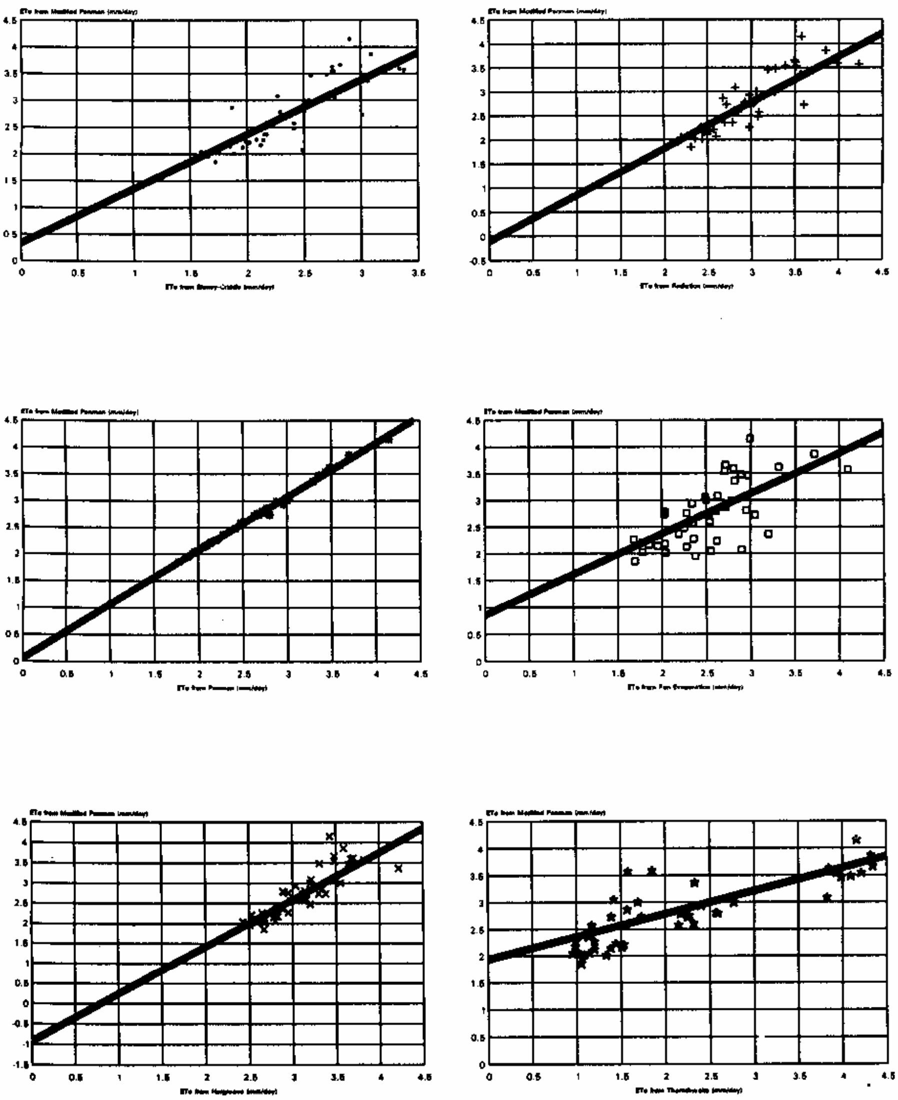


Fig. 6.7 : **Scatter plots between ETo of Modified Penman v/s other methods by using seasonal data for Wheat**

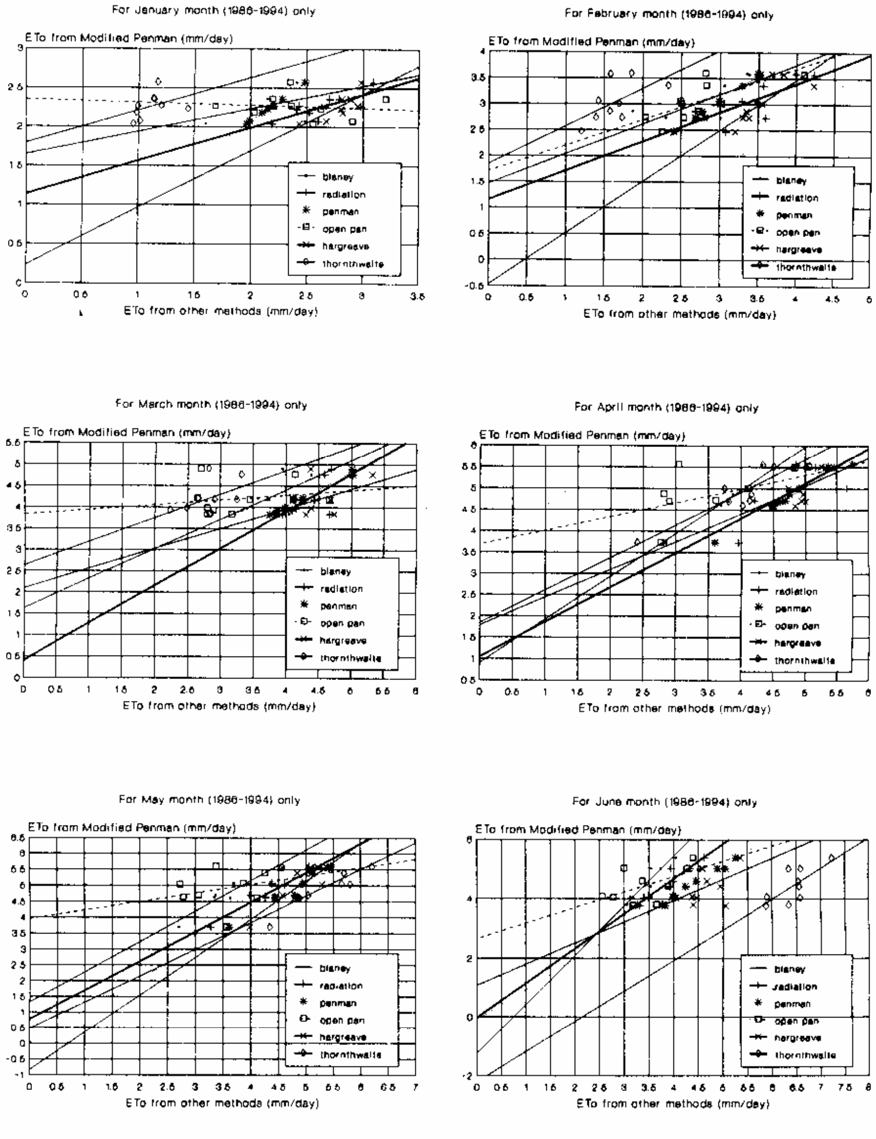


Fig. 6.8 : Scatter plots between ETo of Modified Penman v/s other methods by using monthly data for the month from Jan to June

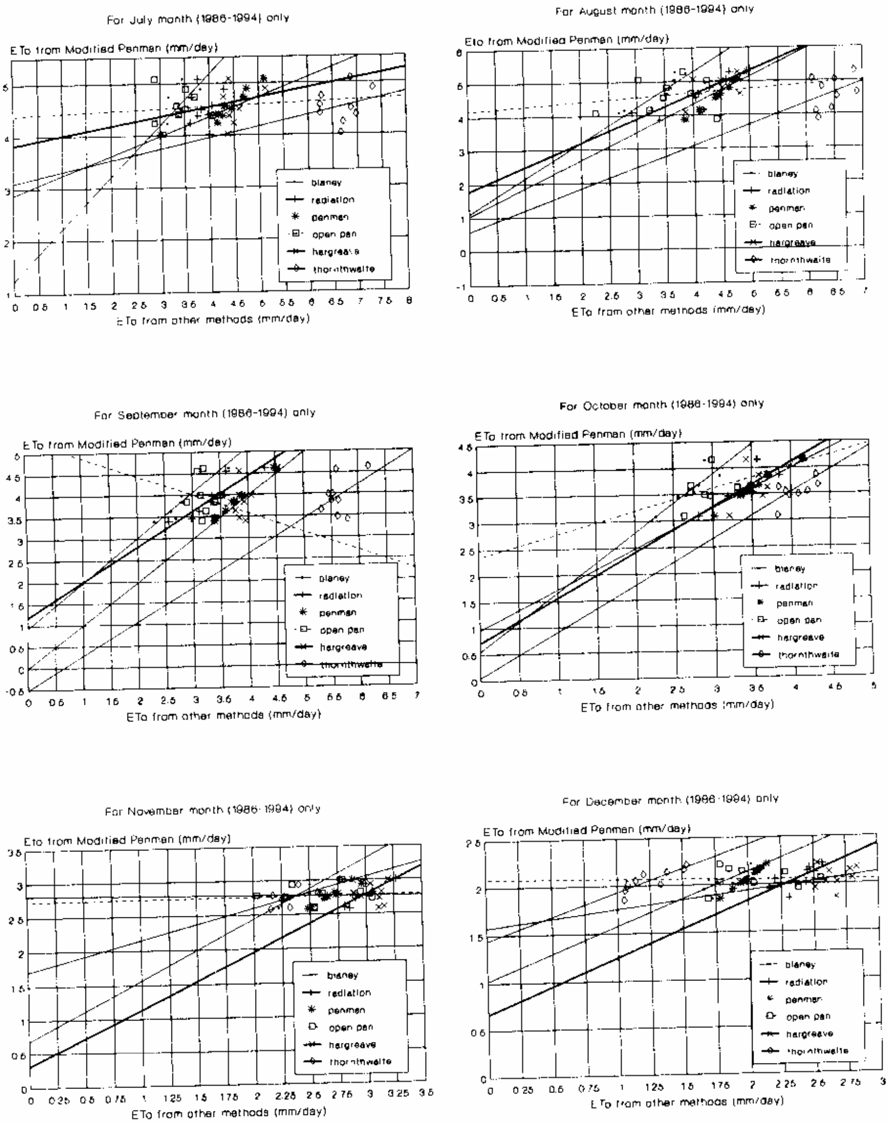


Fig. 6.9 : Scatter plots between ETo of Modified Penman v/s other methods by using monthly data for the month from July to Dec.

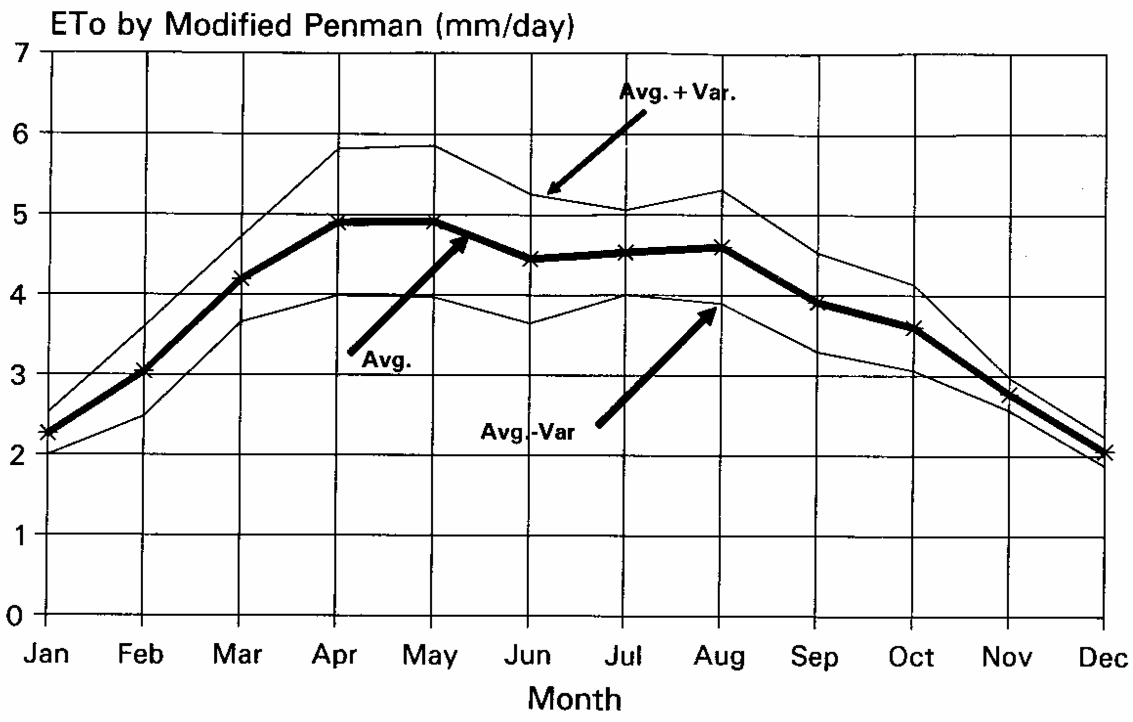


Fig.6.10 : Stretch of ETo from average

The percentage deviation of ETo values evaluated from the relationships and the actual ETo values have been worked out and presented in Table 6.9 to 6.11.

It is observed from the deviation that the equations of the 3rd relationship i.e. monthly relationship are most suitable to estimate ETo values when there is lack of data for Modified Penman method for all cases.

The ETo values have been plotted between the Modified Penman values and the ETo values of other methods to see the correlation between the two. The scatter plots have been shown in Fig.6.1 to 6.9 for the yearly, seasonal and monthly relationships. A stretch diagram (Fig. 6.10) of mean monthly ETo by Modified Penman for different months has been prepared, so that design value of ETo for different applications under the command area can be taken from the figure. Stretch diagram is prepared by taking account of average range of variation from mean value criteria as given by Helfrick and Cooper (1990). Design value should not cross the boundary limit of average range of variation as shown in Fig. 6.10.

6.4 RESULTS OF CROP AND IRRIGATION WATER REQUIREMENTS

The ETo values estimated and shown in Table 6.1 can be used for estimating the crop water, and irrigation water requirements. A sample output by using the mean monthly ETo data for Modified Penman method (from Fig. 6.10) is given in Appendix-I. In the same manner other methods can also be used for determination of crop water requirements by the project authority.

7.0 CONCLUSIONS

The most important and difficult task for crop water requirement analysis, irrigation water management and water balance study is to work out the value of ETo accurately. This is a basic information needed in any water resources planning, design and management of system at micro level. The key to effective irrigation water management lies in proper estimation of crop water requirements, which are primarily based on cropping pattern, rainfall in the area and accurate estimation of ETo. Modified Penman method (FAO-24) of ETo estimation has been considered the most rational and elaborate and values of ETo by this method given in this report will definitely provide very usefull tool to the project authority. ETo by Modified Penman method needs huge climatological data, huge time and advanced computing facilities. It is always not possible to get advanced computing facilities and all the required climatological data. In such constraints we have to search other method for ETo estimation by simple methods and less dependency on huge climatological data with compromise of accuracy in ETo values. For krishnai irrigation project developed relationships between Modified Penman method and other methods is the solution of this problem.

Based on the results, following conclusions can be made :

(1) We can determine reliable crop evapotranspiration even if all climatological data are not available for Modified Penman method, by the developed regional relationships of different methods with the most rational approach.

(2) In this study, it is observed that monthly relationship is most suitable for the determination of ETo values when there is lack of data for Modified Penman method.

(3) The methods Blaney-Criddle, Radiation and Penman have good correlation with Modified- Penman method for development of linear relationship between the two.

(4) To improve management practices we should install automatic weather station in the command area which cost will be a very minor fraction. This will also reduce energy, time and error in collecting data like rainfall, humidity, radiation, wind velocity, wind direction etc.

SCOPE FOR FUTURE STUDIES :

(1) The mathematical model can be extended by collecting and incorporating more data for different river basins and irrigation projects of Assam.

(2) The meteorological data may be collected on daily basis which will lead to develop more reliable relationship.

(3) The study can be done with field methods like Lysimeter, Tensiometer etc. and may be verified with calculated ETo by different methods.

(4) Developed relationships can be further modified by taking next 5, 10 or 15 years climatological data for the region.

(5) Relationship can be established with other methods also which are not included in this study.

(6) Programme may be modified as user's friendly menu driven type.

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PROPOSED CROP PATTERN FOR KRISHNAI IRRIGATION PROJECT

1>KHARIF		2>RABI		3>PERENNIAL	
AHU PADDY(REGUL)	875-ha	MUSTARD	700-ha	SUGARCANE	0.00-ha
(21 APR-5 AUG)		(OCT-20 JAN)		(---)	
NURSERY PER.:1-20APR.					
SALI PADDY	2275-ha	POTATO	175-ha		
(26 JUN-SEP)		(21 OCT-20 FEB)			
NURSERY PER.:1-25JUNE					
EARLY AHU PADDY	525-ha	WHEAT	122-ha		
(21 FEB-MAY)		(21 NOV-MAR)			
NURSERY PER.:11-20FEB.					
JUTE	0.00-ha	PULSES	525-ha		
(---)		(OCT-JAN)			

MEAN MONTHLY ETcrop (mm/month) VALUES (NURSERY PERIOD NOT INCLUDED)

MONTH	AHU-REG.	SALI	AHU-EAR.	JUTE	MUSTARD	POTATO	WHEAT	PULSES	SUGARCANE
JAN	0.00	0.00	0.00	0.00	32.10	65.11	36.58	38.04	0.00
FEB	0.00	0.00	26.81	0.00	0.00	23.71	66.39	0.00	0.00
MAR	0.00	0.00	149.37	0.00	0.00	0.00	94.82	0.00	0.00
APR	51.45	0.00	191.10	0.00	0.00	0.00	0.00	0.00	0.00
MAY	179.61	0.00	147.64	0.00	0.00	0.00	0.00	0.00	0.00
JUN	173.55	23.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JUL	141.83	168.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AUG	8.97	171.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SEP	0.00	111.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OCT	0.00	0.00	0.00	0.00	20.09	7.92	0.00	49.10	0.00
NOV	0.00	0.00	0.00	0.00	44.04	55.68	2.22	78.11	0.00
DEC	0.00	0.00	0.00	0.00	54.92	63.22	12.13	60.67	0.00

CROP WATER REQUIREMENTS FOR KHARIF SEASON (BY MODIFIED PENMAN)

					NURSERY/FIELD PREPARATION REQUIREMENT			
	AHU-REG.	SALI	AHU-EAR.	JUTE	AHU-REG.	SALI	AHU-EAR.	TOTAL (ha-mm)
JAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FEB	0.00	0.00	14076.72	0.00	0.00	0.00	14204.40	28281.12
MAR	0.00	0.00	78421.09	0.00	0.00	0.00	0.00	78421.09
APR	45018.75	0.00	100327.50	0.00	79747.50	0.00	0.00	225093.75
MAY	157156.83	0.00	77512.94	0.00	0.00	0.00	0.00	234669.77
JUN	151856.25	54162.06	0.00	0.00	0.00	242970.00	0.00	448988.31
JUL	124105.01	383373.90	0.00	0.00	0.00	0.00	0.00	507478.91
AUG	7848.75	389298.00	0.00	0.00	0.00	0.00	0.00	397146.75
SEP	0.00	253514.62	0.00	0.00	0.00	0.00	0.00	253514.62
OCT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DEC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	485985.59	1080348.59	270338.25	0.00	79747.50	242970.00	14204.40	2173594.33

GRAND TOTAL = 2173594.33 ha-mm

CROP WATER REQUIREMENTS FOR RABI SEASON (BY MODIFIED PENMAN)

	MUSTARD	POTATO	WHEAT	PULSES	TOTAL (ha-mm)
JAN	22467.20	11394.67	44810.50	19972.68	98645.05
FEB	0.00	4149.60	81332.16	0.00	85481.76
MAR	0.00	0.00	116154.13	0.00	116154.13
APR	0.00	0.00	0.00	0.00	0.00
MAY	0.00	0.00	0.00	0.00	0.00
JUN	0.00	0.00	0.00	0.00	0.00
JUL	0.00	0.00	0.00	0.00	0.00
AUG	0.00	0.00	0.00	0.00	0.00
SEP	0.00	0.00	0.00	0.00	0.00
OCT	14061.60	1386.00	0.00	25779.60	41227.20
NOV	30830.10	9743.48	2714.60	41009.85	84298.03
DEC	38443.72	11063.74	14863.41	31850.17	96221.06
TOTAL	105802.62	37737.49	259874.81	118612.31	522027.22

GRAND TOTAL = 522027.22 ha-mm

TOTAL MONTHLY REQUIREMENTS (ha-mm) FOR

	1>KHARIF	2>RABI	3>PERENNIAL	TOTAL(ha-mm)	TOTAL(mcm)
JAN	0.00	98645.05	0.00	98645.05	0.98645050
FEB	28281.12	85481.76	0.00	113762.88	1.13762830
MAR	78421.09	116154.13	0.00	194575.22	1.94575220
APR	225093.75	0.00	0.00	225093.75	2.25093750
MAY	234669.77	0.00	0.00	234669.77	2.34669767
JUN	448988.31	0.00	0.00	448988.31	4.48988313
JUL	507478.91	0.00	0.00	507478.91	5.07478913
AUG	397146.75	0.00	0.00	397146.75	3.97146750
SEP	253514.62	0.00	0.00	253514.62	2.53514625
OCT	0.00	41227.20	0.00	41227.20	0.41227200
NOV	0.00	84298.03	0.00	84298.03	0.84298025
DEC	0.00	96221.06	0.00	96221.06	0.96221055
			YEARLY REQUIREMENT--->	2695621.55	26.95621548

IRRIGATION WATER REQUIREMENTS FOR KHARIF SEASON (ha-mm)

	AHU-REG.	SALI	AHU-EAR.	JUTE	NURSERY/FIELD PREPARATION REQUIREMENT			
					AHU-REG.	SALI	AHU-EAR.	TOTAL (ha-mm)
JAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FEB	0.00	0.00	36698.97	0.00	0.00	0.00	46208.40	82907.37
MAR	0.00	0.00	156572.59	0.00	0.00	0.00	0.00	156572.59
APR	56087.50	0.00	123994.50	0.00	138958.75	0.00	0.00	319040.75
MAY	148713.07	0.00	91005.44	0.00	0.00	0.00	0.00	239718.52
JUN	157456.25	68426.31	0.00	0.00	0.00	342615.00	0.00	568497.56
JUL	190290.01	506951.90	0.00	0.00	0.00	0.00	0.00	697241.91
AUG	28341.25	494994.50	0.00	0.00	0.00	0.00	0.00	523335.75
SEP	0.00	434854.87	0.00	0.00	0.00	0.00	0.00	434854.87
OCT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DEC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	580888.09	1505227.59	408271.50	0.00	138958.75	342615.00	46208.40	3022169.32

GRAND TOTAL = 3022169.32 ha-mm

IRRIGATION WATER REQUIREMENTS FOR RABI SEASON (ha-mm)

	MUSTARD	POTATO	WHEAT	PULSES	TOTAL (ha-mm)
JAN	107041.20	44089.92	273971.25	118179.18	543281.55
FEB	0.00	24705.10	274931.16	0.00	299636.26
MAR	0.00	0.00	304154.88	0.00	304154.88
APR	0.00	0.00	0.00	0.00	0.00
MAY	0.00	0.00	0.00	0.00	0.00
JUN	0.00	0.00	0.00	0.00	0.00
JUL	0.00	0.00	0.00	0.00	0.00
AUG	0.00	0.00	0.00	0.00	0.00
SEP	0.00	0.00	0.00	0.00	0.00
OCT	132207.60	12825.75	0.00	99069.60	244102.95
NOV	147597.10	38831.98	70457.10	127965.60	384851.78
DEC	168692.72	43527.99	244648.91	129253.42	586123.05
TOTAL	555538.62	163980.74	1168163.30	474467.805	2362150.47

GRAND TOTAL = 2362150.47 ha-mm

TOTAL MONTHLY REQUIREMENTS (ha-mm) FOR

	1>KHARIF	2>RABI	3>PERENNIAL	TOTAL(ha-mm)	TOTAL(mcm)
JAN	0.00	543281.55	0.00	543281.55	5.43281550
FEB	82907.37	299636.26	0.00	382543.63	3.82543630
MAR	156572.59	304154.88	0.00	460727.47	4.60727470
APR	319040.75	0.00	0.00	319040.75	3.19040750
MAY	239718.52	0.00	0.00	239718.52	2.39718517
JUN	568497.56	0.00	0.00	568497.56	5.68497563
JUL	697241.91	0.00	0.00	697241.91	6.97241913
AUG	523335.75	0.00	0.00	523335.75	5.23335750
SEP	434854.87	0.00	0.00	434854.87	4.34854875
OCT	0.00	244102.95	0.00	244102.95	2.44102950
NOV	0.00	384851.78	0.00	384851.78	3.84851775
DEC	0.00	586123.05	0.00	586123.05	5.86123055
			YEARLY REQUIREMENT--->	5384319.80	53.84319797

CROP CONSUMPTIVE USE COEFFICIENTS

(collected from Ministry of Agriculture)

Percent of crop growing season	Consumptive use evapo-transpiration coefficients, k, to be multiplied by Class A pan evaporation or calculated Eo							
	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	0.73	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	0.9	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

Group A : - *beans, maize, cotton, potatoes, sugar, beets, jowar and peas.*
Group B : - *dates, olives, walnuts, tomatoes and hybrid jowar.*
Group C : - *melons, onions, carrots and grapes*
Group D : - *barley, flax, wheat and other small grains.*
Group E : - *pastures, orchard and cover crops.*
Group F : - *citrus crops, oranges, limes and grape fruit.*
Group G : - *sugar cane and alfalfa.*

Appendix-III

EFFECTIVE RAINFALL IN THE STUDY AREA 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													
50	25	33	35	36	37	40	41	44	48	50	50	50	50	50
75		47	51	54	56	58	61	63	69	74	75	75	75	75
100		50	65	69	73	75	79	83	88	95	100	100	100	100
125			75	83	89	91	96	102	108	116	123	125	125	125
150				97	104	106	113	120	127	136	144	150	150	150
175				100	117	120	128	136	143	154	166	172	175	175
200					125	131	140	148	158	169	184	191	197	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
300							175	195	215	235	246	258	273	288
325								199	220	242	258	275	290	304
350								200	224	245	265	285	303	320
375									225	248	270	292	310	328
400										250	273	296	317	335
425											275	298	320	340
450												300	322	348
475													324	346
500													325	349
														350
525	25	50	75	100	125	150	175	200	225	275	300	325		

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

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