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Modeling Evapotranspiration of Applied Water in the Egypt Delta and Sacramento San Joaquin River Delta, California, USA

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Abstract - **The Egyptian agriculture is facing water shortage problem, which will need to improve irrigation techniques and to find out the possible ways for rationalize irrigation water. Water scarcity has become an increasing constraint to the economic development, particularly of agriculture which is the biggest water consumer, and unreliable water services are prompting people to migrate in search of better opportunities. Agriculture in Egypt is receiving the biggest share of developed water supply; amounting to nearly 85% of the available water resources. The policy of Egypt is to fill the gap in food production, through vertical expansion of the irrigated areas, and the horizontal expansion in new reclaimed lands. Since about 97% of Egypt's water comes from outside Egypt, this requires very effective and serious action programs to reduce water losses and increase water use efficiency and crop water productivity. Finding new efficient ways to improve the matching between water supply and demand is a crucial for dealing with water scarcity, especially in the face of rapid population growth and negative impacts of climate change.**

The California Department of Water Resources and the University of California has developed a weather generator application program "SIMETAW" to simulate weather data from climatic records and to estimate reference evapotranspiration and crop evapotranspiration with the simulated data. The SIMETAW (Simulation of Evapotranspiration of Applied Water) application program is being used by the State of California to estimate the demand for irrigation water to improve water resources management. It has the potential to greatly improve our knowledge about the demand for water and how to efficiently manage the supply and distribution of water. Information on water demand is also needed to efficiently manage water supply and delivery in the Nile Delta of Egypt.

Keywords - Water, Soil, Crop, Weather, Modelling, Climate and Evapotranspiration.

1. INTRODUCTION

The work focusing on collecting the data needed to apply the SIMETAW model for the Nile Delta, run the model, and test its accuracy to provide the irrigation engineers with better statistics on water use within the Nile Delta. In addition, simulated daily rainfall, soil-water holding characteristics, effective rooting depths, and crop evapotranspiration (ETc) are used to determine effective rainfall and to generate hypothetical irrigation schedules to estimate the seasonal and annual evapotranspiration of applied water (ETaw), where ETaw is the net amount of irrigation water needed to produce a crop. It also helped to update some major field crops coefficients for estimating crop evapotranspiration, which will help growers improve their on-farm irrigation efficiency, and how the simulation model determines ETaw as well as other model outputs under Nile Delta conditions.

The California Simulation of Evapotranspiration of Applied Water (SIMETAW) model is a new tool developed by the California Department of Water Resources and the University of California, Davis to perform daily soil water balance and determine crop evapotranspiration (ETc), evapotranspiration of applied water (ETaw), and applied water (AW) for use in California water resources planning. ETaw is a seasonal estimate of the water needed to irrigate a crop assuming 100% irrigation efficiency. The model accounts for soils, crop coefficients, rooting depths, seepage, etc. that influence crop water balance.

The SIMETAW program generates daily weather data from daily mean climate data by month. This allows for the simulation of daily weather data where only monthly means exist, which is a good tool for filling missing data points. In addition, the simulation program is useful for studying the effects of climate change. All of the ETaw calculations are done on a daily basis, so the estimation of effective rainfall and, hence, ETaw is greatly improved over earlier methods. In addition, the use of the widely adopted Penman-Monteith equation for reference evapotranspiration (ETo) and improved methodology to apply crop coefficients for estimating crop evapotranspiration is used to improve ETaw accuracy.

The application uses the daily climate data, i.e., maximum (Tx) and minimum (Tn) temperature and precipitation (Pcp).

The application uses daily weather data to determine reference evapotranspiration (ETo), using the Hargreaves-Samani (HS) equation (Hargreaves and Samani 1982, 1985).

The SIMETAW program can generate daily weather data from monthly mean values for use in studying climate change scenarios and their possible impacts on water demand.

Shwe S. P. and Tin T. H. (2013) determine the crop water requirement of paddy rice for the area around Kyae Bin Et Dam in Myanmar, Irrigation Project. Crop water requirement for paddy rice was determined by using 15-years climatic data from nearest station. Reference crop evapotranspiration (ETo) was determined by using the FAO Modified Penman method.

1.1. Model description

Crop evapotranspiration is computed as the product of reference evapotranspiration (ETo) and a crop coefficient (Kc) value, i.e., ETc = ETo × Kc, and ETaw, which is equal to the seasonal evapotranspiration minus water supplied by stored soil moisture, effective rainfall, and seepage from canals. SIMETAW accounts for contributions from rainfall and for ground water seepage from the rivers and canals when spatial information on the depth to water table is available on the same 4 km × 4 km grid spacing used to characterize soils.

SIMETAW uses batch processing to read the climate data, the surface/crop coefficient values, growth dates to estimate annual curves, soil information, crop and irrigation information, and surface area of each crop and land-use category. Then, the program computes daily ETo, Kc factors, ETc, daily water balance, effective rainfall, ETaw, etc. The water balance model is similar to that used in the Simulation of ET of Applied Water (SIMETAW) application program, which was also developed as a cooperative effort between the UC Davis and the DWR (Snyder et al. 2012). SIMETAW was designed to reduce the time needed for data input and to improve the water use/demand estimates needed for the California Water Plan. The simulation component of

FAO Irrigation and Drainage Paper No. 24 provide general lengths for the four distinct growth stages and the total growing period for various types of climates and locations. These types of models should be verified or validated for the local area or for a specific crop variety using local observations.

1.2. Reference Evapotranspiration Calculation

A modified version of the Penman-Monteith equation with some fixed parameters was recommended to estimate ETref (ASCE-EWRI, 2005). The hourly equation is:

$$ET_{ref} = \frac{0.408\,\Delta(R_n - G) + \gamma \dfrac{C_n}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d\, u_2)} \qquad (1)$$

where Δ is the slope of the saturation vapor pressure curve at mean air temperature (kPa $^{o}C^{-1}$), Rn and G are the net radiation and soil heat flux density in MJ $m^{-2}h^{-1}$, γ is the psychometric constant (kPa $^{o}C^{-1}$), T is the hourly mean temperature (^{o}C), u_2 is the wind speed in m s^{-1}, and e_s - e_a is the vapor pressure deficit (kPa). The units for ETref are in mm h^{-1}. In Eq. 1, the coefficients Cn and Cd are given specific values depending on the reference surface (Table 1).

The values for Cn vary because the aerodynamic resistance is different for the two reference surfaces. The soil heat flux density (G) is assumed equal to 10 % of Rn when Rn ≥ 0 and it is set equal to 50 % of Rn for Rn < 0. In addition, the surface (canopy) resistance is set equal to 50 s m^{-1} during daytime and to 200 s m^{-1} at night.

Table 1. Coefficients used in the ETref equation for a short 0.12 m tall canopy (ETo) and for a 0.50 m tall canopy (ETr)

Calculation	ETo		ETr	
	Cn	Cd	Cn	Cd
Daytim	37	0.24	66	0.25
Nighttime	37	0.96	66	1.70

1.3. Crop coefficients

Crop evapotranspiration is estimated as the product of reference evapotranspiration (ETo) and a crop coefficient (Kc) value. Crop coefficients are commonly developed by measuring ETc, calculating ETo, and determining the ratio:

Kc = ETc / ETo.

Most of the SIMETAW crop coefficient values were developed in California, but some were adopted from Doorenbos and Pruitt (1977) and Allen et al. (1998). Also, Kc values need adjustment for microclimates, which are plentiful and extreme in California. A microclimate Kc correction based on the ETo rate is included in the SIMETAW model. The Kc values and corresponding growth dates are included by crop in the model. These dates and Kc values are used to estimate daily Kc values during a season.

1.4. Field and row crops

Field and row crop Kc values are calculated using a method similar to that described by Doorenbos and Pruitt (1977) and Allen et al. (1998). In their method, the season is separated into initial, rapid, midseason and late season growth periods. Kc values are denoted KcA, KcB, KcC, KcD and KcE at the ends of the A, B, C, D, and E growth dates, respectively. During initial growth, the Kc values are at a constant value, so KcA=KcB. During the rapid growth period, when the canopy increases from about 10 to 75% ground cover, the Kc value increases linearly from KcB to KcC. The Kc values are typically a constant value during midseason, so KcC=KcD. During late-season, the Kc values decrease linearly from KcD to KcE at the end of the season. Doorenbos and Pruitt (1977) provide estimated number of days for each of the four growth periods to help identify the end dates of growth periods. Because there are climate and varietal differences, however, and because it is difficult for growers to know when the inflection points occur, irrigators often find this confusing. To simplify this problem, percentages of the season from planting to each inflection point rather than days in growth periods are used. Irrigation planners need only enter the planting and end dates and the intermediate dates are determined from the percentages, which are easily stored in a computer program. During initial growth of field and row crops, a default Kc=KcB=KcA unless it is overridden by entering an initial growth Kc based on rainfall or irrigation frequency. The values for KcC=KcD depend on the difference in light interception, crop morphology effects on turbulence, and physiological differences between the crop and reference crop. Some field crops are harvested before senescence, and there is no late season drop in Kc (for example, silage corn and fresh market tomatoes). Relatively constant annual Kc values are possible for some crops (for example, turfgrass and pasture) with little loss in accuracy.

Some field crops and landscape plants (type-2 crops) have fixed Kc values all year. However, if the significant rainfall frequency is sufficient to have a higher Kc for bare soil than for the selected crop, then the higher bare soil Kc should be used. The bare soil Kc value serves as a baseline for the crop coefficient, and the higher of the fixed crop Kc or the bare soil Kc is used to estimate ETc for the crop.

2. RESULTS AND DISCUSSIONS

2.1. Weather Data Integrity and Quality

The accuracy of determining ETo from weather data is based on the integrity and the quality of the original weather data sets. Therefore, assessments of weather data integrity and quality need to be conducted before data are utilized in ET equations. Determining C the quality of solar radiation data could be good indicator for the quality of the weather data sets and it could be evaluated for a particular weather location by plotting hourly or daily average readings of solar radiation (Rs) against computed short wave radiation that is expected to occur under clear sky conditions (Rso). Under clear sky condition, the value of Rs/Rso returns to one.

Figures (1) show the values of Rs/Rso of daily measured weather data which represent the general trend of the study location. The values of Rs/Rso ratio are closed. From the obtained results, shown in Figure (1) indicated that there is a good agreement between measured and simulated values of solar radiation.

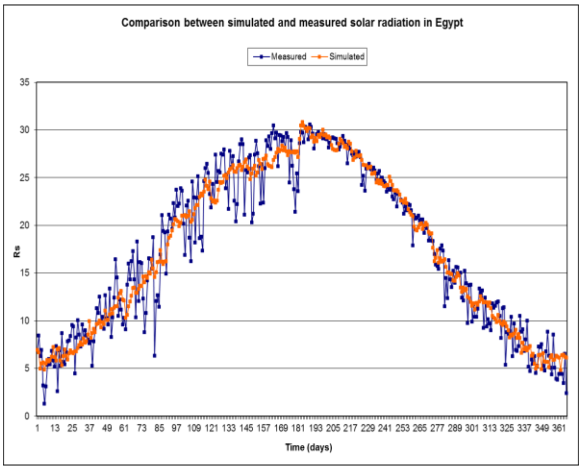

Fig. 1. Comparison of measured and simulated daily solar radiation (Rs).

From the obtained results, shown in Figure (2) indicated that there is a good agreement between measured and simulated values of maximum air temperature Tmax (ºC).

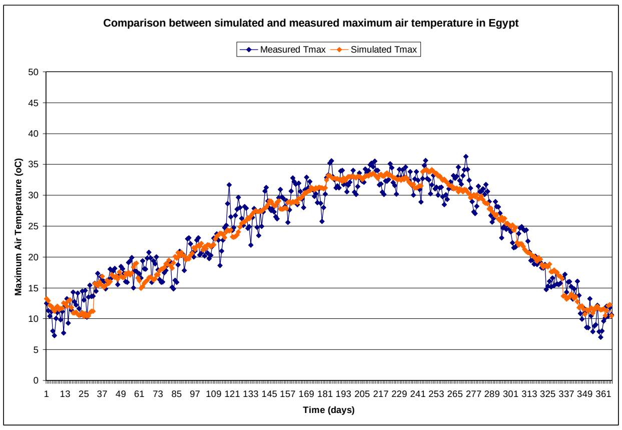

Fig. 2. Comparison of measured and simulated daily maximum air temperature Tmax (ºC).

From the obtained results, shown in Figure (3) indicated that there is a good agreement between measured and simulated values of minimum air temperature Tmin (ºC).

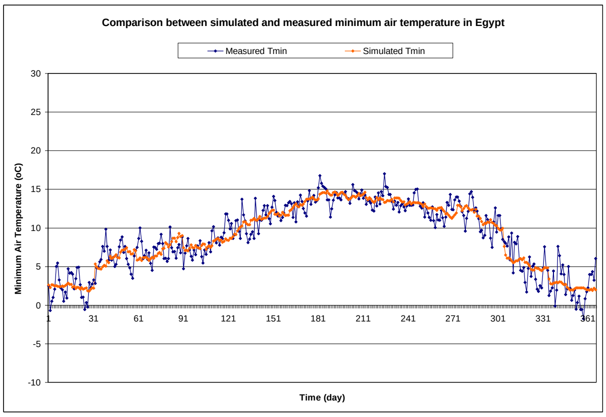

Fig. 3. Comparison of measured and simulated daily minimum air temperature Tmin (ºC).

From the obtained results, shown in Figure (4) indicated that there is a good agreement between measured and simulated values of wind speed u_2 (m s^{-1}).

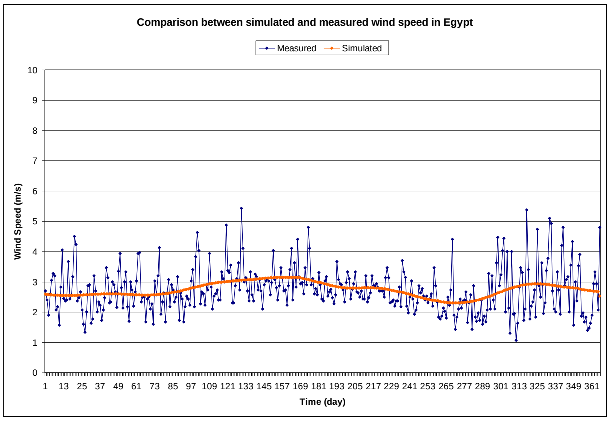

Fig. 4. Comparison of measured and simulated wind speed u_2 (m s^{-1}).

From the obtained results, shown in Figure (5) indicated that there is a good agreement between measured and simulated values of precipitation Pcp (mm).

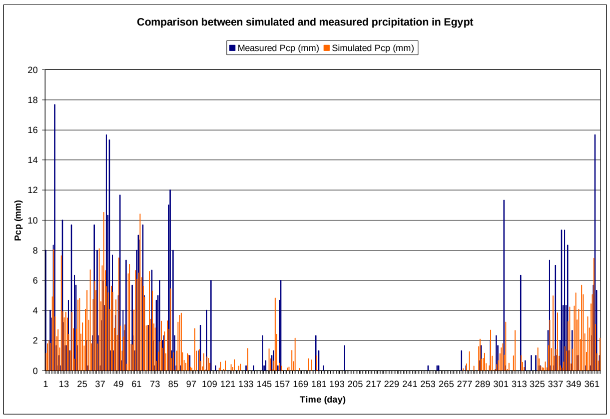

Fig. 5. Comparison of measured and simulated precipitation Pcp (mm).

2.2. *Simulated and estimated daily Evapotranspiration (ETo mm) in Egypt*

From the obtained results, shown in Figure (6) indicated that there is a good agreement between observed and simulated values of simulated and estimated daily ETo mm/day in Egypt Delta .

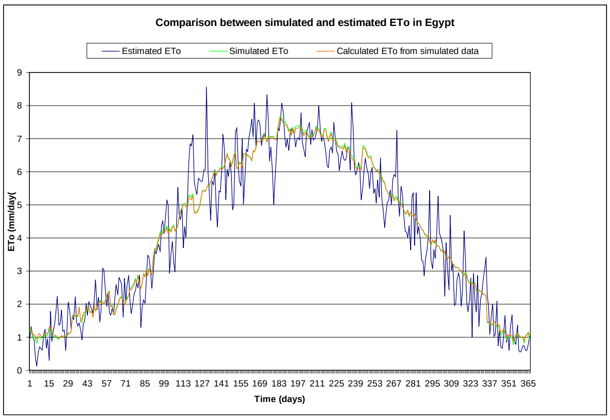

Fig. 6. Comparison of simulated and estimated daily ETo mm/day in Egypt.

3. CONCLUSION

The SIMETAW model determines effective rainfall and evapotranspiration of applied water (ETaw) for crop and land-use categories, which include similar agricultural crops and other surfaces, by different regions having similar ETo rates within California and Egypt Delta. The model uses daily observed or simulated climate data to account for ET losses and water contributions from seepage of groundwater, rainfall, and irrigation on a daily basis over the period of record to simulate a daily water balance. The model can use daily climate data or daily climate data simulated from monthly data to estimate daily ETo.

Then, using the surface areas, volumes of water corresponding to crop evapotranspiration and evapotranspiration of applied water are computed for each crop category by different County to provide water demand information that helps on water supply and distribution needs and solutions. This information is extremely important to develop plans for water supply and distribution across the Nile Delta.

- SIMETAW shows high accuracy in simulating the initial weather parameters needed for calculating ETo, and simulating ETo and ETc for a long time series.

- The SIMETAW model simulations provide a method for determining ETo and ETc using minimum weather data set under Nile Delta conditions. The model estimates ETo from generated daily weather data using the standardized reference evapotranspiration (modified) Penman-Monteith equation for ETo, or the Hargreaves-Samani equation, which uses only temperature.

- Based on inputs, the SIMETAW model determines an efficient irrigation schedule for a particular crop and soil.

- SIMETAW model could tremendously help Egyptian irrigation engineers with limited research funding to improve their knowledge of crop water requirements and to address limited water supplies.

- More calibration is required to assess the effect of the inter-annual climate variability (especially precipitation and wind speed) on the model simulation accuracy.

- More calibration is needed to address the effect of the water stress conditions, and local management procedures in the accuracy of the SIMETAW simulations.

- Since the SIMETAW was calibrated only in the Nile Delta, calibration for the other regions is recommended.

4. ACKNOWLEDGMENTS

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