RICE IRRIGATION SCHEDULING INCORPORATING STOCHASTIC RAINFALL

Lee Teang Shui[1] and Md. Aminul Haque[2]
[1]*Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor*
[2]*Water Resources Planning Organization, Ministry of Water Resources, Dhaka, Bangladesh*

ABSTRACT

An irrigation-scheduling program has been developed to increase irrigation efficiency in a large-scale rice irrigation project in Malaysia. The study focused on predicting daily irrigation deliveries for the main season and off-season and its performance was analyzed. A water balance approach in which rainfall was considered as a stochastic variable was used. Markov chain was used to describe the random occurrence of daily rainfall, and a skewed normal distribution was applied to generate the amount of rainfall on rainy days. Predicted rainfall and evapotranspiration values were later used to estimate weekly irrigation deliveries through the water balance equation. Comparison of the observed and predicted irrigation deliveries values for the 2000/2001 season showed that the observed values were higher than the predicted value indicating excess water supply in the field. It was observed that by modifying the existing schedules, it could save a considerable amount of irrigation water during both the main and off seasons. The periodic results obtained could be used to monitor the allocation of irrigation deliveries for improving the water management system. The present irrigation system was evaluated using an adequacy indicator. The adequacy indicator was computed by comparing the crop water requirement with the water release data. This computation provides information on the uniformity of water distribution and any shortfall or excess.

Keywords : *Stochastic rainfall, Irrigation delivery, Rice irrigation performance*

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 is lower in the wet than in the dry season [9]. The overall irrigation efficiency of the Besut Irrigation Scheme, Malaysia was reported to be 45% [15]. Poor distribution and management of irrigation water is a major factor contributing to this situation. Good management practices in an irrigation scheme usually targets for optimum crop production and efficient use of water resources, while performance assessment is considered to be one of the most critical elements for improving irrigation management [2].

Water allocation in an irrigation system is a complex problem. During each irrigation period, one must determine whether irrigation is necessary then, and if so, how much water is required during the period to achieve optimum crop growth. This problem is further complicated by the randomness of rainfall and the variability of crop evapotranspiration. Efficient use of rainfall is mandatory for improvement of irrigation efficiency, and necessitates management decisions designed to capture and store as much rainfall as possible within the field. If estimates of irrigation needs include making maximum use of the expected future rainfall, then significant amounts of water could be saved [8]. Computer models for real time irrigation scheduling can be used in combination with rainfall forecast to compute specific and timely amounts of irrigation. Rain forecasting, either of probability calculation or with the help of rainfall simulations under real-time scheduling, can be beneficially incorporated into irrigation scheduling. The contribution of rainfall to rice irrigation requirements can never be more very significant.

The estimation of irrigation delivery, its schedule and duration is a key element in any irrigation system. This decision-making process referred to as irrigation scheduling, depicts the use of water management strategies to prevent over-application of water while minimizing yield loss due to water shortage or drought stress. The standard method adopted for the calculation of crop water requirements is based on the evaporative demand of the crops for each prevailing stage of growth. There is potential for structuring information to improve the irrigation deliveries, and to develop an information system to improve decision-making in the operation and management of the scheme. The 'Irrigation Scheduling' program has been developed to determine irrigation deliveries to discrete units of a rice irrigation system.

STUDY AREA

The Besut Irrigation Scheme, located in the northeastern corner of Peninsular Malaysia in the state of Terengganu, is shown in Figure 1. The scheme consists of two subdivisions, namely the Angga barrage subdivision and the Besut barrage subdivision. These subdivisions are further divided into four compartments, with one compartment in the Angga subdivision (Compartment 2) and three compartments in the Besut subdivision (Compartments 1, 3, and 4). Compartments 1, 3 and 4 (totaling 4017 ha) receive irrigation supply by gravity flow from the Besut River, whilst compartment 2 (1147 ha) receives its irrigation supply also by gravity, from the Angga River. The entire scheme area is further divided into 39 irrigation blocks (water-user groups) for management purposes. One important aspect of the scheme is that the production cycle is based primarily on the annual rainfall pattern and distribution. The total mean annual rainfall is about

2900 mm, with extreme rain intensities reaching 400 mm/day. Monthly rainfalls of 280, 590, 550 and 180 mm occur respectively in October, November, December and January (JICA, 1998). About 40% of the total annual rains generally fall during this period (October – January). Significantly dry periods with low monthly averages are from March to August. Therefore, rainfall plays a very significant role for rice production in this scheme.

WATER BALANCE APPROACH

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

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

where, WD is water depth in the field, RF is rainfall reaching the field surface, IR is the amount of irrigation, ET is crop evapotranspiration, SP is mean seepage and percolation rate, 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 1 day. In Equation 1, the storage term is not considered due to the soil being essentially saturated during the growing season.

The water balance equation can be used for determining the irrigation schedules. The depth of water to be applied for irrigation can also be determined. Based on the initial depth of water in the field, the rainfall occurring on the day if any will be added (to the extent that the field is capable of retaining additional water) to the water balance equation. Excess rainfall will be removed through surface drainage.

Thus, if part of the water requirement is contributed through effective rainfall, then the daily net irrigation requirement can be expressed as:

$$NIR_j = ET_j + SP_j - ERF_j + RP_j - WD_{j-1} \quad (2)$$

where NIR is the daily net irrigation requirement, daily RP is the required ponding depth, ERF is the daily effective rainfall while all other terms are as previously described. When the field's current day's ponding depth (RP_j) is equal to its previous day's water depth (WD_{j-1}), then the current day's net water consumption is $NIR_j = (ET_j + SP_j - ERF_j)$ as is commonly practiced in rice irrigation. However, it is rare that RP_j and WD_{j-1} are equal. This inequality between RP_j and WD_{j-1} leads to four possible different water balance conditions and therefore daily net water requirements, determined mainly by which level, WD_{j-1} falls short of or exceeds the required surface ponding depth. These conditions and net irrigation requirements are summarized in Table 1.

When the required current day's ponding depth RPj is the same as the water depth in the field the previous day's WD_{j-1} that is when ($WD_{j-1} - RP_j$) equals to zero, then the current days' net irrigation requirement is ($ET_j + SP_j - ERF_j$). In the event when the previous day's water depth is more than the required current day's ponding depth, that is ($WD_{j-1} - RP_j$) greater than zero and $\{(WD_{j-1} - RP_j) - (ET_j + SP_j - ERF_j)\}$ equals or more than zero, then there is no need for irrigation for the day. In the case when the previous day's water depth is more than the required current day's ponding depth, that is ($WD_{j-1} - RP_j$) greater than zero but less than ($ET_j + SP_j - ERF_j$) then the current day's net water requirement is ($ET_j + SP_j - ERF_j - \Delta S$) with absolute $\Delta S = | WD_{j-1} - RP_j |$. Finally, when the previous day's water depth is less than the required current day's ponding depth, that is ($WD_{j-1} - RP_j$) less than zero, then the current day's net water requirement is ($ET_j + SP_j - ERF_j + \Delta S$).

The basic assumptions in this model were: (i) the average paddy bund height is 150 mm, (ii) a uniform distribution of rainfall over each discrete unit and (iii) homogeneous soils within each unit. The terms WD_{j-1}, and RP_j in Equation 2 are known values. RP_j is set at 100mm for all fileds. The value of seepage and percolation, SP_j is assumed to be constant throughout the growth period based on the value used for the design stage and is taken as 3mm/day [5]. The terms ET_j and ERF_j are calculated values. ET_j does not vary widely from day to day and the daily average value of ET_j is estimated using equation. ERF_j is based on historical rainfall data, averaged expected rainfall was taken to estimate effective rainfall using the following criteria: (a) If RF < 50mm, then weekly EFR = 0.6RF in mm and (b) If RF > 50mm then, weekly EFR = 0.3(RF – 50)+30 in mm [22].

The simulation process is based on the summation of daily water requirements for each field in the region based on the Equation 2 and Table 1 for the proposed cropping schedule. The daily values for each week are then totaled. The weekly total for the main season, following the proposed cropping schedule and the present existing schedule, for the whole scheme is then computed and the results are shown in Figure 7 and 8 respectively, bearing in mind that these are from different months (proposed and present schedule). Observed irrigation water delivery information for the main and off-

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

Water Balance Condition	Net Irrigation Requirement (NIRj)
$(WD_{j-1} - RP_j) = 0$	$NIR_j = (ET_j + SP_j - ERF_j)$
$\{(WD_{j-1} - RP_j) - (ET_j + SP_j - ERF_j)\} \geq 0$	$NIR_j = 0$
$0 < (WD_{j-1} - RP_j) < (ET_j + SP_j - ERF_j)$	$NIR_j = (ET_j + SP_j - ERF_j - \Delta S)$
$(WD_{j-1} - RP_j) < 0$	$NIR_j = (ET_j + SP_j - ERF_j + \Delta S)$
	$\Delta S = \| WD_{j-1} - RP_j \|$

season of the present existing schedule (seasons in 2001/2002) obtained from a field survey is similarly together shown in Figures 7 and 8 respectively.

EVAPOTRANSPIRATION MODEL

The correct estimation of evapotranspiration in the water balance model allows for improved water management in rice cultivation. A better understanding of the model is thus essential for exploring water-saving measures. One of the most important aspects of the water balance model is the crop evapotranspiration (ET_c), which is a key factor to determining proper irrigation schedule and to improve water use efficiency in irrigated agriculture. ET_c can be observed by direct measurements of water loss from a soil and vegetation sample using a lysimeter or could be estimated by a reference evapotranspiration (ET_o) and crop coefficient [7, 19]. ET_o can be estimated by many methods [13 - 14, 18]. These methods range from the complex energy balance equations [4] to simpler equations that require limited meteorological data [12]. According to Smith et al., [27], the Penman-Monteith method gives more consistently accurate ET_o estimates than other ET_o methods. Md Hazrat et al., [24] also recommended this method after applying it in the Muda Irrigation Scheme in northwest Malaysia. Reference evapotranspiration was estimated by using Penman-Monteith equation as follows:

$$ET_o = \frac{0.408\Delta (R_n - G) + \gamma \dfrac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1+0.3u_2)} \quad (3)$$

where ET_o is reference crop evapotranspiration (mm/day), Rn 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 (°C), 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 vapour pressure curve (kPa/°C), γ is psychometric constant (kPa/°C) and 900 is conversion factor. One of the limitations of the Penman-Monteith equation is its data requirements. At a minimum, the model requires air temperature, wind speed, solar radiation and humidity.

STOCHASTIC RAINFALL MODEL

Stochastic rainfall models are concerned with the time of occurrence and amount of rainfall. Various rainfall models have been proposed using different time scales. Daily rainfall models have gained wide applicability as being appropriate for use in detailed water balance and agricultural models. Among the proposed methods, a combination of Markov chain and a skewed normal distribution is recognized as a simple approach and is demonstrated to be effective in generating daily rainfall for many environments [10 - 11, 16 - 17, 28]. In this approach, a Markov chain is used to describe the occurrence of daily rainfall, and a skewed normal distribution is applied to predict the amount of rainfall for a rainy day.

Two assumptions underlying the first-order Markov chain are: (1) the probability that the current day is in a particular state (i.e. wet or dry) depends only on the state of the previous day; and (2) for a given season within the year, the stochastic structure of daily rainfall is the same for each day and does not change from year to year. It has been further assumed that these so-called transition probabilities are independent of the particular day within individual months. The probability of occurrence of daily rainfall consists of two transition probabilities, which are the daily rainfall to daily rainfall transition probability P (W/W), and daily non-rainfall to daily rainfall transition probability P (W/D). Therefore, the probability of a wet day after a dry day P (W/D) and the probability of a wet day following a wet day P (W/W) can be calculated directly using the following relationship:

$$P(W/D) = a + b f \quad (4)$$

$$P(W/W) = (1-b) + P(W/D) \quad (5)$$

where, f is perennial mean monthly rainfall frequency, being the ratio of the number of perennial monthly rainfall days and number of days of the month in this month, while a, b are regression coefficients.

Inputs for the model must include monthly probabilities of receiving rainfall. On any given day, the input must include information as to whether the previous day was dry or wet. The random number generation is from a Visual Basic 6.0 program written for this purpose. A random number between 0 and 1 is generated and compared with the appropriate wet-dry probability. If the random number is less than or equal to the wet-dry probability, rainfall is predicted to occur on that day. Random numbers greater than the wet-dry probabilities result in dry days. Since the wet-dry state of the first day is established, the process can be repeated for the next day and so on throughout the simulation period.

When a rainfall event has been predicted, the rainfall amount to be expected can be generated from a skewed normal daily rainfall distribution [25].

$$R_i = \left(\frac{\left[\left[\left(SND_i - \dfrac{SCF_k}{6.0} \right) \left(\dfrac{SCF_k}{6.0} \right) + 1 \right]^3 - 1 \right]}{SCF_k} \right) RSDV_k + \bar{R}_k \quad (6)$$

where R_i is the amount of rainfall in mm and SNDi is the standard normal deviate for day i respectively, while SCF is the skew coefficient, RSDV is the standard deviation of daily rainfall, and R is the mean daily rainfall respectively, for the month k. For each week, the total number of wet days predicted and their total respective sum total of rainfall can then be obtained.

IRRIGATION SYSTEM EVALUATION

The present irrigation system was evaluated using an adequacy indicator, which describes the water delivery system. The adequacy indicator answers the question – to what extent is the quantity of water provided sufficient for growth needs of the crops [1]. The relative water supply (RWS), defined by Nihal [26], describes the adequacy of water supply.

$$RWS = \left(\frac{IR + ER}{ET + SP} \right)$$

RWS is computed by the following expression:

where, ET is crop evapotranspiration from the rice field for a week, IR is the depth of irrigation supply for a week, ER is the effective rainfall for a week, and SP is the seepage and percolation loss for a week.

The RWS helps to identify acute shortage or excess supply of water. It is also useful at the end of every cropping season as part of the evaluation of the irrigation process. It keeps track of water delivery of a sub-system. Remedial action may be taken to rectify the situation.

DATA

A first-order Markov chain and skewed normal distribution method requires many years of daily weather records for estimating the model parameters. Daily rainfall data for six rainfall stations were obtainable from the Data Information Section, Department of Irrigation and Drainage, Malaysia. Three rainfall stations are in the Besut Irrigation Scheme while other stations are in its vicinity. The locations of the six rainfall stations are given in Table 2.

Table 2 : Location of Stations where Daily Rainfall Records were Collected for this Study

Station	Latitude	Longitude	Period of records
Ibu Bekalan Angga	5°36'00" N	102°30'55" E	1951-1998
Sek Keb Kg Jabi	5°40'45" N	102°33'50" E	1980-1998
Sek Keb Keruk	5°29'00" N	102°29'30" E	1980-1999
Sek Keb Kg Tambila	5°44'25" N	102°36'30" E	1980-1999
Rumah Merinyu Taliair	5°44'15" N	102°30'15" E	1948-1991
Pasir Akar	5°38'25" N	102°30'15" E	1980-1990

Weather data such as temperature, relative humidity, wind speed and sunshine hours of the study area for the period of 16 years (1985-2000) were obtained. The crop coefficient (K_c) values are shown in Figure 2 [6] and given in Table 5. Water delivery information was obtained during a field survey.

Table 5: Crop Coefficient Kc values for rice
(Source: Chan and Cheong, 2001)

Days	7	20	46	105	110	115	117	120	125	130
Kc	1.1	1.1	1.35	1.35	1.2	1	1	1	1	1

RESULTS AND DISCUSSION

The analysis of the irrigation-scheduling program is presented and discussed separately in the following sections.

Expected Rainfall

A simple linear regression analysis was performed for each location separately and for the combined data. Results in Table 3 show that none of the intercepts (**a** values) is significantly different from zero and none of the slope coefficients (**b** values) is significantly different from any other slope coefficient among the locations. The combined regression line with a zero intercept and slope 0.75 explains 96% of the total variation that existed among the transitional probabilities across time and space. Monthly transitional probabilities were then calculated with the fractions of wet days, and these are shown in Figure 3. To validate the stochastic rainfall model, which could be used for generating rainfall occurrence and rainfall amount, historical data from one rainfall station, the Angga station, was selected for validation. Figure 4 shows the Visual Basic 6.0 screen where the wet-dry probability calculated is then entered for the month and a random number is generated, after which the condition for the next day is given upon clicking "Start" button to initiate comparison of numbers. Inputting a relevant value into the relevant boxes and clicking "Calculate" button will compute and display the expected rainfall amount in a wet day as is shown in Figure 5. This model value will be used to predict irrigation delivery in the rice scheme. Comparisons of results for the year 2000/2001 seasons are presented (Figure 6). In terms of amount of rainfall, simulated results are very close to the observations, with a slight overestimation in a few weeks. The amount overestimated however is less than 5% of the observations in all cases.

Table 3 : Regression Coefficients a and b of Regressing the Transitional Probabilities of a Dry Day to a Wet Day for the Data at Six Rainfall Stations

Location	a	(s.e)*	b	(s.e)	r^2**
Ibu Bekalan Angga	0.002	0.006	0.725	0.028	0.980
Sek Keb Kg Jabi	0.008	0.041	0.810	0.029	0.975
Sek Keb Keruk	-0.015	0.012	0.856	0.041	0.970
Sek Keb Kg Tambila	0.021	0.004	0.721	0.035	0.969
Rumah Merinyu Taliair	-0.004	0.015	0.645	0.046	0.965
Pasir Akar	0.006	0.005	0.768	0.015	0.890
Combined	0.003	0.014	0.754	0.032	0.958

* s.e is the standard error **r^2 is the correlation coefficient

Crop Evapotranspiration

The monthly averaged daily values of temperature, wind speed, possible sunshine and relative humidity meteorological data, which are required input variables in the evapotranspiration model, were taken from the Kuala Terengganu station (latitude: 5°23'N, and 103°06'E), as it is the only viable meteorological station in the project area. The mean monthly general weather conditions and crop water requirements (CWR) for each month of the year are presented in Table 4. The crop evapotranspiration was found to be 4.20 mm/day and 3.99 mm/day for the off (May – October) and main (November – April) season crop respectively. Crop water requirements were higher for the off-season crop compared to the main season crop, mainly as a result of prevailing weather conditions. It is noted here that the consumptive use of water was also high for the dry season crop in the Muda Irrigation Scheme, Malaysia [20, 21, 23, 29]. The average seasonal consumptive use of water for rice cultivation was 795 mm, out of which ET accounts for 572 mm (72%) and percolation, 223 mm (28%).

Table 4 : General Mean Monthly Weather Conditions for the Study Area

Month	Temperature (°C)	Radiation MJ/m^2)	Sunshine (hr/day)	ET_o (mm/day)	Relative humidity (%)	Rainfall (mm)
January	26.63	17.81	6.40	3.50	81.14	248.56
February	26.83	21.17	8.02	3.94	81.06	117.27
March	27.59	22.14	8.17	4.14	81.57	108.98
April	28.40	22.78	8.68	4.22	81.87	74.12
May	28.63	20.74	7.85	3.89	82.67	142.12
June	28.33	19.52	7.39	3.66	83.12	159.85
July	27.98	18.89	6.83	3.56	83.10	164.76
August	27.79	19.19	6.61	3.61	83.84	201.40
September	27.62	18.77	6.13	3.54	84.47	265.41
October	27.48	17.84	5.78	3.39	85.46	261.99
November	26.82	15.20	4.54	2.90	87.30	514.52
December	26.51	14.68	4.47	3.00	83.93	647.54

Irrigation Delivery

Based on predicted rainfall and crop evapotranspiration, the daily water delivery was determined using the water balance model. Comparisons of the predicted and observed irrigation deliveries are shown in Figures 7 and 8. During the main season and off-season it was observed that the observed deliveries were greater than the predicted deliveries. However, the main season deliveries were higher than the off-season deliveries. This was because the effective rainfall was taken into consideration. It was also observed that the main season water supply was 1045 mm of which 700 mm (67%) was supplied through irrigation and 345 mm (33%) was by rainfall. The off-season water supply was 1040 mm of which irrigation supply accounts for 790 mm (76%) whilst the remaining 250 mm (24%) was fulfilled with rainfall.

Irrigation Scheme Evaluation

The adequacy of water supply to various weeks was characterized by estimating RWS for the season 2000/2001. The weekly RWS values for the main and off seasons are shown in Figure 9. In order to analyze the actual irrigation performance, actual RWS values should compare with the critical RWS value 1.0 and RWS value 1.5. If RWS = 1.0 at any day at the level of a typical block, then the implication is that the combined irrigation supply by the system and rainfall in that day exactly matches the actual demand. RWS value for a particular day should fall between 1.0 and 1.5 for an adequate supply relative to demand [26]. RWS values above this range indicate over supply and below results in an under supply situation. Values of RWS obtained ranged from 0.80 to 3.40. Out of 38 weeks (main and off season), 30 had RWS value more than 1.5. This indicated that farmers in the canal command areas generally tend to over-irrigate. The distribution weeks have been classified into five categories, i.e. excessive water surplus (RWS > 3.0), high water surplus (2.0 < RWS < 3.0), moderate water surplus (1.6 < RWS < 2.0), adequate water (1.0 < RWS < 1.5), and water deficit (0.8 < RWS < 1.0). There are five weeks (weeks 1 – 5) in which the water surplus is more than three times the requirement and four weeks (weeks 8, 9, 10 and 15) where more than twice the water required was received during the main season. During the off season period, the values for weeks 7, 14, and 17 were greater than 1.5 values due to heavier rainfall. If irrigation supply during this time is reduced to fully utilized effective rainfall, a lower demand from the barrage will be possible. It may be pointed out that RWS values for the main season are much more greater than those of the off-season period. This is partly due to the high rainfall that occurred during the main season.

CONCLUSIONS

The irrigation-scheduling program developed was able to predict the irrigation water deliveries of rice crop at a specific time period. In planning irrigation schedules for rice in a large irrigation system, stochastic rainfall is an important factor. A methodology for predicting irrigation deliveries of the rice scheme that incorporates the uncertainty in rainfall and crop evapotranspiration has been developed. The method is based on a water balance relationship that considers the stochastic nature of rainfall and evapotranspiration. It has been observed that the predicted irrigation deliveries were less than the actual irrigation deliveries for both the main and off-season seasons crop. Such information could assist irrigation system managers to reduce the amount of irrigation water that will be required during the coming days to meet crop water demand. The relative water supply irrigation index could be beneficially used to assess the performance of the irrigation scheme as it can provide details for identifying periods of either excess or shortage of water.

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Science, Technology and the Environment, Malaysia, for providing the funds for this study under Project IRPA 01-02-04-0422. The authors also wish to express their sincere gratitude and appreciation to the staff of the Besut Irrigation Scheme at Jertih, Terengganu and staff of the Department of Irrigation and Drainage at Ampang, Kuala Lumpur for their assistance during the course of the study.

REFERENCES

[1] Abernethy, C.L. *"Indicators of the performance of irrigation distribution systems*." In: Proceedings of the Symposium on the Performance Evaluation of Irrigation Systems. International Irrigation Management Institute (IIMI), Colombo, 23 November 1989.

[2] Abernethy, C.L., and Pearce, G.R. *"Research needs in third world irrigation."* Hydraulics Research Limited, Wallingford, UK, 1987.

[3] Agrosains, *"Northern Terengganu integrated development project."* Report prepared for Ministry of Agriculture, Malaysia. pp. 1 – 248, 1984.

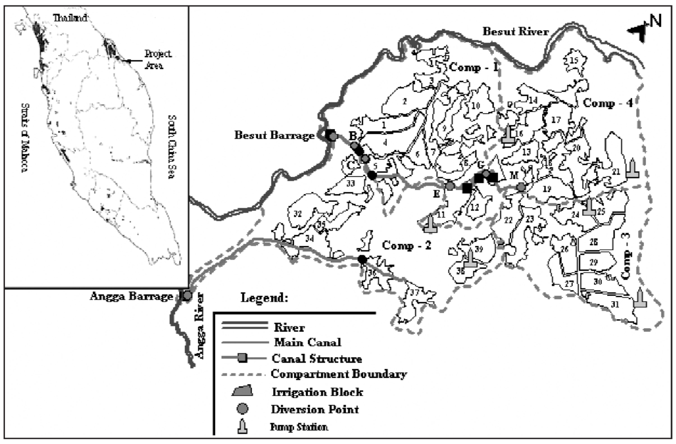

Figure 1: Location Map of the Besut Irrigation Scheme, Terengganu

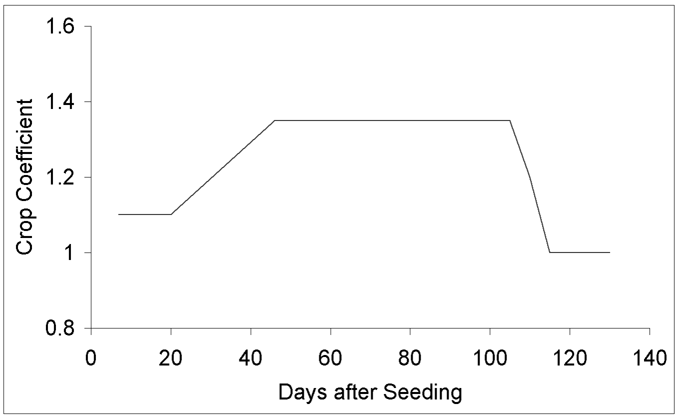

Figure 2: Suggested Crop Coefficient Values for Rice (MR84 Variety)

(Source: Chan and Cheong, 2001)

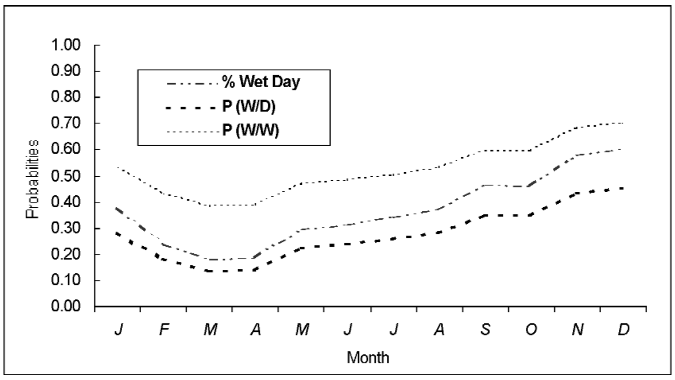

Figure 3: Transitional Probabilities and Fractions of Wet Days for Each Month

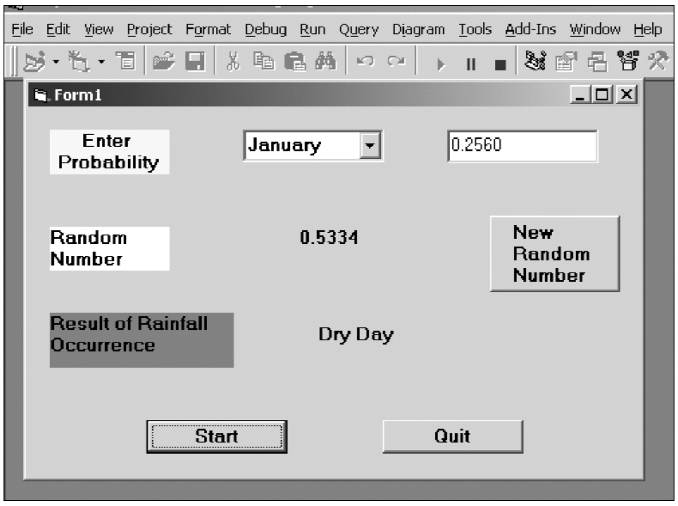

Figure 4: Visual Basic 6.0 Screen Showing the Rainfall Occurrence Result

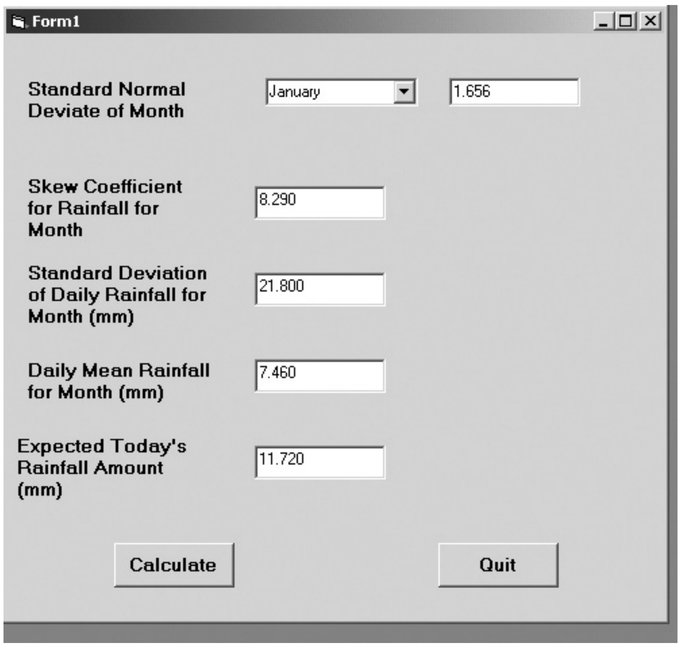

Figure 5: Visual Basic 6.0 Screen Showing the Rainfall Amount Result

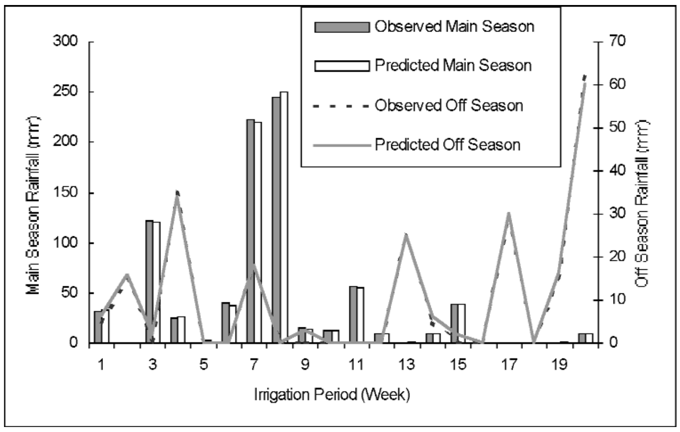

Figure 6: Comparison of Weekly Observed and Predicted Rainfall Values for Years 2000/2001

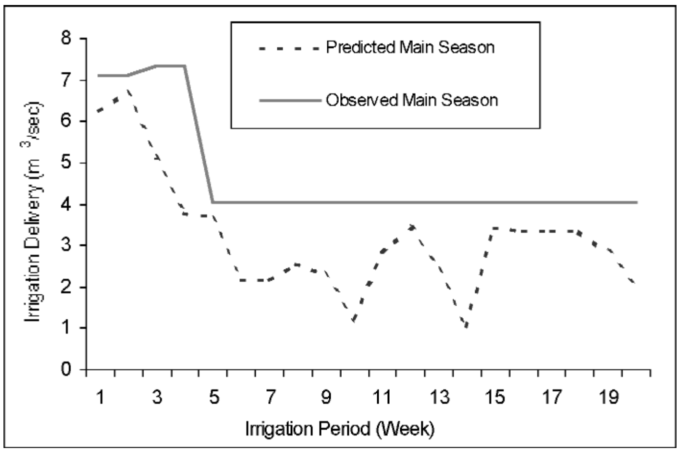

Figure 7: Observed and Predicted Irrigation Delivery for the Main Season

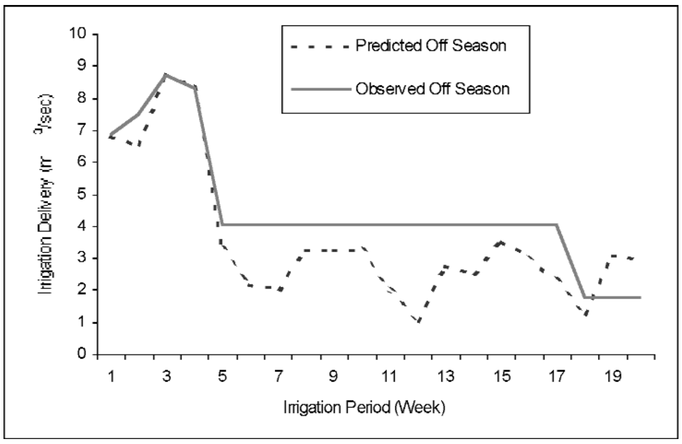

Figure 8: Observed and Predicted Irrigation Delivery for the Off Season

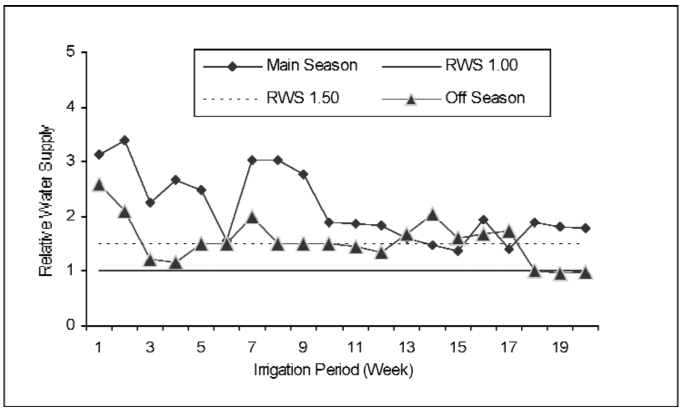

Figure 9: RWS Representing Weekly Irrigation Delivery Performance

[4] Allen, R.G., Jensen, M.E., Wright, J.L. and Burman, R.D. *"Operational estimates of reference evapotranspiration."* J. Agron., Vol. 81, No. 4, pp 650-662, 1989.

[5] Asian Development Bank (ADB), *"Northern Terengannu rural development project (Phase – II), Malaysia."* Interim Report Vol. 1, pp 1-198, 1992

[6] Chan, C.S., and Cheong, A.W. *"Seasonal weather effects on crop evapotranspiration and rice yield."* J. Trop. Agric. and Fd. Sc., Vol. 29, No. 1, pp 77-92, 2001.

[7] Doorenbose, J., and Pruitt, W.O. *"Guideline for predicting crop water requirements."* FAO Irrigation and Drainage Paper No. 24. Rome, Italy, p.193, 1977.

[8] Fathima Z. Siddeek, Theo A. Dillaha, and G.V.Loganathan, *"Water management for lowland rice irrigation."* J. Irrig. Drain. Eng., ASCE Vol. 114, No. 3, pp 407-423, 1988.

[9] Guerra, L.C., Bhuiyan, S.I., Tuong, T.P. and Barker, R. *"Producing more rice with less water."* SWIM Paper 5, IIMI, Sri Lanka, 1998.

[10 Garbutt, D.J., Stern, R.D., Dennett, M.D., Elston, J. *"A comparison of the rainfall climate of eleven places in West Africa using a two-part model for daily rainfall."* Arch. Met. Geophy. Biokl. Ser. B. Vol. 29, pp 137-155, 1981.

[11] Geng, S. *"A simple methods for generating daily rainfall data."* J. Agric. and Forest Meteo. Vol. 36, pp 363-376, 1986

[12] Hargreaves, G.H., and Samani, Z.A. *"Reference crop evapotranspiration from temperature."* Trans. ASAE, Vol. 1, No. 2, pp 96-99, 1985.

[13] Hill, R.W., Hanks, R.J., and Wright, J.L. *"Crop yield models adapted to irrigation scheduling."* Utah Agriculture Experimental Station Report No. 99, Utah State University, Logan, Utah, p.198, 1985.

[14] Jensen, M.E. *"Consumptive use of water and irrigation water requirements."* Irrig. Drain. Am. Soc. Civ. Eng., New York, 1974.

[15] JICA, *"The study on modernization of irrigation water management system in the granary area of Peninsular Malaysia."* Draft Final Report, Volume –II, Annexes, March, 1998

[16] Jimoh O.D. and Webster P. *"Stochastic modeling of daily rainfall in Nigeria: intra-annual variation of model parameters."* J. Hydrol. Vol. 222, pp 1-17, 1999.

[17] Jimoh O.D. and Webster P. *"Optimum order of Markov chain for daily rainfall in Nigeria."* J. Hydrol. Vol. 185, pp 45-69, 1996

[18] Kang, S.Z., Liu, X.M., and Xiong, Y.Z. *"Theory of water transport in soil-plant-atmosphere continuum and its application."* Chinese Hydraulic and Hydro-Power Press, Beijing, p.228, 1994.

[19] Kerr, G., Pochop, L., Fornstrom, K.J., Krall, J.M., and Brown, D. *"Soil water and ET estimates for a wide range of rainfed and irrigated conditions."* J. Agric. Water Manage., Vol. 24, pp 147-159, 1993.

[20] Kitamura, Y. *"Irrigation engineering research on system water management in the Muda scheme."* MADA-TARC Cooperative Study, February: 1-166, 1987.

[21] Kitamura, Y. *"Management of irrigation systems for rice double cropping culture in the tropical monsoon area."* Technical Bulletin of the Tropical Agriculture Research Center, No. 27, 1990

[22] Low, K.S., *Water Resources Assessment on the Tanjung Karang Irrigation Scheme.* Report of the Department of Irrigation and Drainage, 1984

[23] MADA, *"Fesibility report on tertiary irrigation facilities for intensive agricultural development in the Muda Irrigation Scheme."* Alor Setar, Malaysia, 1977.

[24] Md. Hazrat Ali, T.S. Lee, C.Y. Kwok, and A.F.Eloubaidy, *"Modelling evaporation and evapotranspiration under temperature change in Malaysia."* Pertanika J. Sci. & Technol., Vol. 8, No. 2, pp 191-204, 2000.

[25] Nicks, A.D. *"Stochastic generation of the occurrence, pattern and location of maximum amount of daily rainfall."* In Proc. Symp. Statistical Hydrology, Aug-Sept. 1971 Tucson, AZ. US Dept. Agric., Misc. Publ. No. 1275, pp. 154-171, 1974.

[26] Nihal F. *"Monitoring irrigation water delivery performance: the concept of Cumulative Relative Water Supply (CRWS)."* In: Proceedings of an international conference on advances in planning, design, and management of irrigation systems as related to sustainable land use, KUL, Belgium, pp. 525-534, 1992.

[27] Smith, M., Allen, R., Monteith, J.L., Perrier, A., Santos Pereira, L., and Sageren, A. *"Expert consultation on revision of FAO methodologies for crop water requirements."* FAO, Rome, Italy, p.60, 1992.

[28] Stern, R.D. and Coe, R. *"The use of rainfall models in agricultural planning."* J. Agric. Meteo., Vol. 26, pp 35-50, 1982.

[29] Yashima, S. *"Study of rice double cropping in the Muda area-development of field infrastructure."* MADA-TARC Cooperative Study, Quarterly Report No. 12, 1984.