Modeling Equitable Water Allocation for a Run-of-the-River Irrigation Scheme

Rowshon M.K[1]., M.S.M. Amin[2], T. Masumoto[1] and A.R.M. Shariff[2]

[1]Lab. of Hydrology and Water Resources Eng., National Institute for Rural Eng. (NIRE), JAPAN
[2]Dept. of Biological and Agricultural Engineering, Fac. of Eng. Univ. Putra Malaysia

Abstract

Irrigation water is becoming increasingly scarce and an ever-increasing problem in irrigation sector. Increasing competition for water among different sectors is forcing to allocate the available water resources for irrigation supply more efficiently and equitably. Hence techniques must be found to improve agricultural water management to cater for variability in soil and crop conditions, hydrological uncertainties, and erratic flows in the river, canal network and various control structures. A water allocation model was developed for prediction and allocation of available water resources equitably and more efficiently for a paddy irrigation scheme in Malaysia. The model and its all components is integrated with the Geographical Information System (GIS) for data management, retrieval, analysis and decision making. ArcObjects and Visual Basic for Application (VBA) programming languages were used to develop the User-interface inside the powerful ArcGIS software. The model recommends daily equitable and efficient irrigation deliveries among tertiary canals incorporating the allowable, design irrigation supply based on the water demand and available water resources for irrigation supply as the season advances. It distinctly gives information on the uniformity of water distribution and the shortfall or excess using newly developed performance indicators Rice Relative Water Supply (RRWS); and what decisions for water allocation to adopt for the upcoming days. Easy updating system of the associated databases keeps the system always updated with respect to the real field situations. The results are displayed on the computer screen together with color-coded thematic maps, graphs and tables in a comprehensible form that helps irrigation managers to enhance decision-making in the management and operation of the irrigation system. The model was found to be a useful for a more equitable distribution of the available water supply to a wider area and used for water allocation and evaluating future scenarios of various water managements.
Keywords: Water Demand, Equitable Allocation, Evaluation Management Scenarios.

Introduction

Efficient operation and management of an irrigation system plays an important role in the sustainability of irrigated agriculture (Mishra et al., 2001). It is a well-known that in most run-of-the-river irrigation projects, the demand curve seldom satisfactorily matches the erratic flows in the river. In large-scale irrigation systems like Tanjung Karang Rice Irrigation System, where water is continuously delivered over a wide area with varying climate, soil, and crop conditions, the equitable water allocation by the tertiary canals is an important component to improve the system management. A good irrigation depends on the ability of its managers being to apply the right amounts of water accurately and efficiently.

Unfortunately, most irrigation systems still being unable to achieve this are leading to high water losses and poor management. With the ever-increasing demands for water among agricultural, industrial and residential sectors, improved water management by using new tools and techniques to efficiently allocate the available water resources for irrigation supply is therefore a formidable challenge for producing more rice with less water.

Each irrigation system is unique, both in terms of its physical and managerial structures. Nonetheless, experience and insight gained in one location can be useful in another. Canal water deliveries may be unreliable because of drought, limited storage, canal breaches, high seepage losses, manual intervention, malpractices, relative position at the distribution network, and various other management and operational inefficiencies. Water courses located at upper reaches of the distributaries, get more water than their downstream (Kijne and Velde, 1990). Sharama and Oad (1990) and Latif and Sarwar (1994) designed variable-time models for equitable water allocation in rotational irrigation system. Models intended to deliver water among irrigators along tertiary canals by allocating equal time and volume of water per unit of land. Actual water management in some irrigation schemes is carried out depending only on the experience and knowledge of the administrator about the daily water demand. The Tanjung Karang scheme's water demand results in a conflict with agriculture during irrigation seasons when there is no sufficient water to satisfy both water users. Due to unreliable water supply in the absence of a storage reservoir for the scheme, there is a need for daily prediction and allocation of the available water resources equitably and efficiently. Mathematical models alone are not satisfactory tools in the process of decision-making. The modern GIS technique coupled with models can quickly guide the management in decision-making since the temporal and spatial dimensions could be studied at once. Therefore, a mechanism was developed integrated with the water allocation model coupled with GIS for ensuring the use of available water resources efficiently and improving the existing irrigation water management for a large scale irrigation scheme.

Study Area

The study was carried out in the Tanjung Karang Rice Irrigation Scheme located at about $3^{0}25^{/}$ ~ $3^{0}45^{/}$ N latitude and $100^{0}58^{/}$ ~ $101^{0}15^{/}$ E longitude in the district of Kuala Selangor and Sabak Bernam of the state of Selangor in Malaysia. The scheme has a total command area of about 19,848 ha. The scheme is cultivated two times in a year called main season (August to January) and off-season (February to July). The pre-designed standing water depth 2 to 10 cm in paddy fields is practiced during crop growing seasons depending on the farmer's attitude and available water resources for irrigation supply. Irrigation water is mainly diverted from Bernam River through Headworks (BRH). The feeder canal from the BRH passes towards swamp and discharges into Tengi River, and thence to the Tengi River Headworks (TRH) in the main canal. The average annual rainfall is about 1715 mm. The yields of the scheme for 1998-2002 were obtained to be around 4.47 t/ha in the off season and 4.65 t/ha in the main season, respectively.

Development of Equitable Water Allocation Model

There are more than 120 tertiary canals (Offtakes) delivering irrigation water directly from the main canal to the fields. Irrigation systems that deliver water to many offtakes can be difficult to manage, because of limited water resources, manual intervention, malpractices and various other management and operational inefficiencies. These result in decreasing volumes of water delivering to downstream offtakes. Many factors influence equitable irrigation allocation. Irrigation schedules are often adjusted to accommodate cultural practices too. Therefore, it may imply the need to give more attention to offtakes in order to maintain deliveries within an acceptable range of variation. The empirical equation was developed for simulating equitable and allowable irrigation supply through tertiary canals as the irrigation season advances:

$$q_r = IDF_i \times f \times Q_{av} \quad [1]$$

$$IDF_i = \frac{q_i}{Q_d} \quad [2]$$

$$f = \frac{Q_{av}}{\sum_{i=1}^{n} q_i} \quad [3]$$

Where,
q_i = the design discharge of the target offtakes (tertiary canals), m^3s^{-1}
Q_d = the designed discharge of the main canal, m^3s^{-1}
Q_{av} = the average daily available discharges for irrigation supply, m^3s^{-1}
i = the offtake number
IDF_i = the Offtake Irrigation Delivery Factor, which is the ratio of designed discharge of the targeted offtake (Constant Head Orifice, CHO) to the designed discharge of the main canal (Figure 1).
f = the factor depending on the function of Q_{av} and q_i.

The model helps to achieve equitable water allocation towards the downstream end of the canals. The actual or recommended irrigation supply is optimized with field water demand and available water resources for irrigation supply. To cover the targeted irrigation service areas, the recommended irrigation supply (q_r) through each irrigation offtake will be less than allowable and design irrigation supply, when the available discharge for irrigation supply (Q_{av}) is not sufficient to meet the actual field water demand. If the available discharge for irrigation supply is sufficient to meet field water demand then the recommended irrigation supply through each irrigation offtake can be considered higher than allowable and/or design irrigation supply. When available discharge cannot satisfy water demand irrigation managers need to be taken much attention for controlling gate opening among tertiary canals according to the recommended supply. The equitable and recommended irrigation deliveries for tertiary canals must not be exceeded allowable supply and/or design supply during water shortage period. The total recommended demand must be less than available inflows for irrigation supply before preceding water allocation.

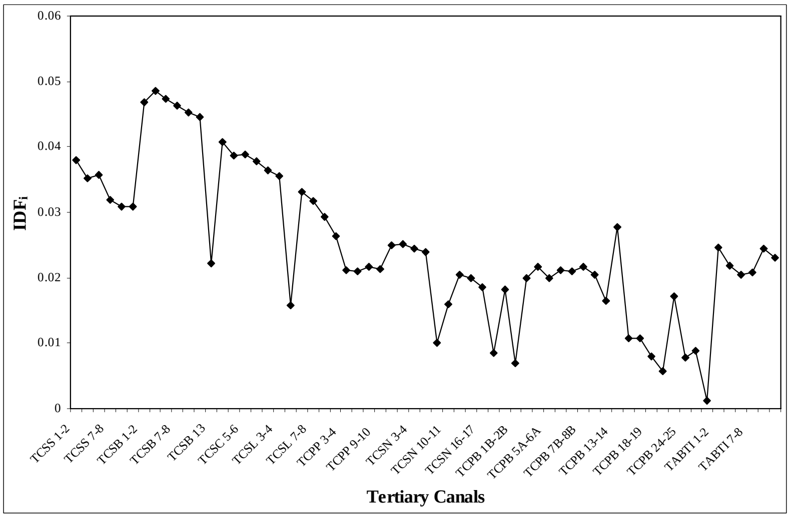


Figure 1: Offtake Irrigation Delivery Factor (IDF_i).

Rice Relative Water Supply (RRWS)

The Rice Relative Water Supply ($RRWS_j$) is defined as the ratio of the total supply as Irrigation requirement (IR_j) and Effective Rainfall (ER_j) to the total demand as the sum of the difference between Maximum Ponding Water Depth and Present Ponding Water Depth ($WSmax_j$-WS_j) for a particular irrigation period; Evapotranspiration (ET_j); and Seepage-Percolation (SP_j) in the service areas for a duration being considered. It can distinctly characterize the oversupply for $RRWS_j > 1.0$ and undersupply for $RRWS_j < 1.0$ for any given period as the season advances. The value of $RRWS_j = 1.0$ indicates irrigation supply is perfectly matched with the paddy water demand. Incorporating depleted ponding water ($WSmax_j$ - WS_j) into eq. (4) is the modification for the Relative Water Supply concept given by Levin (1982) especially useful for evaluating irrigation delivery for paddies. The RRWS for crop growth period is expressed as follows:

$$RRWS_j = \frac{IR_j + ER_j}{\left(WSmax_j - WS_j\right) + ET_j + SP_j} \qquad [4]$$

The oversupply and undersupply can be simply identified for any given irrigation period with the actual RRWS value compared with the RRWS = 1.0. For a particular period, irrigation supply is gradually increased with the amount of depleted water depth until it reaches the maximum level in the field. Without considering this amount, RWS concept incorrectly characterizes the false oversupply. In fact, it is not necessarily an oversupply. A value of RWS = 0.8 may not represent a problem rather it may provide an indication that farmers are practicing deficit irrigation supply to maximize returns on water (Molden et al., 1998). This remark can be adopted for operating irrigation system even at RRWS = 0.5 for a particular period to overcome water shortage and could be helpful to store more rainfall if $WSmax_j$ is retained.

Architecture of GIS-interface for Water allocation Model

Rice Irrigation Management Information System (RIMIS) is a robust and user-friendly interactive information and management system of a run-of-river rice irrigation system. RIMIS is an ArcGIS-VBA user-interface comprised with five major modules, several sub-modules and functions. ArcObjects and Visual Basic for Application (VBA) programming languages were used to develop RIMIS inside the powerful Geographical Information System (GIS) software ArcGIS. On activation within the ArcMap environment, the "RIMIS" main menu appears directly on the Menu Bar. By selection of the menu item "Open RIMIS" allows to view the dialog wizard of the RIMIS as shown in Figures 2 and 3. RIMIS allows equitable water allocation and evaluating water management scenarios for the scheme. The system can be regularly monitored during the irrigation season, so that the improved operation is possible.

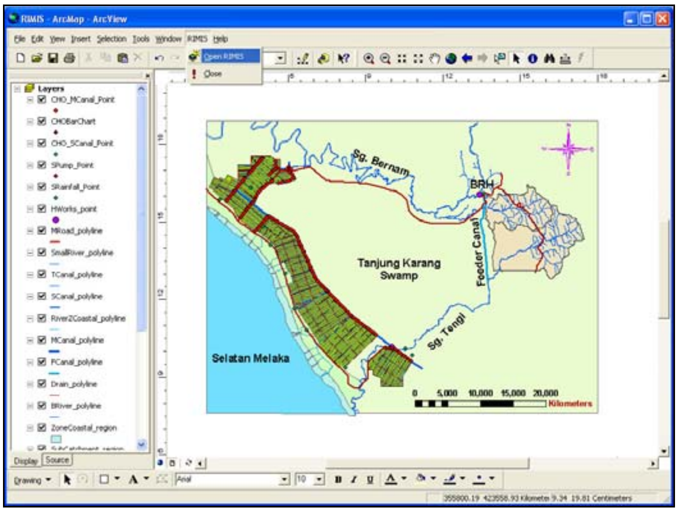


Figure 2: The Menu RIMIS and Tanjung Karang Rice Irrigation Scheme in ArcMap Window.

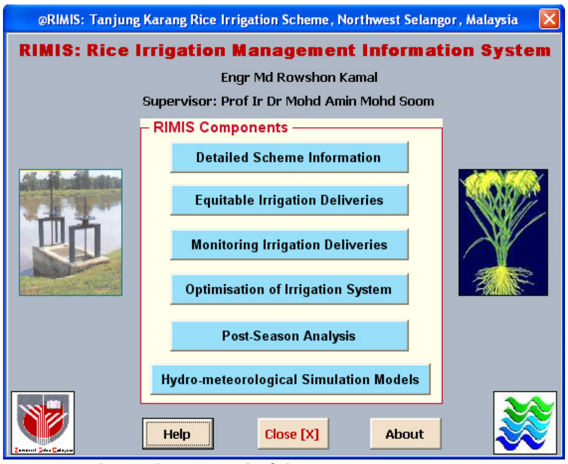


Figure 3: The Dialog Wizard of the Rice Irrigation Management Information System (RIMIS).

Results and Discussions

The recommended irrigation deliveries of tertiary canals are computed for the irrigation service areas as the season advances. A dialog window like that Figure 4 appears by clicking on the "Equitable Irrigation Deliveries" in Figure 3 and the user is required to enter values of present Ponding Water Depth (WS_j), Maximum or Allowable Irrigation Depth (WS_{max} or ASW), average daily Reference Crop Evapotranspiration (ETo_j), average daily Seepage & Percolation (SP_j), expected average daily Rainfall (RF_j), Crop-coefficient (k_c) and Irrigation Efficiency (IE) into the dialog wizard. The sub-routines for FAO Penman-Monteith and stochastic prediction models have written to input daily ETo_j and RF_j under each irrigation service areas (ISA). The WS_j can be obtained from the computation of the water balance equation which is fed into input TextBox using the command buttons ISAI, ISAII, ISAIII, respectively. The available inflow for irrigation supply at TRH is determined using loss rate equation with respect to the upstream inflow records. Before simulating recommended irrigation supply for canals, user can view the irrigation delivery performance on previous days. New indicators were used to characterize the irrigation delivery performance on a previous days and what decisions to adopt for the next day. Irrigation deliveries are then computed by clicking on the Command Button "Equitable Irrigation Supply" in Figure 4. The irrigation manager can instantly view irrigation deliveries for the irrigation operational units for a specified period shown in Figure 5. To optimize the irrigation supply, the recommended irrigation supply should not exceed Allowable Supply and/or Design supply. It may not be possible based on the field condition but the recommended irrigation supply must be less than available water for irrigation supply i.e., 17.21 < 18.21 m^3/s for a particular day (Figure 4). This condition can ensure to cover irrigation supply to the target service areas with available or limited water resources.

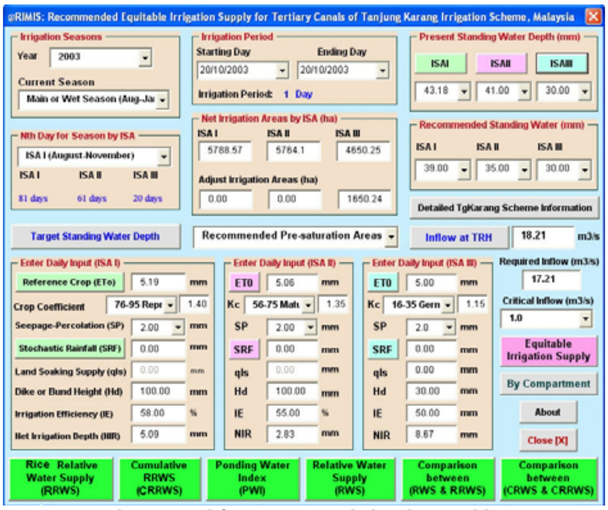


Figure 4: Dialog Wizard for Recommended and Equitable Irrigation Water Allocation by Tertiary Canals, 20 October 2003

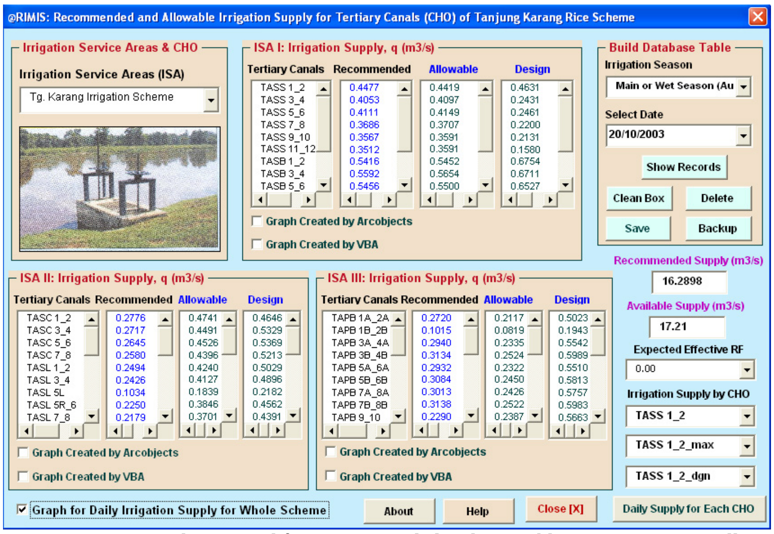


Figure 5: Output Dialog Wizard for Recommended and Equitable Irrigation Water Allocation for all Tertiary Canals, 20 October 2003.

The program allows for saving the daily outputs in MS Access database simply by clicking on the Command Button "Save". The Command Button "Show Records" allows retrieving information into output dialog wizard from database for the selected date. The Command Button "Clean Box" removes all information from the dialog wizard. The Command Button "Delete" permanently deletes all records from database by selecting a particular date. The Command Button "Backup" helps to keep all files as backup any time in operation advances. The results displayed in map, table, and graph forms help the irrigation manager to diagnose the irrigation system and to take proper decision for the gate operators. Clicking the CheckBox "Graph Created by Arcobjects" and "Graph Created by VBA" in the dialog window presents simulated results in tabular and graphical forms instantly. The module allows for viewing irrigation delivery performance before and after a day as season advances. The outputs for recommended and equitable irrigation supply in season's advances (Off Season: 20 April 2003, 10 May 2003 and Main Season: 20 October 2003, 10 November 2003) are shown in Figures 6 to 9. The daily recommended, allowable and design irrigation deliveries together with the planted areas represent in tabular format by tertiary canals shown in Figure 10.

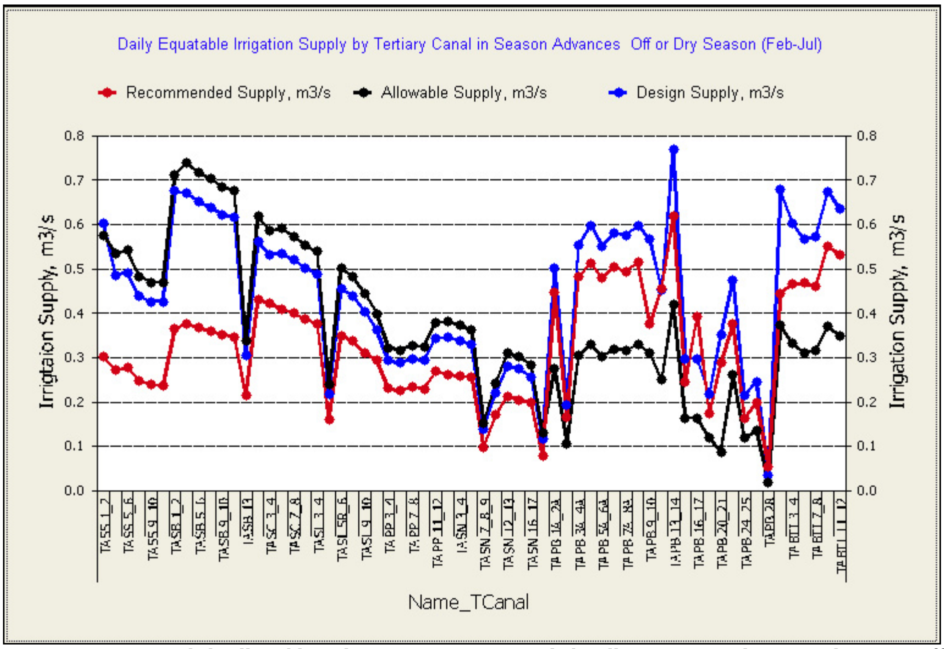


Figure 6: Recommended, Allowable and Design Irrigation Supply by all Tertiary Canals, 20 April 2003 in Off Season.

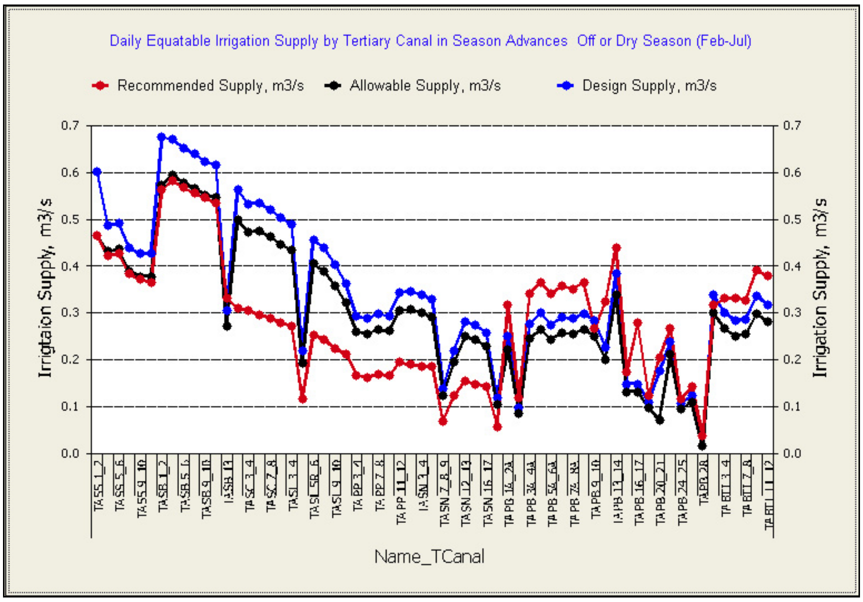


Figure 7: Recommended, Allowable and Design Irrigation Supply by Tertiary Canals, 10 May 2003 in Off- Season.

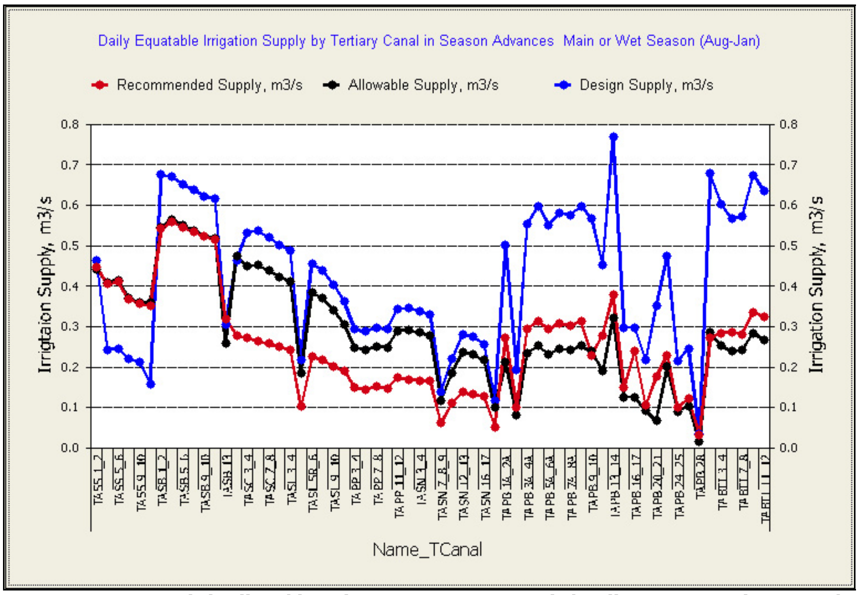


Figure 8: Recommended, Allowable and Design Irrigation Supply by all Tertiary Canals, 20 October 2003 in Main Season.

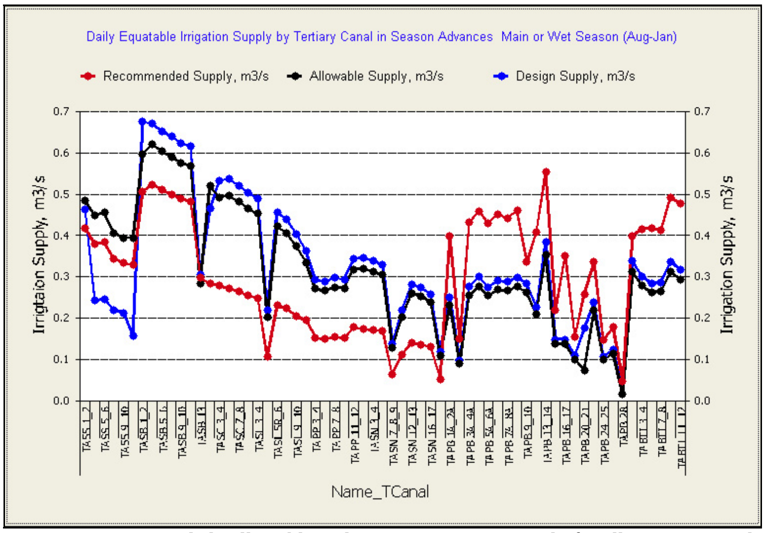
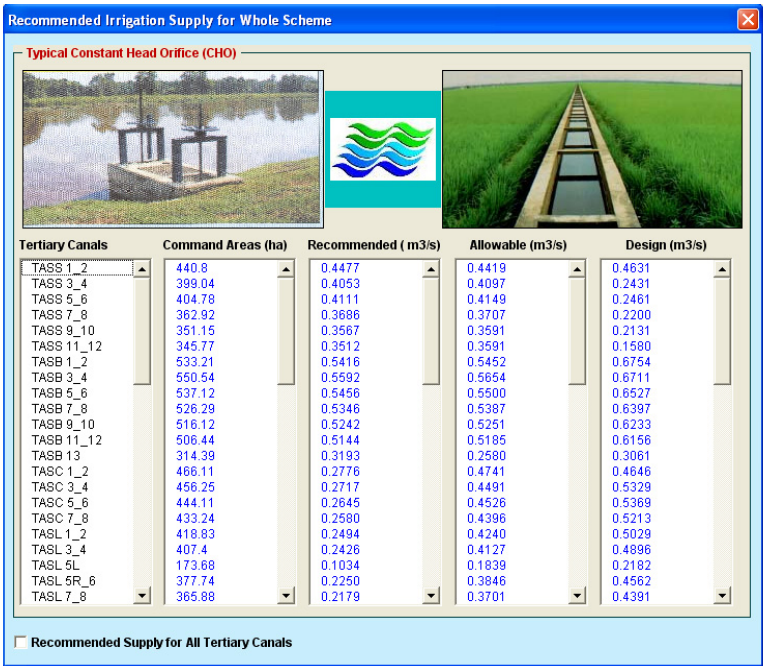


Figure 9: Recommended, Allowable and Design Irrigation Supply for all Tertiary Canals, 10 November 2003 in Main Season.



Tertiary Canals	Command Areas (ha)	Recommended (m3/s)	Allowable (m3/s)	Design (m3/s)
TASS 1_2	440.8	0.4477	0.4419	0.4631
TASS 3_4	399.04	0.4053	0.4097	0.2431
TASS 5_6	404.78	0.4111	0.4149	0.2461
TASS 7_8	362.92	0.3686	0.3707	0.2200
TASS 9_10	351.15	0.3567	0.3591	0.2131
TASS 11_12	345.77	0.3512	0.3591	0.1580
TASB 1_2	533.21	0.5416	0.5452	0.6754
TASB 3_4	550.54	0.5592	0.5654	0.6711
TASB 5_6	537.12	0.5456	0.5500	0.6527
TASB 7_8	526.29	0.5346	0.5387	0.6397
TASB 9_10	516.12	0.5242	0.5251	0.6233
TASB 11_12	506.44	0.5144	0.5185	0.6156
TASB 13	314.39	0.3193	0.2580	0.3061
TASC 1_2	466.11	0.2776	0.4741	0.4646
TASC 3_4	456.25	0.2717	0.4491	0.5329
TASC 5_6	444.11	0.2645	0.4526	0.5369
TASC 7_8	433.24	0.2580	0.4396	0.5213
TASL 1_2	418.83	0.2494	0.4240	0.5029
TASL 3_4	407.4	0.2426	0.4127	0.4896
TASL 5L	173.68	0.1034	0.1839	0.2182
TASL 5R_6	377.74	0.2250	0.3846	0.4562
TASL 7_8	365.88	0.2179	0.3701	0.4391

Figure 10: Recommended, Allowable and Design Irrigation Supply together with Planted Areas in Table, 20 October 2003 in Main Season.

A new performance indicator called Rice Relative Water Supply (RRWS) was developed for evaluating and characterizing irrigation delivery performance correctly as the season advances (Rowshon et al., 2006).The irrigation performance characterizes as over supply for RRWS > 1.0, undersupply for RRWS < 1.0 and good performance for RRWS = 1.0. The irrigation manager can instantly view irrigation delivery performances for previous days by clicking on the Command Buttons “Rice Relative Water Supply (RRWS)” and other performance indicators simultaneously which are shown in Figure 4. Inputs are directly called from output table of the scheduling module. The program allows plotting of irrigation delivery performance as the season progresses, helps to evaluate water allocation scenarios at the field condition and allocate the right amount of irrigation supply for the next day.

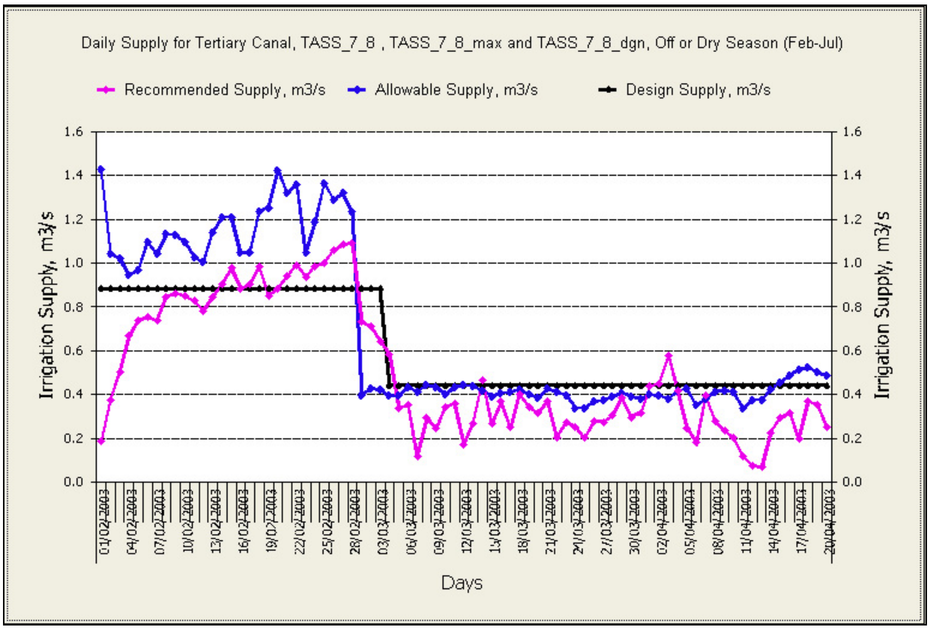


Figure 11: Recommended, Allowable and Design Irrigation Supply by a Single Unit of Tertiary Canals out of 63, 20 April 2003 in Off Season.

The results can be represented by each irrigation service areas staggered by one month for each ISA clicking into the Check Box either "Graph Created by Arcobjects" or "Graph Created by VBA" in Figure 4. The keeping the records on daily irrigation task in database helps user to diagnose the irrigation distribution for each tertiary unit as the season progresses like as Figure 11 for 20 April 2003 & the Figure 12 for the entire off season and Figure 13 for 20 October 2003 & the Figure 14 for the entire main season. There are many options available in this module which helps irrigation manager for proper allocation of available water resources to the targeted service areas. The name and information of the object are displayed on the screen whenever the user clicks on the particular object from the map layout. Therefore, the irrigation manager will be able to know instantaneously, the amount of deliveries and the location of distribution. The program also allows for viewing targeted irrigation deliveries, along with graphical representation for each compartment, Tertiary Canal and block.

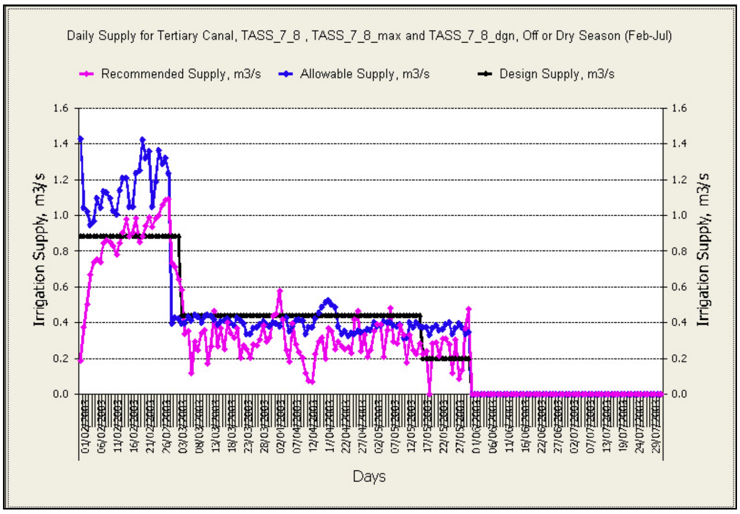


Figure 12: Recommended, Allowable and Design Irrigation Supply by a Single Unit of Tertiary Canals out of 63 for the Entire Off Season.

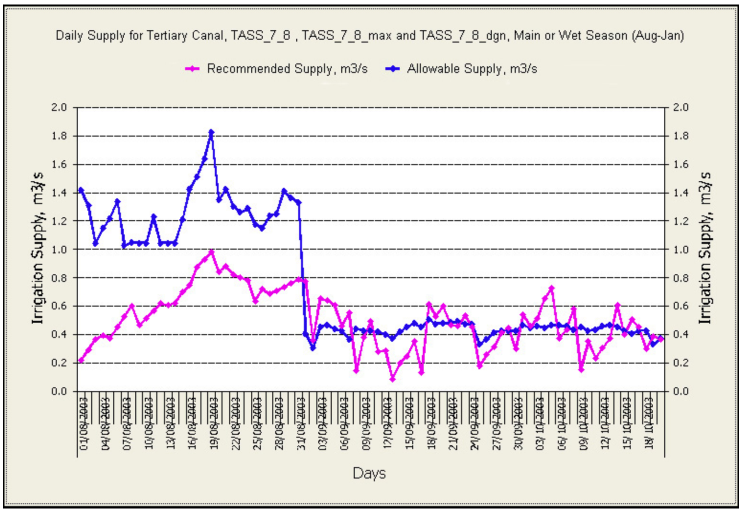


Figure 13: Recommended, Allowable and Design Irrigation Supply by a Single Unit of Tertiary Canals out of 63, 20 October 2003 in Main Season.

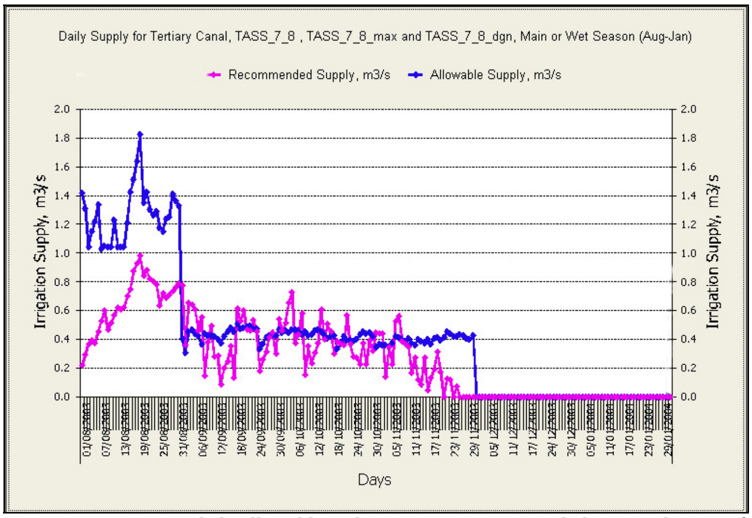


Figure 14: Recommended, Allowable and Design Irrigation Supply by a Single Unit of Tertiary Canals out of 63 for the Entire Main Season.

Conclusion

Allocation of surface water resources is more difficult due to the variability of water use, typical irrigation supply and the pattern of water availability. Mathematical models alone are not satisfactory tools in the process of decision-making. The modern GIS technique coupled has integrated mathematical models to quickly guide the management in decision-making since the temporal and spatial dimensions could be studied at once. Irrigation engineers or water managers need appropriate and regular information related to aspects of irrigation water management for a clear picture of the scheme condition. The easily obtained comprehensive information allows the manager to characterize the irrigation delivery performance faster. The model ensures the equitable irrigation supply and the efficient use of available water resources for the scheme. The daily simulation for equitable and allowable irrigation deliveries among tertiary canals incorporates design irrigation supply, actual field water demand and available water resources as the season advances. The model successfully can provide information on the uniformity of water distribution and the shortfall or excess using newly developed performance indicators and water allocation decisions for the next day. As experience in one location can be useful in another, the model is likely to be adopted into the existing water use mechanisms for irrigation projects in other regions with the appropriate modification including with local information. It was successfully used for allocating and evaluating future scenarios of various water managements for a large scale paddy irrigation scheme.

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