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Modeling Irrigation Water Delivery Schedule for Rice Cultivation in East Coast Malaysia

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ABSTRACT. *An irrigation water delivery-scheduling model has been developed to increase irrigation efficiency for a large-scale rice irrigation project in Malaysia. The study focused on modeling irrigation water delivery schedules during the main season and off-season of the rice-based project. The procedure used a water balance approach in which rainfall was considered as a stochastic variable. Rainfall and evapotranspiration values were used to estimate weekly irrigation water deliveries through the water balance equation. Comparison of the observed and computed irrigation delivery values for the main season and off-season showed that the observed values were higher than the computed values, indicating excess water supply in the field. With the application of this model, it was observed that a modification of the existing irrigation water delivery schedules would save a considerable amount of irrigation water during the main season and off-season. The computed irrigation schedules could save 19% and 11% of irrigation water in the main season and off-season, respectively when compared with the traditional irrigation schedules.*

INTRODUCTION

Many computer-aided models have already been developed with the aim of improving water management of irrigation projects. However, overall irrigation efficiency of rice schemes is less than 50% and lowers in the wet than in the dry season (Guerra *et al*., 1998). Poor distribution and management of irrigation water is a major factor contributing to this situation. Management of the irrigation scheme has usually been used with optimum crop production and efficient use of water resources. Performance assessment is considered to be one of the most critical elements for improving irrigation management (Abernethy and Pearce, 1987).

The estimation of irrigation delivery, its schedule and duration is a key element in any irrigation system. Irrigation water is conveyed in the main canal and secondary canals continuously and deliver water at the head of a secondary canal through a gate. The Japan International Cooperation Agency (JICA) suggested a detailed monitoring of water in individual irrigation compartment, which should be carried out to evaluate compliance with water allocations, but such information is not yet available in the *Besut* irrigation scheme, Malaysia. Effective use of water resources and impartial water allocation with a suitable water management practice are the key factors for increasing rice production (JICA, 1998). This study was conducted to develop an irrigation water delivery schedule model and to apply it to improve irrigation deliveries to discrete units of an irrigation system in Malaysia.

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MATERIALS AND METHODS

Study site

The *Besut* irrigation scheme is situated in the northeastern corner of Peninsular Malaysia in the state of Terengganu. The scheme consists of 2 sub-schemes, namely Angga Barrage sub-scheme and Besut Barrage sub-scheme. Those sub-schemes are further divided into a four compartments, with one compartment in the Angga sub-scheme (Compartment 2) and three compartments in the Besut sub-scheme (Compartment 1, 3, and 4). Compartments 1, 3 and 4 (totaling 4017 ha) receive irrigation supply by gravity flow from the Besut River System, while compartment 2 (1147 ha) receives irrigation supply also by gravity from the Angga River System. Furthermore, the scheme area is divided into 39 irrigation blocks or water-user groups. The main canals convey water downstream and the water is diverted to secondary and tertiary canals through discharge measuring off-take structures. Irrigation infrastructure of this scheme has been provided for double cropping rice. At present, water management problems are the most important constraints confronting the scheme in fulfillment of its goal.

The present cropping pattern is a rice-rice regime. The cropping calendar is characterized by two seasons, the main season and off-season. In the present calendar schedule, the first season crop is defined as off-season crop, and this lasts from May until October. The second season crop (the main-season crop) is cultivated between November and April. The design irrigation water duty of 2.33 l/s/ha for pre-saturation supply is used in this scheme. The average time taken for pre-saturation is 14 days from the time of irrigation water is received (JICA, 1998). After the crop has been planted, the supply is halved for the rest of the season.

Water balance approach

Irrigation delivery scheduling is essentially governed by the net irrigation requirement, which in turn is obtained through a water-balance relationship. Therefore, water balance relationship can be considered for determination of irrigation water requirements in rice field. A generalized water balance equation for a given period in a rice field is:

$$WD_j = WD_{j-1} + RF_j + IR_j - ET_j - SP_j - DR_j \quad (1)$$

where, WD is water depth in the field, RF is rainfall reaching the field surface, ET is crop evapotranspiration, SP is mean seepage and percolation rate, IR is the amount of irrigation, DR is surface runoff and j is the period of water management. These components are expressed in depth units (mm) and the time period considered is one day. Surface runoff is not available in these intensively managed rice plots as the plots are designed to prevent runoff. Therefore, the runoff term is omitted from the above equation.

Thus, daily water requirements in a rice field are the difference between the sum of evapotranspiration, seepage and percolation losses and water needed to raise the ponding depth from the available storage in the field. This can be expressed by a mass balance equation as:

$$WR_j = ET_j + SP_j + RP_j - WD_{j-1} \qquad (2)$$

where, WR is the water requirement (mm), RP is the required ponding depth (mm) and all the other terms are as previously defined. If part of the water requirement is met from rainfall, then the net irrigation requirement can be expressed as:

$$NIR_j = ET_j + SP_j + RP_j - WD_{j-1}\, ERF_j \qquad (3)$$

where, NIR is the net irrigation requirement and ERF_j is the effective rainfall and all other terms are as previously described. When RP_j is equal to WD_{j-1}, then NIR_j is equal to (ET_j + SP_j – ERF_j) which is the same as the water requirement definition commonly used in rice irrigation. However, it is rare that RP_j and WD_{j-1} are equal. The inequality of RP_j and WD_{j-1} leads to five possible different water balance conditions, determined mainly by level which WD_{j-1} falls short of or exceeds the required surface ponding depth. These conditions and net irrigation requirements are summarized in Table 1. The water balance components were analyzed for the entire period of crop growth, excluding land preparation period.

Table 1. Water balance conditions and net irrigation requirements of rice fields.

Water Balance Condition	Net Irrigation Requirement (NIR)
$(WD_{j-1} - RP) = 0$	$NIR = (ET_j + SP_j - ERF)$
$(WD_{j-1} - RP) > (ET_j + SP_j - ERF) > 0$	$NIR = 0$
$(WD_{j-1} - RP) = (ET_j + SP_j - ERF) > 0$	$NIR = 0$
$(WD_{j-1} - RP) < (ET_j + SP_j - ERF) > 0$	$NIR = (ET_j + SP_j - ERF - \Delta S^*)$
$(WD_{j-1} - RP) < 0$	$NIR = (ET_j + SP_j - ERF - \Delta S^*)$

$\Delta S^* = WD_{j-1} - RP_j$

The water balance relationship is used for characterizing the scheduling of irrigation systems. The basic assumptions in this model were: (i) the average paddy bund spill height is 150 mm, (ii) a uniform distribution of rainfall over each discrete unit and (iii) homogeneous soils within each unit. The value of seepage and percolation, SP is assumed to be constant throughout the growth period (3 mm/day) based on the value used for the design stage. However, this value is expected to vary from block to block depending on soil properties and local information could be used whenever available.

Evapotranspiration model

The reference evapotranspiration was estimated by using Penman-Monteith equation as follows:

$$ET_o = \frac{0.408?\,(R_n - G) + ?\,\frac{900}{T + 273}\,u_2\,(e_s - e_a)}{? + ?\,(1 + 0.34u_2)} \qquad (4)$$

where ET_o is reference crop evapotranspiration (mm/day), R_n is net radiation at the crop surface (MJ/m^2/day), G is soil heat flux density (MJ/m^2/day), T is air temperature at 2 m height (^oC), u_2 is wind speed at 2 m height (m/sec), e_s is mean saturation vapour pressure of the air (kPa), e_a is mean actual vapour pressure of the air (kPa), $(e_s - e_a)$ is saturation vapour pressure deficit (kPa), Δ is slope of the vapour pressure curve (kPa/^oC), γ is psychometric constant (kPa/^oC) and 900 is conversion factor. One of the limitations of the Penman-Monteith equation is its data requirement. At a minimum, the model requires air temperature, wind speed, solar radiation and humidity. The crop coefficient values given in published report (Chan and Cheong, 2001) for the study area were used and shown in Fig. 1. The weather data of the study area were collected for a period of 18 years (1985-2002).

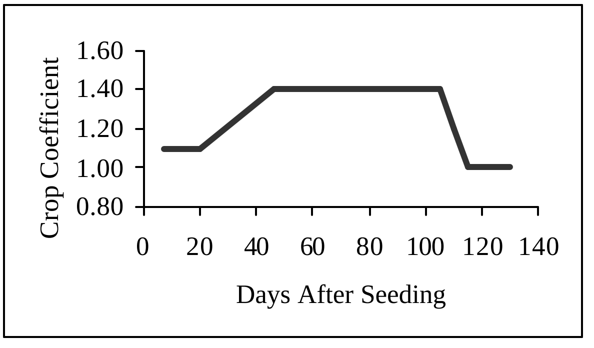

Fig. 1. Suggested crop coefficient (K_c) values for rice (MR84 variety).

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 is stored for and used by the rice fields. The effective rainfall for the irrigated condition can be determined by the drainage model of the International Rice Research Institute (IRRI, 1977) as follows:

$$ERF_j = \left(1 - \frac{DR_j}{RF_j + IR_j}\right) * RF_j \quad (5)$$

where RF_j is the rainfall during the period j, IR_j is the irrigation requirement during the period j, DR_j is the drainage requirement from the paddy field during period j, ERF_j is the effective rainfall during the period j, and j is duration in day.

In *Besut* irrigation scheme, where water is continuously supplied, excess water is drained whenever it exceeds maximum allowable level of water (RP) in the field. When standing water depth (WD_j) exceeds the maximum allowable water depth in the field, drainage is required as:

$$DR_j = WD_j - RP_j, \text{ if } WD_j > RP_j \quad (6)$$

For efficient water use, rainfall should be fully utilized and unnecessary percolation eliminated. For the purpose of this study, daily rainfall data for a period of 48 years (1951 – 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.

Diversion irrigation water delivery

The correct amount of irrigation water delivery is the key element to improving irrigation management of the scheme. For each period, all the water balance components have to be accounted for. During the main season, when rainfall is both frequent and heavy, incorporating rainfall can significantly reduce irrigation water. Spatial and temporal irrigation water delivery for a block through a gate can be estimated according to field requirements. Referring to Fig. 2, if water depth at the end of a period, WD_j is less than maximum allowable water depth, RP (*i.e.* WD_j <RP) then the sum of depleted standing water depth ($RP - WD_j$) and losses from rice field ($ET_j + SP_j$) and effective rainfall (ERF_j) are considered in the scheduling process, using the following equation:

$$Q_p = \frac{[(RP_j - WD_j) + (ET_j + SP_j - ERF_j)t]A}{8.64tE_s} \tag{7}$$

The amount of losses from the rice field ($ET_j + SP_j$) and effective rainfall (ERF_j) is considered during the scheduling process, where water depth remains the same or higher than the maximum allowable water depth (i.e. $WD_j = RP_j$). Then the diversion supply will be:

$$Q_p = \frac{(ET_j + SP_j - ERF_j)A}{8.64E_s} \tag{8}$$

where, Q_p is the predicted diversion water supply from gate in main canal (m^3/s), RP the maximum allowable water depth in the paddy field (cm), ET_j the average daily crop evapotranspiration during period (cm), SP_j the average daily seepage and percolation during period (cm), ERF_j the average effective daily rainfall during period (cm), *A* the irrigation area (ha), *t* the duration of water management period (days), E_s the irrigation efficiency, and 8.64 is the factor for conversion of depth (cm) of water over the area during the period to units of discharge measured in m^3/s. The value of E_s, the overall irrigation efficiency including irrigation efficiency and conveyance efficiency along the secondary canals, is believed to be between 45 and 60% respectively (JICA, 1998).

RESULTS AND DISCUSSION

Crop evapotranspiration

The monthly averaged daily values of temperature, wind speed, possible sunshine and relative humidity data, which were all used as input variables to the evapotranspiration model, were taken from Kula Terengganu station (latitude: $5^o23'N$, and $103^o06'E$), as it is the only viable meteorological station exists in the project. The mean monthly general weather conditions and crop water requirements (CWR) for each month of the year are shown in Fig. 3. The crop evapotranspiration was found to be 4.2

mm/day and 4.0 mm/day for off-season (May – October) and main season (November – April) crop respectively. Crop water requirements were higher during off-season crop compared to the main season crop, mainly as a result of prevailing weather condition. The average seasonal consumptive use of water for rice cultivation was 795 mm, out of which 572 mm (72%) was accounted for by ET and 223 mm (28%) by percolation.

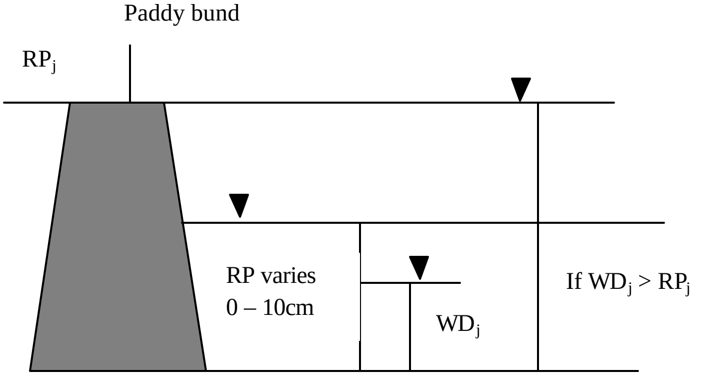

Fig. 2. Water depth in the paddy field.

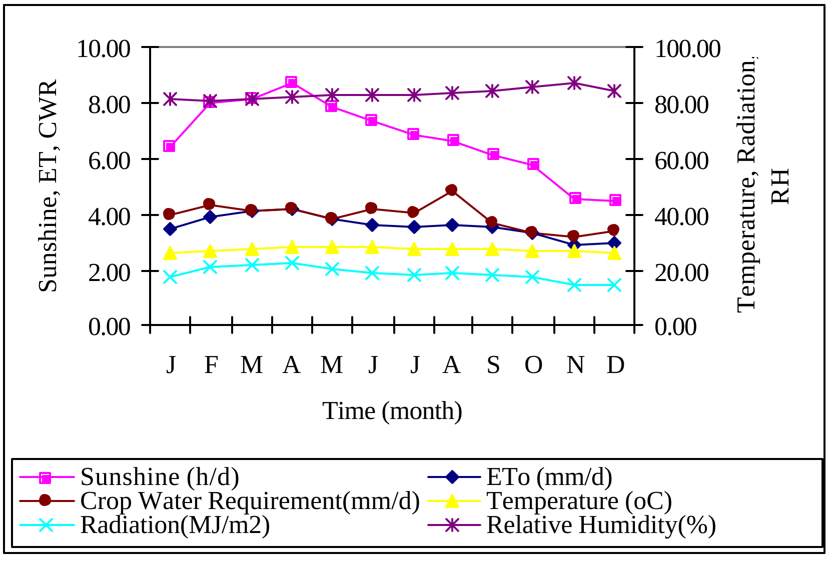

Fig. 3. General mean monthly weather conditions and crop water for the study area.

Rainfall distribution

Generally, crop production during the main season is influenced by the rainfall distribution and the crop duration. The mean monthly rainfall shows two maxima; a higher peak in October-December, and a lower peak in August (Fig. 4). Therefore, heavier rainfalls occur in October, November, December and January with 280, 590, 550 and 180 mm of rainfall, respectively. Almost half of the annual rainfall occurs during this period. Effective rainfall was estimated using the actual rainfall. In the scheme, effective rainfall was estimated at 0.68 during the land preparation period and at 0.54 during the rice growth stage based on the weekly data observed under the present conditions. The weekly effective rainfall for the *Besut* irrigation scheme is presented in Fig. 4. The total effective rainfall in main season was higher than in the off-season. However, the long-term records indicate that maximum rainfall occurs in main season with a monthly mean rainfall of 275 mm.

Irrigation water delivery

Based on effective rainfall and crop evapotranspiration, the daily water delivery was determined using the diversion irrigation model. Actual irrigation deliveries were obtained during a field survey. Comparison of the computed and observed irrigation deliveries is shown in Fig. 5 and 6. During the main season and off-season it was observed that the observed deliveries were greater than the computed deliveries. This was because of the rainfall considered into the computed irrigation water deliveries. There were few weeks (3^{rd}, 6^{th}, 8^{th}, 12^{th}) in which observed irrigation water deliveries were much higher than the crop water requirement during the main season. On the other hand, on 17th week onwards observed irrigation water deliveries were much less than the crop water requirement during the off-season. It was also observed that the main season water supply was 1045 mm of which 700 mm (67%) was supplied by irrigation and 345 mm (33%) by rainfall while the off season water supply was 1040 mm of which 790 mm (76%) was supplied by irrigation and 250 mm (24%) by rainfall.

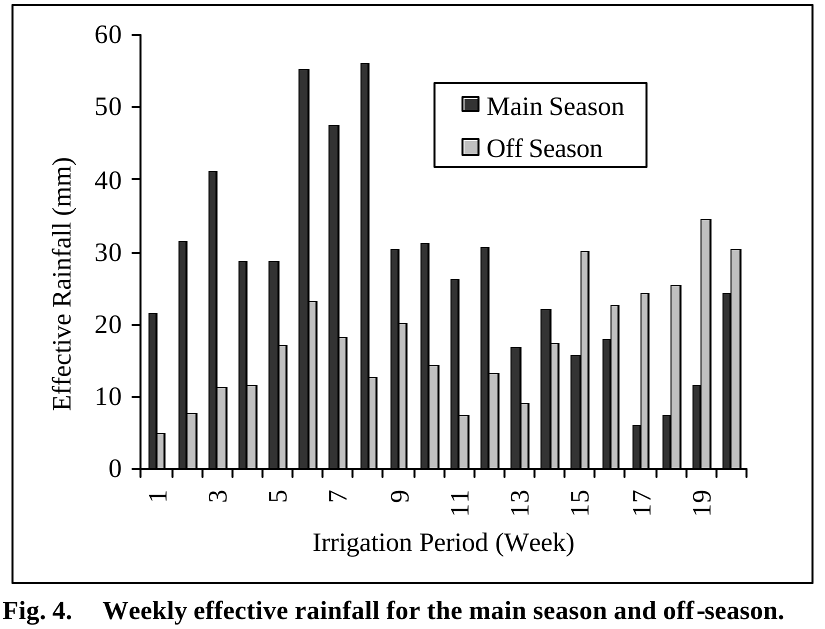

Fig. 4. Weekly effective rainfall for the main season and off-season.

The mean irrigation delivery obtained for the observed delivery period was 2.56 x 10^6 in the main season and 2.95 x 10^6 m^3 in the off-season. In contrast, the computed weekly mean irrigation deliveries are 2.15 x 10^6 and 2.66 x 10^6 m^3 in the main and off-season, respectively. Comparison of the observed and computed irrigation deliveries showed that the observed delivery was 19% and 11% more than the computed delivery for the main season and off seasons. Therefore, computed irrigation schedules could save 19% and 11% of irrigation water in the main season and off-season, respectively when compared with the current irrigation schedules.

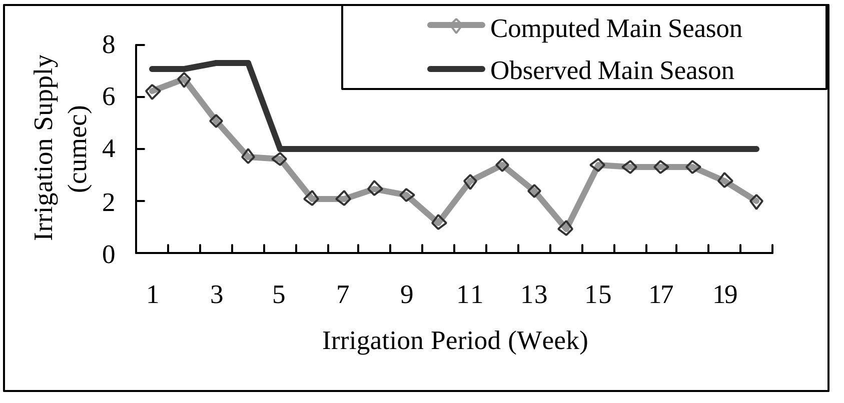

Fig. 5. Observed and computed irrigation water delivery in the main season

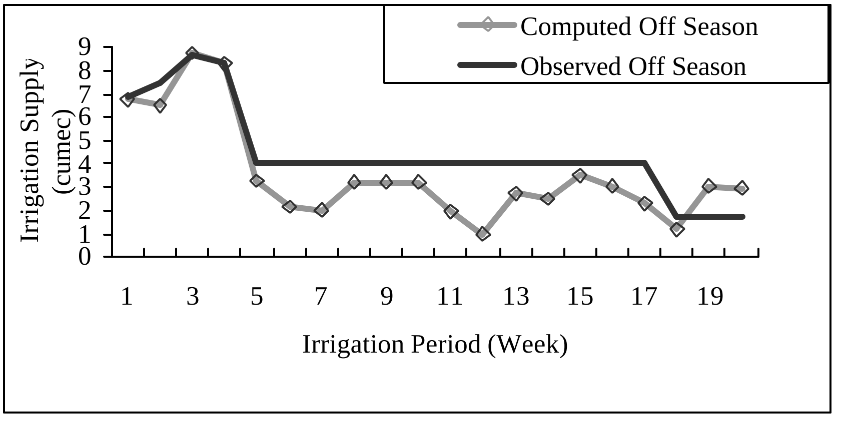

Fig. 6. Observed and computed irrigation water delivery in the off-season.

CONCLUSIONS

Not only is an accurate amount of irrigation water at the appropriate time beneficial for crop growth, but it is also a key to improving the efficiency of irrigation. This paper presents a mathematical model for computing irrigation water deliveries in various parts of the irrigation scheme. Proper estimation of different components of water requirements in the field (evapotranspiration, seepage and percolation) can help to achieve effective use of the available water and to optimize land areas cultivated under rice with limited amounts of irrigation water. The model results were compared with observed data whenever possible. It has also shown that during the seasons of heavy rainfall the water releases can be reduced by taking into account the amounts of effective rain. The study shows that the principle and methods proposed are feasible and rigorous, and the computer program is easy to apply.

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