Engineering Agricultural Water Resources

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ABSTRACT

Malaysia has a long history of experience in rice irrigation which spans from when the first scheme was built in 1892. The Kerian-Sungai Manik Irrigation Scheme which is located at Bagan Serai, Perak has a total acreage of 24000ha and the scheme is still in operation today. With the setting up of the Department of Irrigation and Drainage in 1932, there was more land for rice tilled under irrigation. In the 1960s the MADA Irrigation scheme in Kedah and Perlis, encompassing approximately 97000ha, was completed. With the inclusion of other later schemes such as the Besut Irrigation scheme in Terengganu, KETARA (5200ha,), KADA Scheme in Kelantan (26000ha), the Projek Barat Laut Scheme in Selangor (18000ha), the Seberang Perak Scheme (8500ha), PPPB Scheme in Pulau Pinang (9500ha) and the Kemasin-Semarak scheme (6500ha), make up the eight rice granaries existing today (194700ha, almost 390000ha under double cropping). Irrigation in Malaysia is almost entirely devoted to rice cultivation. Most of the irrigated rice areas in Peninsular Malaysia are located in the eight designed granaries. With recent rice supply being a bit chaotic with the sharp rise in price in the ASEAN region in early 2008, due in part to the calamities faced by some regions in the area, the Malaysian government has decided to increase its rice stockpile as well as place more lands under rice cultivation in Sabah and Sarawak.

Of the available total surface water resources of Malaysia, around 75% (10 billion cubic meters per year) is for use in agriculture. Irrigation is not only the largest consumer of fresh water in terms of volume, it is also associated with comparatively low economic value, low efficiency of use (< 50%) as well as being a highly subsidized natural commodity. However, it is a must-have venture in order to give a guarantee of at least 70% of the staple

food of Malaysia some figure of security. Thus, dams have to be built and maintained, water conveyance channels laid, control structures put in place for irrigation and drainage and pumps operated. All of this is just a part of the larger scheme of things, which incidentally includes the whole range of agricultural practices required in getting the grains to the markets. With the above mentioned scenario and the associated costs incurred, it is thus necessary to seek ways to better engineer and manage the water resources aspect of rice production so as to reduce the total cost of production of per unit tonne of rice grains produced in Malaysia. The total unit cost would invariably include a host of costs, but suffice to say that reducing the cost of water used in its production would help in a long way.

Many have ventured to say that if the water is not used, then we still have to build dams to store it lest it just flows to the sea. These words are true in every aspect but then again, it is during times of water stresses that these dams would be a real blessing to have. So where possible dams will have to be built if not for irrigation then for the sake of domestic supplies when a real emergency crops up like the infamous 1998 El Nino phenomenon. The present climate change agenda around the globe has made all governments more aware of the need to be safe rather than to be sorry.

This talk will cover the following topics: (a) Rainfall Inclusive Rice Irrigation Scheduling, (b) Modeling Run-of-the-River Scheme Water Allocation, (c) Cropping Calendar Scheduling, (d) Water Management Decision Support System: Water Allocation and (e) Water Management Decision Support System: Water Delivery

Lee Teang Shui

RAINFALL INCLUSIVE RICE IRRIGATION SCHEDULING

Introduction

Many computer-aided models have 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 (Guerra et. al, 1998). The overall irrigation efficiency of the Besut Irrigation Scheme, Malaysia was reported to be 45% (JICA, 1998). Poor distribution and management of irrigation water is a major factor contributing to this situation. Good management practices in an irrigation scheme usually targets 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 (Abernethy and Pearce, 1987).

Water allocation in an irrigation system is a complex problem. During each irrigation period, one must determine whether irrigation is necessary at that point of time, 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 (Fathima et al, 1988). Computer models for real time irrigation scheduling can be used in combination with rainfall forecasts to compute specific and timely amounts of irrigation. Rain forecasting, either by probability calculation or with the help of rainfall simulations under real-time scheduling, can be beneficially incorporated into irrigation scheduling. The significance of the contribution of rainfall to rice irrigation requirements can never be over emphasized.

The estimation of irrigation delivery, its schedule and duration, are key elements 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.

The Besut Irrigation Scheme completed by 1977, is located in the northeastern corner of Peninsular Malaysia in the state of Terengganu. as shown in Figure A1. 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 in October, November, December and January, respectively (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. Hence, rainfall plays a very significant role in 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. Hence, a water balance relationship can be considered for the determination of irrigation water requirements in rice fields. 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 to determine 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:

$$NIR_j = ET_j + SP_j - ERF_j + RP_j - WD_{j\text{-}1} \quad [2]$$

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 ponding depth (RP_j) is equal to the 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 are 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 A1.

Table A1 Water balance conditions and net irrigation requirements of rice fields

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

The four different possible water balance conditions are:

(a) When the required current day's ponding depth RP_j is the same as the water depth in the field the previous day, WD_{j-1} that is when ($WD_{j-1} - RP_j$) equals to zero, then the current days' net irrigation requirement is ($ET_j + SP_j - ERF_j$);

(b) In the event when the previous day's water depth is more than the required current day 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;

(c) In the case where the previous day's water depth is more than the required current day 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 $\Delta S = | WD_{j-1} - RP_j |$;

(d) Finally, when the previous day's water depth is less than the required current day 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 fields. 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 (Low, 1984).

The simulation process is based on the summation of daily water requirements for each field in the region based on Equation 2 and Table A1 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 (predicted main season) and the present existing schedule (observed main season), for the whole scheme is then computed and the results are shown in Figure A7, bearing in mind that these are from different months for the proposed schedule which differs from the months for the present schedule. Observed irrigation water delivery information for the off-season of the present existing schedule (seasons in 2001/2002) obtained from a field survey is similarly shown together with the predicted values (following the proposed cropping schedule for the off-season) in Figure A8.

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 crop evapotranspiration (ET_c), which is a key factor in determining proper irrigation scheduling 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 (Doorenbose and Pruitt, 1977; Kerr et al, 1993). ET_o can be estimated by many methods (Hill et al 1985, Jensen 1974, Kang et al, 1994). These methods range from the complex energy balance equations (Allen et al, 1989) to simpler equations that require limited meteorological data (Hargreaves and Samani, 1985). According to Smith et al., (1992), the Penman-Monteith method gives more consistently accurate ET_o estimates than other ET_o methods. Md Hazrat et al., (2000) 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:

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

where ET_o is reference crop evapotranspiration (mm/day), 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 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 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 (Garbutt et al, 1981; Geng et al, 1986; Jimoh and Webster, 1996 & 1999; Stern and Coe, 1982). 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 rainfall to daily non-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:

$$P\,(W/D) = a + b\,f \qquad [4]$$

$$P\,(W/W) = (1\text{-}b) + P\,(W/D) \qquad [5]$$

where, f is perennial mean monthly rainfall frequency, being the ratio of the number of perennial monthly rainfall days and number of days in that particular 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 (Nicks, 1974).

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

where R_i is the amount of rainfall in mm and SND_i is the standard normal deviate for day i respectively, while SCF is the skew coefficient, RSDV is the standard deviation of daily rainfall, and $\overline{R}$ is the mean daily rainfall, respectively, for the month k. Hence for each week, the total number of wet days predicted and the 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 (Abernethy, 1989). The relative water supply (RWS), defined by Nihal (1992), describes the adequacy of water supply. RWS is computed by the following expression:

$$RWS = \left(\frac{IR + ER}{ET + SP} \right) \quad [7]$$

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 for Rainfall Modelling

A first-order Markov chain and skewed normal distribution method requires many years of daily weather records to estimate the model parameters. Daily rainfall data for six rainfall stations were obtained from the Data Information Section, Department of Irrigation and Drainage, Malaysia. Three rainfall stations are in the Besut Irrigation Scheme while the other stations are in its general vicinity. The locations of the six rainfall stations are given in Table A2.

Weather data such as temperature, relative humidity, wind speed and sunshine hours for a period of 16 years (1985-2000) were obtained. The crop coefficient (K_c) values are shown in Figure A2 (Chan and Cheong, 2001) and given in Table A5. Water delivery information was obtained during a field survey.

Table A2 Location of Stations where Daily Rainfall Records were Collected

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

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 separately for each location and for the combined data. Results as presented in Table A3 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 A3. 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 A4 shows the Visual

Basic 6.0 screen where the wet-dry probability calculated is entered for the month and a random number is generated, after which the condition for the next day is given upon clicking the "Start" button to initiate comparison of numbers. Inputting a relevant value into the relevant boxes and clicking the "Calculate" button will compute and display the expected rainfall amount on a wet day, as is shown in Figure A5. This value will be used to predict irrigation delivery in the rice scheme. Comparisons of results for the year 2000/2001 seasons are presented (Figure A6). In terms of amount of rainfall, simulated results are very close to the observations, with a slight overestimation for a few weeks. The amount overestimated is however less than 5% of the observations in all cases.

Table A3 Regression Coefficients *a* and *b* from 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 A4. The crop evapotranspiration was found to be 4.20 mm/day and 3.99 mm/day for the off season (May – October) and main season (November – April) crops, 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 high for the dry season crop in the Muda Irrigation Scheme, Malaysia (Kitamura, 1987 & 1990; MADA, 1977: Yashima, 1984). 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 A4 General Mean Monthly Weather Conditions

Month	Temperature (°C)	Radiation MJ/m²)	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. Comparison of the predicted and observed irrigation deliveries is shown in Figure A7 and A8. 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%) 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 by rainfall.

Irrigation Scheme Evaluation

The adequacy of water supply in 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 A9. In order to analyze the actual irrigation performance, actual RWS values should be compared with the critical RWS value 1.0 and RWS value 1.5. If RWS = 1.0 for any day at the level of a typical block, then the implication is that the combined irrigation supply by the system and rainfall on 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 (Nihal,1992). RWS values above this range indicate over supply and when 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 of 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 were five weeks (weeks 1 – 5) in which the water surplus was 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 utilize effective rainfall, a lower demand from the barrage will be possible. It may be pointed out that RWS values for the main season were far greater than those of the off-season period. This is partly due to the high rainfall that occurred during the main season.

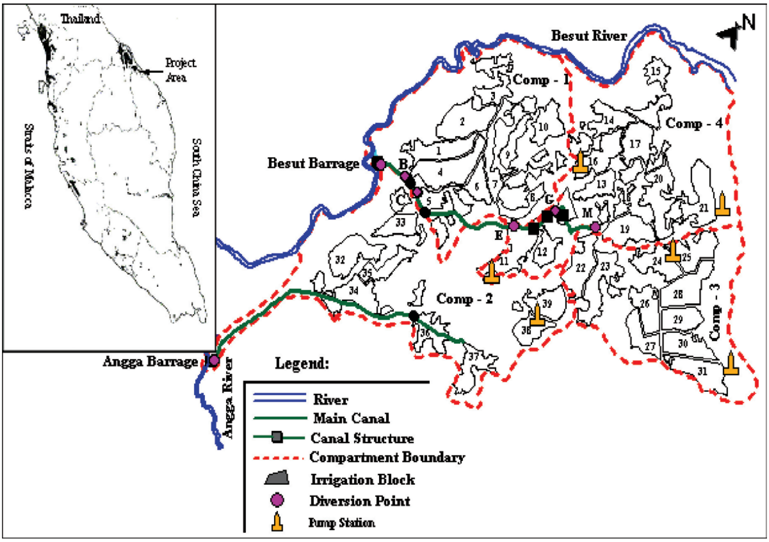


Figure A1 Location Map of the Besut Irrigation Scheme, Terengganu

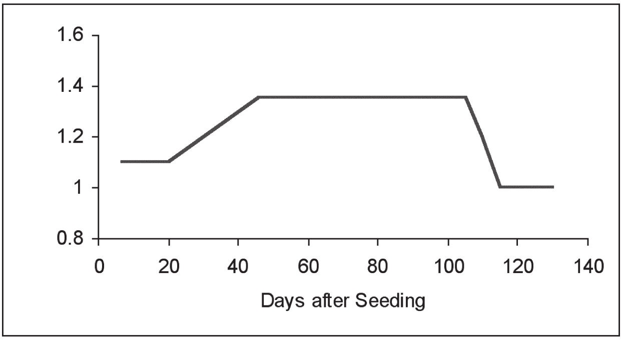


Figure A2 Suggested Crop Coefficient Values for Rice (MR84 Variety)
(Source: Chan and Cheong, 2001)

Table A5 Crop Coefficient Kc values for rice

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

(Source: Chan and Cheong, 2001)

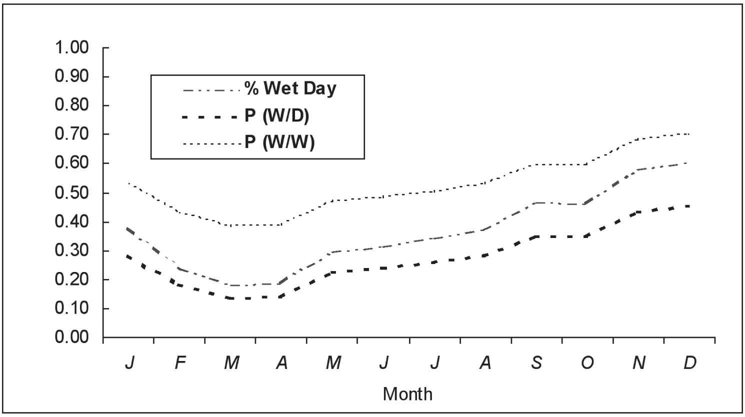


Figure A3 Transitional Probabilities and Fractions of Wet Days for Each Month

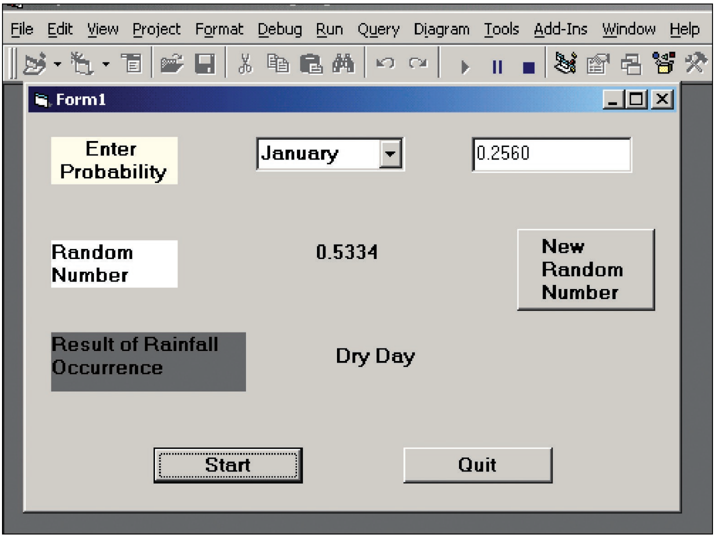


Figure A4 Visual Basic 6.0 Screen Showing the Rainfall Occurrence Results

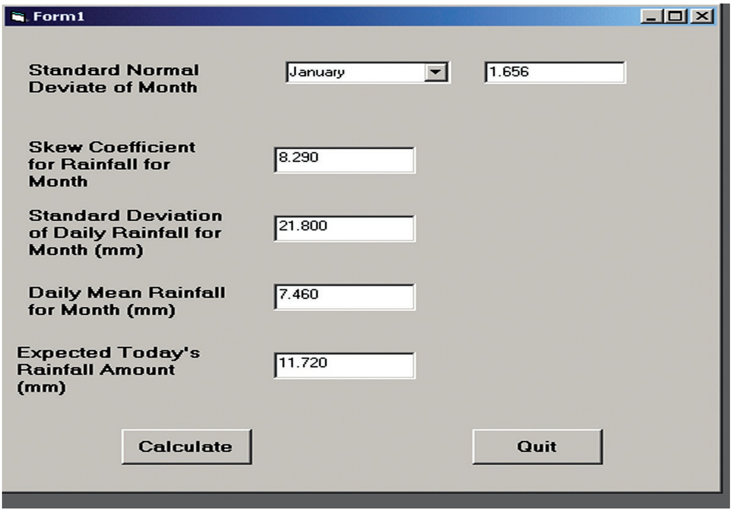


Figure A5 Visual Basic 6.0 Screen Showing the Rainfall Amount Results

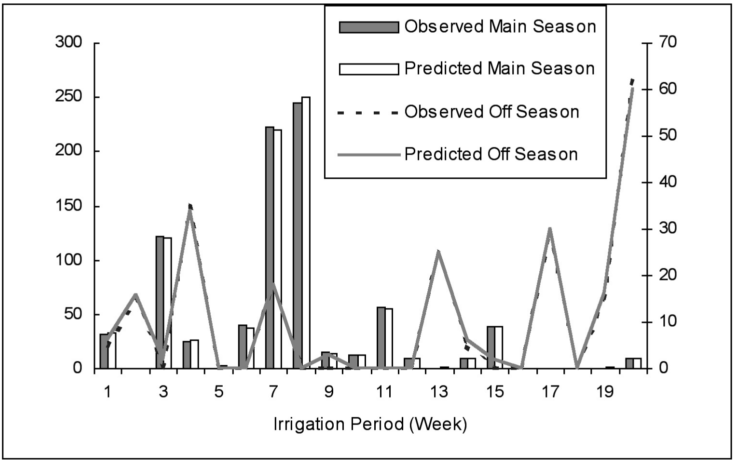


Figure A6 Comparison of Weekly Observed and Predicted Rainfall Values for Years 2000/2001

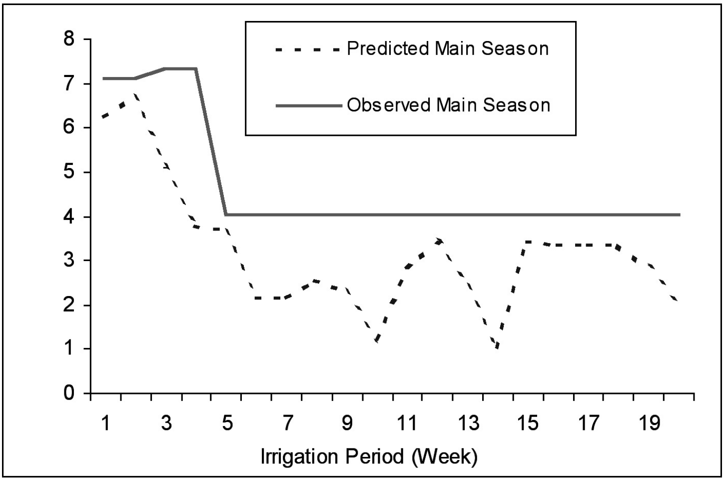


Figure A7 Observed and Predicted Irrigation Deliveries for the Main Season

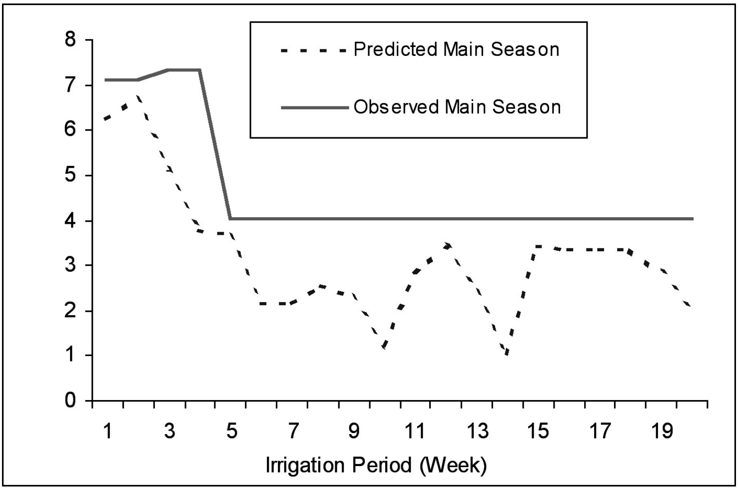


Figure A8 Observed and Predicted Irrigation Deliveries for the Off Season

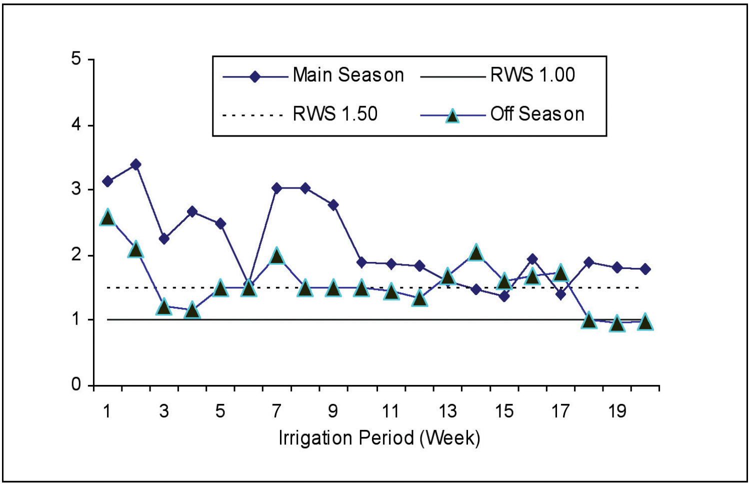


Figure A9 RWS Representing Weekly Irrigation Delivery Performance

Lee Teang Shui

MODELING RUN-OF-THE-RIVER SCHEME WATER ALLOCATION

Introduction

In irrigation schemes, water management has generally been used to refer to the practical management of available water resources. The aim is to achieve optimal crop production and efficient use of water. This may mean reliable, equitable and predictable water supply for farmers. Therefore, water management is an inherent component of the overall irrigation system management. Irrigation water management includes optimal allocation of water for irrigation purposes, over an irrigation season or number of seasons, and selection of a cropping pattern for a given land area and water availability. For this, it is necessary to have a guaranteed adequate water source, a good conveyance system and a distribution method to spread water over the land. Water management therefore, embraces the control of water for optimum crop yield with the best use of limited supply of water.

Water shortages have become more frequent and farmers often face deficiencies in water delivery, resulting in reduced yields and incomes. More efficient irrigation must be introduced for better food production which at the same time diverts water for other uses. Increased efficiency in the use of water is essential for future food security in Asia where rice production has to be increased by 70% of the present amount by the year 2025 (Hossain, 1997; Tuong and Bhuiyan, 1999). It is clear that irrigation services today have to take on multiple objectives aiming at specific targets with irrigation performance rather than just measuring how well water is delivered or managed. The final output from the overall system must justify the continued service of irrigation. A saving of 5% in irrigation water can meet 15% of the water demand from the domestic and industrial sectors (Teh, 1998). Thus, the operation and management policy of the irrigation system is vital to satisfy the supply required by the crop in each field. The water levels along main canals need to be maintained according to the system guidelines in order to supply the required flows to each location within the irrigation system. Therefore, it is essential to have an appropriate management policy with feasible options for the widely variable range of conditions possible in an irrigation scheme. The primary objective is to investigate effective allocation of available water resources in order to achieve higher water productivity.

The main canals in the Besut Irrigation Scheme convey water, which is then diverted into secondary and tertiary canals through discharge measuring offtake structures. Check gates are provided along the main as well as the secondary canals, to increase the water level in the canals if needed. Irrigation infrastructure in the scheme has been provided for double cropping rice with a canal density of 48 m/ha, a drain density of 37 m/ha and farm road density of 24 m/ha (Teh and Mat, 1999). Irrigation water supply adequacy is dependent on water levels at the Besut and Angga barrages. When the water levels (above mean sea level) of Besut and Angga rivers are above +13.9 m and +16.5 m respectively, the whole scheme can be irrigated continuously. However, when the water levels fall below these desired levels, the scheme will have to be irrigated selectively, or on a rotational basis.

When drought occurs, the drains become supplementary sources of water. There are six recycling pumping locations for re-use. There are two planting seasons each year, the main season and the off-season. This scheme faces water scarcity during both seasons with the present pre-saturation schedule. Pre-saturation water management problems are the most important constraints confronting the scheme in fulfillment of its goal.

Data

A proper irrigation water management system can benefit from availability of many years of daily climate records for estimating different parameters. Data and information such as weather records, hydrological data, water delivery records and canal diversions and discharges are required. The weather events such as temperature, relative humidity, wind speed and sunshine duration were collected from the Malaysia Meteorological Service (MMS). Rainfall data (rainfall stations in the scheme) were obtained from the Department of Irrigation and Drainage (DID), Malaysia. The canal conFigureuration data such as canal bed width, side slope, canal length, gate structures and specifications, water depth, full supply levels and main canal flow rates at different gauging points were obtained from the DID Headquarters, Malaysia. Water delivery information was obtained during a field survey. The relevant basic meteorological and canal information and data used are described in Table B1.

Table B1 Basic information and data collected

No.	Station	Data type	Period of record
1	Kuala Terengganu	Temperature (°C), Relative Humidity (%), Wind Speed (m/sec), Sunshine (hrs)	1985 -2000
2	Ibu Bekalan Angga (DID Rainfall Station)	Daily Rainfall	1951-2000
3	Rumah Merinyu Taliair (DID Rainfall Station)	Daily Rainfall	1948-1991

4	Sek Keb Kg Jabi (DID Rainfall Station)	Daily Rainfall	1980-1998
5	Canal Network Maps	Canal ConFigureuration Data, Full Supply Level	

Hydraulic Model

The *CanalMan* (Canal Management Software) model was used to perform hydraulic simulations of unsteady flow in branching canal networks. The CanalMan model developed by Utah State University, Logan, Utah, USA (Merkley, 1997) is based on partial differential equations (the Saint-Venant equations for one-dimensional flow) that allow the flow rate and water level to be computed as functions of space and time. It computes the flow rate and water level simultaneously, so that the model more closely approximates the actual unsteady non-uniform nature of flow propagation in a canal. The model is highly interactive and includes integrated data editing capabilities, with numerous options for canal system conFigureuration, hydraulic simulations, and output of results. Internal data cross-checking and input range restrictions on individual parameters help prevent infeasible conFigureurations and operating conditions. Canal networks are built interactively by inserting and arranging nodes graphically in a system layout window on-screen, where nodes represent locations of flow control structures and canal bifurcations.

CanalMan implicitly solves an integrated form of the Saint-Venant equations of continuity and motion (Strelkoff, 1969) for one-dimensional unsteady open-channel flow. The model uses computational nodes internally, and these are automatically inserted along the length of a canal reach, between the system layout nodes that are created. Simulations can be started by filling an empty canal system, continuing a previous simulation, or from a specified steady or unsteady flow condition. The model directly simulates the layout of canal systems, including branching canals. Canal reaches are separated by in-line control structures such as gates, or weirs. Several in-line structures can be independently simulated in parallel at the downstream end of a canal reach. Turnouts can be used to remove water from the simulated canal system or divert water into laterals or sub-laterals within the system.

The model uses canal conFigureuration data. Canal reach conFigureuration data files contain information about canal cross-section, length, depth, base width, slope, side slope, invert rise, Manning's roughness and seepage rate. In-line and turnout structure conFigureuration data files contain information about upstream and downstream depth, structure type, structure dimensions and operational settings. The canal system layout was demarcated to reach nodes considering canal structural specifications. One or more flow control structures are located at each node in the layout. A point where the dimension changes along canals was considered to be a demarcation of a reach. Each reach was parameterized with its own values in physical dimensions, upstream and downstream water depth, Manning's roughness and seepage rate. The structures at reach nodes are called in-line structures and those at bifurcation nodes are called lateral off-take structures. When there is an off-take, such as a diversion to a branching canal or a field off-take, it is parameterized with the gate or structure specific data. The end controls of the canals were also specified with their particular physical dimensions. Results from the model include flow depths in the canal reaches, volumetric flow rates and control structure (gate) settings at all as a function of time.

The collected data was used to determine data input into the model for the simulation of flows along main, secondary and tertiary canals. With information on the canal system, simulations were done to determine the validity of the simulation results. For this process, the available main canal data from field observations at different control structures (at diversion points B, C, E, G and M in Figure A1) were used. Four simulations were done with all the gate settings to check the validity of the model simulations with the measured flows at the diversion points. The validated model was then used to simulate water supply schedules.

Crop Water Requirements

Double cropping of rice demands plenty of water. More than half of the water supplied is used for pre-saturation; i.e. to presaturate and inundate fields before planting of the crop. The rice plant does not consume this pre-saturation water at its initial stage of growth. During pre-saturation period, the system should deliver at maximum capacity in order to reach all the fields as quick as possible to avoid delaying the planting of the rice. The water requirement for pre-saturation is theoretically 150 – 200 mm, but can be as high as 650 –900 mm when its duration is long (24 – 48 days) (De Datta, 1981; Bhuiyan et al., 1995). The water required during pre-saturation period can be calculated as follows:

$$LP = S + D + E + SP \qquad [1]$$

where, LP is water requirement during pre-saturation, S is saturation water, D is initial depth of flooding, E is evaporation rate and SP is percolation loss.

During the normal irrigation supply period, water required can be calculated on the basis of the formula (JICA, 1998) shown below:

$$DWR = \frac{ET_o * K_c + SP - ERF}{E} \qquad [2]$$

where, DWR is diversion water requirement, ET_o is reference evapotranspiration, K_c is crop coefficient, ERF is effective rainfall, and E is overall irrigation efficiency. The value of overall irrigation efficiency which includes irrigation efficiency and conveyance efficiency along the secondary canals, is believed to be 45% (JICA, 1998).

For soil saturation depth, a DID standard value of 150 mm is applied. For standing water depth, 100 mm is used for the pre-saturation period. The percolation, SP value is assumed to be constant throughout the growth period (3 mm/day). This result is based on the findings from many field tests on SP conducted by the Ministry of Agriculture, Malaysia and published by the Asian Development Bank (ADB 1992). Several forms of reference evapotranspiration (ET_o) equations appear in literature, each of which provides estimates of ET_o that differ from others (Wright, 1982; Allen et al., 1989; Jensen et al., 1990), but the FAO Penman-Monteith (Monteith, 1965; Allen et al., 1998) is now recommended as the standard method for the definition and computation of the ET_o. Md Hazrat et al. (2000) also recommended this method after applying it to the Muda irrigation scheme in northwest Malaysia. The crop water requirement was then determined from the product of reference evapotranspiration and crop coefficient. The crop coefficient (K_c) values given in a published source for the area were used (Chan and Cheong, 2001).

If part of the water requirement is met from rainfall, then the net irrigation requirement on day i (NIR_i) can be expressed as:

$$NIR_i = (ET_o * K_c)_i + SP_i - ERF_i + RP_i - WL_{i-1} \qquad [3]$$

where, RP_i is the required impounding depth, WL_{i-1} is field water level at time i-1, When RP_i is equal to WL_{i-1}, then NIR_i is equal to $((ET_o * K_c)_i + SP_i - ERF_i)$ and the water requirement commonly used in rice irrigation is as in Equation 2 above. However, it is rare that RP and WL_{i-1} are equal. The inequality between RP and WL_{i-1} leads to the possibility of four different water balance conditions, determined mainly by WL_{i-1} that falls short of or exceeds the required surface impounding depth This was mentioned in the first article and the same concepts are used again.

Canal Flow Simulation

Canal flow simulation was performed for the pre-saturation and normal irrigation supply periods. Different flow rates for the Besut and Angga barrages were used in the canal simulation process because flow rates change during the main season and the off-season. Canal simulation was started with design flow capacity and then a step-by-step decreased flow approach was applied at the Besut and Angga barrages. In each step of the simulation process, simulated flow values were compared with design canal flow values to obtain pre-saturation schedules. Canal gate openings were adjusted whenever the simulation flow was higher than the demand. All simulation results were analyzed and possible water distribution areas were identified for the pre-saturation period.

Based on the irrigation water requirements mentioned above, diversion water requirement at field off-take at the tertiary canals was then estimated for individual fields. The sum total of all the tertiary canals' requirements determines each of the secondary canal requirements needed at the main canal. These diversion water requirements obtained from model simulations were used in order to obtain normal irrigation schedules. Figure B1 shows the step-by-step procedure of model simulation.

Results and Discussion

The investigation revealed that 250 mm of water is needed for the pre-saturation phases for the main season and off-season. The mean monthly general weather conditions and crop water requirements (CWR) for each month of the year are shown in Figure B2. The evapotranspiration (ET) was found to be 4.20 mm/day and 3.99 mm/day for the off-season and main 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. The average amount of water expended for rice cultivation was 795 mm, out of which 572 mm (72%) was accounted for by ET and 223 mm (28%) by percolation. The average seasonal water supply was 1045 mm of which 732 mm (70%) was supplied by irrigation and 313 mm (30%) by rainfall.

The simulation results used to validate the CanalMan model is illustrated in Figure B3. It shows a deviation of less than ± 5% at all the diversion points. The highest average deviation is at point G (4.6%), while the lowest average deviation is at point E (-0.5%). There is no significant difference between observed and simulated flow values at the 95% confidence level.

During the pre-saturation period considered for model simulation, in the first two weeks, the requirement for the rice crop comprises only the water requirement for land preparation. During this period, various flow rates for the Besut and Angga barrages were used in the model simulation process. Simulation results were compared with the canal design capacity, as actual canal flow information was not available. Table B2 shows the example of the secondary canal flow simulation for the case of available flows of 9.00 m^3 s^{-1} and 3.00 m^3 s^{-1} at the Besut and Angga barrages respectively. Pre-saturation schedules were obtained from such comparisons for varying flow availability from the Besut and Angga barrages.

During the pre-saturation period, it was found that the total scheme area could not be inundated continuously in a single operation unless flow rates were 9.00 $m^3 s^{-1}$ and 3.00 $m^3 s^{-1}$ for the Besut and Angga barrages respectively. It was also noted that if flow rates were ever to fall below these values, pre-saturation water supply activity should then be carried out over two or three phases. Thus, based on these model simulations, the areas recommended to receive water are identified and presented in Table B3 as management schedules. Phase-I area is supplied first for a pre-saturation period of 14 days at 2.10 $l s^{-1} ha^{-1}$. After 14 days, the same rate is supplied to the Phase-II areas. However, if the flow rate is between 5.00 and 5.50 $m^3 s^{-1}$ at the Besut barrage then pre-saturation should be carried out in three phases. In this case, in each phase, water is to be supplied for pre-saturation time of 21 days at 1.38 $l s^{-1} ha^{-1}$. Should the flow rates fall below 5.00 $m^3 s^{-1}$ and 1.50 $m^3 s^{-1}$ at the Besut and Angga barrages respectively then pre-saturation inundation should be supplemented by using recycling pumps. Under this circumstance, cultivation of the whole area will not be ensured. Table B4 shows the results of the percentage of acreage that can be supplied with water using the present pre-saturation schedule and the simulated schedule. It was found that the irrigable area could be increased by 10% with better knowledge, control and allocation of available river flows.

After pre-saturation, from the fifth week onwards, the normal irrigation water supply period commences and lasts through the next 100 days. Canal simulations combined with water balance approach can also determine the normal irrigation schedules. During this normal irrigation supply period, 5.00 $m^3 s^{-1}$ and 1.50 $m^3 s^{-1}$ flow rate for Besut and Angga barrages must be maintained, respectively, throughout the entire period to provide the requirements for the whole scheme. In the event available flows fall short of the expected values stated above, the simulation process can be repeated to identify areas suitable for irrigation and those best left alone in view of limited supplies.

Since available irrigation water in the run-of-the-river scheme is quite limited, proper operation of diversion gates as well as timely water distribution is essential for maximum exploitation of water resources. It has been practically observed that excess supply of water into branch canals occursthrough some gates . It is good practice to adjust these gates to ensure that only adequate amounts of water are diverted into the canals. When the Besut barrage flow is above 7.00 m^3 s^{-1}, it was found that most of the gates opening could be adjusted by up to 75% rather than keeping them fully opened. Few gates could be operated satisfactorily at 50% opening. Intermittently, it must be mentioned that as of now, there is no provision for storage of water saved. Unused water flows flow into the sea which is not far from the scheme. However, excess water can contribute to the buffer to the advancing intruding fresh water – seawater interface.

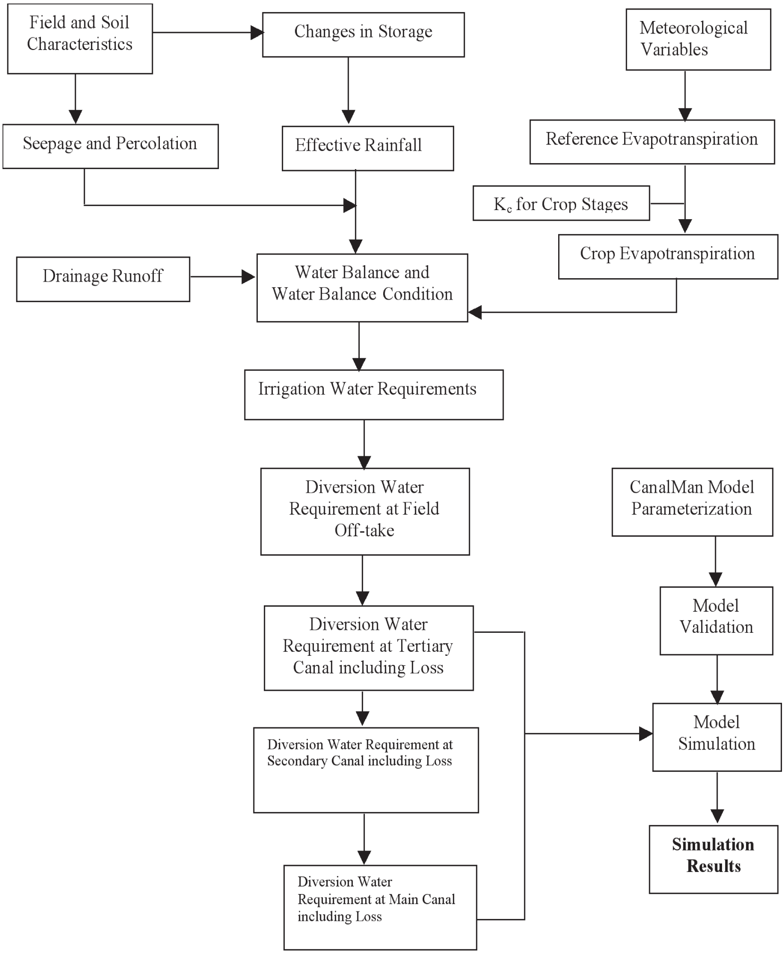


Figure B1 Step-by-step procedure of model simulation combined with crop water requirement

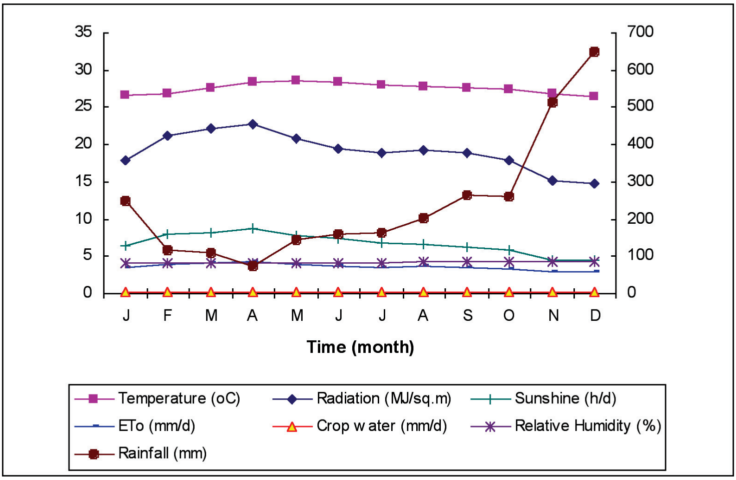


Figure B2 General mean monthly weather conditions and crop water requirements (CWR)

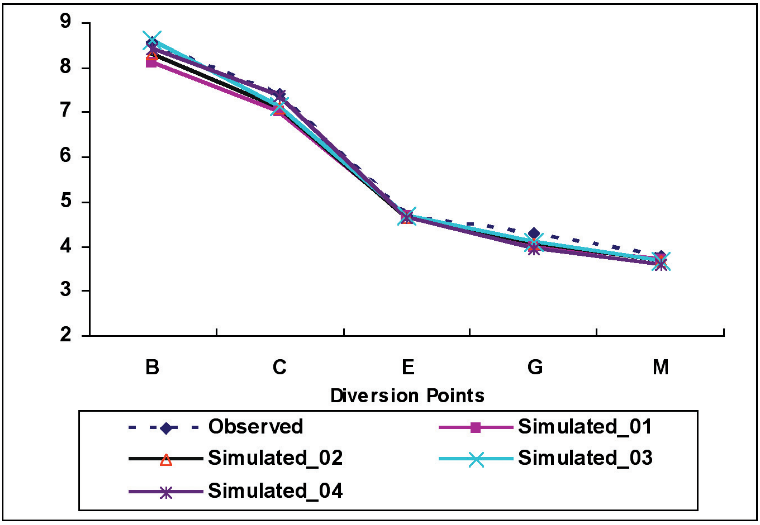


Figure B3 Comparison of simulated and observed flow at diversion points

Table B2 Example showing model simulation results in the pre-saturation period

Secondary Canal Name	Design Flow	Simulated Flow	Secondary Canal Name	Design Flow	Simulated Flow
	(l/sec)	(l/sec)		(l/sec)	(l/sec)
Besut barrage sub-scheme (Compartment 1, 3, 4)					
Comp- 1					
Lubuk Kawah	1075	1080	Lubuk Agu	456	457
FC1/CD	80	80	FC2/CD	80	81
FC1/DE	41	40	FC2/DE	55	56
FC3/DE	80	80	Gong Lawan	46	48
FC4/DE	60	62	Telaga Nibong	1464	1467
Tok Nga	94	94	Kayu Kelat	133	134
Gong Kulim	205	206	Kubang Depu	256	256
Pulau Ribu	254	255	Tok Bugis	124	125
Chenerong	96	97	Gong Rengas	126	126
Comp - 3					
NN1	275	277	NOa	177	178
FC1/NO	155	155	OO1	567	570
PP1	572	571	QQ1	415	416
QQ2	944	945	Q2a	262	260

Q2b	286	285	Q2c	396	396
Comp - 4					
Apal	118	119	FC1/FG	262	262
M1a	264	266	M1b	213	215
HH1	168	170	II1	525	528
IJ	719	719	JK	455	456
KK1	107	110	KL	152	150
LL1	64	66			
Angga barrage sub-scheme (Compartment 2)					
Comp - 2					
Padang Baloh	756	760	Melintang	86	86
Awek	555	555	RR1	80	81
FC1/RS	32	33	FC2/RS	56	55
SS1	227	230	ST	750	752

Table B3 Pre-saturation schedules based on available discharges derived from model simulation

Subdivision Name (compartments)	Barrage Flow (m^3/sec)	Irrigable Area (KPA* Unit)		
		Phase-I Area	Phase-II Area	Phase-III Area
Besut Barrage (1,3,4)	> = 9.00	C – 1 (KPA - All); C – 3 (KPA - All); C – 4 (KPA - All);	----	---
	8.20 – 8.90	C – 1 (KPA – All); C – 4 (KPA – All); C – 3 (KPA – 22 – 25);	C – 3 (KPA – 26 – 31);	---
	7.20 – 8.10	C – 1 (KPA – All); C – 4 (KPA – 11 – 20); C – 3 (KPA – 22 – 25);	C – 4 (KPA – 21); C – 3 (KPA – 26 – 31);	---
	6.20 – 7.10	C – 1 (KPA – All); C – 4 (KPA – All);	C – 3 (KPA – All);	---
	5.60 – 6.10	C – 4 (KPA – All); C – 3 (KPA – 22 – 25);	C – 1 (KPA – All); C – 3 (KPA – 26 – 31);	---
	5.00 – 5.50	C – 4 (KPA – 11- 20); C – 3 (KPA – 22 – 23);	C – 1 (KPA – All);	C – 4 (KPA – 21); C – 3 (KPA – 24 – 31);

< 5.00	Start pumping for recycled water for irrigation			
Angga Barrage (2)	> = 3.00	C – 2 (KPA – All);	---	---
	2.20 – 2.90	C – 2 (KPA – 32 – 35);	C – 2 (KPA – 36 – 39);	---
	1.50 – 2.10	C – 2 (KPA – 32, 33, 35);	C – 2 (KPA – 36 – 39);	---
	< 1.50	Start pumping for irrigation		

*KPA- Kumpulan Pengguna Air [local Name; i.e. irrigation water user's group]

All denotes all KPA units, C denotes compartment, KPA – 22 – 25 denotes from unit KPA 22 to unit KPA 25 etc.

Table B4 Comparison of pre-saturation gravity flow schedules and area (%) completed based on available discharges

Subdivision (compartment)	Available Flow rate (m^3/sec)	Under Existing schedules		Total area (%) supplied	Under Simulated schedules		Total area (%) supplied
		Phase-I	Phase-II		Phase-I	Phase-II	
Besut Barrage (1, 3, 4)	>= 9.00	100	---	100	100	---	100
	8.2 – 8.9	74	18	92	82	18	100
	7.2 – 8.1	72	19	91	77.5	22.5	100
	6.2 – 7.1	62	28	90	68	32	100
	5.6 – 6.1	45	44	89	51	49	100
	5.0 – 5.5	36	29 (24)*	89	40	31(29)*	100
Angga Barrage (2)	>= 3.00	100	---	100	100	---	100
	2.2 – 2.9	39	44	83	56	44	100
	1.5 – 2.1	39	40	79	39	44	83

* Phase-III area (%) – supply over three phases required in view of low flows

CROPPING CALENDAR SCHEDULING

Introduction

Water management methods that improve irrigation efficiency have the potential to greatly increase rice production. Generally, the prospects for increased rice production depend on an increase in yield per hectare and the number of crops cultivated per year (Zandstra, 1980). Hence, research into methods that increase annual output per unit area must be intensified. In most rice-growing areas, the year is divided into distinct rainy (wet) seasons and non-rainy (dry) seasons. During the rainy season, rice is grown with supplemental irrigation whereas during the drier season, rice cultivation is fully irrigated. Efficient utilization of rainfall during the rainy season helps in saving irrigation water that can be utilized in the dry season. Efficient use of the rainfall is only possible by designing and operating the system to capture the maximum amount of rainfall without affecting the crop, and retaining it in the field (Fathima et al. 1988; Azhar et al. 1992). This also means adjusting the irrigation schedules in such a way as to take into consideration the rainfall. However, adherence to the pre-determined cropping schedule plays a very important role in the efficient use of resources and also brings about the desired cropping intensity in a rice double-cropping system. This investigation focuses on the fixation of cropping schedule with particular reference to rainfall, river flow conditions and crop water requirements.

The main objective of the Besut Irrigation Scheme was to enhance production of rice through double cropping and improved farming practices. The major constraints confronting the irrigation scheme in fulfillment of its prescribed goals are: (a) constraints related to water management problems; and (b) insufficient water in the canal system to meet the demands of the entire irrigable land.

Present Cropping Schedule

The present cropping pattern is a rice-rice regime. The cropping calendar is characterized by two seasons, the main season and the off-season. In the present calendar schedule, the first season crops are defined as off-season crop, and this lasts from May until September. The second season crop (the main-season crop) is cultivated between November and March. The rice variety widely adopted is the MR84, which is classified as the short maturation and high yielding type. This rice variety has growth duration of 120 to 125 days. The preferred planting method is that of direct seeding using the wet-bed-wet-seeding technique. The field is first presaturated (usually referred as the first presaturation period) to a standing water level of 100 mm, followed by land preparation and drainage of excess water. Pre-germinated seeds are then sown when there is a thin layer of water in the rice field and the standing water is then allowed to build up in tandem with the height of the rice plant (referred to as the second presaturation period). A final water depth of 100 mm is provided to control weeds throughout the period of rice plant growth. Careful control of water depth in the rice field is crucial during the second presaturation period because water depth in excess of the height of the plant can result in drowning of the rice seedlings. For administration of irrigation, the scheme is divided into Phase I and Phase II. Each phase is sub-divided into compartments. Phase I comprises of compartments 1, 2/1 and 4, while Phase II comprises compartments 2/2 and 3. The existing crop cultivation calendar for the main season and off-season is summarized as shown in Figure C1. The Cropping schedule traditionally follows the rainfall pattern in Malaysia (Hill, 1977). This is also the case in India (Sakthivadivel and Shanmugham, 1986) and Sri Lanka (Medagama, 1986; Perera, 1986; Balasuriya, 1987), as it is in the case of the Besut Irrigation Scheme, albeit not with reference to long-term records.

Rainfall Pattern and River Discharges

Rainfall plays a very important role in agricultural production. Even with the presence of irrigation facilities rainfall still plays a major role in so far as meeting crop water requirements is concerned. For the purpose of this investigation, daily rainfall data recorded at three stations were obtained from the Data Information Section, Hydrological branch, Irrigation and Drainage Department, Malaysia. The stations were chosen with due consideration to their spatial representation as well as the availability of adequate data. The locations of the three rainfall stations are given in Table C1. The rainfall data were analyzed to obtain the mean, maximum and minimum monthly amount of rainfall. Daily rainfall data were also used to estimate irrigation needs during the main season and off-season.

For the system operation and alternative water resource development study, monthly and yearly records of river flows are required for making decisions on water release through barrage using various hydrological techniques. Staff gauge readings for Sungai Angga at Angga Barrage and Sungai Besut at Jerteh, and the daily records of the water level were obtained from the Department of Irrigation and Drainage, Malaysia. River flow records are available for the Besut Barrage and Angga Barrage for an approximate period of 45 years i.e. 1946-1990. River flow data were analyzed to obtain the mean, maximum and minimum monthly flow rate amount.

Methodology

The water availability for the scheme is fully dependent on rainfall and river flows. Thus, rainfall patterns and river flows were considered as prime factors for fixation of cropping schedule for the area. On the other hand, evapotranspiration is the single most important factor in estimating water demand in the rice fields during the entire duration of plant growth. Another important consideration in irrigation supply is replenishing water lost through percolation and seepage. The irrigation requirement includes catering for seepage and percolation losses, as well as taking into account the amount of rainfall and evapotranspiration (climatic conditions) that occur during the irrigation period in a water balance model. The proposed cropping schedule was adjusted based on rainfall pattern, river flow conditions and crop water requirements. This schedule does not however, take into account other factors such as social preferences, political and economic agenda, etc.

Results and Discussion

Cropping schedule based on rainfall distribution

Generally, crop production during the main season is influenced by rainfall distribution and crop duration. The long-term rainfall records (Table C2) indicate that maximum rainfall occurs in September, October, November, December and January with monthly mean rainfall values of 265, 262, 514, 647 and 248 mm, respectively. To make best use of this rainfall, rice cultivation should be adjusted so that the vegetative and reproductive growth stages of the crop are timed for early October to mid December and the ripening stage for the months with less rainfall. The growth duration of the rice varieties commonly grown in the area is about 120 days (17 weeks). Allowing two weeks for land preparation (LP), the total growth duration of the crop is 19 weeks. Since the monsoon peak occurs from early November to mid January, the start of September is the most promising time to begin land preparation in order to have maximum in-field storage of rainfall to make best use of it. Hence, it was suggested that land preparation commences on September 15 and is completed by October 2nd (two weeks). The existing main season crop (2001/2002) schedule for land preparation in the area was November 1 to November 15. Rainfall usually increases beginning from September, but November and December are the two months with highest precipitation. This means that the existing schedule will not benefit fully in terms of the in-field storage, from the September rainfall. In fact, the existing schedule poses the risk of flood damage, if land preparation is delayed. Annual flooding in the low-lying areas of the Besut river basin is a common phenomenon, with Sungai Besut over-flowing its banks frequently during this time. The North East monsoon is also coupled with strong winds and heavy rains. Intense torrential monsoon storms bring major floods to the area during the November-January period. It usually results in postponement of the cultivation schedule and the subsequent off-season cultivation being cancelled.

Taking into account the above consideration, the pre-saturation (or soaking) and land preparation for main season rice fields have to be started in September in order to harvest in February/March. March is the month with low rainfall. Farmers dry their grain making use of the sunshine and there is no difficulty in doing so in February or March. Thus the initial proposed cropping schedule is as mentioned above.

Cropping schedule based on river discharge

The Besut Irrigation Scheme consists of 2 sub-schemes, namely Angga Barrage sub-scheme and Besut Barrage Sub-Scheme. There are two main sources of water supply to the scheme consisting of the Sungai Angga and Sungai Besut rivers. Monthly river flows from both Sungai Angga and Sungai Besut were analyzed and the results are presented in Table C3. The minimum low river flow rates were found to be 8.93 m^3/sec and 7.69 m^3/sec for Besut Barrage and 1.18 m^3/sec and 1.02 m^3/sec for Angga Barrage in the months of July and August respectively. July and August are the driest months of the year. The year 2002 off-season period followed with land preparation scheduled from May 5 to May 20. The off-season crop suffered during the vegetative and reproductive growth stages because of shortage of river flow. To avoid this shortage, the off-season cropping schedule should be adjusted to begin on March 15 with harvesting in July / August. There will be no problems in drying the off-season crop despite the rains due in September as this is usually done by the Lembaga Padi Negara (local National Rice Board) rice mills as well as several commercial mills which have drying facilities.

On the other hand, the peak river flow rates were found to be 153.00 m^3/sec and 94.50 m^3/sec for Besut Barrage and 20.20 m^3/sec and 12.5 m^3/sec for Angga Barrage in the month of December and January, respectively. The water level in the Besut River is higher than the water surface of streams during the time of flooding (Agrosains, 1984; ADB, 1992; JICA, 1998). Gravity drainage appears impossible at that time and the water is backed up thereby inundating the rice fields. Further, there are a number of isolated low land areas, which cannot be drained by gravity.

Consequently, the crop-planting schedule has been adjusted in order to generate the maximum benefit from river flows as well as from rainfall distribution. The proposed cropping schedule is shown in Figure C2.

Cropping schedule effect on crop water requirement

The water balance model presented earlier was adopted in evaluating the performance of an irrigation system, in determining crop water requirements, and in establishing criteria for a water management scheme. The magnitude of the different water balance components needs to be accurately predicted in order to improve irrigation performance. Based on long-term climatic parameter values water requirements for both the present and proposed cropping schedules are shown in Figure C3. In the present cropping schedule, the evapotranspiration was found to be 4.20 mm/day and 3.99 mm/day for off-season crop and main season crop, respectively. 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. On the other hand, the average seasonal water supply was 1045 mm of which 732 mm (70%) was supplied by irrigation and 313 mm (30%) by rainfall. However, in the proposed cropping schedule, the evapotranspiration was found to be 4.26 mm/day and 3.50 mm/day for the off-season crop and main season crop respectively. The average seasonal consumptive use of water was 770 mm, out of which 524 mm (68%) was accounted for by ET and 246 mm (32%) by percolation. The average seasonal water supply was 1015 mm of which 670 mm (66%) was supplied by irrigation and 345 mm (34%) by rainfall. As a result, a substantial amount of water can be saved in the proposed cropping schedule.

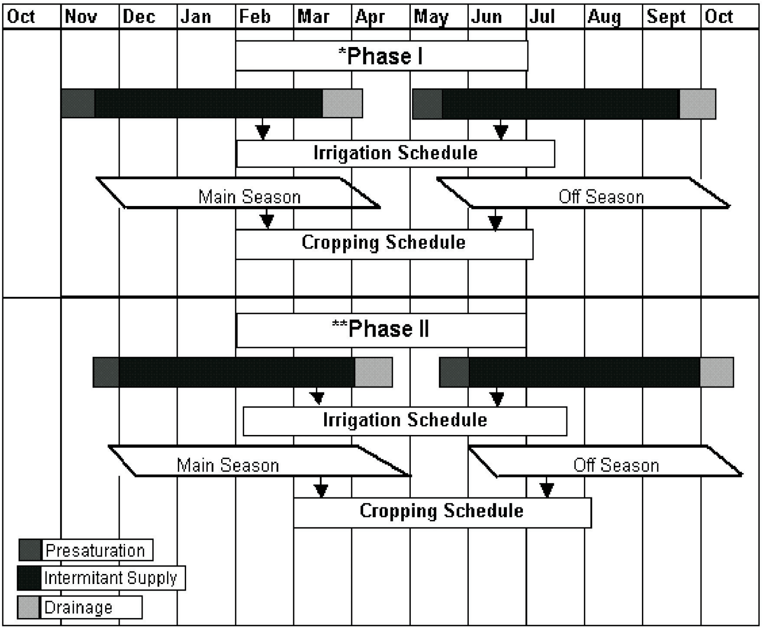


Figure C1 Current cultivation calendar in Phases I and II of the Besut Irrigation Scheme

* Land preparation starts on 1 November and 5 May for the main and off season crops respectively.

** Land preparation starts on 15 November and 20 May for the main and off season crops respectively.

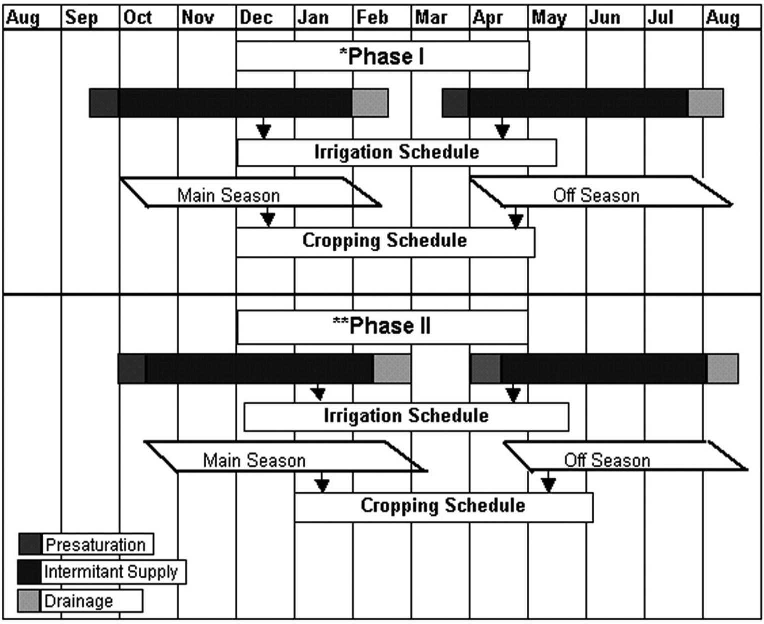


Figure C2 Proposed cropping schedule for both the main and off season crops for the Besut Irrigation Scheme

* Land preparation starts on 15 September and 15 March for the main and off season crops respectively.

** Land preparation starts on 1 October and 1 April for the main and off season crops respectively.

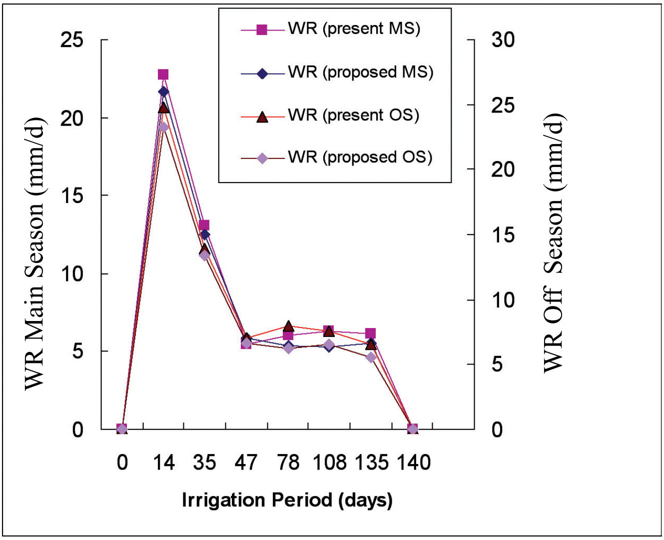


Figure C3 Comparison of water requirements for both the main season (MS) and Off-season (OS)

Table C1 Location of rainfall stations

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
Rumah Merinyu Taliair	5°44’15” N	102°30’15” E	1948-1991

Table C2 Long term mean monthly rainfall (mm) distribution for three stations

Month	Station 1	Station 2	Station 3	Average
Main Season Crop				
November	512	483	548	514
December	674	618	650	647
January	374	161	210	248
February	160	92	100	117
March	100	115	111	108
April	83	60	80	74
Off Season Crop				
May	150	122	155	142
June	166	150	164	160
July	168	145	180	164
August	200	170	234	201
September	270	240	286	265
October	291	218	277	262

Table C3 Long-term monthly river discharges of the Besut and Angga rivers

	Sungai Besut River (m^3/sec)			Sungai Angga River (m^3/sec)		
Month	Mean	Maxi-mum	Mini-mum	Mean	Maxi-mum	Mini-mum
Jan	94.5	267.0	23.9	12.5	35.4	3.17
Feb	45.0	103.0	13.1	5.97	13.7	1.74
Mar	33.8	121.0	12.3	4.49	16.1	1.63
Apr	19.0	46.6	11.4	2.52	6.18	1.52
May	17.8	33.4	10.8	2.36	4.43	1.44
Jun	15.9	30.0	9.71	2.10	3.98	1.29
Jul	15.0	24.4	8.93	1.99	3.23	1.18
Aug	15.3	23.4	7.69	2.02	3.11	1.02
Sep	23.7	35.7	13.8	3.14	4.74	1.83
Oct	28.0	50.5	11.9	3.71	6.69	1.58
Nov	68.5	254	20.1	9.09	33.7	2.67
Dec	153.0	419	26.9	20.2	55.5	3.57

WATER MANAGEMENT DECISION SUPPORT SYSTEM: WATER ALLOCATION

Introduction

The Besut Irrigation Scheme is served through two gravity intakes; one on the Besut river and the other on the Angga river, which is a tributary of the Besut river. The irrigation systems of the two areas are interconnected, giving a total irrigation area of 5, 164 ha for the whole scheme. The scheme area is further divided into 39 irrigation blocks (KPA-Kumpulan Pengguna Air in the local Malay lingua franca - water user's group). The present double cropping pattern follows a rice-rice regime. The cropping calendar is characterized by two seasons, the main season and the off-season. In the present calendar schedule, the first season crop (off-season crop) lasts from May until September. The second season crop (the main-season crop) is cultivated between November and March. The rice type widely adopted is the MR84 variety, which is classified as the short maturation and high yielding type with growth duration of 120 to 125 days.

Under current practice, at the beginning of each season, the scheme area is divided into Phase I and Phase II for land preparation and pre-saturation. Water is supplied first to areas in Phase I at a flow rate of 2.54 l s^{-1} ha^{-1} for a period of 14 days followed by the Phase II areas, at the same flow rate. Each phase is subdivided into compartments. However, water supply adequacy is dependent on water levels at the Besut and Angga barrages. Should the water levels fall below desired levels, water shortage would occur and failure of crops becomes imminent. Hence, the pre-saturation areas need to be optimized considering the water availability, which is based on predicted inflows and demand for water. Two important decisions, pertaining to the operation of this scheme, that were identified are: (1) the decision regarding irrigable area and (2) determination of optimal irrigation water releases.

Water has been a major factor in the development of many agricultural regions in the world, and conflicts in regional water allocation have culminated in huge problems affecting water resources planning and management. Irrigation planners need to analyze complex climate-soil-plant relationships and apply mathematical optimization techniques to determine optimally beneficial crop patterns and water allocations. A computer-based model to simulate the climate-soil-plant systems with novel mathematical optimization techniques could assist irrigation planners in reaching sound decisions. New methods for addressing water resource problems are continuously being developed and implemented and these usually incorporate advanced computer-based capabilities for data management, analysis, and direct information communication to water system managers and operators for decision support (Sheng-Feng et al., 2000).

Knowledge-based decision support systems can aid in operational decisions, allowing the incorporation of heuristic, subjective, and judgmental knowledge into the solution process (Fenves, et al. 1984, Johnson, 1986). In knowledge-based systems, the domain knowledge that is derived from experts and other sources is organized to provide decisions in that domain (Waterman, 1986) and integrated with algorithmic techniques. Knowledge based DSSs are found to be effective and popular in the field of water resources management (Bhatty 1991; Simonovic 1992; Arumugam and Mohan 1997; Mahmood and Wall 2002). Rehak (1983) reported that there are three significant chunks of knowledge that can be put into the DSS: (1) Heuristic knowledge gained from experience; (2) conventional knowledge regarding facts; and (3) inferential knowledge obtained after a review of the results. The third item is the expert knowledge encountered in most engineering applications, and this knowledge plays an important role in irrigation water management.

Decision-making is a difficult task for water resources field engineers considering the innumerable parameters involved. While computers aid decision makers in arriving at solutions for several problems they are used only for carrying out computations while experts make the key decisions. With the emergence of expert systems, computers can now be used as a tool for making qualitative assessment of various problems for which solutions could previously have been obtained only with the help of an expert with considerable experience. This aspect is very much true in the case of managing irrigation water particularly in a run-of-the-river system. Water resource shortage is also the major restriction which hinders sustainable agriculture development in west Malaysia. Generally speaking, the irrigation water use efficiency is still quite low in Malaysia, averaging about 0.4, which is enough to warrant greater adoption of good management practices. This section addresses the allocation of water to irrigable areas under a DSS model.

Water Allocation Activities

The two main tasks confronting irrigation authorities are the allocation of water to the water users, and the operation of the hydraulic infrastructures to achieve it. Water allocation via the irrigation authority consent process is one way by which better irrigation practices can be encouraged. The consumption of water in a rice irrigation scheme is affected by many factors such as canal system, rice field conditions, field off-take flow and, unfortunately, also by farmers' response towards irrigation. Under the continuous irrigation mode, farmers are expected to start planting simultaneously. However, the availability of water normally determines the area to be planted and consequently the farmers will only start planting once there is sufficient water in their plots. As a result the progress in planting differs from one part of the scheme to another. In view of this the application of a decision support system to enhance the decision making process is appropriate. Computation of the water allocation schedule is carried out in two stages: pre-saturation and normal irrigation.

Pre-saturation and Land Preparation Stage

The management of water allocation during land preparation was identified as the major problem faced by the Besut Irrigation Authority. The land preparation needs to be completed within 14 – 21 days in order to adhere to the cropping schedule. Thus the authority needs to implement an orderly system of water allocation and distribution that can promote not only an adequate, equitable and reliable supply to intended beneficiaries, but also to ensure that it is used efficiently.

In rice irrigation, more than half of the water supplied is used for pre-saturation; i.e. to pre-saturate and inundate fields before planting of the crop. Pre-saturation is the water required to bring the field to full saturation level before land preparation and includes standing water head required for plowing. Reducing the pre-saturation period may lead to water savings. Thus, the system should deliver at maximum capacity in order to reach all the fields as quickly as possible. The water requirement for pre-saturation is theoretically 150 – 200 mm, but can be as high as 650 – 900 mm when its duration is prolonged, i.e. 24 – 48 days (De Datta, 1981; Bhuiyan et al. 1995). The water required during the land soaking and land preparation period can be calculated as follows:

$$S_k = \frac{\frac{ds}{t_s} + E_v + DP + \mathrm{Re}_k}{8.64E_a} \qquad [1]$$

where, S_k is land soaking water requirement [$l\ s^{-1}\ ha^{-1}$], ds is depth of water required to saturate the soil [mm], E_v is evaporation rate [mm/day], t_s is time required to saturate the soil [days], Re_k is effective rainfall during time period k [mm/day] and DP is percolation rate [mm/day].

$$P_k = \frac{\frac{d_p}{t_p} + E_v + DP - \mathrm{Re}_k}{8.64E_a} \qquad [2]$$

where P_k is land preparation requirement [$l\ s^{-1}\ ha^{-1}$], d_p is depth of water required for crop submergence [mm] and t_p is time required for land preparation [days].

The Department of Irrigation and Drainage, Malaysia uses a 250 mm water depth during pre-saturation and land preparation period for both the main season and off-season. 150 mm of this water is applied and left standing for 4 days (pre-saturation) before land preparation begins whence the standing water head of 100 mm is applied. Upon completion of land preparation, the fields are drained. Seeding follows upon completion of drainage.

Normal Irrigation Stage

A standing water depth is applied gradually increasing up to 100mm in depth within 14 days, following the growth of the seedlings. This normal irrigation water supply period commences for the next 100 days. This standing water depth of 100 mm is maintained till a week before harvesting when the fields are gradually drained. The value of seepage and percolation, DP is assumed to be constant at 3 mm/day throughout the growth period (ADB, 1992). During the normal growth period, continuous supplementary irrigation is required to sustain losses due to seepage and percolation as well as evapotranspiration. The correct amount of irrigation delivery is the key element to improving irrigation management in the scheme. Irrigation supply for a field block, through a gate, can be estimated according to field water requirements. In normal irrigation supply periods, water required can be calculated on the basis of the formula (JICA, 1998) shown below:

$$DWR = (ET_o \times K_c + DP - ERF) / E_s \qquad [3]$$

where, DWR is diversion water requirement, ET_o is reference evapotranspiration, K_c is crop coefficient, ERF is effective rainfall and E_s is overall irrigation efficiency. The value of E_s, the overall irrigation efficiency which includes irrigation efficiency and conveyance efficiency along the secondary canals, is believed to be 45 % (JICA, 1998). Evapotranspiration rate was not measured at the site, but was estimated from meteorological data collected from the nearby sites.

Canal Flow Modeling

Based on field water requirements during the pre-saturation and normal irrigation supply periods and available flows at the intake gates, water allocation was performed through canal flow simulation. Canal flow simulations were performed with the help of the *CanalMan* model developed by Utah State University, Logan, Utah, USA (Merkley, 1997). The model incorporates turnout structures and in line structures. It can simulate canal operations in a manual mode. *CanalMan* implicitly solves an integrated form of the Saint-Venant equations of continuity and motion for one-dimensional unsteady open-channel flow. Simulations can be started by filling an empty canal system, continuing a previous simulation or from a specified steady or unsteady flow condition.

Data required for canal simulation includes the canal bed width, side slope, canal length, gate structure and specification, water depth, canal cross-section, elevations, Manning's roughness and seepage rate. These data were obtained from the Map Unit, DID Headquarters Malaysia in Kuala Lumpur. During the pre-saturation period, various flow rates for the Besut and Angga intake gates (flow rates change during the main season and off-season) were used in the canal simulation process. The design discharges are 9.00 m^3/sec and 3.00 m^3/sec for the Besut and Angga Barrage respectively. Canal simulation was started with maximum capacity with subsequent simulations were based on a step-by-step decreased flow capacity approach for both the Besut and Angga Barrages. In each simulation process, simulated flow values were compared with full supply flow values (main and secondary canals) to obtain water allocation area. The simulation results were not compared with actual canal capacity because no such information was available. Tertiary canal gates were adjusted with estimated field water requirements. Moreover, canal gate openings were adjusted whenever the simulation flow rate was higher than the demand. Finally, all simulation results were analyzed and the water allocation area possible for pre-saturation period identified in phases. The simulation process was then repeated for periods when irrigation supply is to be allocated for the entire scheme.

Canal Filling Time

The canals in the irrigation system must be filled in the order of firstly the main canal followed by the secondary canals and finally the tertiary canals. The canals are filled from downstream to upstream. When the last reach is full, the control drop or check at the head of the reach is set according to the design full supply level (FSL). All the secondary off-take gates are closed when filling the main canal. When the main canal is filled to FSL, all tertiary off-takes and all direct field off-takes along the secondary canals are closed before filling the secondary canals. The simulations were done to find the canal filling time for the main and secondary canals during pre-saturation period, and to analyze the water release time with as many as possible water level scenarios. Tertiary canals filling time was not estimated due to their small canal lengths. However, lag time was also estimated during the normal supply period in order to make decisions on water release from the barrages.

Design and Development of DSS

Design Approach

A water allocation management decision support system (WMDSS) for operation of a rice irrigation scheme is intended to support the activities required for good management of an irrigation system, such as planning for subsequent seasons. The WMDSS involves the derivation of decision-making knowledge and simple logic procedural techniques. The WMDSS consists of four major components: (1) database management (2) model management (3) knowledge base and (4) user interface. These components are integrated for effective decision-making.

Data needed for decision support systems are typically historical with extrapolation potential. A variety of data is incorporated into the database, including weather, hydrology, and irrigation canal, and soil and crop data. These historical data are used in the model management for calculating actual crop water requirement and for obtaining optimal irrigation canal water discharge and gate opening. The knowledge base is a collection of information and an inference engine that examines the knowledge base and answers the questions posed by the user. The knowledge base contains specific information obtained from the application domain, using several structures. One of these structures is the rule. The models were used to extract knowledge related to water management aspects. Thus, the findings of the models were converted into rules and used as the basis for the construction of the decision support system framework. The extracted knowledge was further checked by experts to verify reliability. All the extracted knowledge was added to the final decision support system as rules. The WMDSS is designed to utilize the Expert System shell that runs under windows, which combines the rules and procedures.

Knowledge Base Structure

While optimal operational knowledge was obtained from the results of the models, heuristic knowledge was obtained from the field exerts. Field experts were consulted in order to incorporate their experiential knowledge into the knowledge base. Discussions were held to determine the extent of the problem of area allocation and to identify problems and factors causing these problems. The experts also verified water allocation rules obtained from the models before these were incorporated into the knowledge base. These two sources of knowledge were combined and the rules representing different situations (in if-then format) were synthesized for the main and off-season periods. The situations reflected various water-availability, water-demand and supply conditions. These situations are the antecedents and the water allocation decision is the consequent, in the rules of the knowledge base.

The acquired knowledge was implemented using the wxCLIPS (Julian Smart, 1997) expert system development shell. The knowledge base created using this shell was continually tested for consistency and appropriateness and updated throughout the development stage. The rules derived from the optimization methodology were also examined by experts and suitably modified, where necessary, by incorporating experts' heuristics. Some examples of the rules in the knowledge base are listed here for illustration:

RULE 5

IF *Scheme = Angga Sub-scheme* ***AND***
Intake gate flow > = 3.00 (m^3*/sec)* ***AND***
Period = Pre-saturation ***AND***
Season = Main Season

THEN *Land preparation should be completed in one phase* ***AND***
Phase I area = C – 2 (KPA – All)

RULE 20

IF *Scheme = Besut Sub-scheme* ***AND***
Intake gate flow > = 8.20 (m^3*/sec)* ***AND***
Intake gate flow < = 8.90 (m^3*/sec)* ***AND***
Period = Pre-saturation ***AND***
Season = Main Season

THEN *Land preparation should be completed in two phases* ***AND***
Phase I area: C – 1 (KPA – All); C – 4 (KPA – All); C – 3

(KPA – 22 – 25);
Phase II area: C – 3 (KPA – 26 – 31); ***AND***
Supply water first in Phase I area

RULE 55

IF *Scheme = Besut Sub-scheme* ***AND***
Intake gate flow > = 5.00 (m^3/sec) ***AND***
Intake gate flow < = 5.50 (m^3/sec) ***AND***
Period = Pre-saturation ***AND***
Season = Off Season

THEN *Land preparation should be completed in three phases* ***AND***
Phase I area: C – 4 (KPA – 11- 20); C – 3 (KPA – 22 – 23); ***AND***
Phase II area: C – 1 (KPA – All); ***AND***
Phase III area: C – 4 (KPA – 21); C – 3 (KPA – 24 – 31); ***AND***
Supply water first in Phase I area

RULE 82

IF *Scheme = Angga Sub-scheme* ***AND***
Intake gate flow > = 2.20 (m^3/sec) ***AND***
Intake gate flow < = 2.80 (m^3/sec) ***AND***
Season = Main Season

THEN *Land preparation should be completed in two phases* ***AND***
Phase I area: C – 2 (KPA – 32 – 35); ***AND***
Phase II area: C – 2 (KPA – 36 – 39); ***AND***
Supply water first in Phase I area

RULE 95

IF *Scheme = Besut Sub-scheme* ***AND***
Intake gate flow >= 9.00 (m³/sec) ***AND***
Period = Pre-saturation ***AND***
Canal Area = C – 1 (KPA – All) + C – 3 (KPA – All) + C – 4 (KPA – All)

THEN *Water should release five days before beginning of pre-saturation* ***AND***
Fill canal from downstream **AND**
Time required for filling canals are:

Compartment	*Main canals (hrs)*	*Secondary canals (hrs)*
Compartment - 1	*15.0*	*24.0*
Compartment - 4	*21.0*	*35.0*
Compartment – 3	*24.0*	*40.0*

RULE 136

IF *Scheme = Besut Sub-scheme* **AND**
Intake gate flow >= 5.70 (m³/sec) **AND**
Intake gate flow < = 6.10 (m³/sec) **AND**
Period = Pre-saturation **AND**
Canal Area = C – 3 (KPA – 22 - 25) + C – 4 (KPA – All)

THEN *Water should be released three days before beginning of pre-saturation* ***AND***
Fill canal from downstream ***AND***
Time required for filling canals are:

Compartment	*Main canals (hrs)*	*Secondary canals (hrs)*
Compartment - 4	*25.0*	*40.0*
Compartment - 3	*28.0*	*35.0*

Depending on water availability, land preparation could be done in one continuous stretch for all the compartments (rule 5). According to rule 20, if water availability is less than demand, then supply is restricted to the available water, irrespective of the demand. However, land preparation could be done in two phases or over three phases during the main and off- season periods (rule 55). In a three-phase land preparation period, the pre-saturation time of 21 days is considered with low irrigation duty. However, land preparation should be started at the same time as that of the other subdivisions if the water source is different (rule 82).

It is important to know the canal filling times in order to release water through the intake gates. When flow rate is equal to or greater than 9.00 m^3/sec at the Besut intake gate, the starting date of water supply should be five days before the beginning of the pre-saturation date in order to maintain supply to the whole Besut subdivision (rule 95). Water should be released three days before the beginning of the pre-saturation period of the season when flow rates are between 5.70 and 6.10 m^3/sec at the Besut intake gate (rule 136).

User Interface Mechanism

The graphical user interface (GUI) is the most important feature of the program as it provides better interaction between the model and the user. It is based on a mouse-driven approach with pop-up windows, pull-down menus and button controls. It also works with the inference engine and the knowledge base to provide a means of communication for the user to enter queries into the system and subsequently receive answers. In such a system, interfacing can be in response to questions generated by the knowledge base and reasoning mechanism combinations. The interfacing mechanism is shown in Figure D1, and it is a crucial part of the DSS.

Area Allocation Module

The “Irrigable Area” module has been developed to determine the irrigable area for land preparation. This module provides the user with a list of selection choices and is integrated with a text file related to choice selection. The Besut intake gate flows are divided into seven classes: > 9.00, 8.20 – 8.90, 7.20 – 8.10, 6.20 – 7.10, 5.70 – 6.10, 5.00 – 5.60, < 5.00 m^3/sec while the Angga intake gate flows are divided into four classes: > 3.00, 2.20 – 2.90, 1.60 – 2.10 and < 1.60 m^3/sec. The options available for the user to select under the “Irrigable Area” module are shown in Figure D2. Examples of water management scenarios of the Besut and Angga subdivisions, based on selected options, are shown in Figure D3 and Figure D4. The module outputs are in the form of recommendations on land preparation areas by blocks and information on the water schedule as well as a display of water allocation areas. Such water schedule information includes (1) the start and end of the irrigation season (2) second standing water supply (3) seeding (4) drainage and (5) harvesting time. This module also gives recommendations on pumping requirements when the intake gate flow is not enough to supply designed discharge in canals for land preparation. The output indicating pumping requirements is shown in Figure D5.

The “Irrigation Water Demand” module has been developed to calculate the crop water requirement for a particular irrigation block during the normal supply stage. While processing the crop water requirement, the system takes care of effective rainfall, evapotranspiration rate, and percolation rate and the corresponding crop coefficient value depending on the crop growth stage. The options available for the user to enter the required values are shown in Figure D6. The water releases from the intake gates through the canals are scheduled accordingly.

Time Allocation Module

Based on water allocation area and intake gate flows, time allocation in filling the main and secondary canals was determined in order to release water from the barrages. The available options for time allocation during the pre-saturation period are shown in the "Water Release Time" module in Figure D7. This module gives recommendations on water release times from the barrage. However, water users are informed of main and secondary canals filling time within compartments. In addition to release time, this module also provides information on main and secondary canal filling guidelines to the water users. Canal filling guidelines are shown in Figure D8 as text outputs. The irrigation blocks under this scheme are scattered all over the entire area. Therefore, water-traveling time during this stage varies with blocks and this is input as knowledge under the "Water Release Time" module. Knowledge outputs with release times for the Besut subdivision are shown in Figure D9.

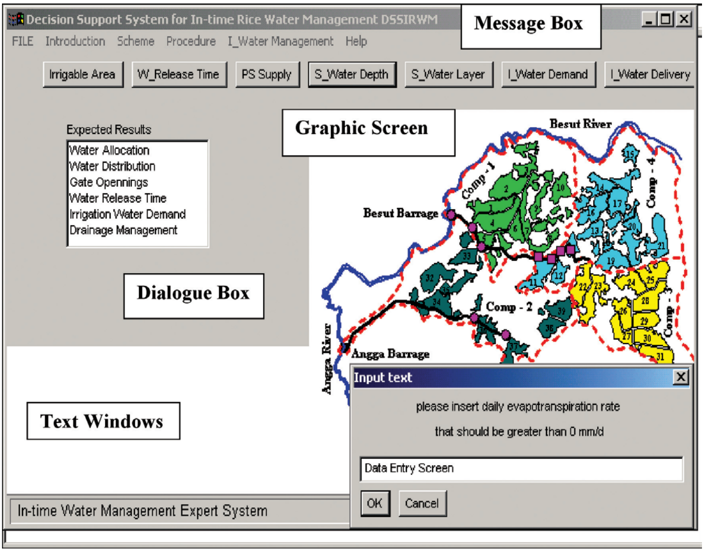


Figure D1 Template showing graphic user interface mechanisms

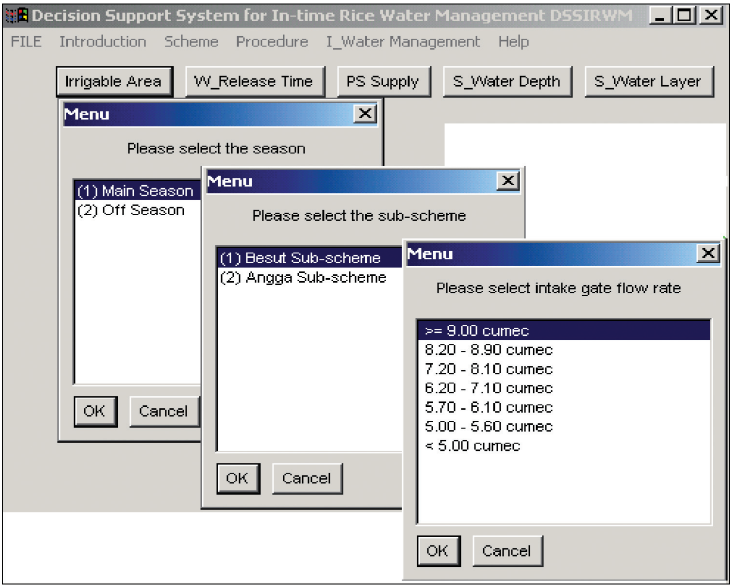


Figure D2 Options available under the “Irrigable Area” module

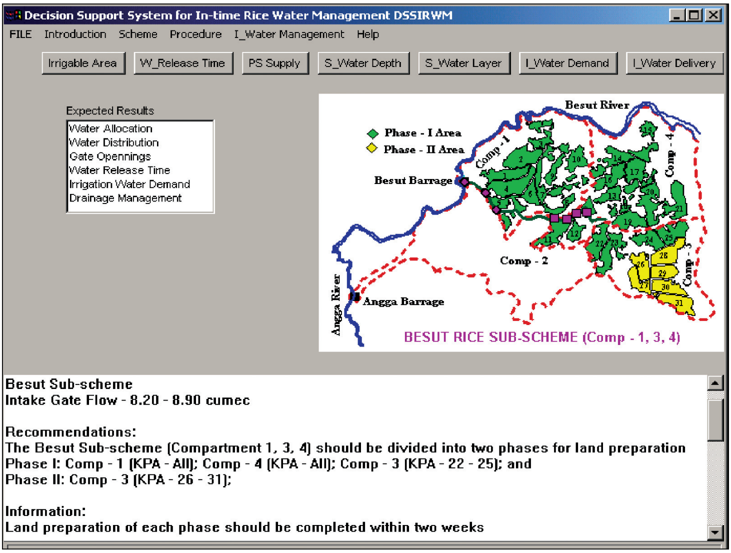


Figure D3 Knowledge output with area allocation when the Besut intake gate flow is 8.20 – 8.90 m^3/sec

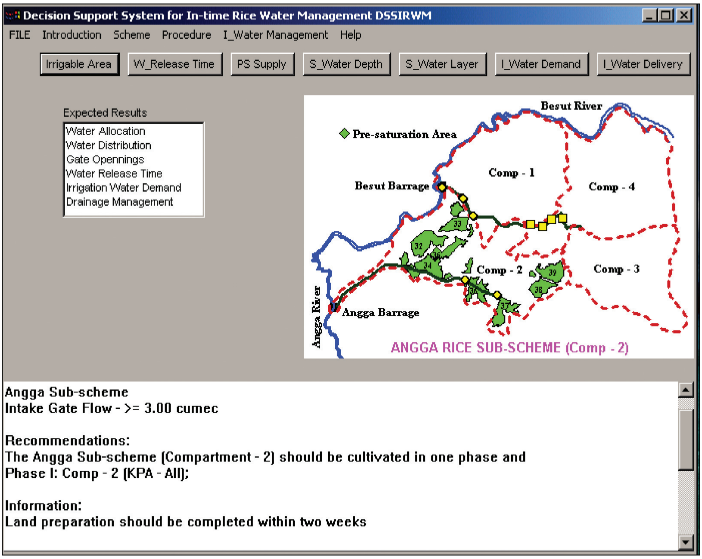


Figure D4 Knowledge output with area allocation when the Angga intake gate flow is 3.00 m³/sec

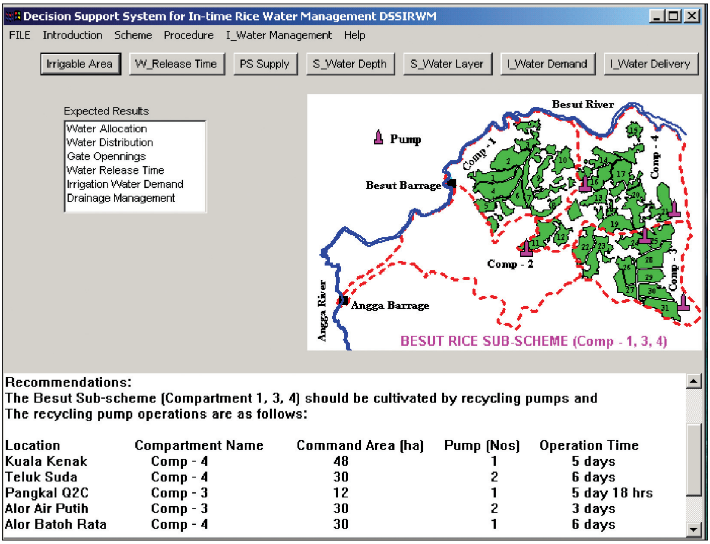


Figure D5 Output showing pump operations when the Besut intake gate flow is less than 5.00 m³/sec

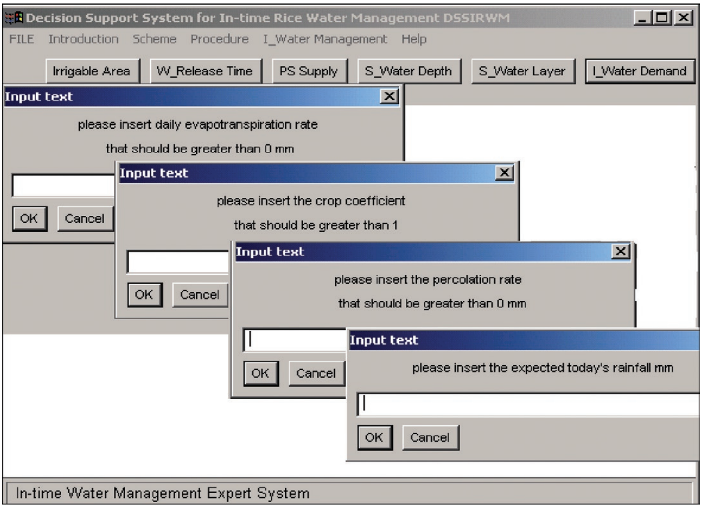


Figure D6 Data entry boxes under the "Irrigation Water Demand" module

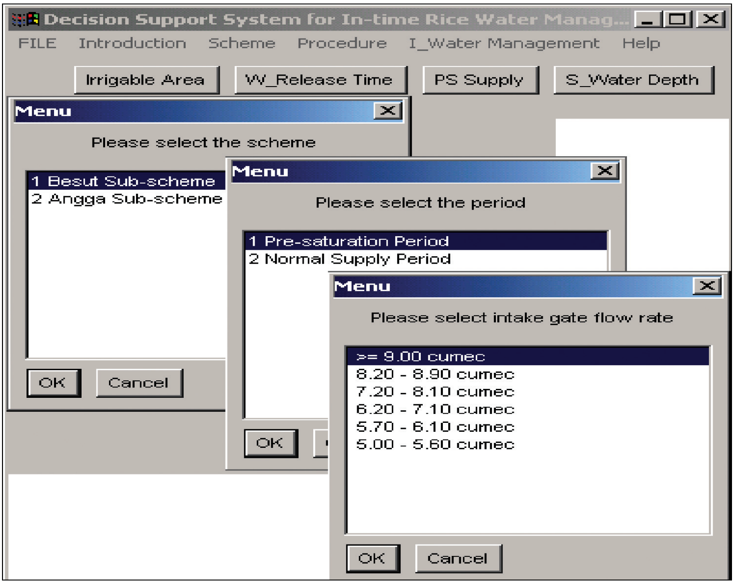
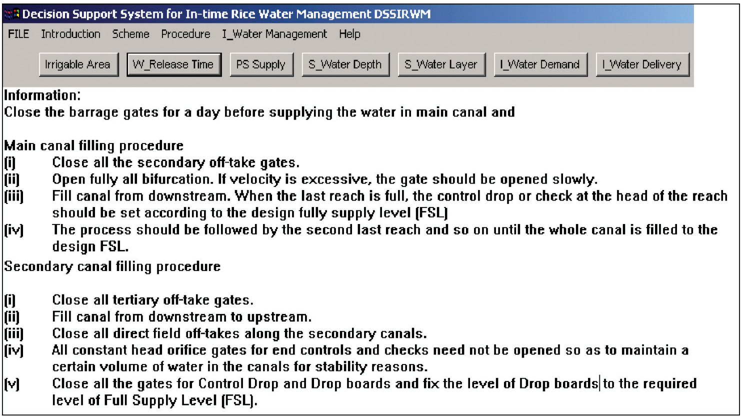


Figure D7 Selection options available under the "Water Release Time" module



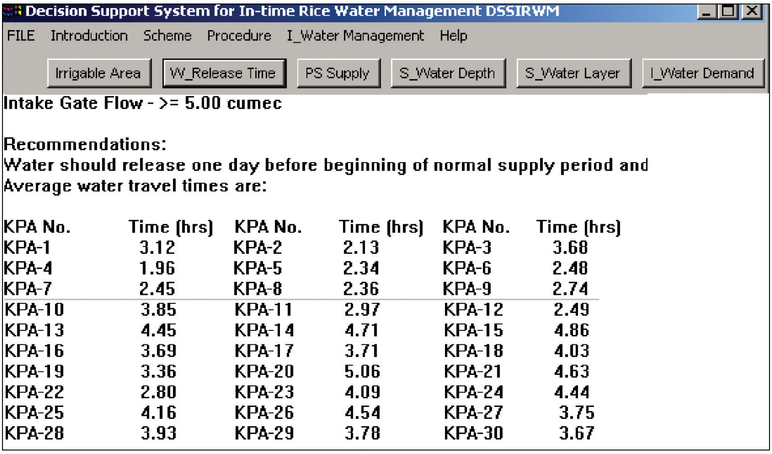
Information:
Close the barrage gates for a day before supplying the water in main canal and

Main canal filling procedure
(i) Close all the secondary off-take gates.
(ii) Open fully all bifurcation. If velocity is excessive, the gate should be opened slowly.
(iii) Fill canal from downstream. When the last reach is full, the control drop or check at the head of the reach should be set according to the design fully supply level (FSL)
(iv) The process should be followed by the second last reach and so on until the whole canal is filled to the design FSL.

Secondary canal filling procedure

(i) Close all tertiary off-take gates.
(ii) Fill canal from downstream to upstream.
(iii) Close all direct field off-takes along the secondary canals.
(iv) All constant head orifice gates for end controls and checks need not be opened so as to maintain a certain volume of water in the canals for stability reasons.
(v) Close all the gates for Control Drop and Drop boards and fix the level of Drop boards to the required level of Full Supply Level (FSL).

igure D8 Text output with main and secondary canals filling procedure before pre-saturation period



Intake Gate Flow - >= 5.00 cumec

Recommendations:
Water should release one day before beginning of normal supply period and
Average water travel times are:

KPA No.	Time (hrs)	KPA No.	Time (hrs)	KPA No.	Time (hrs)
KPA-1	3.12	KPA-2	2.13	KPA-3	3.68
KPA-4	1.96	KPA-5	2.34	KPA-6	2.48
KPA-7	2.45	KPA-8	2.36	KPA-9	2.74
KPA-10	3.85	KPA-11	2.97	KPA-12	2.49
KPA-13	4.45	KPA-14	4.71	KPA-15	4.86
KPA-16	3.69	KPA-17	3.71	KPA-18	4.03
KPA-19	3.36	KPA-20	5.06	KPA-21	4.63
KPA-22	2.80	KPA-23	4.09	KPA-24	4.44
KPA-25	4.16	KPA-26	4.54	KPA-27	3.75
KPA-28	3.93	KPA-29	3.78	KPA-30	3.67

Figure D9 Text output with water traveling time of the Besut subdivision during the normal supply period

Lee Teang Shui

WATER MANAGEMENT DECISION SUPPORT SYSTEM: WATER DELIVERY

Introduction

A primary objective of water management is the maintenance of a reliable supply through varying climatic and hydrologic conditions. This management is difficult because of unpredictable demands, uncertain stream flows, and the multi-objective and multi-institutional characteristics of water supplies. Open channel conveyance systems are the technology of choice for water distribution in a vast majority of irrigation projects worldwide. The apparent simplicity of using open channel systems to transport water for irrigation belies the actual complexity of the technology, the diversity of physical and operational characteristics, the significant costs incurred to construct and operate such systems and the poor performance frequently experienced by irrigation projects dependent on this type of water delivery system (David and Schaalje, 1993). The basic aim of optimal canal operation is to convey the water to the required command in minimal travel time in order to minimize the stress on the plant for optimal production.

Various control methods for water delivery systems have been developed in the past to improve efficiency, provide better service to consumers, minimize water losses, optimize distribution of available water, minimize overall investment and to keep operational costs to a minimum. Three types of variables are being controlled in the water delivery system: water depth, discharge and water volume (Cobbaert et al., 1992). Proper operation of the canal system in a large irrigation system is important in order to supply the exact amount to each plot at the right time. The operation and management policy of the irrigation system is vital to satisfy the supply required by the crop in each plot. The water levels along main canals need to be maintained according to the system guidelines in order to supply the required flows to each location within the irrigation system. The operation of the irrigation system is not a simple task as needs and supplies or flows vary due to temporal and spatial variability. It is therefore, essential to have an appropriate management policy with feasible options to cater for the widely variable range of conditions possible in an irrigation scheme. This section assesses the performance of the DSS in water management practices of the 2001/2002 season in the Besut Rice Irrigation Scheme.

Water Balance and Stochastic Rainfall Model

The concepts developed in the previous sections for these two components are also incorporated in this development of a Decision Support system for the irrigation scheme.

Water Delivery Policies

The irrigation water delivery, on its own, has no value until it becomes part of a package of inputs at the disposal of the farmer, or farm manager, whose skill and effort, or the lack of these, will be reflected in the performance of the farming enterprises and of the project as a whole. Since water is the prerequisite for other inputs to intensive agriculture, its timely and reliable delivery is the basis for increased productivity and for diversification into higher value crops. Water planning is developed to prepare water diverting and water distribution schedules. Water diverting and water delivery plans were worked out with due consideration to the water application and water source conditions and canal capacity. However, irrigation water management is to operate the irrigation system so that the timing and amount of irrigation water applied match crop water needs. Efficient management of irrigation systems involves appropriate water deliveries to match crop water requirements, control of seepage from the conveyance system and land grading to attain higher application efficiencies. The water delivery system comprises, the main diversion structure at the source ("intake gates"), the primary and secondary canals with their structures, including the tertiary off-takes for supplying the irrigation blocks. Water delivery policies are divided into the following supply stages:

Pre-saturation Water Supply

Pre-saturation water supply focuses on the hydraulic structures associated with the efficient use of existing water supplies. Decisions on pre-saturation water supply are often based on likely rainfall series. Rainfall is one of the major climatic elements that affect land preparation development. Only a portion of total rainfall is used effectively in promoting the shortening of the duration of land preparation and significantly reduces the non-beneficial evaporation and seepage percolation. The remaining portion goes out as surface drainage from the crop field due to lack of proper management practices. The "Pre-saturation Water Supply" module provides 7 and 6 class numbers for rainfall and intake gate flow time series, respectively. All possible options of this module are shown in Figure E1. This module gives recommendations on canal gate openings, intake gate openings, barrage gate openings and six-control point operations with various combination options. Recommended gate-opening locations and control points along the main canal are displayed on the screen. A few possible combinations of intake gate flow and rainfall amount output scenarios are illustrated in Figure E2 and Figure E3.

Standing Water Supply

Following the pre-saturation period, the standing water supply commences for the next 14 days. The standing water supply module computes the gate setting instruction to accomplish the scheduled water allocation through the canal system. The aim of the operation is to provide an efficient and effective water supply, taking into account actual field conditions and established targets. The allocation plan defines the discharges to be supplied and the module also computes the gate settings that are needed to accomplish the scheduled water allocation. The module recommends barrage gate openings, intake gate openings and intake gate flow rate in order to supply the right amount of irrigation water in the field. The outputs of this module, with various options, are shown in Figure E4 and Figure E5.

Normal Irrigation Water supply

For each day of the irrigation period that follows, it is necessary to decide whether the daily irrigation volume can be supplied. To do this, the ponding water depth for the present day is measured and the possibility of rainfall in the immediate future predicted. Monitoring of ponding water depth is also useful in the determination of the field storage between two irrigation events, being an input parameter to the water balance studies. Irrigation is commonly done on a daily basis. The normal irrigation water supply period lasts the next 100 days (3 – 4 months). Thus, each month has different water requirements due to the fact that the rice crop consists of different growth stages of different duration during the growing season. The selection options available under the "Normal Irrigation Water Supply" module are shown in Figure E6. Based on the irrigation water demand, normal irrigation water supply is carried out continuously at varied discharge rates with proper gate openings in order to maintain desired water levels. Based on the selection options, the module gives recommendations on intake gate flow rate, intake gate openings, barrage gate openings, and control points operation. However, this module may suggest not to supply irrigation water based on rainfall possibility. In addition to this, the water users are informed of ending time of irrigation, standing water depth, and harvesting time. Water management scenarios for different months are illustrated in Figure E7 and Figure E8.

DSS Model Evaluation

The DSS for the rice scheme allows for real-time operation on a daily basis. For real-time operation, one needs to know the values of the system variables, namely, intake gate flow and rainfall during any period at the beginning of the period itself. Hence, there is a need to forecast these variables (forecast knowledge) in order to accomplish real-time operations. The actual values of these variables (perfect/complete knowledge) are available at the end of each period. The forecast information on intake gate flow and rainfall are used to provide operational guidelines in a real-time setting. They are obtainable using time series models while rainfall is estimated using a Markov chain probability distribution function.

The DSS was empirically evaluated using one-year's water management data (2001/2002), which was not used in the development of the DSS. The decision-making capability of the DSS in comparison with the actual management practice of irrigation authorities was addressed as the performance indicator. This issue was framed, and discussed with the irrigation authorities in order to comprehensively evaluate the effectiveness of the DSS. The actual supplies by the irrigation authorities during the 2001-2002 cropping season were compared with the supply decisions simulated by the DSS. It must be pointed out that currently irrigation releases are made by the irrigation authorities based on a fixed demand. Water requirements from the irrigated areas were not explicitly considered for computing the irrigation demands. In contrast, the DSS considers both optimal crop areas and estimates of irrigation demands. Irrigation demands were taken as the reference to evaluate the actual releases from the DSS. Table E1 shows this comparison for the year 2001/2002. For this evaluation, the DSS was run continually with the data available for the management period of the rice scheme (40 weeks a year).

The total irrigation water supply resulting from the actual releases made by the irrigation authorities was found to be very high. The mean of total supply obtained from the operation weeks in the actual supply period was 2.56×10^6 and 3.17×10^6 m^3 in the main season and off season respectively. In contrast, the release decisions obtained from the DSS resulted in weekly total supply in the range of $0 - 4 \times 10^6$ m^3 during the main season (Table E1). It was found that the excesses in water supply resulting from the release decisions of the DSS were less than those computed for the actual operations practiced by the irrigation authorities. Based on this comparison, it was inferred that the DSS is an effective tool for decision making under practical situations. The optimal operational knowledge stored in the DSS is useful for providing better release decisions compared to the actual management practice by the irrigation authorities.

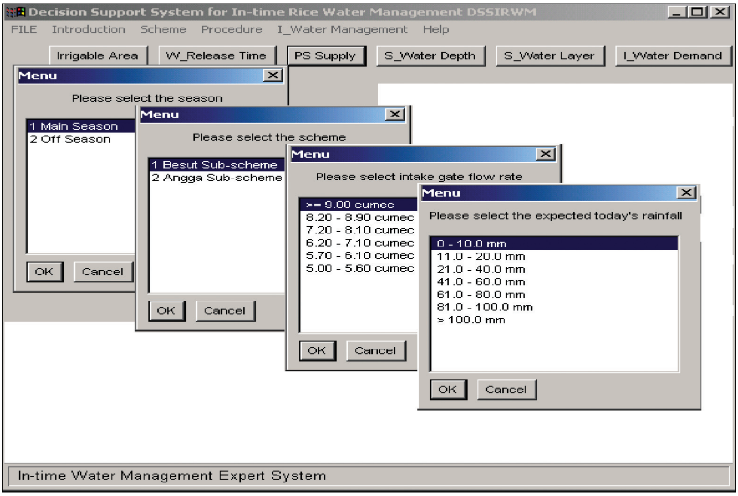


Figure E1 Selection options available under the "Pre-saturation Supply" module

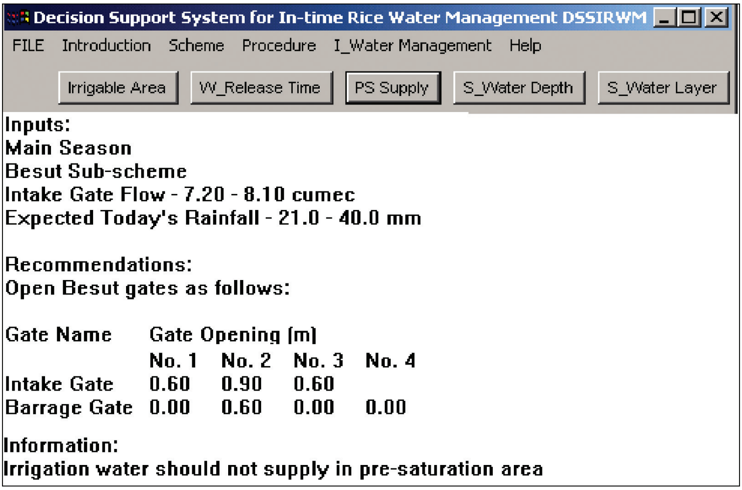


Figure E2 Output generated for Besut gate openings when intake gate flow is 7.20 - 8.10 m^3/sec and rainfall is 21 – 40 mm

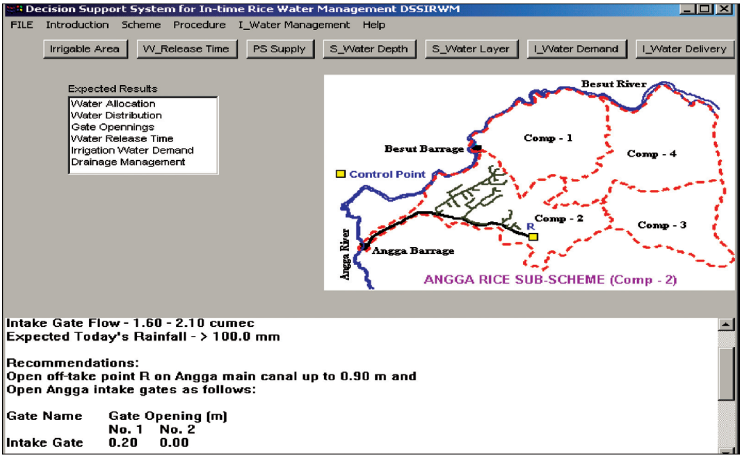


Figure E3 Output generated for the Angga sub-scheme when intake gate flow is 1.60 - 2.10 m³/sec and rainfall is above 100 mm

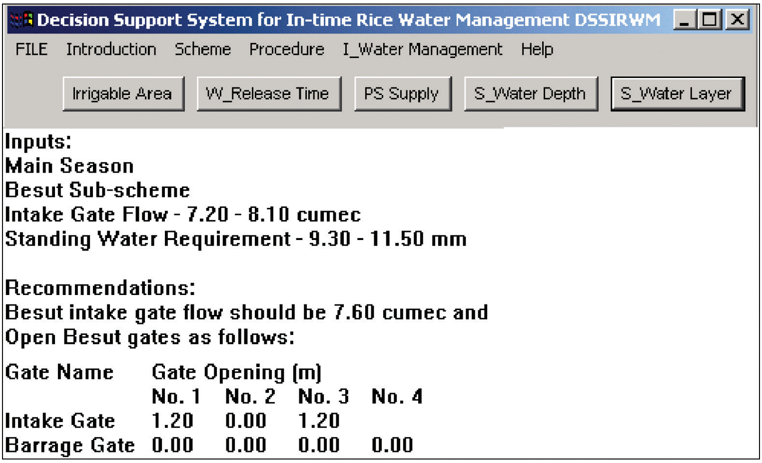


Figure E4 Knowledge output with Besut gate openings in the main season when intake gate flow is 7.20 – 8.10 m³/sec

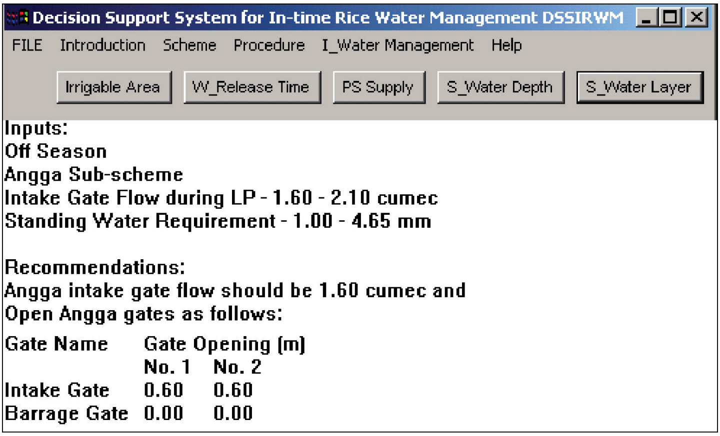


Figure E5 Knowledge output with Angga gate openings in the off-season when intake gate flow is 1.60 – 2.10 m^3/sec

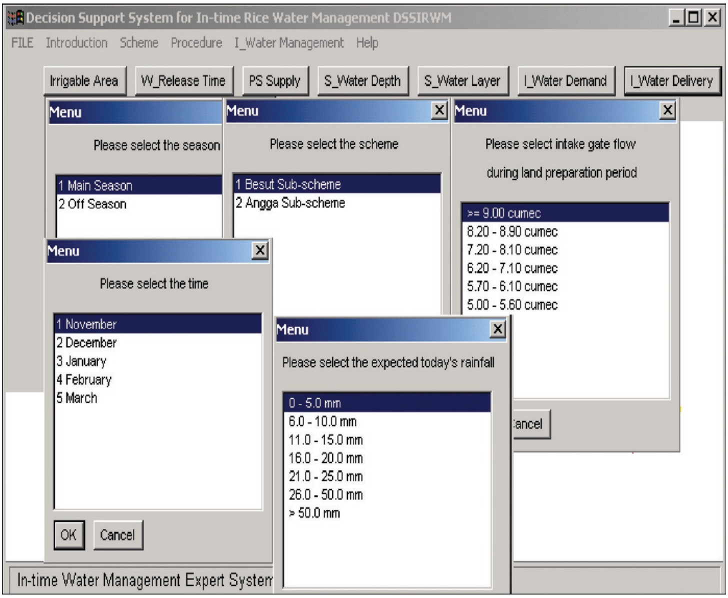


Figure E6 Selection options available under the "Irrigation Water Supply" module

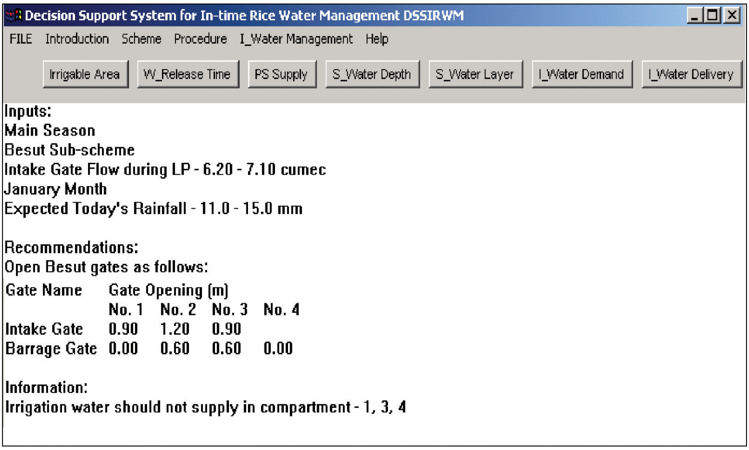


Figure E7 Text output with Besut gate setting for the month of January when Expected rain is 11.0 – 15.0 mm

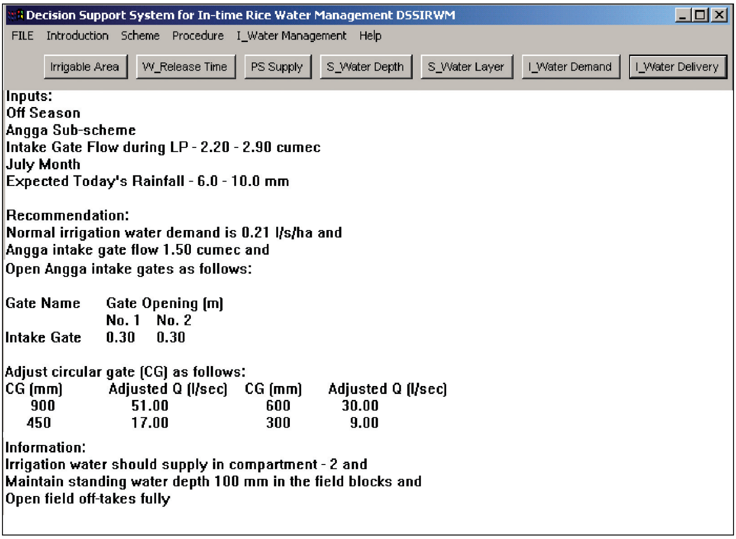


Figure E8 Text output with Angga gate settings for the month of July when Expected rain is 6.0 – 10.0 mm

Table E1 Comparison of actual releases with release decisions of the DSS

Scheme Operation Week	Rainfall Amount (mm) Observed	Rainfall Amount (mm) Simulated	Irrigation Demand (mm)	Actual Supply (Mm^3)	Supply by DSS (Mm^3)
Main Season – Besut Sub-scheme (Compartment 1, 3, 4)					
1	32.00	32.87	102.65	3.326	3.155
2	0.00	0.00	125.00	4.112	3.842
3	122.00	120.00	92.50	3.931	3.374
4	25.00	26.00	156.30	5.261	4.013
5	0.00	3.00	87.20	3.326	3.044
6	40.00	38.00	66.70	3.024	2.488
7	223.00	220.00	0.00	1.088	Nil
8	245.00	250.00	0.00	Nil	Nil
9	15.00	14.00	34.65	1.991	1.809
10	13.00	12.85	35.27	1.991	1.416
11	57.00	55.50	12.25	1.088	0.640
12	10.00	9.50	37.05	2.991	1.934
13	0.00	2.00	44.30	2.991	2.313
14	10.00	10.00	38.90	2.991	2.031
15	39.00	38.60	23.50	1.991	1.227
16	0.00	0.00	44.30	2.991	2.313
17	0.00	0.00	42.98	2.991	2.244
18	0.00	0.00	42.98	2.991	2.244
19	0.00	2.00	42.98	1.088	0.923
20	10.00	9.80	37.70	1.088	0.809
Off Season – Besut Sub-scheme (Compartment 1, 3, 4)					
1	5.00	6.00	121.00	4.838	3.590
2	15.00	15.90	114.20	3.991	3.389
3	0.00	2.00	174.00	5.262	4.271
4	35.00	34.00	150.90	5.262	4.270
5	0.00	0.00	91.20	3.354	3.307
6	0.00	0.00	91.20	3.356	3.307
7	17.50	18.00	32.50	2.356	1.697
8	0.00	0.00	42.20	3.810	2.203

9	0.00	3.00	41.40	3.265	2.161
10	0.00	0.00	41.40	3.265	2.161
11	0.00	0.00	41.40	2.117	2.161
12	0.00	0.00	41.40	3.838	2.161
13	25.00	25.00	32.05	2.384	1.673
14	5.00	6.00	42.40	3.233	2.214
15	0.00	2.00	45.60	3.233	2.381
16	0.00	0.00	45.60	2.810	2.381
17	29.00	30.00	22.60	2.175	1.180
18	0.00	0.00	38.80	2.721	2.026
19	15.00	16.00	30.10	1.116	0.678
20	62.00	60.00	6.50	1.116	0.146

CONCLUSIONS

The irrigation-scheduling program developed was able to predict the irrigation water deliveries for rice crop for 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 for 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 season crops. Such information could assist irrigation system managers to reduce the amount of irrigation water supplied during the coming days to meet crop water demand. The relative water supply irrigation index could be used beneficially to assess the performance of the irrigation scheme as it can provide details to identify periods of either excess or shortage of water.

Depending on water availability and field water requirements, pre-saturation schedules were obtained through canal flow simulations. Recommendations from such simulations are that pre-saturation supply can be carried out in one continuous stretch for all the compartments or over different phases depending on availability of existing river flows. When the river flow rate at the Besut and Angga barrages falls below 5.00 and 1.50 $m^3 s^{-1}$ respectively, the pre-saturation inundation requirement should be supplemented by pumped drained water re-use. Canal simulations combined with water balance indicate that during normal irrigation supply periods, to maintain irrigation throughout the whole scheme, there must be flow rates of 5.00 $m^3 s^{-1}$ and 1.50 $m^3 s^{-1}$ at the Besut and Angga barrages respectively. This investigation also showed that the irrigable area could be increased by 10% with better controls. The model simulation results can therefore have major implications in relation to future management programs directed toward better decision-making and a water efficient rice culture.

Long-term rainfall patterns, river flow conditions, crop variety and crop water requirements have been considered to act as guides in determining the cropping schedule. The prevailing practice of land preparation starting in November is based purely on the notion that rainfall is highest then. The proposed cropping schedule also takes the following factors into consideration: (1) pre-saturation period to coincide with rainfall (2) target harvesting of the crop in dry periods and (4) avoid planting in the months of November/December. Accordingly, the main season crop should be scheduled for between the months of September and February of the following year, while the off-season crop should be between the months of March and July in the same year. The planting schedules have been laid out such that the main season crop starts before the onset of North East monsoon, and ends with harvesting in the dry month of February. For the off-season crop, it is targeted for harvest in the month of July, to avoid the coming North East Monsoon wet spell in September. The proposed rescheduling of the cropping calendar is recommended for better water management in the Besut Irrigation Scheme in Terengganu, Malaysia.

Decision support systems have been applied in many areas of water resource management and are typically based on a similar fundamental structure. Decision support systems is an emerging area of computer applications for real world problems in which the computer is expected to make use of a knowledge base built into a program to make recommendations. A DSS based on a canal flow simulation and crop water estimation model, a knowledge base and a database, has been constructed for the Besut Irrigation Scheme. It can be used to support decision-making, provide information about area allocation during pre-saturation and normal irrigation, as well as indicate canal filling time allocation in order to release water from barrage to achieve timely allocation of water. The DSS developed should make tedious and cumbersome water management practices a thing of the past.

Computer models based on mathematical relationships, which govern such variations and other conditions along canal systems are useful tools to help management achieve management goals in terms of canal flow management. The mathematical models alone are not sufficient in the process of decision-making as they are laborious and more technical in nature. Furthermore, they do not guide the management in making quick decisions, as the management has to analyze the outputs of the model in conjunction with other available information. Therefore, mathematical models are incorporated into decision-making tools with a knowledge base, to quickly guide the management in decision-making. This DSS is expected to be very helpful in advising decision makers on increasing crop water use efficiency in the Besut Rice Irrigation scheme.

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BIOGRAPHY

Lee Teang Shui started his primary education at the Pasar Road English School (1) in Kuala Lumpur in 1961. He then continued with his lower secondary education at the Cochrane Road Englsih Secondary School in Kuala Lumpur from 1967 to 1969. From 1970 to 1972 he was with the Technical Institute for his upper secondary education. He completed his final year of upper secondary education at the Riccarton High School in Christchurch, New Zealand in 1973. In 1974 he pursued his tertiary education at University of Canterbury, Ilam, Christchurch following the program on agricultural engineering which required that the last two years of the program to be taken at the then Lincoln College also in the Canterbury Plains.

In 1977, he was awarded the Bachelors of Engineering (Agricultural) majoring in Water Resources Engineering. In 1978 he started his career as an assistant engineer with the Soil and Water Section, Ministry of Works and Development at Christchurch, New Zealand engaging with irrigation and drainage works in the irrigation schemes of the Canterbury Plains, In June 1979 he returned to join the Faculty of Agricultural Engineering (later known as Faculty of Engineering), Universiti Pertanian Malaysia, UPM (now Universiti Putra Malaysia) as a tutor. In late 1980 he furthered his studies at Utah State University at Logan Utah and in May 1982 he obtained his Masters of Science (Irrigation and Drainage Engineering). He rejoined UPM then and has since remain as a lecturer with the Department of Biological and Agrciltural Engineering, Faculty of Engineering. In 1985 he continued his post-graduate research studies on a part-time basis at the Faculty of Engineering, UPM and was subsequently awarded a PhD (Structural Engineering) in 1990.

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- Staff of The Kerian Irrigation Scheme in Bagan Serai, Perak
- Staff of The Muda Irrigation Scheme at Ampang Jajar, Alor Setar, Kedah, and
- Postgraduate students under his supervision at the Faculty of Engineering

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