Computer-Aided Mapping Irrigation Scheduling for Arab Republic of Egypt

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Abstract

A friendly user computer program was developed to schedule irrigation (daily, ten days and monthly basis) for different locations positioned geographically on the Egyptian map. This computer program was named "Computer-Aided Mapping Irrigation Scheduling Model"; CAMISM and written using visual basic software (Version 6) to include all modules to calculate the irrigation amount required for an area and the likely time of irrigation application. The modified FAO Penman-Monteith method for ETo calculations was used. To evaluate and verify the CAMISM predictions; all necessary steps required to develop such models were followed with proper justification. On real application three different locations were chosen to represent study cases to validate the CAMISM output results. Toshka, Maruot and Kafer Al-Sheekh were considered in this respect. Verification proved that CAMISM predictions are either above or below and/or at the perfect line of agreement according to suitability of ETo method for the chosen location as well as availability of weather data. Nevertheless, in all cases the CAMISM predictions were highly significantly correlated with the ETo values obtained from the Central Laboratory of Agricultural Climate "CLAC", Desert Research Institute and Sakha Research Station. The amount of water saved by CAMISM has reached a total of 102.2, 128 and 143.3 million m3 for corn crop in Toshka, groundnut in Maruot and wheat in Sakha regions respectively.

Keywords: Computer , Modeling , Irrigation Scheduling , Mapping , evapotranspiration**.**

Introduction

Irrigation scheduling is an important aspect of farm management. Modeling for irrigation scheduling attempts to answer two basic questions posed by irrigators; when to irrigate and how much water to apply. These two decisions require a through understanding of the complex behavior of climatic, soil and plant factors which independently determine irrigation frequency and water quantity for crops. There are many methods of calculating reference crop evapotranspiration (ETo), some of these methods or formula gives reasonable accuracy under certain climatological conditions. The most widely methods for computing reference crop evapotranspiration are Blaney-Criddle ,Radiation, Penman and Pan evaporation (Doorenbos and Pruitt 1984). Crop evapotranspiration (ETc) is calculated by multiplying ETo by a crop coefficient (Kc) (Richard 2003). Crop rooting depth varies with crop species, type, and stage of growth. Annual crops planted from seed each year will typically have very shallow root zones

(150 mm) at crop emergence. Generally, root zone expansion with depth progresses linearly to maximum rooting depths as the crop develops above-ground vegetative cover to full effective cover stage. This occurs approximately when 70% of the ground surface is shaded by the crop canopy. Perennial crops may exhibit similar root zone expansion during the first year of establishment, or the process may take several years, as in the case of trees and vine crops. Once a perennial crop has established its maximum effective rooting depth, that value is used in the determination of available soil water (Thomas, *et al.* 1994). Readily Available Water is the actual amount of water in the soil that is allowed to be removed from the soil prior to irrigation. Readily available water (RAW) is a function of The Management Allowable Deficit (MAD) and the available water. The available water (AW) is a function of the effective root depth and the available water per unit depth in the soil. To calculate the "Readily Available Water" (RAW), determine the available water based on the predominant soil type, and the effective root depth for the crop (Thomas *et al.* 2002). MAD is the amount of water allowed to be depleted from the root zone before irrigation is scheduled. At the time of irrigation, the soil water deficit should be less than or equal to the MAD. The goal of any irrigation scheduling scheme is to keep the water content in the root zone above this allowable deficit level. This ensures that the crop will not suffer from water stress and will produce maximum potential yield (Al-Kaisi and Brone 1992). For many crops, the MAD is set to 40-50% in the root zone of the crop. Some crops such as vegetable crops, are more sensitive to large fluctuations of soil moisture and the MAD are set to lower levels (Martin 2001). The critical soil water deficit level depends on several factors: crop factors (rooting density and developmental stage), soil factors (AWC and effective root depth), and atmospheric factors (current ET rate). Therefore, no single level can be recommended for all situations; however, allowable deficits of 1/3 to 2/3 of the available soil water are commonly used to schedule irrigation. The smaller allowable deficits are required for sensitive crops and at critical stages of growth. The greater deficits are allowed for less sensitive crops and at less-critical growth stages. As a "Rule of Thumb", an allowable water deficit of ½ of AWC should be used if more specific data are not available (Smajstrla *et al.* 2002). MAD is primarily a function of the type of crop being grown. For high value crops, MAD may be 40 percent or less. For lower value or large orchard crops (such as trees) MAD may be 60 percent. A MAD of 50 percent is reasonable for most row crops (Thomas *et al.* 2002). Leaching requirements (LR) and irrigation method efficiency (Ea) was needed to estimate gross irrigation water. Leaching requirements (LR) is the ratio of the net depth of leaching water to the net depth of irrigation water that must be applied for consumptive use and leaching. It presents the minimum amount of water (in terms of a fraction of the applied water) that must pass through the root zone to prevent salt buildup (Keller and Bliesner 1990). The application efficiency (Ea) is a term that tells how much of the water applied by the system actually is stored in the root zone for crop use (Smeal and Tomko 2001).

Tuzet *et al.* (1992) Presented a simulation model for predicting crop irrigation requirement. Crop evapotranspiration is calculated as the sum of two terms throughout the growing season. The first is the amount of water evaporated from soil surface under vegetation. The second is the volume of water transpired by the crop. The two terms depend on climatic demand, soil water availability and plant structure. According to

Bos *et al.* (1996) a simulation model named CRIWAR was developed to calculate the irrigation water requirements (either per month or per 10-day period) of a cropping pattern in an irrigated area, for various stages of crop development throughout the crops growing season. The crop irrigation water requirements consists of the potential evapotranspiration, ET_o, minus the effective precipitation, P_e.

The main objective of this study was to develop a friendly user computer program to schedule irrigation for different areas under Egyptian conditions. The specific objectives of this program were to:

1- Develop a module (subroutine) to calculate the reference crop evapotranspiration using four different methods; Blaney-Criddle, Solar radiation, Modified FAO Penman-Monteith and Pan evaporation.
2- Develop a module to calculate the crop evapotranspiration of seven crop categories representing 65 crop types and species according to three crop development stages.
3- Develop a module to compute the available soil water for 13 different soil texture at progressive effective rooting depth.
4- Evolve the real time irrigation scheduling for 36 mapped Egyptian zones.
5- Develop a module to add that amount of water required to control salinization (i.e. Leaching requirements).
6- Evolve a module to compute that extra amount of water accounted for the application deficiency of four types of irrigation systems; surface, improved surface, sprinkler and drip.
7- Evaluate and verify the computer program predictions in five scattered Egyptian zones to validate the output results.

The Methodology

The Computer-Aided Mapping Irrigation Scheduling Model (CAMISM) was written and implemented using Microsoft Visual Basic version 6.0 to accomplish the aim of this study. The CAMISM model flow chart Fig. (1) describes the required input data and the output results.

Model computation methods

The model user can choose one of the following Methods to estimate reference crop evapotranspiration (ETo) according to the standards of every method.

1- The Blany-Criddle formulae

This method is used to estimate Reference crop Evapotranspiration (ETo) using monthly data or more. The very famous publication by Food and Agriculture Organization of the United Nations (FAO 24) Doorenbos and Pruitt, (1977) proposed the use of this method for areas where the air temperature data are the only measured weather data available. This method is still spread in arid and semi arid regions as in Egypt.

The original graphical method published by Doorenbos and Pruitt, (1977) was modified in the CAMISM model to facilitate the computation process using Minitab statistical software (Schaefer and Anderson, 1989). Where ETo values were correlated and regressed with different weather parameters and conditions in order to achieve the best fitting equations. These developed equations were specifically developed for the Egyptian locations (Latitudes 22° 30' N to 35° N) and used in CAMISM model instead of the visual method originally shown in FAO 24. Table (1) shows the developed models to calculate the ETo.

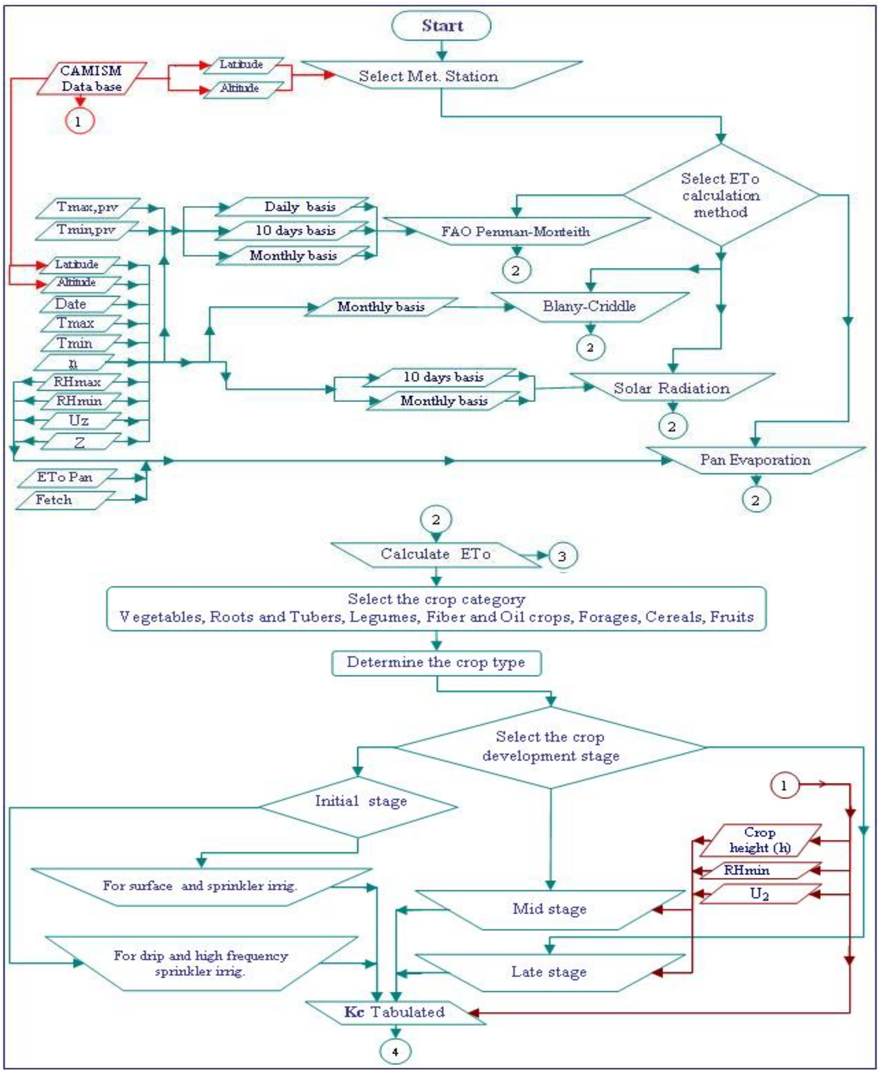
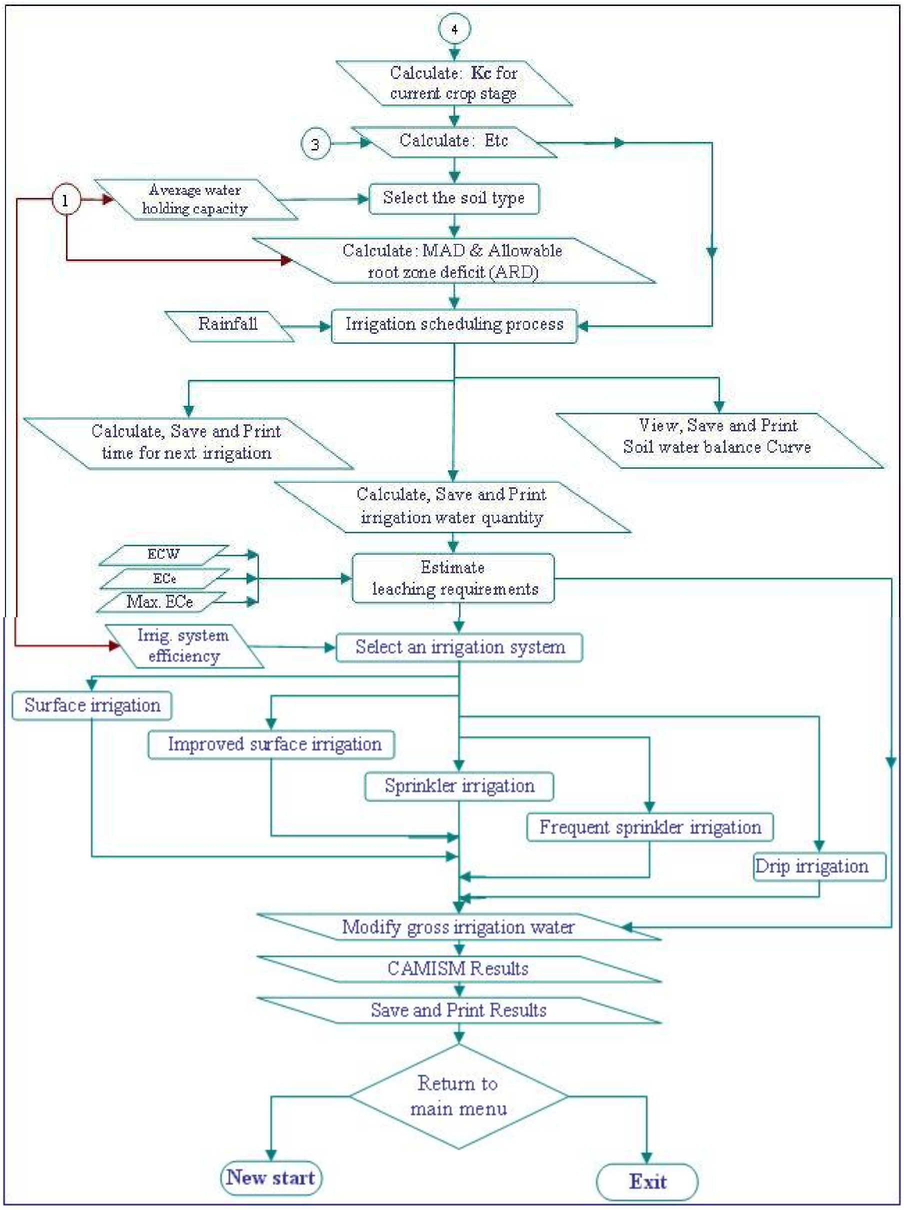


Fig. (1): The CAMISM irrigation scheduling model flow chart



Continued Fig. (1)

The values of P (mean daily % of total annual daytime hours) and N (maximum daylight hours for different latitudes for the 15th of the month) were also modeled using the Curve fitting for programmable calculators (Kolb, 1987). The developed models for P and N calculations are shown in Table (2) and (3) respectively.

Wind speed was also included in ETo calculations. Wind speed at 2 m height was used. For other heights, wind speed data were standardized at 2 m height using the formula suggested by FAO (56):

$$U_2 = U_z \frac{4.87}{\ln(67.8z - 5.42)} \qquad .... \quad 1$$

where;

U_2=wind speed at 2m above ground surface (m/s)
Uz=measured wind speed at z m above ground surface (m/s)
Z= height of measurement above ground surface (m)

2- Solar Radiation Method

This method is used to estimate Reference Crop Evapotranspiration (ETo) on ten days basis. This method is suggested for areas where air temperature, sunshine, cloudiness or radiation, are the only available climatic data.

Table (1) : The developed models for CAMISM between latitudes 22° 30' N and 35° N

Wind speed	RH mean < 0.2	RH mean (0.2 -0.5)	RH mean > 0.5
0 – 2 m/s	ETo = - 4.036 + 1.435 f + 2.997 n/N R^2 = 0.99	ETo = - 3.897 + 1.288 f + 2.796 n/N R^2 = 0.99	ETo = - 3.342 + 1.031 f + 2.241 n/N R^2 = 0.99
2 -5 m/s	ETo = - 4.328 + 1.625 f + 3.551 n/N R^2 = 0.99	ETo = - 4.04 + 1.412 f + 3.154 n/N R^2 = 0.99	ETo = - 3.373 + 1.119 f + 2.308 n/N R^2 = 0.99
5 -8 m/s	ETo = - 4.761+ 1.833 f + 4.17 n/N R^2 = 0.99	ETo = - 4.329+ 1.548 f + 3.555 n/N R^2 = 0.99	ETo = - 3.505 + 1.191 f + 2.572 n/N R^2 = 0.99

ETo= reference crop evapotranspiration in mm/day for the month considered
RH= relative humidity
f= P(0.46 T+8.13)
T= mean daily temperature in (°C)

Table (2) : The developed models to calculate the mean daily percentage annual day time hours (P) between latitudes 22° 30' N and 35° N

January	February	March
$P = \frac{1}{0.0011\,(L - 20.6019)^2 + 4.1027}$ $R^2 = 0.91$	$P = \frac{1}{-0.0009\,(L - 37.43)^2 + 4.0163}$ $R^2 = 0.89$	$P = 0.27$
April	**May**	**June**
$P = 0.2411 + \frac{2.9483}{L} - \frac{43.8619}{L^2}$ $R^2 = 0.89$	$P = \frac{1}{0.0007\,(L - 37.1)^2 + 3.3223}$ $R^2 = 0.89$	$P = \frac{1}{0.0013(L - 33.5258)^2 + 3.1207}$ $R^2 = 0.99$
July	**August**	**September**
$P = \frac{1}{0.0005\,(L - 18.9627)^2 + 3.2707}$ $R^2 = 0.90$	$P = \frac{1}{0.0007\,(L - 37.1)^2 + 3.3223}$ $R^2 = 0.89$	$P = 0.28$
October	**November**	**December**
$P = \frac{1}{0.002\,(L - 25.8804)^2 + 3.8319}$ $R^2 = 0.97$	$P = \frac{1}{0.0014\,(L - 18.1913)^2 + 3.9601}$ $R^2 = 0.99$	$P = 0.29 - 0.002\,(L)$ $R^2 = 1.00$

Where L is the northern latitudes ranged from 22° 30` to 35° N.

The global positioning of different Meteorological Stations in Egypt was stored in the program database.

Table (3) : The developed models to calculate the mean daily duration of maximum possible sunshine hours (N) between latitudes 22° 30' and 35° N

January	February	March
$N = 11.6132\,(0.9934^L)(L^{0.0263})$ $R^2 = 1.00$	$N = 18.2481(1.0032^L)(L^{-0.1743})$ $R^2 = 1.00$	$N = 8.2157(0.9934^L)(L^{0.1691})$ $R^2 = 0.95$
April	**May**	**June**
$N = 14.524\,(1.006^L)\,(L^{0.0878})$ $R^2 = 1.00$	$N = 8.4788 + 0.1212(L) + \frac{45.0037}{L}$ $R^2 = 1.00$	$N = 17.9566(1.0118^L)(L^{-0.1762})$ $R^2 = 1.00$
July	**August**	**September**
$N = 13.6374(1.0079^L)(L^{-0.0434})$ $R^2 = 1.00$	$N = 16.5742\,(1.0087^L)(L^{-0.1427})$ $R^2 = 1.00$	$N = 10.3556(0.9985^L)(L^{0.0661})$ $R^2 = 0.89$
October	**November**	**December**
$N = 8.0826\,(0.9913^L)(L^{0.1805})$ $R^2 = 1.00$	$N = 12.4 - 0.06\,(L)$ $R^2 = 1.00$	$N = 8.7814\,(0.9869^L)(L^{0.1602})$ $R^2 = 1.00$

The recommended relationship between the radiation formula and reference crop evapotranspiration (ETo) is given by FAO 24 and expressed as:

$$ETo = b_1(W \cdot Rs) + b_2 \quad mm/day \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where; W = weighting factor which depends on temperature and altitude

Rs= short wave solar radiation expressed in equivalent evaporation in mm/day

b_1,b_2=factors depends on mean relative humidity RH_{mean} and average wind speed at level of 2 m above ground surface

Reference crop Evapotranspiration (ETo) was calculated using the developed models (Table, 4) which was used instead of the graphical method. Wind speed (U_2) at 2m above ground surface was calculated (FAO 24) using equation (1)

$$Rs = [0.25+0.5(n/N)]\ Ra \quad \ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where Ra is the extra terrestrial radiation expressed in equivalent evaporation in mm/day, and n is the mean daylight hours The developed models for CAMISM to calculate the extra terrestrial radiation (Ra) for different months and Egyptian latitudes (22° 30' to 35° N) are presented in Table (5).

Table (6) shows the Weighting factor (W) models developed for CAMISM over an acceptable range of temperatures and altitudes.

Table (4) : The developed models for CAMISM using solar radiation and short wave parameters

RH_{mean}	Wind speed 0 – 2 m/s	Wind speed 2 - 5 m/s	Wind speed 5 – 8 m/s	Wind speed > 8 m/s
Low <40%	ETo= 1.03x - 0.4 R^2 = 1.00	ETo = 1.13x - 0.34 R^2 = 1.00	ETo = 1.21x - 0.34 R^2 = 1.00	ETo = 1.27x - 0.23 R^2 = 1.00
Low Medium 40-55%	ETo = 0.98x - 0.42 R^2 = 1.00	ETo = 1.06x - 0.39 R^2 = 1.00	ETo = 1.11x - 0.27 R^2 = 1.00	ETo = 1.20x - 0.25 R^2 =1.00
Medium High 55-70%	ETo = 0.90x - 0.43 R^2 = 1.00	ETo = 0.97x - 0.40 R^2 = 1.00	ETo = 1.03x - 0.39 R^2 = 1.00	ETo = 1.08x - 0.34 R^2 = 1.00
High >70%	ETo = 0.80x - 0.35 R^2 = 1.00	ETo = 0.85x - 0.32 R^2 = 1.00	ETo = 0.91x - 0.32 R^2 =1.00	ETo = 0.95x - 0.29 R^2 = 1.00

X= W·Rs

Table (5) : The developed models for CAMISM to calculate the extra terrestrial radiation (Ra) for different months and latitudes in Egypt (22° 30' to 35° N)

January	February	March
$Ra = (3.2824)(0.9483)^{L}(L)^{0.7585}$ $R^2 = 1.00$	$Ra = 15.0952 - 0.0757(l) - 0.0024(l)^2$ $R^2 = 1.00$	$Ra = (6.1768)(0.973)^{L}(L)^{0.4622}$ $R^2 = 1.00$
April	**May**	**June**
$Ra = (6.123)(0.9814)^{L}(L)^{0.4318}$ $R^2 = 0.96$	$Ra = (10.5272)(0.9944)^{L}(L)^{0.1813}$ $R^2 = 0.91$	$Ra = (9.6977)(0.9962)^{L}(L)^{0.1972}$ $R^2 = 0.98$
July	**August**	**September**
$Ra = (7.8805)(.9917)^{L}(L)^{0.2956}$ $R^2 = 0.98$	$Ra = (13.7179)(0.996)^{L}(L)^{0.0745}$ $R^2 = 0.89$	$Ra = (6.8691)(0.9782)^{L}(L)^{0.4015}$ $R^2 = 1.00$
October	**November**	**December**
$Ra = (4.332)(0.9636)^{L}(L)^{0.6168}$ $R^2 = 1.00$	$Ra = 13.2778 - 0.0291(L) - 0.0033(L^2)$ $R^2 = 1.00$	$Ra = 13.0432 - 0.06(L) - 0.0033(L^2)$ $R^2 = 1.00$

The latitudes of different Meteorological Stations in Egypt was stored in the data base of the software program.

Table (6): The weighting factor (W) models developed for CAMISM under different Temperature degrees and altitude from 0 to 500 m above sea level

Temperature (ºC)	W at altitude 0 – 500 m above sea level	
2 – 16	$W = 0.4+0.015\,T$	$R^2 = 1.00$
16 – 21	$W = 0.4371\,(1.0111)^{T}(T)^{0.0738}$	$R^2 = 1.00$
21 – 28	$W = 0.1817\,(0.9946)^{T}(T)^{0.4787}$	$R^2 = 1.00$
28 -34	$W = 6.4867\,(1.0447)^{T}(T)^{-1.0076}$	$R^2 = 1.00$
34- 40	$W = 0.65 + 0.005T$	$R^2 = 1.00$

3- FAO Penman-Monteith method

This method is used to estimate Reference crop Evapotranspiration (ETo) on daily and/or ten days basis. This method requires radiation, temperature, humidity, and wind speed rate. The values of ETo can be calculated according to (Allen *et al.*, 1998) as follows:

$$ETo = \frac{0.408\,\Delta(Rn - G) + \gamma\,\frac{900}{T+273}\,u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)} \qquad \ldots 4$$

Where;

Rn = net radiation at the crop surface (MJ/m²·day),

G = soil heat flux density (MJ/m²·day),
es = saturation vapour pressure (Kpa),
ea = actual vapour pressure (Kpa),
es-ea = saturation vapour pressure deficit (Kpa),
Δ= slope vapour pressure curve (Kpa/ ºC),
γ = psychrometric constant (Kpa/ ºC).

4- Pan Evaporation Method

This method is used to estimate Reference crop Evapotranspiration (ETo) using ten days data or longer. Reference crop evapotranspiration (ETo) for Class A Pan and Colorado sunken pan can be obtained according to (Allen *et al.*, 1998) as follows:

ETo = Kp · Epan ………… ….………………… 5

Where;

Epan=Pan evaporation (mm/day)
Kp=Pan coefficient

Values of Pan Coefficients (Kp) is depending on the location of the pan.

Crop evapotranspiration (ETc) calculations

Crop evapotranspiration (ETc) was calculated after FAO (24) as:

ETc=Kc ×ETo ……..…………………….……..... 6

Crop coefficient (Kc) varies during the crop growing period due to the changes in ground cover and vegetation. To determine the crop coefficients, three values for Kc are required. The values of Kc ini, Kc mid and Kc end for the selected crops are stored in the program database according to the FAO (56) .

The crop coefficient for the initial development stage can be determined according to the used irrigation method as follows:

1- For drip and high frequency sprinkler irrigation, the following function is used (Wright, 1981):

$$Kc\ ini = Kc\ ini_{(tab)} \times 1.25 \quad \ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where; $Kc\ ini_{(tab)}$ = the values of Kc ini, (Allen *et al.*, 1998)

2-For surface and non frequent irrigation $Kc\ ini = Kc\ ini_{(tab)}$

For adjustment in climates where RH_{min} differs from 45% or where u_2 is larger or smaller than 2 m/s, the Kc mid and Kc end is adjusted as by the FAO (56) formula:

$$Kc_{mid\ or\ end} = Kc_{mid\ or\ end(Tab)} + \left(0.04(U_2 - 2) - 0.004(RH_{\min} - 45)\right)\left(\frac{h}{3}\right)^{0.3} \quad \ldots 8$$

Where;

$Kc_{mid\ or\ end\ (Tab)}$ = the value for Kc_{mid} or Kc_{end} (Allen et al., 1998)
U_2 = the mean value for daily wind speed at 2 m height over grass during the mid season growth stage (m/s), (1 m/s ≤ U_2 ≤ 6 m/s).
RH_{min} = the mean value for daily minimum relative humidity during the mid season growth stage (%), (20% ≤ RH_{min} ≤ 80%).
h = mean plant height during the mid season stage (m), (0.1 m< h <10 m).

In the mid season growth stage, mean plant height adjusted according to *Wright (1981)* as follows:

$$h = h_{(Tab)} \times 0.75 \quad .... 9$$

Where; $h_{(Tab)}$ = the maximum crop height (Allen et al., 1998)

Root zone Available Water (RAW)

The capacity of the soil profile to store water depends on the irrigated soil type and the effective root depth. Average water holding capacity (AWC) for different soil types are shown in Table (7) according to keller and Bliesner (1990) . the values of Table (7) were used in the CAMISM data base. To calculate the RAW, the following equation was used:

$$RAW = AWC \times Rd \quad .... 10$$

Where;

AWC = available water holding capacity mm/m, Table 7.

Rd = development stage effective root zoon depth in mm, (Allen *et al*., 1998 and Thomas *et al*., 1994).

The effective root depth varies according to the crop development stage. The data base of CAMISM uses Rd equals to 1/3, 2/3 and 1 effective root depth in the initial, mid and crop late stage respectively (Pair *et al.,* 1986).

Management Allowable Depletion (MAD)

Management Allowable Deficit (MAD) in percentages (MAD %) for different crop types (Allen *et al*., 1998 and Thomas *et al*., 1994) were stored in the CAMISM data base. The values were entered in the scheduling calculations.

Table (7) : Average water holding capacity (AWC) mm/m soil depth for different soil types.
(after Keller and Bliesner 1990)

Soil type	Available water holding capacity (AWC) mm/m
Very coarse sand	42
Coarse sand	
Fine sand	83
Loamy sand	
Sandy Loams	125
Very fine sandy loams	
Loams	167
Silt loams	
Clay loams	
Silty clay loams	183
Sandy clay loams	
Sandy clays	
Silty clays	192
Clays	

Allowable Root Zone Depletion (ARD)

Allowable Root Zone Depletion (ARD) or the depth of the water applied to the soil per irrigation turn is determined according to Keller and Bliesner (1990) by the following equation:

$$ARD = RAW \times MAD \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 11$$

Where;

ARD =Allowable Root Zone Depletion, mm.
RAW = Root zone available water, mm.
MAD = Management Allowable Depletion, %

Implement of irrigation scheduling procedure

Good irrigation scheduling means applying the right amount of water at the right time in other words, making sure that water is available when the crop needs it. To determine when to irrigate and how much water to apply every irrigation turn, the following steps were followed:

1- select one of the methods to compute ETo, 2- Compute reference evapotranspiration (ETo). 3- Compute crop evapotranspiration (ETc), 4- Compute accumulative crop water use according to Etc, 5- Determine soil type, 6- Determine crop category and type, 7- Determine crop growth stage and its rooting depth, 8- Compute the soil water storage in the active root zone, 9- Compute Management Allowable Depletion (MAD) according to the soil type and active root zone, 10- Determine effective rainfall, 11- Compute soil water balance according to crop water use and rainfall by the following equation:

$$D_i = D_{i-1} + (ETc - R)_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 12$$

Where;

Di = soil water depletion in mm on day i,
Di-1 = soil water depletion on day i-1 in mm, and
R = effective rainfall in mm,

D is increased daily by addition of the estimated daily Etc_i and decreased on the rainfall days or when irrigations are applied. When rainfall or irrigation amounts equal to or excess field capacity (i.e. D_i=0); the excess amount of rainfall or irrigation is assumed lost to deep percolation.

The above steps can be computed easily on daily bases using the CAMISM model. Irrigator can determine when to irrigate and how much water to apply according to soil and crop type from planting to harvesting.

Time for next irrigation

Irrigation time can be determined when D_i value is equal to or exceed the management allowable depletion (MAD). The computer program alarms the user on next irrigation time.

Irrigation quantity

The amount of water to be added to the soil (i.e. gross irrigation water requirements) equals to the soil water depletion (D_i) on the irrigation day in addition to that amount computed for the leaching requirements and efficiency of irrigation method.

Leaching requirements (LR) calculations

One of the advantages of the CAMISM model is that it controls the salinity levels in soil profile. The CAMISM model calculates the leaching requirements according to the irrigation method used. For surface irrigation and sprinkler methods the following equation was used after Doorenbos and Pruitt, (1977):

$$LR = \frac{ECw}{5\ ECe - ECw} \qquad \text{………..…… 13}$$

For drip and high frequency sprinkler the LR is calculated according to the same reference as follows:

$$LR = \frac{ECw}{2\ MaxECe} \qquad \text{……….......... 14}$$

where;

ECw = electrical conductivity of the irrigation water, dS/m,

ECe = electrical conductivity of the soil saturation extract (dS/m) for a given crop, appropriate to the tolerable degree of yield reduction.

MaxECe = maximum tolerable electrical conductivity of the soil saturation extract for a given crop, dS/m.

Irrigation system efficiency (Ea)

The CAMISM data base allows for that percentage of water which must be added to overcome the lack of irrigation system efficiency. Table 8 shows the percentage of water added to each irrigation run.

Table (8) : Percentage of irrigation water added for the irrigation method chosen.

Irrigation method	% of water added to each irrigation run
Surface irrigation	50
Improved surface irrigation	40
Sprinkler irrigation	25
Drip irrigation	5

Gross irrigation water requirements (GIR)

The following equation was used in the CAMISM subroutine to Adjust the irrigation water quantity by leaching requirements and efficiency of the irrigation system. The gross irrigation water requirements were calculated by the following equation :

$$GIR = \frac{D_i}{1 - LR} \times (1 + W_a) \quad \ldots\ldots\ldots\ldots\ldots 15$$

Where; W_a = % of water added to each irrigation run

Results and Discussion

In order to evaluate and verify the CAMISM output results, the methods described by France and Thornley (1984) was used and the program was executed many times. Three different locations were chosen as shown in Table (9).

Table (9): Locations, crop types, year and ETo method under which the CAMISM was evaluated and verified.

Evaluation and verification area	Location on the Egyptian map	Tested crop	Experimented year
Toshka	South-West	Corn	2002
Maruot	North-West	Groundnut	2002
Sakha (Kafer Al-Sheekh)	Delta	Wheat	2001/2002

Toshka case study:

The Penman-Monteith method was used in this new reclaimed area to verify the CAMISM prediction. Table (10) shows Toshka input data. The Penman-Monteith method has achieved better results where the slope of the prediction line was almost 1.0. Good accuracy of the relationship was attained (R^2=0.87, Fig. 2). The Penman-Monteith method has proved wide usage all over different places (Steduto *et. al*., 1996). The mean square residual error is 0.019 and the calculated F was highly significant at 1% level.

The next step was to execute the crop module where corn was selected. Three crop physiological stages were used in the evaluation right from the beginning of planting and through to harvest. Sandy loam type was tested in the execution. The CAMISM detailed output for corn real time irrigation scheduling in Toshka areawere indicated. Figure (3) shows the moisture status as growth advances. The CAMISM has assigned three levels of management allowable deficit (MAD) at which irrigation should take place immediately or within the next day at maximum estimation. The general practice here is that the delay must equal to one day ETo or less. The MAD for three corn crop growth stages were 18.75, 37.5 and 56.25 mm for the first, second and the third stages, respectively.

The CAMISM has determined and calculated these values based on models included in the soil module. These figures are legitimated since CAMISM calculations are based in this module part on available water at effective growing rooting depth. Available water increases as the effective root depth increases. One may argue that what are the reasons to use three MAD. In other words, why you did not use one MAD right through the growing season. The justified answer is to conserve water and energy at the first and last stages. Where crop growth is very young and still progressing (i.e. seedling) in addition to the effective rooting depth is unmentionable right at the beginning of the first stage. On the last stage, the crop has reached maturity stage with more available water and irrigation intervals should be spaced out. The results shows that corn crop required 19 irrigations totaling 635.5 mm/season divided in average over three or four days intervals at most.

To add the leaching requirements the specific module was executed. Irrigation system deficiency is also accounted to calculate that extra amount of irrigation water to overcome system application problems. The gross irrigation needed for the corn crop grown in the summer season of 2002, in Toshka was 756.6 mm/season. The amount of water saved by CAMISM has reached a total of 102.2 million m^3 for con crop in Toshka area.

Table (10) : Initial input data for case study of Toshka area.

Area	Toshka
Crop	Corn
Planting date	1/6/2002
Length of the growing season "days"	120
Development stages length "days"	Ini.stage= 50, mid stage = 40,late stage= 30
Soil texture	Sandy loam
Effective root depth "cm"	90
MAD	50%
Leaching requirments	ECw=1.1, ECe=1.7, Max. ECe=10
Last irrigation	2 to 3 weeks before harvesting
Irrigation system	Center pivot

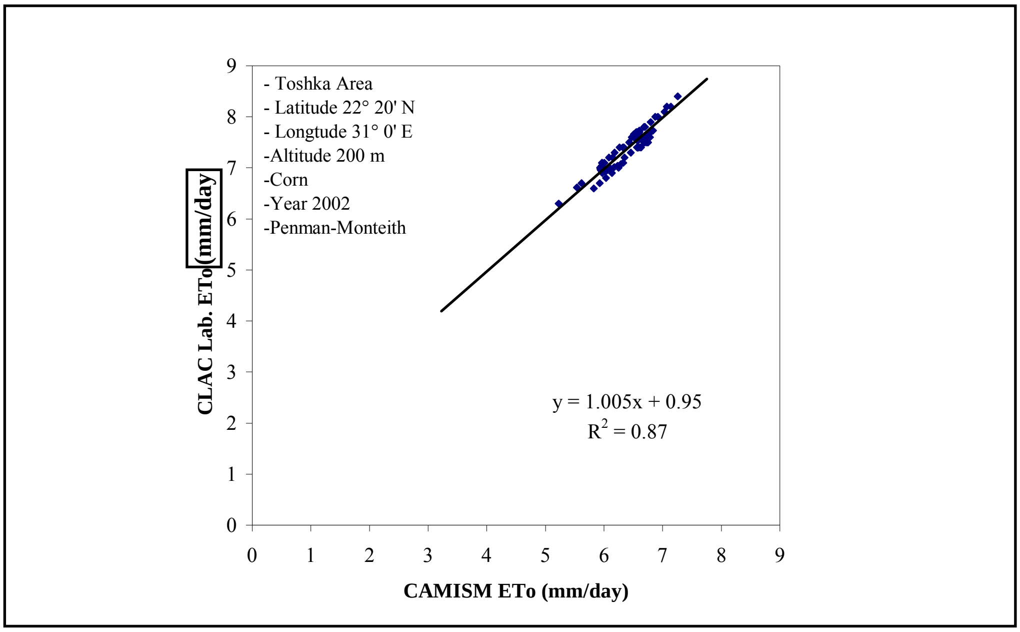


Fig. (2): The relationship between the CAMISM predicted ETo and "CLAC Lab." ETo for the Corn crop in Toshka area.

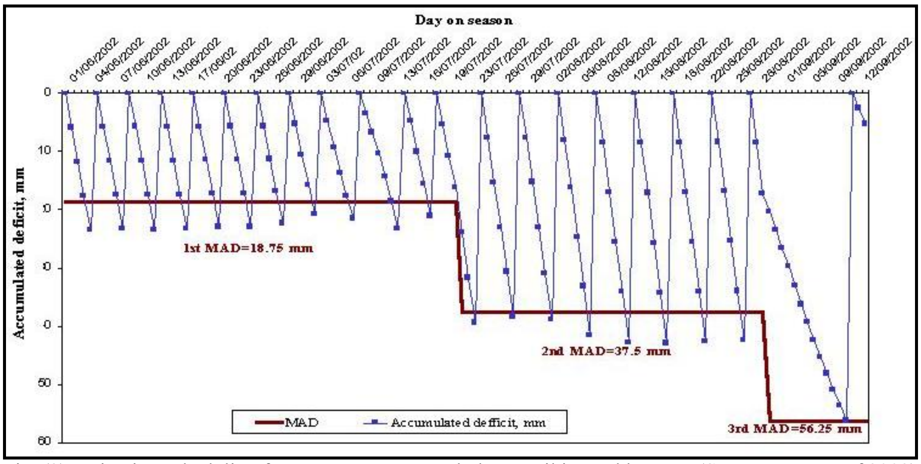


Fig. (3): Irrigation scheduling for corn grown on sandy loam soil in Toshka area (Summer season of 2002)

Maruot case study

In Maruot area the CAMISM predictions were verified with the groundnut crop. Table (11) shows the initial input data for the case study. The CAMISM predictions were highly and significantly correlated with the Desert Research Institute ETo values. The coefficient of the determination was accurate; R^2=0.86. The modified FAO Penman-Monteith method has given ETo values with very small residual error (i.e. 0.028). The calculated F value was highly significant at 1% level. Figure (4) shows soil moisture status during the growing season of 2002. Groundnut needed 31 irrigations totaling 484.6 mm/season divided in average over two or three days intervals. The gross irrigation need was 595.2 mm/season. The amount of water saved by CAMISM has reached a total of 128 million m^3 for groundnut crop in Maruot area.

Table (11): Initial input data for case study of Maruot area.

Area	Maruot
Crop	Groundnut
Planting date	1/5/2002
Length of the growing season "days"	140
Development stages length "days"	Ini. stage= 75, mid stag = 40, late stage= 30
Soil texture	Fine sand
Effective root depth "cm"	50
MAD	50%
Leaching requirments	ECw=2.1, ECe=3.2, Max. ECe=7
Last irrigation	Two weeks before harvesting
Irrigation system	Drip irrigation

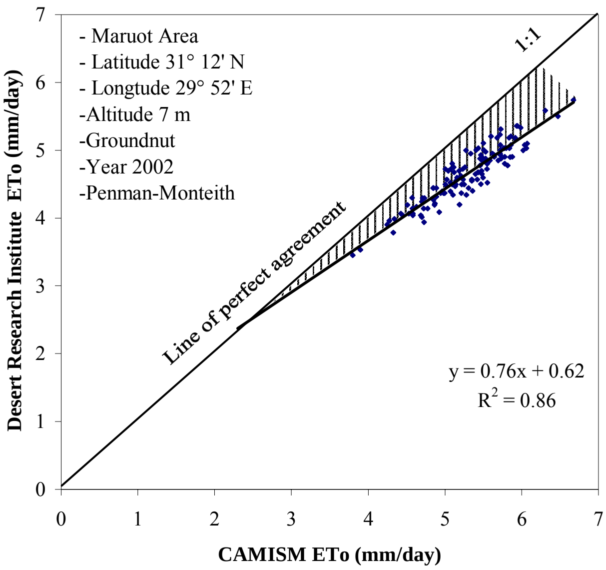


Fig. (4): The relationship between the CAMISM predicted ETo and the Desert Research Institute ETo in Maruot area (summer season of 2002**).**

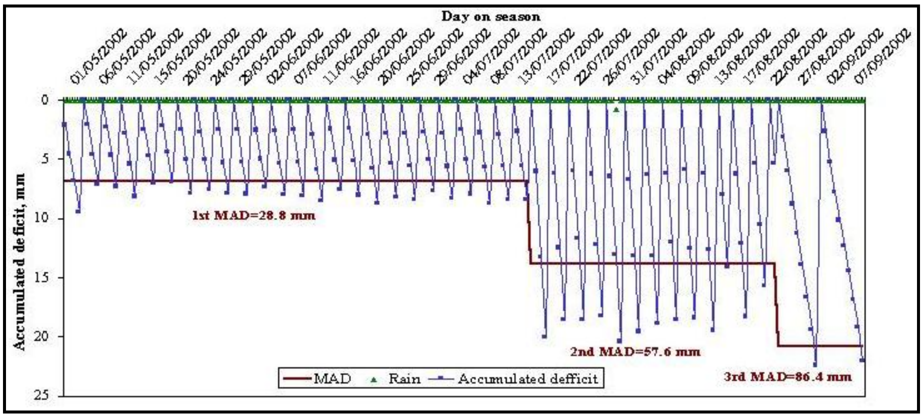


Fig. (5) : Irrigation scheduling for Groundnut grown on Fine sand soil in Maruot area (Summer season of (2002)

Sakha case study

Table (12) shows the initial input data to verify the Wheat ETo CAMISM predictions. Figure (6) represents the relationship between the program predictions and ETo values obtained from Sakha Station (Kafr Al-Sheekh). Significant linear relationship was attained with high accuracy of determination coefficient (i.e. R^2=0.85). The modified FAO Penman-Monteith has given very small residual error (i.e. ≈ 0.37) for the relationship. Figure 7 shows the growing season soil moisture status. Wheat crop needed 7 irrigations totaling 258.8 mm/season. The gross irrigation was 458.8 mm/season. The amount of water saved by CAMISM has reached a total of 143.3 million m^3 for wheat crop in Sakha area

Table (12): Initial input data for case study of Sakha area.

Area	Sakha
Crop	Wheat
Planting date	20/11/2001
Length of the growing season "days"	160
Development stages length "days"	Ini. stage= 70, mid stage= 60, late stage =30
Soil texture	Silty clay
Effective root depth "cm"	90
MAD	55%
Leaching requirments	ECw=4, ECe=6, Max. ECe=20
Last irrigation	10 to 15 days before harvesting
Irrigation system	Surface irrigation

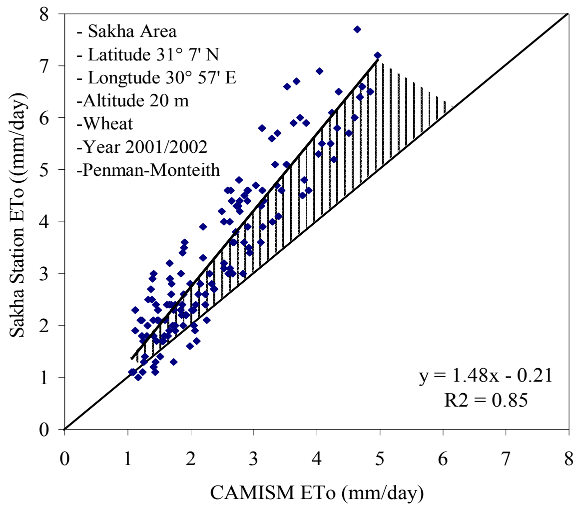


Fig. (6): The relationship between the CAMISM predicted ETo and Sakha Station ETo in Sakha area (winter season of 2001/2002).

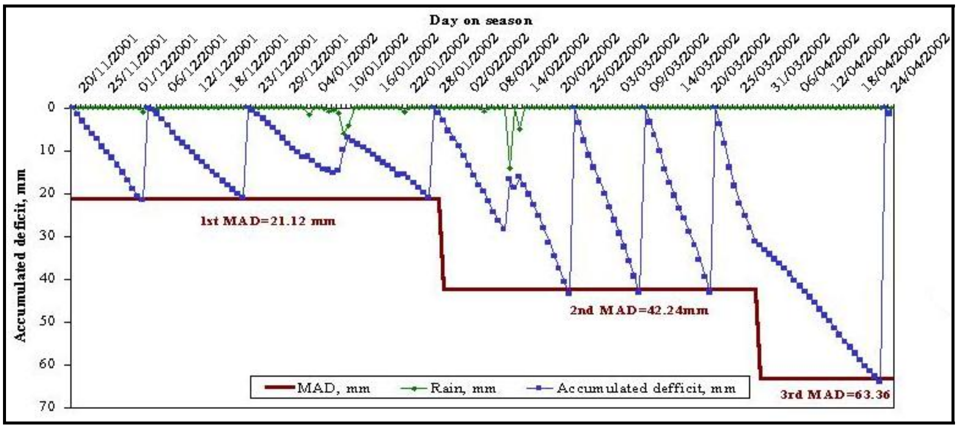


Fig. (7): Irrigation scheduling for Wheat grown on a Silty Clay soil in Sakha area (Winter season of 2001/2002)

Conclusions

The CAMISM real time irrigation scheduling program was developed and validated. The necessary models and modules were developed using appropriate regression and correlation analysis. The coefficients of determination for these models were statistically calculated. The precision of the relationships were highly significant at 1% level. To evaluate and verify the CAMISM predictions; all necessary steps required to develop such models were followed with proper justification. On real application three different locations were chosen to represent study cases to validate the CAMISM output results. Toshka, Maruot, and Kafer Al-Sheekh were considered in this respect. Verification proved that CAMISM predictions are either above or below and/or at the perfect line of agreement according to suitability of ETo method for the chosen location as well as availability of weather data. Nevertheless, in all cases the CAMISM predictions were highly significantly correlated with the ETo values obtained from the Central Laboratory of Agricultural Climatic "CLAC", Desert Research Institute and Sakha Station. The modified FAO Penman-Monteith method for ETo calculations has given best verification proving once more the fact of its wide application. The amount of water saved by CAMISM has reached a total of 102.2, 128 and 143.3 million m^3 for con crop in Toshka, groundnut in Maruot and wheat in Sakha regions respectively

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خرائط جدولة مياه الري بمساعدة الحاسب الآلي في بجمهورية مصر العربيـــة

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تم استنباط نموذج بالحاسب الآلي لجدولة مياه الري وإخراجه في شكل برنامج كمبيوتر سهل الاســتخدام سُـــمى هذا البرنامج CAMISM. تم إعداده باستخدام لغة الفيجوال بيسك (الإصدار الـــسادس Ver. 6.). البرنامج يحدد للقائمين على عملية الري الوقت الحقيقي للري وكمية مياه الري الواجب إضافتها للتربة تبعا للآتي:

1- دوال العوامل الجوية حيث يتم منها حساب قيمة البخر نتح المرجعى باستخدام اربع طرق مختلفة وهي بلانى كريدل والإشعاع وبنمان مونتيث و حوض البخر.

2- دوال النبات لحساب بخر نتح النبات لعدد 65 محصول مختلف تبعا لعمر النبات الفسيولوجى.

3- وال التربة لتحديد كمية المياه المتاحة في منطقة الجذور الفعالة طبقا لـــ 13 نوع من التربة.

4- حساب كمية مياه الري الكلية المضافة للتربة طبقا للاحتياجات الغسيلية وكفاءة نظام الري المستخدم.

يشمل البرنامج 36 موقع لمحطات أرصاد جوية موزعين على الخريطة الشمالية والجنوبية لمصر (تقع هـــذه المحطات بين خطى عرض 30' 22° و 35° شمالا) مع إمكانية إضافة مواقع أخرى.

لتطبيق البرنامج واستخدامه على نطاق واسع تم تقييم بيانات البخر نتح المتحصل عليها من البرنامج وعمل علاقة بين قيم البخر نتح لمناطق توشكا و مريوط و سخا بكفر الشيخ وبين القيم المحسوبة باستخدام طريقة بنمـــان مونتيث وذلك خلال موسم زراعة محاصيل الذرة والفول السوداني والقمح على الترتيب وكانـــت قيمـــة معامـــل الارتباط لها 0.87 ، 0.86 ، 0.85 على التوإلي حيث تم استخدام بيانات أرصاد يومية لهذه المناطق. كان الارتبـــاط بين مخرجات البرنامج والقيم المتحصل عليها من المعمل المركزي للمناخ الزراعي ومعهد بحوث الـــصحراء ومحطـــة أبحاث سخا بكفر الشيخ ارتباطا معنوياً وان حالات زيادة أو نقص التقدير بالمقارنة بخط الجوية في بعض المنـــاطق او الاضطرار الموافقـــــة المثالي Perfect line of agreement يمكـــن إيعازهـــــا

لعدم كفاية مدخلات عناصر الأرصاد لاستخدام متوسطات زمنية تحتوى على بيانات أرصاد جوية. نتيجة استخدام النموذج تم توفير 102.2 ، 128 ، 143.3 مليون متر مكعب مياه .