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# Development of a GIS Based Water Management Tool for a Large Scale Rice Irrigation Scheme

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## ABSTRAK

Satu model berasaskan GIS telah direka untuk menggabungkan pelbagai maklumat spatial dari kawasan pengairan Kerian. Kawasan pengairan ini dibahagi kepada lapan kompatmen yang terdiri daripada 28 blok. Model ini mengandungi tiga modul, iaitu Penjadualan (Scheduling) yang mengira pembekalan air berasaskan maklum balas spatial dan temporal daripada sawah, sementara modul Pemantauan (Monitoring) menunjukkan maklumat tentang keseragaman bekalan air antara semua blok dan kompatmen. Petunjuk-petunjuk seperti Relative Water Supply (RWS), Water Use Efficiency (WUE), Cumulative Relative Water Supply (CRWS), dan Water Productivity Index (WPI) ditentukan dengan modul Penilaian (Evaluation). Analisis lepas musim menggunakan maklumat hidro-klimatik mingguan, bekalan air dan indeks pengairan mingguan bagi setiap blok. Berdasarkan tempoh seminggu, didapati bahawa julat RWS ialah antara 1.01 hingga 2.24 dan WUE ialah antara 45% hingga 99% bagi musim utama, sementara pada luar musim nilai RWS ialah antara 1.04 hingga 1.87 dan WUE ialah antara 53.57% hingga 96.15%. Nilai purata WPI ialah 0.13kg/m$^3$ pada musim utama dan 0.22kg/m$^3$ di luar musim. Peta tematik berkod warna telah disediakan untuk mengesan Hasil Musim, dan Keamatan Penanaman Musim (Cropping Intensity), mengikut blok dan kompatmen. Maklumat dipamerkan dalam bentuk jadual dan graf akan memudahkan proses membuat keputusan sepanjang musim oleh pihak pengurusan. Model yang berasaskan maklum balas daripada sawah ini dapat mempertingkatkan lagi sistem pengurusan pengairan di jelapang padi.

## ABSTRACT

A GIS based model was developed to integrate the vast amounts of spatially distributed information from the Kerian Irrigation Scheme comprising eight compartments which are further subdivided into 28 blocks. The model consists of three modules. The "Scheduling" program computes irrigation deliveries based on spatial and temporal demand of the paddy field by each compartment, block or secondary canal. The "Monitoring" program gives information by compartment and by block on the uniformity of water distribution and the shortfall or excess. Relative Water Supply (RWS), Water Use Efficiency (WUE), Cumulative Relative Water Supply (CRWS), and Water Productivity Index (WPI) were computed by the "Evaluation" module. The post-season analysis uses weekly information on hydro-climatic parameters, irrigation delivery and irrigation indices by block within each compartment. On a weekly basis, RWS and WUE were found to range from 1.01 to 2.24 and 45% to 99% respectively in the main season and 1.01 to 1.87 and 53.57% to 96.15% respectively in the off season. The average values of RWS and WUE were found to be 1.53 and 68.15% in the main season and 1.33 and 78.47% in the off season respectively. The average values of WPI were also found to be 0.13 and 0.22 $kg/m^3$ in the main season and off seasons respectively. Color-coded thematic maps were produced for the monitoring of Seasonal Yields and Cropping Intensity (CI) by block and compartment of the scheme. The results are displayed allowing the manager to view maps, tables and graphs in a comprehensible form to ease decision making as the season progresses. This study would be useful to improve the irrigation system management based on feedback of field information.

**Keywords: Water management, rice irrigation, user-interface and GIS**

## INTRODUCTION

Rice is the staple food in Malaysia. The Government has targeted rice production of 1.20 million tons by 2010 at a self-sufficiency level of 65 percent in National Agricultural Policy, NAP 1992-2010. According to a JICA and DID report (Anon 1998), effective use of water resources by rationalizing irrigation systems and impartial water allocation with a suitable water management practice are key factors for increasing rice production. Irrigation performance has received growing attention during the last decades. Vast amounts of data are distributed spatially at district levels. These could be integrated to help improve water management. Geographical Information Systems (GIS) is a tool with great potential for structuring information to improve monitoring and evaluation of irrigation and drainage projects and assist in related policy decisions. Salman *et. al.* (1997) used Remote Sensing (RS) and GIS to monitor and evaluate irrigation and drainage projects in Pakistan. This study concentrated on the estimation of crop related indicators such as area under different crops and cropping intensity. Assessing performance requires a clear identification of the performance indicators, the scale at which performance is to be assessed, and the level of accuracy required by the potential users of this information. A GIS based software (NAGA Version 1) is being tested for monitoring and diagnosis of irrigation projects in Thailand. It expects improved stability of delivery at the secondary level by "real time" monitoring; monitoring of the global indices of efficiency and identification of mismanagement, easy weekly assessment of performance.

In irrigation projects there is significant variation in the spatial and temporal data. GIS capabilities to integrate spatial data from different sources, with diverse formats, structures, projections or resolution levels, constitute the main characteristic of these systems, thus providing needed aid for those models that incorporate information in which spatial data has a relevant role (Goodchild 1993). Bradly (1993) stated that the capability of GIS makes it appropriate for decision-making. GIS provides a platform for retrieval and structuring of that information to improve irrigation deliveries, monitoring and evaluation of irrigation and drainage projects and related policy decisions. The objective of this study is to develop a GIS interface program for Water Management of rice irrigation to improve regular or periodic irrigation delivery and monitoring, and post-season analysis to evaluate the irrigation performance.

*Study Area*

The Kerian Irrigation Scheme is one of the oldest Schemes in Malaysia. It is situated at the northwest corner of the State of Perak in Peninsular Malaysia. *Fig. 1* shows the layout of the 28 blocks which make up a total irrigated area of 23,800 ha. The catchment area of the reservoir is 489 $km^2$ and active storage of the reservoir is 56 MCM with a dead storage of 19 MCM. It serves as the source of irrigation water for compartments (E to H), while a pumping station supplements four compartments (A to D) at the tail end of the scheme.

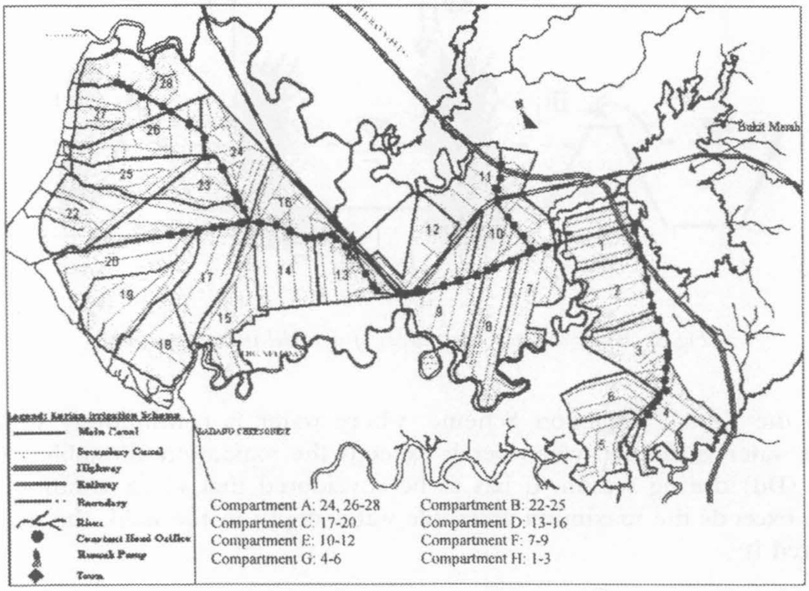


*Fig. 1. Digitized layout of Kerian Irrigation*

## METHODOLOGY

*Water Balance in a Rice Field*

The field water balance is used to characterise scheduling, monitoring and evaluation of the rice irrigation system. For a continuous irrigation system, how well water is distributed among plots within a block for a particular irrigation period needs to be answered. Adequate monitoring and evaluation of performance is needed to improve water management practices to achieve a satisfactory level of efficiency. The schematic diagram of water balance components in a paddy field is shown in *Fig. 2,* while the balance equation is expressed as follows:

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

Where,

$WD_j$ = depth of water in the paddy field at the end of period, cm.
$WD_{j-1}$ = depth of water in the paddy field at the beginning of a period, cm.
$IR_j$ = depth of diversion of irrigation water supply during the period, cm
$RF_j$ = rainfall during the irrigation period, cm.
$ET_j$ = evapotranspiration from the paddy field during the period, cm.
$SP_j$ = average seepage and percolation loss from the paddy field, cm.
$DR_j$ = drainage requirement during the period, cm.
j = period of water management for irrigation scheme, days.

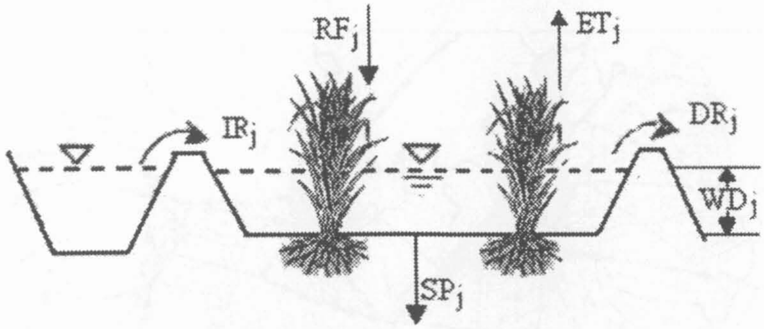


*Fig. 2. Water balance components of a model in a paddy field*

In the Kerian Irrigation Scheme, where water is continuously supplied, excess water is drained whenever it exceeds the maximum allowable level of water (Dd) during season. It has to be considered that when standing water depth exceeds the maximum allowable water depth in the field, the drainage required is:

$$DR_j = WD_j - Dd \text{ if } WD_j > Dd \quad (2)$$

*Targeted Diversion Irrigation Supply*

Precise estimation of irrigation delivery is a key element in any irrigation system. Accurate estimation of the expected rainfall and evaporation is difficult. Taking into account expected rainfall before performing the scheduling processes can save significant amounts of irrigation water. Spatial and temporal irrigation supply for a single CHO can be estimated according to paddy field requirements. If $WD_j$ is less than the targeted depth, Dd (ie., $WD_j < Dd$) then the sum of depleted standing water depth ($WD_j$ - Dd) cm, and losses from the paddy field and expected rainfall ($ET_j + SP_j - ER_j$) are considered in the scheduling process, using the following equation:

$$Q_p = \frac{\left[(Dd - WD_j) + (ET_j + SP_j - ER_j) * t\right]A}{244.66\ t * Es} \tag{3}$$

When only the amount of losses from the paddy field and expected rainfall ($ET_j + SP_j - ER_j$) are considered during the scheduling processes when water depth remains the same as the maximum allowable water depth, then the diversion supply will be

$$Q_p = \frac{\left[(ET_j + SP_j - ER_j) * j\right]A}{244.66\ j * Es} \tag{4}$$

Where,

$Q_p$ = predicted diversion water supply from CHO in main canal, $m^3/sec$
Dd = designed water depth maintained in the paddy field, cm
$ER_j$ = expected rainfall, cm
A = irrigation area, ha
j = period of water management for irrigation scheme, days and
Es = irrigation system efficiency.

*Water Use Efficiency, WUE*

The WUE involves the efficiency concept traditionally used in engineering in which the efficiency is a comparison of output with input. It provides a simple way of determining water use relative to total water supply from irrigation and rainfall sources. It also serves as a useful indicator of the irrigation system performance when rainfall is negligible and how efficiently the available water supply is used in the system. Water use efficiency as defined as below, has been used as an index of field water utilization efficiency in rice irrigation systems (IRRI 1974).

$$WUE = \left(\frac{ET_j + SP_j}{IR_j + ER_j}\right) * 100 \tag{5}$$

Where,

$IR_j$ = depth of diversion water supply during the period in cm.
$ER_j$ = effective rainfall during the irrigation period in cm.
$ET_j$ = evapotranspiration from the paddy field during the period in cm.
$SP_j$ = average seepage and percolation loss during the period, cm.

*Relative Water Supply, RWS*

Relative water supply proposed by Levin (1982) is the ratio of total water supply from rainfall and irrigation sources to total evapotranspiration need and seepage and percolation losses.

$$RWS = \left( \frac{IR_j + ER_j}{ET_j + SP_j} \right) \tag{6}$$

It is a simple ratio of supply to demand. It is useful for analysis and interpretation of irrigation system performance for different time intervals, monthly, annual, seasonal or special periods such as land preparation and for the different locations at system and subsystem levels. RWS is a more practical indicator than the irrigation system efficiency for rice irrigation practices. It represents the amount utilized for crop production and the amount of water delivered to meet crop water demand. Due to this, it gives a clear understanding and planning for the behavior of the major parameters in the irrigation management process to the irrigation managers and farmers.

*Cumulative Relative Water Supply, CRWS*

It is defined as the accumulated value of the ratio of supply to the demand computed over short intervals of time (i.e. daily, weekly or any period) starting from a particular time of the season. The RWS helps to identify acute access or shortage while the CRWS gives the integrated value. It is also useful at the end of every season as part of the evaluation of the irrigation process. It is expressed mathematically as follows:

$$CRWS = \sum RWS_j \tag{7}$$

Where, $\sum RWS_j$ is the cumulative value of all the RWS values over short time duration up to that time.

*Water Productivity Index, WPI*

The water productivity index measures effectiveness of the irrigation in terms of gross rice yield per volume of water applied. The realistic range of the water productivity index should be from 0.30 to 0.60 kg/m$^3$. Both the increases of rice yield per hectare and water use efficiency are essential to improve Water Productivity Index. However, yields are not a function of water alone, it also depends on soil fertility, climate, pests, diseases and agricultural practices. It is expressed as:

$$WPI = \frac{\text{Specific Yield in kg / ha}}{\text{Specific Supply in ha / m}^3} = \frac{Y}{q_s * 1000} \text{kg / m}^3 \tag{8}$$

where, Y the specific yield is the yield per ha (kg/ha) for the season in the area concerned, and $q_s$ the specific supply is the total supply including rainfall per ha for the season in the area concerned, $m^3$/ha.

### *GIS User-interface*

The design of the GIS user-interface and its application in the Kerian Irrigation Scheme are presented below. The desktop mapping software package MapInfo for Windows and MapBasic Programming Language were used for developing the user-interface tools. The schematic in *Fig. 3* illustrates the components and operation strategies.

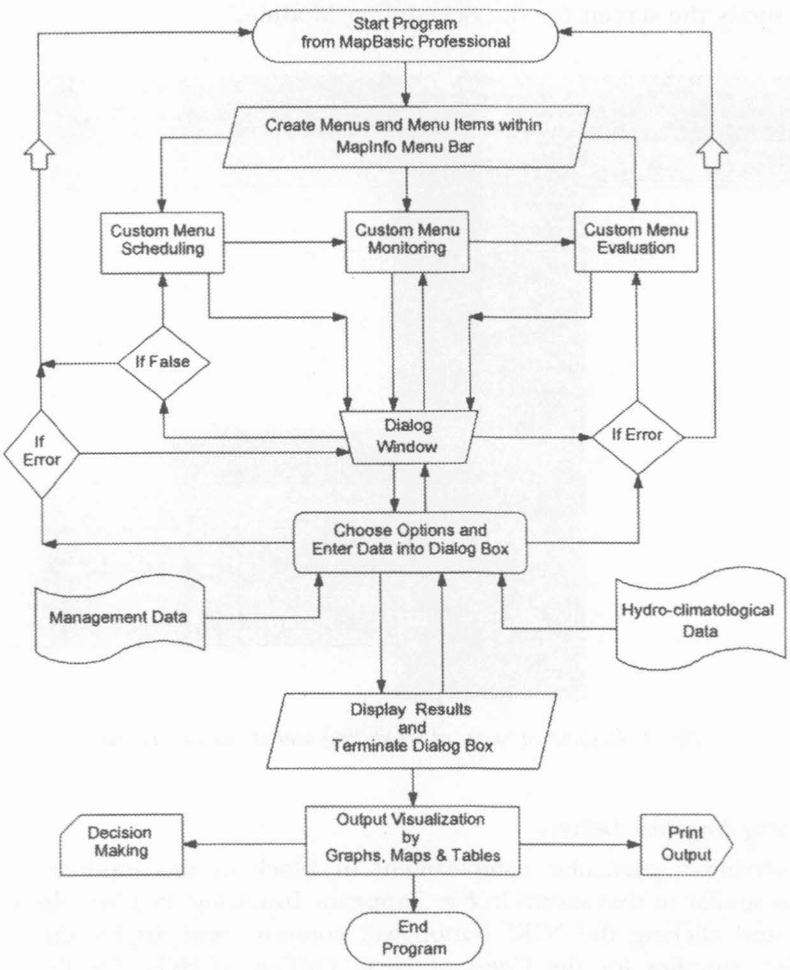


*Fig. 3. Schematic diagram illustrates the operation procedure of the user-interface technique*

Three modules were developed, namely Scheduling, Monitoring and Post Season Analysis (Evaluation). Scheduling was used to determine the Target Irrigation Delivery, while the second was used to monitor Irrigation Deliveries such as Relative Water Supply and Water Use Efficiency. The last, as its name implies, is carried out at the end of the season to consider yields, Water Productivity Index and Cumulative Relative Water Supply. An identical user interface was implemented at the beginning of the model. The selected module's name appears in the MapInfo menu bar. Clicking on this menu item activates a drop-down menu which allows the user to select any one of the eight compartments. Within each compartment, further selection of an individual block is possible. After this point, menus specific to the module will be used. *Fig. 4* shows the screen for the Scheduling Module.

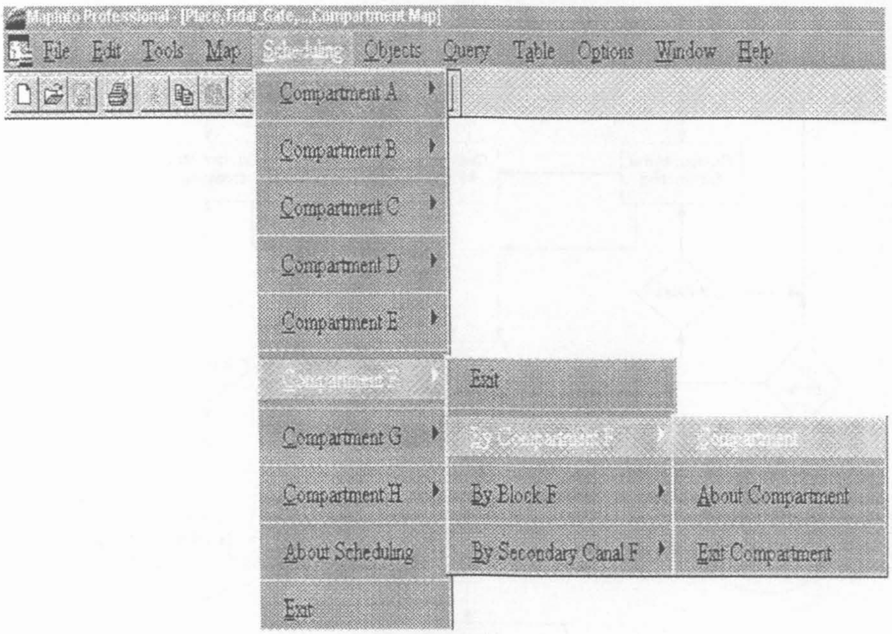


*Fig. 4. Customized menu of scheduling and its menu structures*

*Scheduling Irrigation Delivery*

On selecting a particular compartment or block in this module, a dialog window similar to that shown in *Fig. 5* appears. Inputting data into the relevant boxes and clicking the "OK" button will compute and display the targeted diversion supplies for the Constant Head Orifices (CHOs) for the selected blocks/compartments.

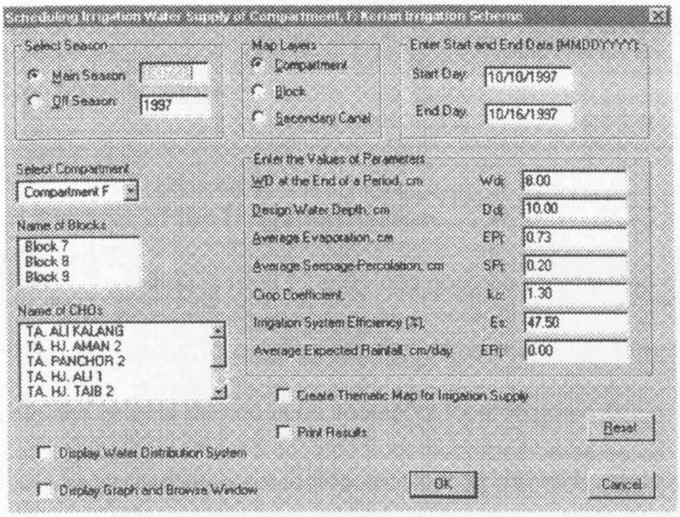


*Fig. 5. Dialog window for scheduling of compartment F by compartment*

*Monitoring of Irrigation Delivery*

In the Monitoring Module, a dialog window like that shown in *Fig. 6* appears. By entering values into the appropriate boxes and then clicking the "OK" button, output for the Monitoring Module for a particular block or compartment will be calculated and displayed in the form of maps, tables or graphs.

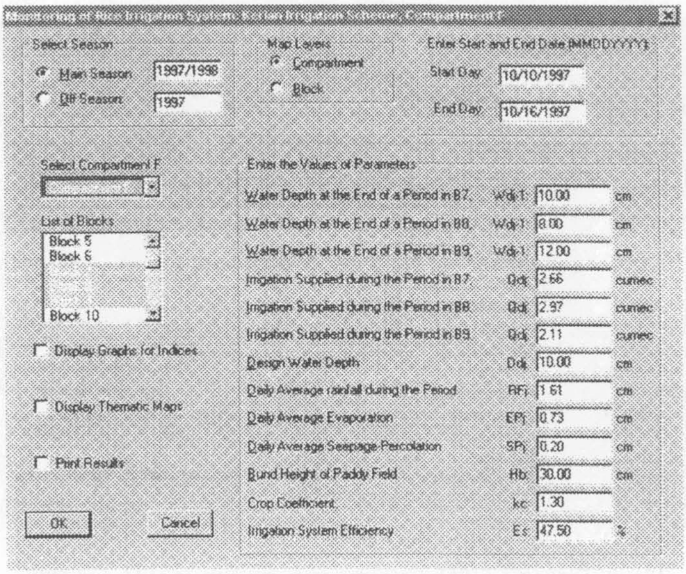


*Fig. 6. Dialog window for Monitoring Module by compartment*

*Post-season Analysis of the Irrigation System*

The "Evaluation" module is used to carry out post-season analysis for the irrigation system. On selection of this module a dialog window similar to that in *Fig. 7* appears. The user enters data and selects the indicator to analyse and display. When yield and Water Productivity Index are to be determined a dialog window as shown in *Fig. 8* appears.

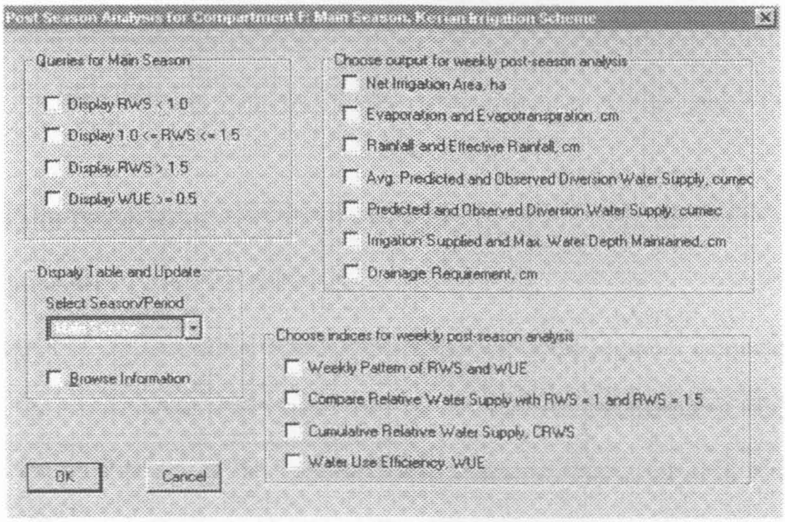


*Fig. 7. Dialog window for post-season analysis for the main season, 1997/98*

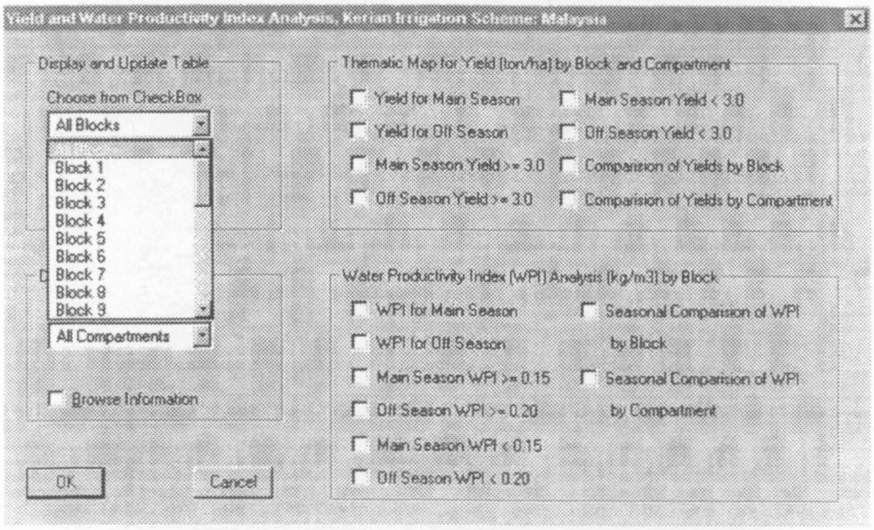


*Fig. 8. Dialong window for post-season analysis of yield and WPI*

## RESULTS AND DISCUSSIONS

### *Recommended Irrigation Deliveries*

Output of the interactive dialog window shown in *Fig. 5* computes irrigation deliveries for service areas under each CHO of any selected compartment. The results are shown in *Fig. 9* which is the recommended irrigation supply for each hydraulic unit (CHO) of compartment F during 10 to 16 October 1997 in the main season. The thematic bar chart together with browser window shows discharges for all CHOs of compartment F in *Fig. 10* when the user clicks on the CheckBox dialog "Display water distribution system". The name of the CHO is also displayed on the screen when the cursor is targeted on the map object.

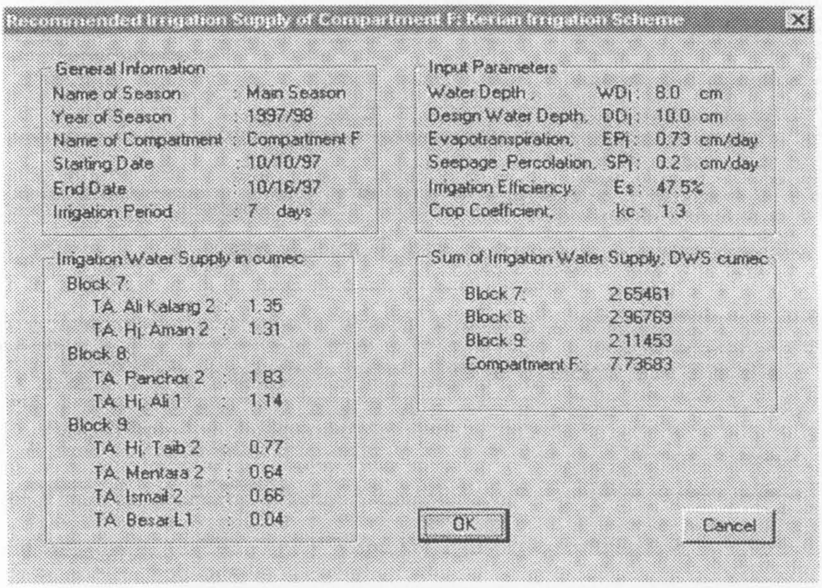


*Fig. 9. Weekly recommended irrigation supply for the main season*

### *Monitoring Periodic Irrigation Delivery*

The daily, weekly, and periodic appraisal can characterize the irrigation delivery performance and improve the irrigation management as the season progresses. The water balance components are analyzed at the end of each period. This module allows the irrigation manager to monitor the situation within a block as well as the spatial and temporal irrigation performance between blocks within the compartment. The color-coded maps and graphs are displayed instantly when users select the CheckBox "Display Thematic Maps" from the dialog window shown in *Fig. 6*. It views computed results together with detailed information for a given period as illustrated in *Fig. 11*. *Fig. 12* represents spatial variation of RWS and WUE displayed as thematic bar chart.

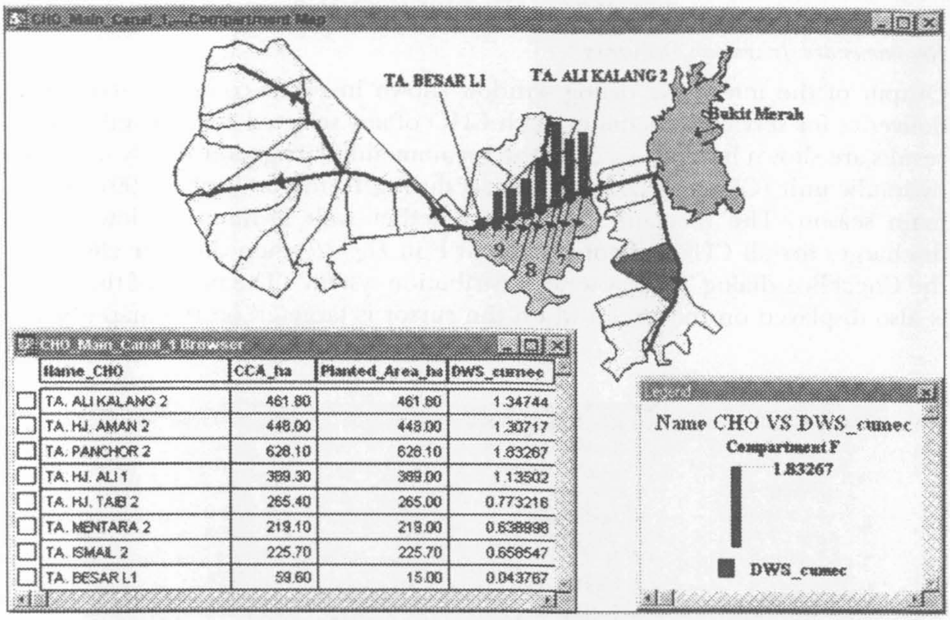


*Fig. 10. Recommended irrigation supply for Compartment F shown on a map*

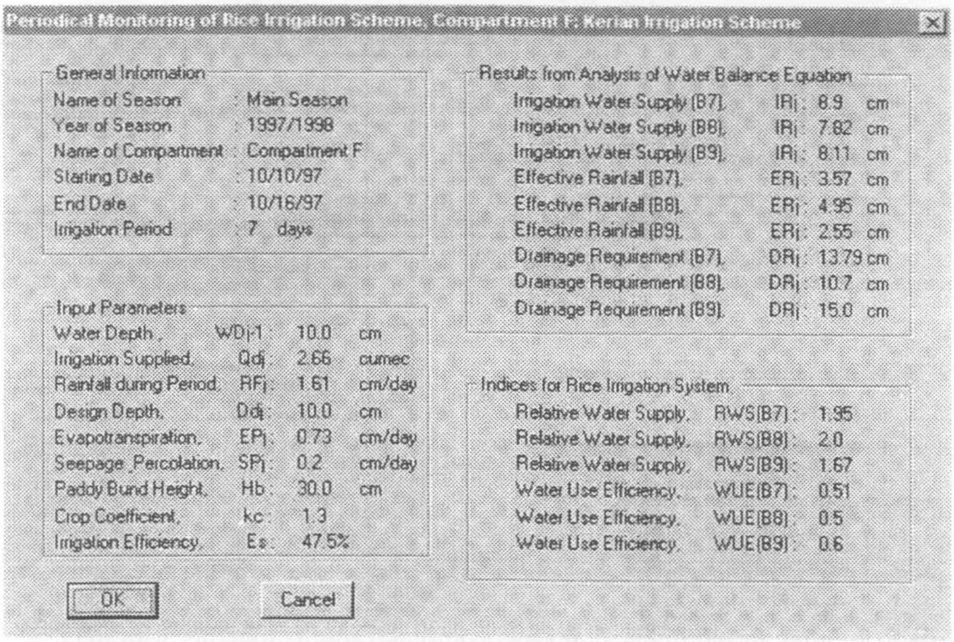


*Fig. 11. Monitoring Module: Computed results for compartment F in main season, 1997/98*

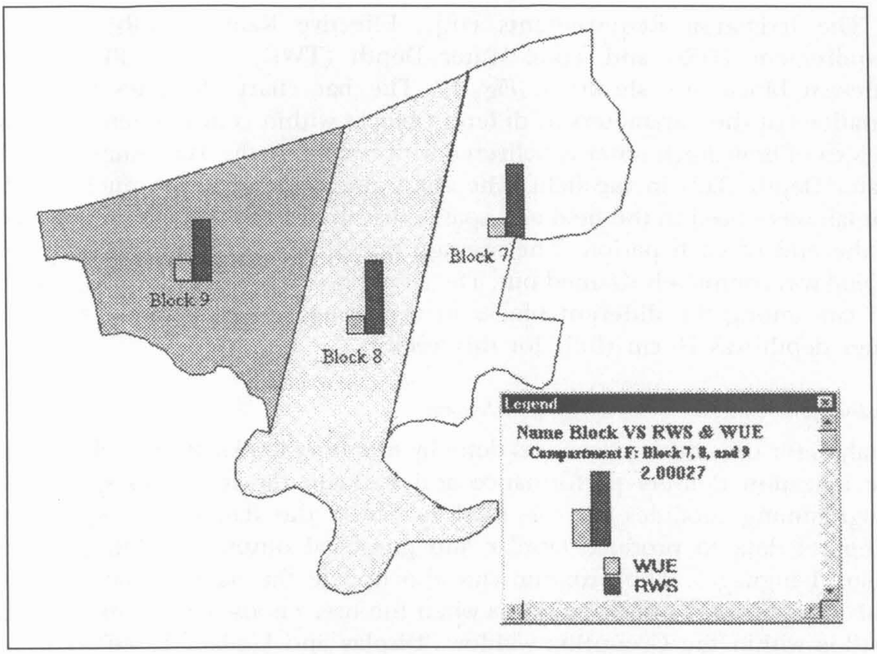


*Fig. 12. Thematic Bar Chart showing the spatial variation of RWS and WUE*

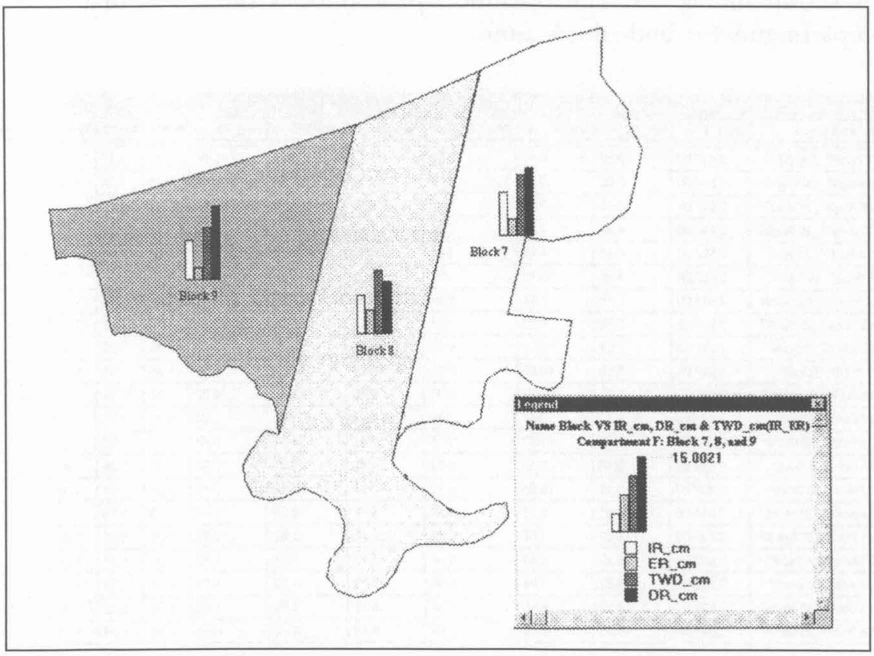


*Fig. 13. Spatial variation of the $IR_j$, $ER_j$, $DR_j$, and $TWD_j$ among the blocks of compartment F for a week*

The Irrigation Requirements (IRj), Effective Rainfall (ERj), Drainage Requirement (DRj) and Total Water Depth (TWDj = IRj + ERj) for the different blocks are shown in *Fig. 13.* The bar chart illustrates the spatial variations of the parameters of different blocks within compartment F. It gives an idea of how much water is delivered with respect to the Maximum Allowable Water Depth (Dd) in the field. The chart also illustrates how much effective rainfall was stored in the field and spatial distribution of drainage requirement at the end of each period. The average rainfall of 1.61 cm/day during that period was completely drained out. The irrigation deliveries were 6.98, 5.95 and 6.5 cm among the different blocks in the compartment F where maximum water depth was 10 cm (full) for this week.

*Post-season Analysis of the Irrigation System*

Analysis for the entire season was done by summing weekly data to characterize the irrigation delivery performance and evaluate the irrigation system. The programming modules can be used to access the database of spatial and temporal data to produce tabular and graphical output by SQL (Structure Query Language). The program can also update the database on a random basis. The browser window displays when the user chooses an option from the ListBox within the GroupBox window "Display and Update Table". The user can update weekly information during ongoing seasons through options available in the dialog windows. The analyzed data for the main season of compartment F is shown in *Fig. 14.* The operation procedure is similar to that of other compartments for both the seasons.

CompartF_MS Browser

| Period_Days | CCA_F_ha | SW_ET_cm | SW_RF_cm | DWS_cumec | Avg_IR_cm | Avg_DR_cm | Avg_ER_cm | RWS7 | RWS8 | RWS9 | RWS | WUE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Aug97_7 Aug97 | 2,697.00 | 2.80 | 0.00 | 3.93 | 4.22 | 0.13 | 0.00 | 1.06 | 0.93 | 1.03 | 1.01 | 1.00 |
| 8 Aug97_14 Aug97 | 2,697.00 | 3.85 | 0.00 | 6.13 | 8.72 | 1.48 | 0.00 | 1.76 | 1.54 | 1.70 | 1.67 | 0.60 |
| 15 Aug97_21 Aug97 | 2,697.00 | 3.57 | 3.08 | 8.49 | 9.11 | 4.22 | 2.02 | 2.32 | 2.12 | 2.27 | 2.24 | 0.45 |
| 22 Aug97_28 Aug97 | 2,697.00 | 4.27 | 7.98 | 7.93 | 8.52 | 8.82 | 3.72 | 2.22 | 2.07 | 2.18 | 2.16 | 0.46 |
| 29 Aug97_4 Sep97 | 2,697.00 | 4.48 | 4.13 | 8.31 | 8.92 | 4.20 | 2.81 | 2.57 | 1.92 | 2.03 | 2.21 | 0.46 |
| 5 Sep97_11 Sep97 | 2,697.00 | 3.85 | 9.45 | 4.92 | 5.28 | 9.49 | 3.37 | 1.69 | 1.59 | 1.67 | 1.65 | 0.61 |
| 12 Sep97_18 Sep97 | 2,697.00 | 3.15 | 1.47 | 4.29 | 4.58 | 1.50 | 1.11 | 1.29 | 1.19 | 1.27 | 1.25 | 0.60 |
| 19 Sep97_25 Sep97 | 2,697.00 | 3.76 | 4.27 | 4.84 | 5.19 | 4.31 | 2.33 | 1.50 | 1.40 | 1.48 | 1.46 | 0.69 |
| 26 Sep97_2 Oct97 | 2,697.00 | 2.94 | 2.17 | 4.07 | 4.37 | 2.21 | 1.44 | 1.38 | 1.28 | 1.36 | 1.34 | 0.75 |
| 3 Oct97_9 Oct97 | 2,697.00 | 5.16 | 10.57 | 6.18 | 6.84 | 10.62 | 4.05 | 1.66 | 1.56 | 1.64 | 1.62 | 0.62 |
| 10 Oct97_16 Oct97 | 2,697.00 | 4.97 | 11.27 | 5.99 | 6.43 | 11.32 | 4.07 | 1.68 | 1.59 | 1.66 | 1.64 | 0.61 |
| 17 Oct97_23 Oct97 | 2,697.00 | 4.83 | 3.57 | 5.86 | 6.29 | 3.62 | 2.26 | 1.41 | 1.31 | 1.39 | 1.37 | 0.73 |
| 24 Oct97_30 Oct97 | 2,697.00 | 4.06 | 11.62 | 5.16 | 5.53 | 11.66 | 3.72 | 1.73 | 1.63 | 1.70 | 1.68 | 0.59 |
| 31 Oct97_6 Nov97 | 2,697.00 | 3.43 | 3.57 | 4.52 | 4.85 | 3.61 | 2.04 | 1.47 | 1.38 | 1.45 | 1.43 | 0.70 |
| 7 Nov97_13 Nov97 | 2,697.00 | 5.11 | 10.08 | 6.12 | 6.57 | 13.13 | 2.13 | 1.38 | 1.27 | 1.35 | 1.33 | 0.75 |
| 14 Nov97_20 Nov97 | 2,697.00 | 4.62 | 6.16 | 5.49 | 6.04 | 8.20 | 2.02 | 1.39 | 1.28 | 1.38 | 1.34 | 0.75 |
| 21 Nov97_27 Nov97 | 2,697.00 | 5.25 | 2.87 | 6.22 | 6.68 | 2.92 | 1.98 | 1.35 | 1.25 | 1.33 | 1.31 | 0.76 |
| 28 Nov97_4 Dec97 | 2,697.00 | 4.27 | 5.60 | 5.34 | 5.73 | 7.64 | 1.82 | 1.37 | 1.27 | 1.35 | 1.33 | 0.75 |
| 5 Dec97_11 Dec97 | 2,697.00 | 5.32 | 3.08 | 5.95 | 6.39 | 4.13 | 1.74 | 1.32 | 1.22 | 1.33 | 1.29 | 0.78 |
| 12 Dec97_18 Dec97 | 2,697.00 | 4.27 | 4.55 | 5.34 | 5.72 | 6.59 | 1.63 | 1.34 | 1.23 | 1.31 | 1.29 | 0.77 |
| 19 Dec97_25 Dec97 | 2,697.00 | 5.04 | 0.70 | 5.70 | 6.12 | 0.75 | 0.65 | 1.16 | 1.04 | 1.13 | 1.11 | 0.90 |

*Fig. 14. Database for main season of the compartment F in the browser window*

*Irrigation Water Depth (IR)*

*Fig. 15* shows computed irrigation depth with respect to the desirable management limits when the user selects CheckBox "Irrigation Supplied and Max. Water Depth Maintained, cm" from the dialog window. The maximum allowable water depth (Dd) in the field varies from 0 to 10 cm during the crop season and starts from the origin of the graph. The middle part of the Dd line represents the peak crop water demand during the season. The irrigation depth among the blocks of a compartment shows the irrigation deliveries with respect to Dd. The gap between the lines of Dd and computed IR during peak demand period illustrates the contribution of rainfall. The savings in utilization of reservoir water can be significant if more rain is stored in the field.

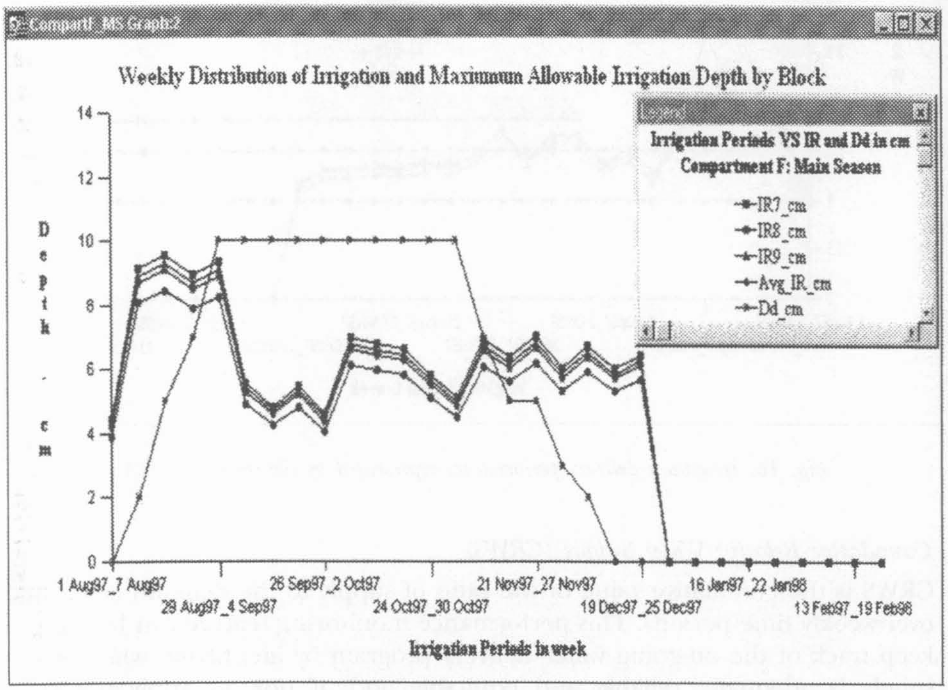


*Fig. 15. Irrigation requirement and maximum allowable irrigation depth*

*Relative Water Supply, RWS*

The weekly RWS values for the main season are represented in *Fig. 16.* In order to analyse the actual performance, actual RWS values have been compared with the critical RWS value for 1.0 and RWS value for 1.5. If RWS = 1.0 at any given week, at the level of a typical block, then the implication is that the combined irrigation supply by the system and rainfall in that week exactly matches the actual demand. RWS value for a particular week should be between above 1.0

to 1.5 for an adequate supply relative to demand. RWS values higher than this range indicate over supply and a value lower than the critical level indicates under supply.

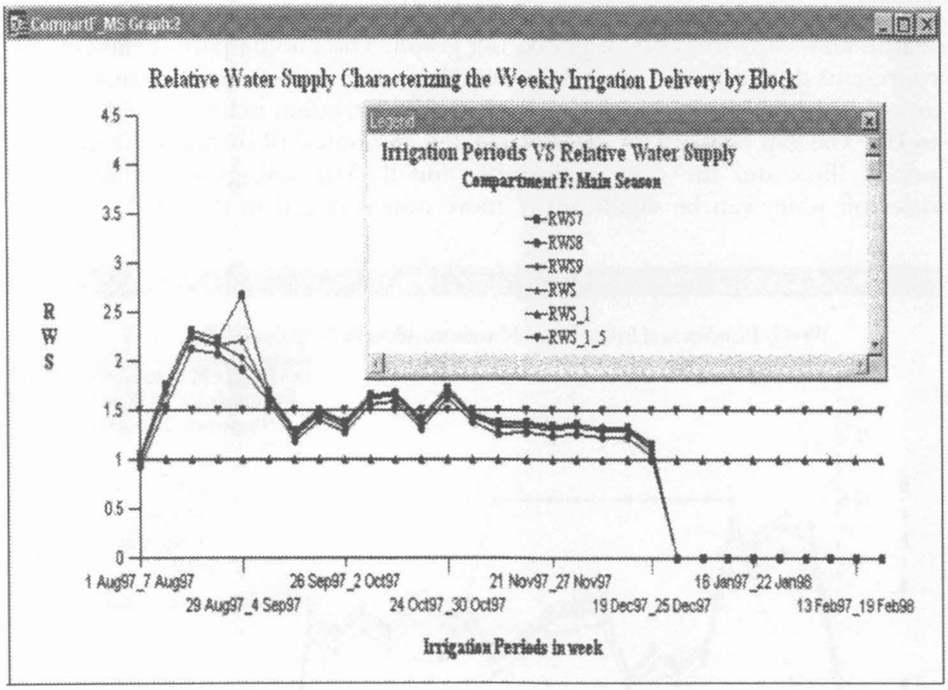


*Fig. 16. Irrigation delivery performance represented by the concept of RWS*

*Cumulative Relative Water Supply (CRWS)*

CRWS is the cumulative value of the ratio of supply to the demand computed over weekly time periods. This performance monitoring feature can be used to keep track of the on-going water delivery program by identifying whether the supply is adequate, reliable and equitable and, if not, to apply necessary adjustments and management interventions to rectify the situation. This is shown in *Fig. 17*. In adopting the CRWS curves, it is possible to select an operational range of upper and lower bound RWS values. The upper bound value may be determined assuming there is no rainfall whilst the lower bound value indicates that even if rainfall occurs, it has to be maintained either at RWS = 1.0 or at a slightly higher. If there is an increasing slope of the CRWS curve with CRWS being closer to the upper bound value it means that irrigation supply can be slightly curtailed in the next period. On the other hand, if the slope is downwards and is reaching the lower bound value, supply has to be increased to maintain it within the desired boundaries.

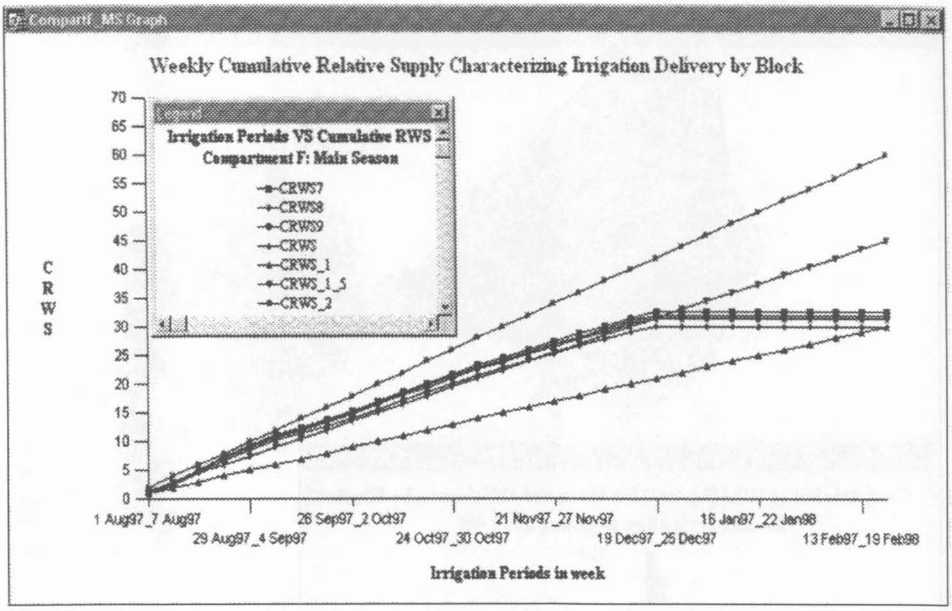


*Fig. 17. Irrigation delivery performance represented by the concept of CRWS*

*Water Productivity Index (WPI)*

The Water Productivity Index provides a measure of the irrigation system's effectiveness in terms of gross grain yield. The values of WPI ranged from 0.07 to 0.19 kg/m$^3$ in the main season and 0.10 to 0.31 kg/m$^3$ in the off-season respectively. The average values for the main season and off-season were found to be 0.13 and 0.22 kg/m$^3$ respectively. Results indicate that blocks 3 and 21 were the most productive in the main season 1997/98 and block 15 in the off-season 1997. The overall WPI for the Kerian Irrigation Scheme was only 0.17 kg/m$^3$. This is below the desirable targets of 0.30 to 0.60 kg/m$^3$. The two factors, which directly affect the WPI are specific supply (m$^3$/ha) and specific yield (kg/ha). The specific supply can be reduced by curtailing irrigation deliveries during the rainy days. With the effective use of irrigation and rainfall, better yield targets for water productivity from 0.30 to 0.60 kg/m$^3$ can be within reach.

## CONCLUSION

The development of sustainable rice farming depends on the urgent necessity of achieving sustainable management of water resources. Improved management of water allocation systems, monitoring techniques and post-season analysis in the existing irrigation scheme using advanced technology such as Geographical Information System (GIS) can greatly help to achieve efficient water management

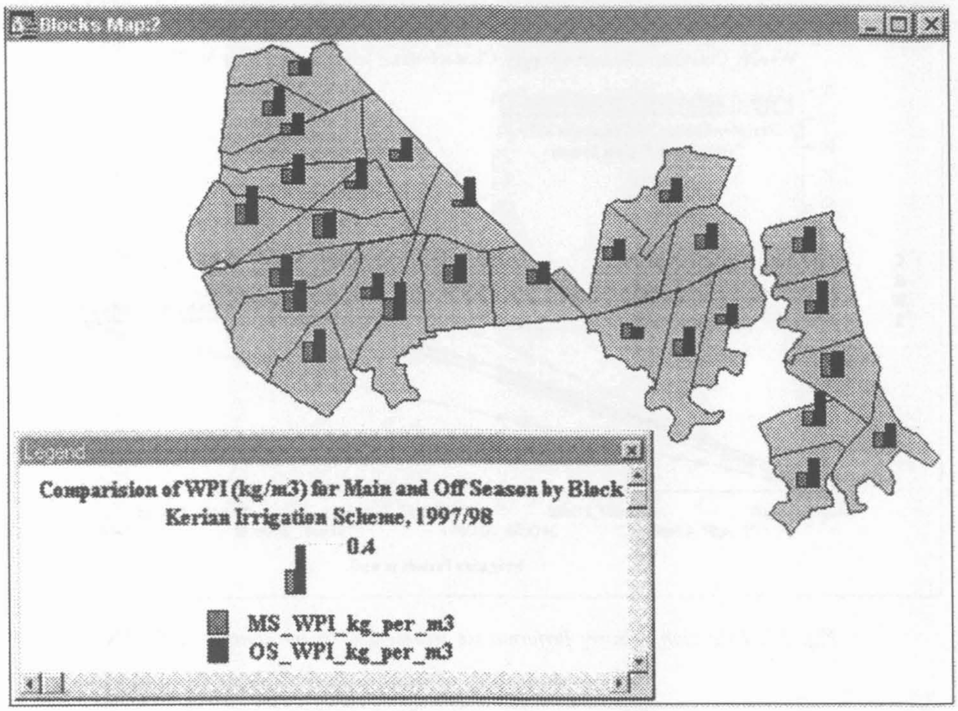


*Fig. 18. Seasonal WPI by the thematic bar chart on the block layer*

and targeted rice production. GIS interface is suitable as its features allow it to process and analyze a vast amount of spatially distributed information. This study would be useful for improving the irrigation system management when combined with actual feedback from the field.

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