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In-time Rice Irrigation Water Management Under Limited Water Supply

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ABSTRAK

Edaran air pengairan bertahap tepat-masa kepada petani merupakan suatu masalah utama kepada pengurus, perancang dan penyelidik berkenaan dengan pengairan sawah padi. Kajian ini menganalisis cara edaran air dan pelepasan air tepat-masa perlu diamalkan di kawasan sawah padi pada jangka masa praketepuan dan jangka masa bekalan pengairan biasa. Analisis dibuat menggunakan data terkumpul di Projek Pengairan Besut, terletak di negeri Terengganu, Malaysia. Projek tersebut ini terbentuk daripada dua kawasan, berjumlah luasan pengairan 5,164 hektar. Berdasarkan keperluan air di ladang dan aliran yang wujud, simulasi saluran dibuat dan keputusan menunjukkan bahawa tugas persediaan ladang tidak digalakkan secara berterusan sekiranya terdapat kadar sumber aliran sungai kurang daripada 9.00 meter isi padu sesaat dan 3.00 meter isi padu sesaat masing masing di Empangan Besut dan Empangan Angga. Sekiranya kadar aliran kurang daripada jumlah tersebut, maka tugas persediaan ladang baik dilakukan dalam dua fasa berturut-turut. Akan tetapi, sekiranya aliran berada pada tahap 5.00 hingga 5.50 meter isi padu sesaat di Empangan Besut, tugas persediaan ladang disyorkan dilakukan dalam tiga fasa berturut-turut. Pada jangka masa pengairan biasa, kadar aliran 6.00 dan 1.75 meter isi padu sesaat masing masing di Empangan Besut dan Empangan Angga mesti wujud bagi mengairi keseluruhan projek berturut-turut dan sekiranya aliran kurang daripada tersebut, maka pengairan berpilihan atau pengairan bergiliran terpaksa dikuatkuasakan. Apabila wujudnya kadar aliran 7.20 sehingga 9.00 meter isi padu sesaat dan 1.70 sehingga 3.00 meter isi padu sesat masing masing di Empangan Besut dan Angga, maka air perlu dilepaskan masuk ke saluran utama dan sekunder dua hari sebelum tugas persediaan ladang dimulakan. Demikian juga, air dilepaskan masuk tiga hari sebelum permulaan tugas persediaan ladang jika kadar aliran di antara 5.00 dan 7.00 meter isi padu sesaat di Empangan Besut. Lepasan air masuk ke saluran perlu dimulakan lima jam terlebih dahulu pada jangka masa pengairan biasa demi untuk memenuhi jadual pengairan bertahap tepat-masa.

ABSTRACT

In-time water distribution of canal water to the farmers has been a major concern of managers, planners and researchers involved in irrigation. This study analyzed the ways for water distribution and timely water release in a rice-growing area during the pre-saturation period and the normal irrigation supply periods. The analyses were carried out using field data collected at the Besut Irrigation Scheme located in the northeastern corner of Peninsular Malaysia in the state of Terengganu. The scheme comprises two sub-schemes, giving a total irrigation area of 5, 164 ha for the overall Besut Irrigation Scheme. Based on field water requirements and available flows at the intake gates, canal simulations were performed and results show that land preparation should not be done continuously unless flow rates are at least 9.00 m^3/s and 3.00 m^3/s at the Besut Barrage and Angga Barrage respectively. If the respective flow rates fall below these values, then land preparation should be done in two phases. However, when the flow rate is between 5.00 and 5.50 m^3/s at the Besut Barrage, land preparation is recommended to be carried out over three phases. During the normal irrigation supply period, flow rates of 6.00 m^3/s and 1.75 m^3/s for the Besut and Angga Barrage respectively, are to be maintained for the entire irrigation scheme, otherwise selective irrigation or irrigation on a rotational basis has to be enforced. When flow rates are 7.20 – 9.00 m^3/s and 1.70 – 3.00 m^3/s at the Besut and Angga Barrage respectively, then water should be released two days before the beginning of the pre-saturation period for the filling main and secondary canals. However, water should be released three days before the beginning of the pre-saturation period when flow rates are between 5.00 and 7.00 m^3/s at the Besut Barrage. But irrigation water should release 5.00 hours before beginning the normal supply period in order to maintain the in-time irrigation schedule.

Keywords: Canal flow simulation, water allocation, canal filling time, and rice irrigation.

INTRODUCTION

Malaysia is a rice-growing country and with the sophistication in rice cultivation practices, emphasis has been placed on farm water manalgement. Rice has been cultivated in the coastal plains in Malaysia for a long time. Rice cultivation was carried out once in a year using local traditional systems. Double cropping of rice was fully implemented in 1988. The efficient utilization of water resources needs information, such as annual effective rainfall, runoff, consumptive use, and water release policy, etc. and this is possible through the application of computer modeling system in water management.

Ideal water management may be defined as the delivery of the right amount of irrigation water at the right time to the fields to increase crop yield. A lot of water is needed, especially during the critical time of the double cropping planting when the 'pre-saturation' and 'saturation' requirements have to be met. This requirement happens to be fulfilled at one peak time with the limited water resource. The Department of Irrigation and Drainage (DID) of Malaysia introduced the practice of 'Rotational Irrigation' for rotating the supply from plot to plot in the granary irrigation schemes. It is difficult to irrigate one big scheme especially when shortage of water occurs. Water losses are very critical due to the increasing rate of evaporation from the surface of the earth during the hot dry season, whence the production of rice needs more water. This means that we need to provide double the amount of water during the drought season when the storage of water has in fact decreased. The key to saving water and achieving high efficiency is through proper management and distribution of water. But the problem is how to distribute the water equitably to all rice fields with high distribution efficiency. In time water management is one technique that can be implemented in rice irrigation schemes. This technique involves the effective use of irrigation water, reduction of operation loss (raise in efficiency) and increase of crop production. This will lead to savings in costs for operation and management.

Study Area

The area of study, Besut Irrigation Scheme, is located in the northeastern corner of Peninsular Malaysia in the state of Terengganu. The scheme consists of 2 sub-schemes, namely Angga Barrage sub-scheme and Besut Barrage sub-scheme. These sub-schemes are further sub-divided into 4 compartments, which are one compartment in the Angga sub-scheme (Compartment 2) and three compartments in the Besut sub-scheme (Compartment 1, 3, and 4). There are two sources of water supply for the scheme namely the Sungai Angga and Sungai Besut River. Compartments 1, 3 and 4 (totaling 4017 ha) receive irrigation supply by gravity from the Besut River System, while compartment 2 (1147 ha) receives irrigation supply also by gravity from the Angga River System. Moreover, the scheme area is divided into 39 irrigation blocks or water users' group as shown in *Fig. 1*. The main canals convey water downstream and the water is diverted to secondary and tertiary canals through discharge measuring offtake structures. Check gates are provided along the main as well as secondary canals to increase the water levels in the canals, when necessary. Irrigation infrastructure of this scheme has been provided for double cropping with a canal density of 48 m/ha, a drain density of 46 m/ha and farm road density of 24 m/ha (Teh and Mat, 1999). Water supply adequacy is sensitive to the 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, then the whole scheme is irrigated continuously. On the other hand, when the water levels fall below the above desired levels, the scheme is irrigated on a rotational basis. When drought occurs, the drains become supplementary sources of water. At present, water management problems are the most important constraints confronting the scheme in the fulfillment of its goal. Hence, the primary objective of this study is to investigate methods of in-time allocation of available water in order to achieve higher water productivity.

METHODS

Description of the Hydraulic Model

The *CanalMan* (Canal Management Software) model was used for performing hydraulic simulations of unsteady flow in branching canal networks. The *CanalMan* model was developed by Utah State University, Logan, Utah, USA (Merkley 1995). This model 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. The advantage of the model is that it computes the flow rate and water level simultaneously, so that

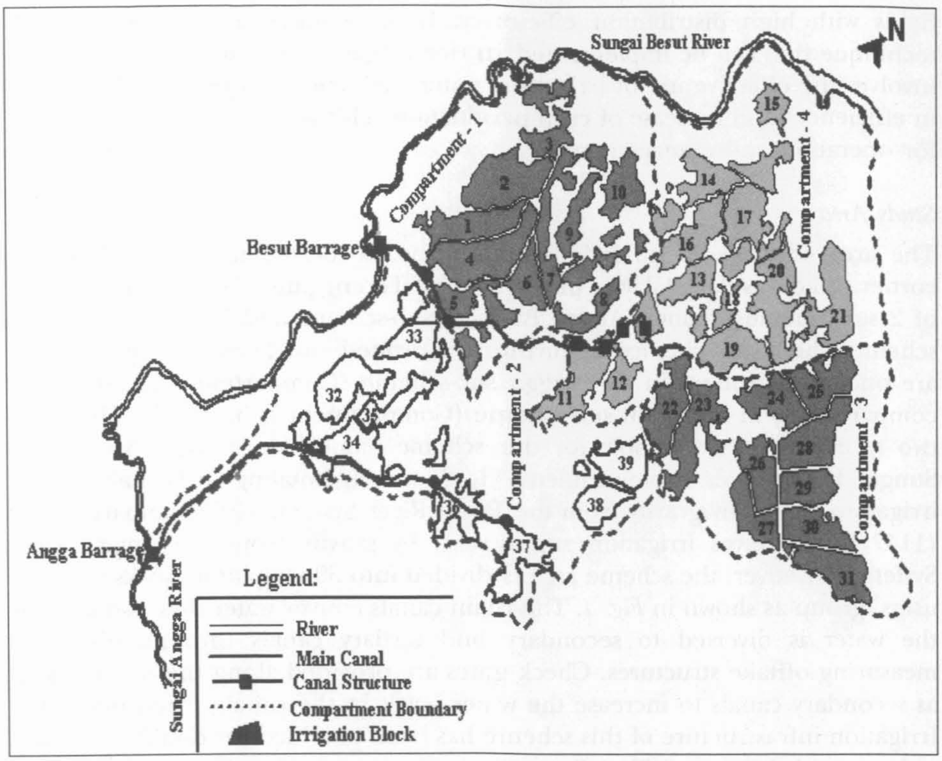

Fig. 1: Schematic map of the Besut Irrigation Scheme, Terengganu

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 configuration, hydraulic simulations, and output of results. Internal data cross-checking and input range restrictions on individual parameters help prevent unfeasible configurations 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.

The model determines approximate travel (or lag) times in canal reaches by applying a simplified equation for the celerity of a shallow-water wave (French 1985);

$$c = \sqrt{\frac{gA}{T}} \tag{1}$$

where c is wave speed or celerity (m/s), A is cross-sectional area of flow (m^2), T is top width of flow (m), and g acceleration due to gravity (approximate 9.81 m/s^2).

The top width of flow is a function of the cross-sectional area and the channel shape and size. Eqn. [1] gives a wave speed that is equivalent to the mean flow velocity for critical flow in a section because it is the same as setting the Froude number equal to unity. The model determines the celerity for each canal reach using the current average values of flow area, A, and top width, T, then divides the reach length by the celerity to yield the lag time in seconds. The largest lag time of all reaches is multiplied by a coefficient between 1.0 and 2.0 (as a safety factor), and is taken as the minimum period between calculations of reach inflows by the gate scheduling algorithms, as discussed above.

Crop Water Requirements

Double cropping of rice is an activity that uses plenty of water. 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 crop. Reducing the pre-saturation period may lead to saving water. For that reason, during the pre-saturation period the system should be in delivery mode at maximum capacity in order to reach all the fields as fast as possible so that planting of rice could be done without delay. 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 land soaking and land preparation period can be calculated as follows:

$$S_k = \frac{\dfrac{d_s}{t_s} + E_V + DP + \mathrm{Re}_k}{8.64E_a} \tag{2}$$

where, S_k is land soaking water requirement (l/s/ha), d_s 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 the time period k (mm/day), DP is percolation rate [mm/day] and E_a is the application efficiency.

$$P_k = \frac{\dfrac{d_p}{t_p} + E_V + DP + \mathrm{Re}_k}{8.64E_a} \tag{3}$$

where P_k is land preparation requirement (l/s/ha), d_p is depth of water required for crop submergence (mm), t_p is time required for land preparation (days).

The correct amount of irrigation delivery is the key element to improving irrigation management of the scheme. Irrigation supply for a field block through a gate can be estimated according to field water requirements. In normal irrigation supply period, water required can be calculated on the basis of the formula (JICA 1998) shown below.

$$DWR = (ET_o \times K_c + SP - ERF) \ / \ E_s \tag{4}$$

where DWR is diversion water requirement, ET_o is reference evapotranspiration, K_c is crop coefficient, SP is seepage, ERF is effective rainfall and E_s is overall irrigation efficiency. The value of E_s, the overall irrigation efficiency includes irrigation efficiency and conveyance efficiency along the secondary canals, is believed to be 45% (JICA 1998). For soil saturation depth, the Department of Irrigation and Drainage (DID), Malaysia standard value of 150 mm is applied. For standing water depth, 100 mm is used for the pre-saturation period. Percolation values were obtained from operation and maintenance manuals collected from the DID local office.

Crop evapotranspiration (ET_c) is a key factor to determine a proper irrigation schedule and to improve water use efficiency in irrigated agriculture. ET_c can be estimated by a reference crop evapotranspiration (ET_o) and crop coefficient (Doorenbose and Pruitt 1977; Kang 1986; Kang *et al.* 1992 and Kerr *et al.* 1993). ET_o can be estimated by many methods (Jensen 1974; Hill *et al.* 1985 and 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 (Monteith 1965) 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 the Muda Irrigation Scheme in northwest Malaysia. Therefore, reference evapotranspiration was estimated by using the Penman-Monteith equation as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.3u_2)} \tag{5}$$

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 (°C), u_2 is wind speed at 2 m height (m/s), 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 (k Pa ^{o}C^{-1}), γ is psychometric constant (k Pa ^{o}C^{-1}) and 900 is conversion factor. The data of temperature, relative humidity, wind speed and sunshine hours were used for estimating reference evapo-transpiration. The crop water requirement was then determined from the product of the reference evapotranspiration and the respective crop coefficient. The crop coefficient K_c values given in published sources for the study area were used (Chan and Cheong 2001). The weather data such as temperature, relative humidity, wind speed and sunshine hours of the study area were also collected for a period of 16 years, i.e. 1985-2000. The recent 40 years daily rainfall data (from 3 rainfall stations in the scheme) used in this study was obtained from the Central Data Information Section, Hydrological Branch, Department of Irrigation and Drainage (DID) Malaysia Headquarters in Kuala Lumpur. Water delivery information was obtained during a field survey.

Canal Flow Simulation

Data required for the canal simulations were canal bed width, side slope, canal length, gate structure and specification, water depth, canal cross-section, elevations, Manning's n and seepage rate. *CanalMan* input parameters include those data to be supplied to the *CanalMan* database files in order to run the model. These data were obtained from the Map Unit, DID Headquarters Malaysia in Kuala Lumpur. Canal 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 off-season. The full supply discharges are 9.00 m^3/s and 3.00 m^3/s for the Besut and Angga Barrage respectively. Thus, canal simulation was started with full supply capacity and then with a step-by-step decreased flow capacity approach for the Besut and Angga Barrages. In each simulation process, simulated flow values were compared to design canal flow values (main and secondary canals) to obtain the water distribution area. 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 possible water distribution area identified for pre-saturation period in phases and also repeated for the irrigation supply period for the whole scheme.

Canal Filling Time

The canals in the irrigation system must be filled in the order of first, the main, then the secondary and finally the tertiary canal. The canals were 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 offtake gates were closed during the time of filling the main canals. When the main canal is filled to FSL, all tertiary offtakes and all direct field offtakes along the secondary canals are closed before filling secondary canals. Therefore, the model estimated the filling time of the main and secondary canals during the pre-saturation period. Tertiary canals filling time was not estimated due to small canal length. However, lag time was also estimated during normal supply period in order to make decisions on in-time water release from the barrages.

RESULTS AND DISCUSSION

Water Demand

A huge quantity of information is available and is needed for management decisions. Land preparation consists of soaking, ploughing and puddling of the soil. The study revealed that 250 mm water is needed for land preparation in both the main season and off-season. The mean monthly general weather conditions and water requirements for each month of the year are shown in *Fig. 2*. The average evapotranspiration was found to be 4.20 mm/day and 3.99 mm/day for off-season and main season crop respectively. Crop water requirements were higher during off-season crop compared to the main season crop, mainly as a result of prevailing weather conditions. The average seasonal consumptive use of water for rice cultivation was 795 mm, out of which 572 mm (72%) was accounted for ET and 223 mm (28%) for 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. The water requirement was especially high for pre-saturation compared to supplementary supply in the main and off-season.

Water Allocation and Distribution

For the the period considered for canal simulation, in the first two weeks, the requirement comprises only the water requirement for land preparation. During this period, various flow rates for the Besut and Angga Barrages were used in the canal simulation process. The simulation results, when compared to the canal design capacity were satisfactory. Table 1 shows a canal simulation

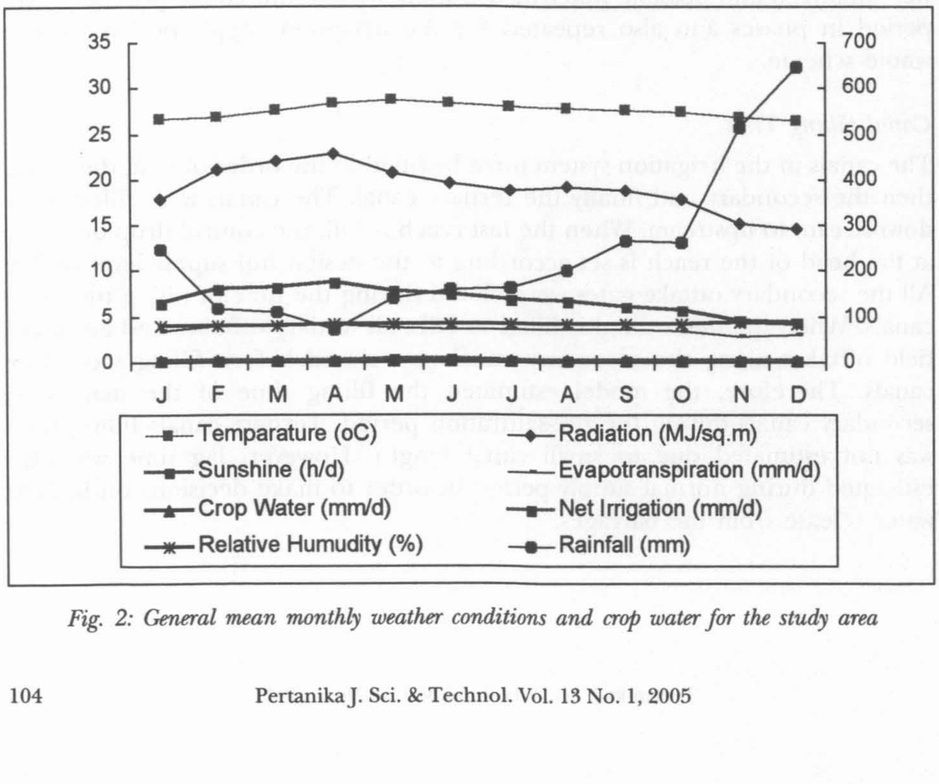

Fig. 2: General mean monthly weather conditions and crop water for the study area

TABLE 1
Example showing canal simulation results in the pre-saturation period during the main season and off-season

Compartment & Canal Name	Design Q_p	Simulated Q_p	Canal Name	Design Q_p	Simulated Q_p
	(l/s)	(l/s)		(l/s)	(l/s)
		Besut Barrage (Compartment 1, 3, 4)			
Comp - 1		Barrage Flow Rate = 9.00 m^3/s			
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 (Compartment 2)			
Comp - 2		Barrage Flow Rate = 3.00 m^3/s			
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

for the case of 9.00 m^3/s and 3.00 m^3/s for the Besut and Angga Barrage respectively. This serves as a check on the design values that were computed much earlier by designers of the scheme.

During the land preparation period, it was found that the total scheme area could not be inundated continuously in a single operation unless flow rates are at least 9.00 m^3/s and 3.00 m^3/s for Besut and Angga Barrage respectively. It was also noted that if flow rates fall below these values then pre-saturation should be done in two phases. Accordingly, the areas recommended for receiving water are identified and are presented in Table 2. The Phase I area is supplied first for pre-saturation time of 14 days at 2.10 l/s/ha. After 14 days, the same rate is supplied to the Phase II area. But if flow rate is between 5.00 and 5.50 m^3/s in Besut Barrage, then pre-saturation should be done in three phases. In this case, each phase is supplied for pre-saturation time of 21 days at 1.38 l/s/ha. However, when the flow rate falls below 5.00 m^3/s and 1.50 m^3/s for Besut and Angga Barrage respectively, then pre-saturation inundation should be supplemented using recycling pumps. In this case, the drains would be utilized as supplementary sources of water, and pumped up to irrigation canals by six (6) recycling pumps. No study on the pumping requirements was carried out in this study.

After pre-saturation, from the fifth week onwards, the irrigation water supply period commences for the next 100 days. During the normal growth period, continuous supplementary irrigation is required to sustain losses due to seepage and percolation as well as evapotranspiration. The standing depth of water in each block is maintained at 100 mm and this depth is necessary for direct seeding rice. During this normal irrigation supply period, 6.00 m^3/s and 1.75 m^3/s flow rate for Besut and Angga Barrage respectively must be maintained throughout the entire period. Should available flows fall below the expected values stated above, then the simulation process must be repeated to identify optimal areas for irrigation and also areas where it may be best to leave alone in view of inadequate flows available.

Gate Operation and Water Release

Since available irrigation water in the scheme is quite limited, proper operation of diversion gates as well as even timely water distribution is essential for water saving. The study reveals that the farmers in the lower reaches (Compartment 3) get much less water per unit area than the farmers in the upper reaches (Compartment 1) resulting in an inequitable distribution of water. It has also been observed that few gates supply excess amount of water into the canals, which cause overflow into the fields. For proper functioning of the gates in controlling water, the gates must be opened adequately. This has led to the development of gate openings schedule for pre-saturation period and is presented in Table 3. On the other hand, the time lag of water traveling in the system is an important factor that determines the losses of irrigation water in the system itself. Thus, the model was used to calculate the required time in filling the main and secondary canals during the pre-saturation period. The average time for filling canals are summarized in Table 4. The details pertaining to each canal, though computed, are not reported in this table due to limitation of space. It has been observed that when flow rates are 7.20 – 9.00 m^3/s and 1.70

TABLE 2

Water distribution area during pre-saturation and normal irrigation supply periods derived from water demand and water availability

Intake Gate Flow (m^3/s)	Irrigable Area (KPA* Unit)		
	Pre-saturation Period – Besut Barrage (Compartment 1, 3, 4)		
	Phase - I	Phase - II	
> = 9.00	C – 1 (KPA - All); C – 3 (KPA - All); C – 4 (KPA - All)		
8.20 – 8.80	C – 1 (KPA – All); C – 4 (KPA – All); C – 3 (KPA – 26 – 31);	C – 3 (KPA – 22 – 25);	
7.20 – 8.00	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 – 7.00	C – 1 (KPA – All); C – 4 (KPA – All);	C – 3 (KPA – All);	
5.70 – 6.00	C – 4 (KPA – All); C – 3 (KPA – 22 – 25);	C – 1 (KPA – All); C – 3 (KPA – 26 – 31);	
	Phase - I	Phase - II	Phase - III
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 recycling pumps for irrigation		
	Pre-saturation Period – Angga Barrage (Compartment 2)		
> = 3.00	C – 2 (KPA – All);		
2.20 – 2.80	C – 2 (KPA – 32 – 35);	C – 2 (KPA – 36 – 39);	
1.70 – 2.00	C – 2 (KPA – 32, 33, 35);	C – 2 (KPA – 36 – 39);	
< = 1.50	Start recycling pumps for irrigation		
	Irrigation Period – Besut Barrage (Compartment 1, 3, 4)		
6.00	C – 1 (KPA – All); C – 4 (KPA- All); C – 3 (KPA – All);		
	Irrigation Period - Angga Barrage (Compartment 2)		
1.75	C – 2 (KPA – All);		

*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.

– 3.00 m^3/s at the Besut and Angga Barrages respectively, then the starting date of water supply for the season should be two days before the beginning of the pre-saturation date in order to maintain irrigation scheduling in time. But water should be released three days before beginning of the pre-saturation period of season when flow rates are between 5.00 and 7.00 m^3/s at the Besut

TABLE 3
Gate opening schedules in pre-saturation period

Barrage Flow (m^3/s)	Canal Name	Gate Opening (%)		Canal Name	Gate Opening (%)	
		Existing	Suggested		Existing	Suggested
Besut Barrage (Compartment 1, 3, 4)						
>= 9.00	TLK	100	80	L. Agu	100	80
	FC1/CD	100	70	FC3/DE	100	70
	T.Nibong	100	75	FC4/TG	100	70
	FC2/TLA	100	75	Tok Nga	100	70
	Kayu Kelat	100	70	G. Kulim	100	80
	K. Depu	100	75	P. Ribu	100	75
	Tok Bugis	100	50	Chenrong	100	70
	G. Rengas	100	70	Apal	100	70
	FC1/FG	100	50	FC1/TG	100	70
	FC1/GM	100	70	FC2/GM	100	70
	HH1	100	70	II1	100	70
	FC1/MN	100	50	NOa	100	70
	FC1/NO	100	70	FC3/PP1	100	75
	FC1/QQ1	100	70	FC2/QQ1	100	70
	Q2a	100	60			
8.2 – 8.80	TLK	100	80	L. Agu	100	80
	T.Nibong	100	75	FC2/TLA	100	75
	Tok Nga	100	70	Kayu Kelat	100	70
	G. Kulim	100	80	K. Depu	100	75
	P. Ribu	100	75	Tok Bugis	100	50
	Chenrong	100	70	Apal	100	70
	FC1/FG	100	50	FC1/GM	100	70
	FC2/GM	100	70	HH1	100	70
	II1	100	70	FC1/MN	100	50
	NOa	100	70	FC1/NO	100	70
7.0 - 8.00	L. Agu	100	80	T.Nibong	100	75
	Tok Nga	100	70	Kayu Kelat	100	70
	G. Kulim	100	80	K. Depu	100	75
	P. Ribu	100	75	Tok Bugis	100	50
	Chenrong	100	70			
Angga Barrage (Compartment 2)						
3.00	TPB	100	75	Awek	100	70
	FC1/Awek	100	50	FC2/RS	100	70
	SS1	100	70			

TABLE 4

Average filling time in main and secondary canals during pre-saturation period

Barrage Name/ Flow	Compartment Name	Average Filling Time (hours)	
	Pre-saturation Period		
(m^3/s)		Main Canals	Secondary Canals
Besut Barrage 9.00	Comp- 1	15.00	24.00
	Comp- 4	21.00	35.00
	Comp- 3	24.00	40.00
Angga 3.00	Comp- 2	17.00	24.00
Besut Barrage 8.20 – 8.80	Comp- 1	16.00	26.00
	Comp- 4	22.50	40.00
	Comp- 3	26.00	42.00
Angga 2.20 – 2.80	Comp- 2	19.00	26.00
Besut Barrage 7.20 – 8.00	Comp- 1	17.50	28.00
	Comp- 4	25.00	44.50
	Comp- 3	27.00	46.00
Angga 1.70 – 2.00	Comp- 2	22.00	29.00
Besut Barrage 6.20 – 7.00	Comp- 1	19.00	31.00
	Comp- 4	27.00	48.50
	Comp- 3	30.00	51.00
Besut Barrage 5.70 – 6.00	Comp- 1	21.50	33.50
	Comp- 4	30.00	50.00
	Comp- 3	32.00	53.50
Besut Barrage 5.00 – 5.50	Comp- 1	23.00	33.50
	Comp- 4	31.00	50.00
	Comp- 3	33.00	55.00

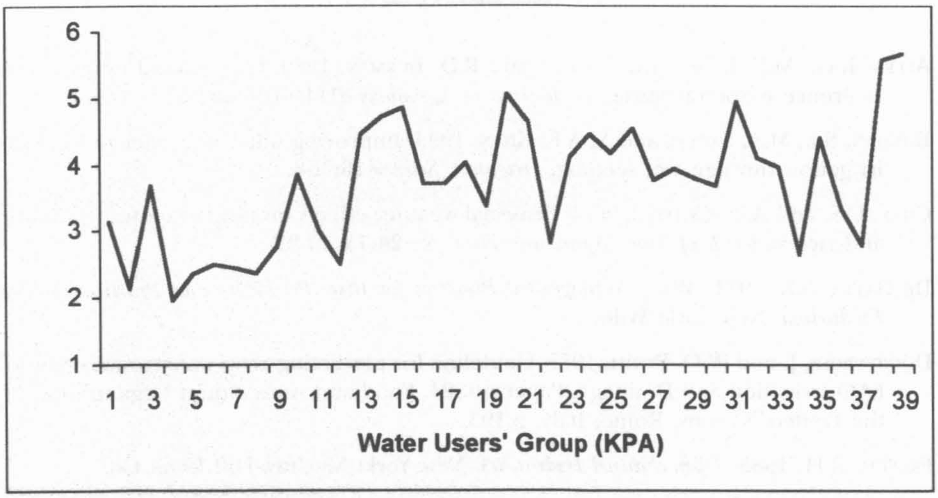

Fig. 3: Water travel time in irrigation blocks during normal supply period

Barrage. The time of arrival of water in irrigation blocks (KPA) from the Besut and Angga barrages during normal supply period are shown in *Fig. 3*. During the normal supply period, water should be released 5.00 hours before flow rates are 5.00 - 6.00 m^3/s and 1.75 - 2.00 m^3/s at the Besut and Angga Barrages respectively. In order to save water, irrigation supply should be reduced if there is rainfall. However, the amount to be reduced must be determined based on rainfall and canal discharge. This can be done through reducing the flow at the intake gate and adjustment of the orifice gate of secondary constant head.

CONCLUSIONS

Depending on water availability, land preparation can be done in one continuous stretch for all the compartments or over different phases as suggested by the simulation. During the irrigation period, should water resources in the river system be deemed inadequate, then the hydraulic simulation can be pursued, to identify the units and compartments that are best irrigated given that not all units can be supplied in view of the circumstances. The gate at each canal is constructed to permit the water flow to serve the unit adequately and equally among the farmers. Thus, gate operation must be managed properly. Time required in filling canals during pre-saturation are important for making decisions on water release from barrages. The canal simulation results therefore can have major implications in relation to future management programs directed toward more decision-making and water efficient rice culture. The use of *CanalMan* model to simulate irrigation canals as a means of improving in-time water management in rice double cropping systems through proper gate settings and establishing the extent of choice irrigated areas is therefore recommended.

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