MODELING WATER BALANCE COMPONENTS IN RICE FIELD IRRIGATION

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ABSTRACT

In this study, a water balance equation approach was applied to the irrigation practiced at the Besut Rice Irrigation Scheme. Each component of the equilibrium equation, where not measured, was modeled using equations sourced from the literature. Results obtained from the modeling exercise were compared with measured data whenever available. The reference evapotranspiration (ET_o) modeled with the Penman-Monteith equation for the monthly time series; was evaluated to be 3.6 mm/day and 3.5 mm/day for off-season (May – October) and main season (November – April) crops respectively. Effective rainfall was estimated using the water use-rainfall ratio method, with monthly rainfalls data from 1951 to 1998, for three rainfall stations. It has been observed that 68% and 54% of rainfall accounts as effective rainfall during the pre-saturation and crop growth periods respectively. The water subsidence technique was used to estimate the average daily seepage cum percolation rate, and results showed this to be 2.4 mm/day for the site. Comparisons between model component outputs and observed and recorded field data are good. The water balance components can be adequately used to monitor field conditions for rice irrigation in Malaysia.

Keywords: *Effective Rainfall, Evapotranspiration, Water Balance Model*

INTRODUCTION

Irrigation in Malaysia is almost entirely devoted to rice cultivation. The total physical rice area in Malaysia is about 600,000 ha. Of this, irrigated rice constitutes 324,000 ha or about 54%, while the rest follow a rain-fed regime. All of the irrigated rice areas in Peninsular Malaysia are concentrated in the eight government-designed granaries, with a total of 217,000 hectares. One of such granary is the Besut irrigation scheme, which was completed in 1977. This area is located between 102˚30’ ~ 102˚35’E and between 5˚37’ ~ 5˚45’N. The area encompasses 5,164 hectares of land, with climatic conditions favorable for rice production. One important aspect of the scheme is that the production cycle is based primarily on the annual rainfall pattern and distribution.

Evapotranspiration involves a highly complex set of processes, which are influenced by many local factors such as precipitation, soil moisture condition, plant water requirements, and the physical nature of the land cover [6]. In the Besut area, Malaysia, it is found from the 1985–2000 measured data that 65% of the mean annual precipitation becomes the mean annual actual evaporation. In view of this huge proportion, a good modeling of evaporation and evapotranspiration is required if water sustainability is to be achieved. Measurements of evapotranspiration are rarely available. In the absence of measurements, an alternative approach is to use mathematical models to predict the variations in evapotranspiration. The present study uses the Penman-Monteith evapotranspiration model [10], as well as the Pan evaporation method to estimate ET_o separately.

A fundamental part of understanding and improving water management is to be able to provide quantitative estimates of the major components of field water balance. The concept of the water balance or equilibrium is one of the greatest advances in understanding the response of crops in water-limited environments [4]. In existing irrigation systems, the proper estimation of different components of water requirements in the field (e.g. evapotranspiration, seepage, percolation and runoff) can lead to effective use of the available water resources and to optimise land areas cultivated with limited amounts of irrigation water. The water balance components can be quantified through field experiments, but this is often prohibitive because of the excessive time and expenditure involved in the execution, not to mention the tedious work that comes with it. Hence, mathematical models are being increasingly used in soil-plant-water relationships research. Once validated, these models allow for quantitative estimates of different parameters under varying conditions. The objectives of this study are to: (i) to compare simulated reference evapotranspiration with that derived from observed pan evaporation; (ii) to estimate seepage and percolation rate; and (iii) to determine effective rainfall for stable double cropping of rice for the selected irrigation scheme.

METHODOLOGY

The water balance components considered in the model are shown in Equation 1. The water balance equation for a single paddy field plot can be expressed as:

$$WD_j = WD_{j-1} - ERF_j + IR_j - ET_{cj} - SP_j - DR_j \qquad (1)$$

where:

WD water depth in the field

ERF effective rainfall reaching the field surface

ET_c	crop evapotranspiration (in general crop evapotranspiration is obtained by multiplying reference ET_o with a crop coefficient k_c which is dependent on the on among other factors, the stage of crop growth)
SP	mean seepage cum percolation rate
IR	the amount of irrigation supplied
DR	drainage
j	the period of water management considered

These components are expressed in depth units (mm) and the time period considered is one day. The inflow to the field consists of the total water supplied through precipitation and irrigation, whereas the outflow is made up of water leaving the field through evapotranspiration, surface runoff, seepage and percolation. The assumptions made are that the field storage is considered sufficiently represented by the impounded surface water and that the soil moisture is constant throughout the crop growth period. If the maximum depth of water possible in the rice field, the optimum depth and the minimum depth at which irrigation is to be given, are known or preset, then the water balance equation can be used for determining the irrigation schedules and the depth of water to be applied at each irrigation event. Rainfall occurring on the day will add to the water balance equation to such an extent that the field is capable of retaining the rainfall based on the initial depth of water on the day. Any excess rainfall will go out of the system as free drainage.

REFERENCE EVAPOTRANSPIRATION

The correct estimation of evapotranspiration in the water balance model allows improved water management in rice cultivation. One of the most important aspects of the water balance model is the crop evapotranspiration (ET_c), which is a key factor to determine proper irrigation schedule to improve water use efficiency in irrigated agriculture. Reference evapotranspiration (ET_o) can be estimated by many methods [11, 12]. These methods range from the complex energy balance equation (1) to simpler equations that require limited meteorological data [9]. According to Smith et. al; [14] the Penman-Monteith method gives more consistently accurate ET_o estimates than other methods. Md Hazrat et al. [13] also recommended this method after applying it in the Muda irrigation scheme in northwest Malaysia. Therefore, reference evapotranspiration was estimated by using Penman-Monteith equation as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (2)$$

where:

ET_o	reference crop evapotranspiration (mm/day)
R_n	net radiation at the crop surface (MJ/m^2/day)
G	soil heat flux density (MJ/m^2/day)
T	mean daily air temperature at 2 m height (˚C)
u_2	wind speed at 2 m height (m/sec)
e_s	saturation vapour pressure of the air (kPa)
e_a	actual vapour pressure of air (kPa)
$(e_s – e_a)$	saturation vapour pressure deficit (kPa)
Δ	slope vapour pressure curve (kPa/˚C)
γ	psychometric constant (kPa/˚C)

One of the limitations of the Penman-Monteith equation is that many data is required for its evaluation. At a minimum, the model requires air temperature, wind speed, solar radiation and humidity. The weather data of the study area were collected for a period of 18 years (1985-2002).

The other method recommended by Allen *et.al.* [3] to determine ET_o is the Pan Evaporation method. This method is by measuring pan evaporation (mm/day) using standard open water surface evaporation pans and relating this to ET_o by multiplying with an empirically derived pan coefficient.

EFFECTIVE RAINFALL

Effective rainfall (ERF) is that portion of rainfall that can contribute to the water requirements of growing rice in the field. The rainfall is only effective when it stored for and used in the rice fields. The effective rainfall for the irrigated condition can be estimated from the water use-rainfall ratio method [5] as follows:

$$ERF = \frac{ET_c + SP}{RF} * 100 \qquad (3)$$

where:

RF	total rainfall (mm)
ERF	effective rainfall, in percent
ET_c	crop evapotranspiration (mm)
SP	seepage cum percolation (mm), for 3-day periods

For efficient water use, rainfall should be fully utilised while unnecessary percolation is to be eliminated wherever possible. Daily rainfall data for a period of 48 years from 1951 through 1998 were obtained from the Department of Irrigation and Drainage (DID), Malaysia. Three stations were chosen considering their spatial representativeness as well as the availability of adequate data for the study. Weighted mean effective rainfall values were computed by taking means for the desired week, month, and season.

SEEPAGE AND PERCOLATION

Seepage and percolation losses in paddy fields involve horizontal and vertical movement of water through the soil profile respectively. In this study, soil conditions are assumed to be uniform and isotropic. Seepage cum percolation (SP) can be estimated by using the water subsidence technique as suggested by Ghani [7] and Giron and Wickham [8]; and is given as:

$$SP_t = \frac{WD_{t-1} - WD_t - ET_t}{5} \quad (4)$$

where:

WD — water depth measuring on the meter stick (mm) installed with 5:1 slope

ET_t — daily rate of crop evapotranspiration (mm)

t — the day of measurement

When rainfall occurred, an adjustment was made with overflow via the drainage structures provided in each field plot. The water depth information was obtained during a field survey.

DRAINAGE

Drainage in paddy fields is essentially a distributed process because the flow rate, velocity, and depth vary in space and time throughout the field plot. Drainage on any day occurs in the field, if the depth of impounded water on that day exceeds the height of the drainage gate structure. The amount of drainage predicted by the model is based on the equation given below:

$$DR_j = WE_j - \text{Gate height or Gate setting} \quad (5)$$

where the gate setting is 100 mm in this scheme.

In general, farmers have the tendency to irrigate rice fields whenever irrigation water is available in order to attain the maximum possible water level. In such a situation, if rainfall occurs, the fields are unable to capture any of the rainfall for storage so that a considerable amount of water is lost as drainage. To sustain water being impounded in a field for rice cultivation, the fields are leveled and surrounded by bunds of height 150 mm.

RESULTS AND DISCUSSION

The water balance model given above can be used for determining the water requirements of crops at a specific time period of the project. The model components are compared with data collected from the Besut irrigation scheme, Malaysia. The analysis of the model outputs is presented and discussed separately in the following sections.

REFERENCE EVAPOTRANSPIRATION

Daily average values of temperature, wind speed, possible sunshine and relative humidity taken from the Kuala Terengganu meteorological station were used as input variables to the reference evapotranspiration model. The mean monthly general weather conditions for each month of the year are shown in Figure 1. The reference evapotranspiration was evaluated to be 3.6 mm/day and 3.5 mm/day for off-season (May – October) and main season (November – April) crops respectively. Long-term daily average values were compared with the USBR Class-A Pan mean daily evaporation (1985 – 2001). Figure 2 shows that the long-term daily average estimates of reference evapotranspiration are within 95%

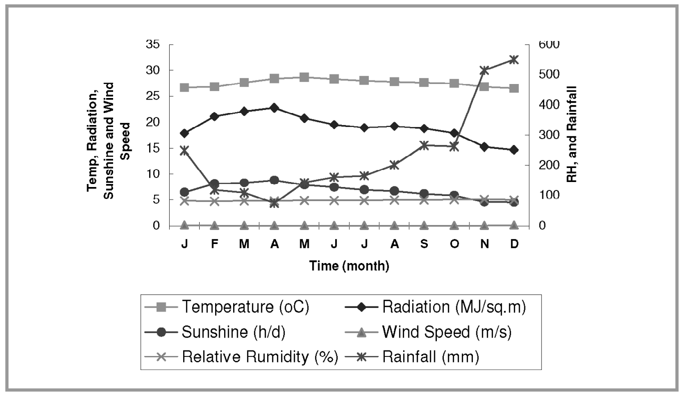

Figure 1: Mean monthly weather conditions at Kuala Terengganu, Malaysia (Source: Malaysian Meterological Services, Kuala Terenggau)

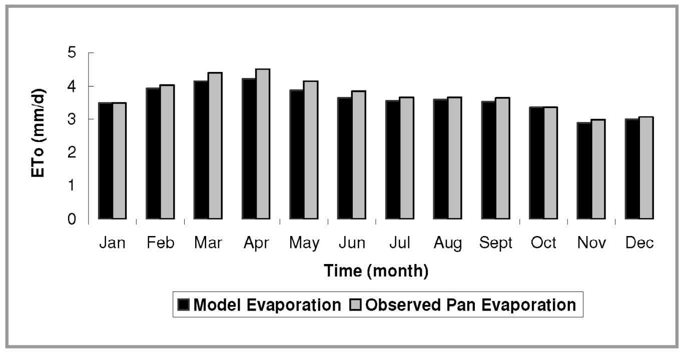

Figure 2: Comparison of modelled evapotranspiration and evapotranspiration derived from observed pan evaporation

agreement when compared with observed pan evaporation. The variations are however slightly higher from March to June.

EFFECTIVE RAINFALL

The distribution and effectiveness of rainfall were analysed for the study sites. The maximum total monthly rainfall in the study area occurs in October, November, December and January with 280, 590, 550 and 180 mm respectively, and these value are higher than the monthly evapotranspiration. Effective rainfall was estimated using the actual rainfall. The effective rainfall, based on the weekly data observed under the present conditions, was estimated to be 68% of total rainfall received during the pre-saturation period and 54% of total rainfall received during the rice growth stage. The weekly effective rainfall for the Besut irrigation scheme is presented in Figure 3. Figure 3 clearly indicates that irrigation supply can be reduced in the main season because of more rainfall occurrence during that period. With the

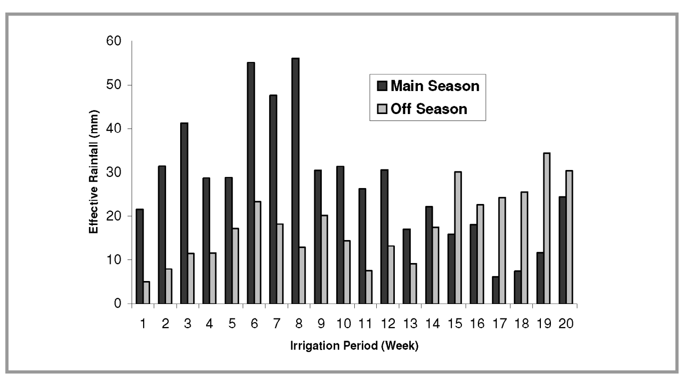

Figure 3: Weekly effective rainfall for both the main season and off-season

estimate of effective rainfall for the respective irrigation week, it is possible therefore to control pumping of water required (the scheme at present is on a run-of-the-river basis) or where possible if storage facility can be made available, excessive flows can be held to augment rainfall when required.

SEEPAGE AND PERCOLATION

In this study, seepage cum percolation was considered as single term SP. Based on field observation the seepage and percolation rate was estimated using Equation (4) and results are presented in Figure 4. The average seepage and percolation rate for the site was 2.2 mm/day in the main season, while during the off-season period the average rate was 2.7 mm/day. Many field tests on SP conducted by the Ministry of Agriculture, Malaysia [1] found that the SP rate is 2 - 3 mm/day for the site.

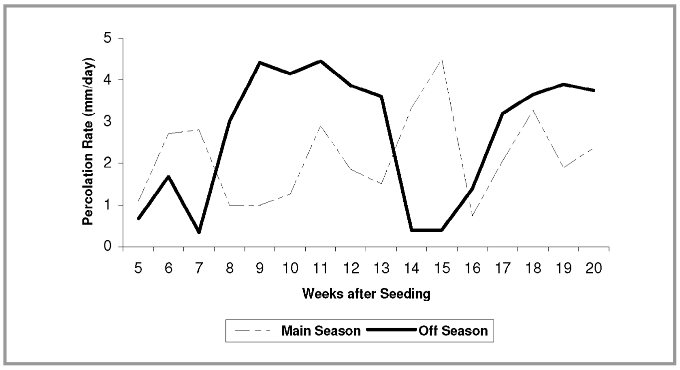

Figure 4: Seepage and percolation loss in the rice field

CONCLUSIONS

Efficient management of irrigation systems involves appropriate water deliveries to match crop water requirements and control of seepage from the conveyance system for attaining higher application efficiencies. Methods used to calculate the water balance components without model calibration were described. The model results were compared with observed data whenever possible. The reference evapotranspiration was found to be 3.6 mm/day and 3.5 mm/day for off-season and main season crops respectively. The referenced evapotranspiration estimated from observed pan evaporation values are slightly higher from April to June. The average seepage and percolation rate was found to be 2.2 mm/day and 2.7 mm/day for the main season and off-seasons respectively.

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