Using the IRMOS model for diagnostic analysis and performance enhancement of the Rio Cobre Irrigation Scheme, Jamaica

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Abstract

The Rio Cobre Irrigation Scheme, Jamaica, supplies water to 5000 ha by allocating a fixed unit discharge at each offtake. A computer water management model, IRMOS, was used to assess the scheme’s performance during a typical operating year and to identify water management constraints to performance. An optimal water allocation policy was used as a benchmark against which the actual performance was evaluated. The comparison identified constraints in the scheme which can be improved by a variety of measures which include modifying the water allocation policy, operational procedures and physical components of the scheme. Despite the fact that operating under an optimal water allocation policy requires more data, better monitoring and a higher calibre of staff, the analysis shows that the potential benefits far outweigh the additional costs.

The process shows how the use of modelling to identify performance shortfalls followed by management (rather than infrastructural) interventions can be a valid way forward to improving scheme performance. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Irrigation management; Diagnostic analysis; Performance; Computer model; Optimization

1. Introduction

The IRMOS (Irrigation Management and Optimization System) model has been developed as a tool for improving water management on irrigation schemes. The model
has been developed (Hales, 1994) to accept and process data on a regular basis for planning and monitoring water allocation within irrigation systems. In addition the model contains sub-models which makes it possible to simulate possible water allocation scenarios and determine the possible outcomes on crop yields of such water allocations. An optimization sub-model allows the water allocation to be made based on a policy which maximizes the net production benefit.

Data for the Rio Cobre Irrigation Works (RCIW) Scheme in Jamaica was collected and analysed for the 1992 calendar year using the IRMOS model. Using the optimization sub-model the optimal water allocation policy was derived and used as a benchmark against which to assess the actual recorded water allocation procedures. Following this analysis certain performance shortfalls were identified and further investigation undertaken. As a consequence of the analysis various conclusions can be drawn and recommendations made to improve the performance of the Rio Cobre Scheme, whilst demonstrating the application of the process as a valuable way forward in performance enhancement of irrigation systems.

2. The IRMOS model

The IRMOS model is written in Visual Basic and SQL (Structured Query Language) database in a Windows format which facilitates data entry and data presentation. The model is structured so as to be used in four separate modes: planning; in-season forward planning; in-season water allocation; performance assessment.

The model has several modules which perform the following functions:

Data management. The HR Wallingford INCA (Irrigation Network Control and Analysis) program (Bird and Makin, 1992) is used to allow data to be entered to describe any irrigation network. Using INCA the irrigation network is drawn on the screen and data can be accessed at key locations by pointing using the mouse. A separate Visual Basic database was created to enable regular operational data to be entered as required, either for pre-seasonal planning or for regular in-season water allocation. Historical data for river discharge, Main Canal inflow, pan evaporation and climatic data can be entered and statistical parameters derived.

Water management. The water management module controls the water management in the irrigation network, from the source to the crop root zone, for all four of the above mentioned operational modes. The water management module comprises routines for maintaining soil moisture balance in each field unit; determining the crop yield at harvest based on yield response to water algorithms (Doorenbos and Kassam, 1979; Rao et al., 1988); allocating water according to the selected water allocation policy, of which there are 10 possible polices, a development of previous work in this field (Burton, 1993, 1994); summatting discharges at control points and allowing for conveyance losses; predicting (from historical data) the anticipated water supply, crop water requirements and effective rainfall for the coming time periods. The module also contains a sub-routine which monitors canal condition and carrying capacity.

The irrigation system is modelled as an irrigation network delivering water to Water Management Units, which comprise tertiary canals supplying water to fields with a unique cropping pattern, soil type and irrigation method.
Analysis and reporting. The analysis and reporting module presents the data in schematic map and tabular form on the computer screen, with colour coding to show salient features. Data can be displayed showing the canal network and the water supply situation for Water Management Units. Data can be displayed on irrigation water requirements, water allocations, water supplied vs demand, relative evapotranspiration, individual field soil moisture balance, crop production losses, crop production summaries and performance summaries using selected performance indicators. All this data can be printed to hard copy as required.

3. Scheme overview and data collection for modelling

The Rio Cobre Irrigation Scheme supplies water to approximately 5000 ha and some 400 farmers. Annual rainfall in the irrigated area averages <600 mm, of which 40% falls in the months of September and October. The average Class A pan evaporation is some 1865 mm per year with a range of from 2 to 8 mm. The discharge in the river is such that the water that can be diverted into the system is generally inadequate to meet the requirements of the crops during some months of the growing season, even during a wet year. The scheme grows a variety of crops including sugarcane, pasture, vegetables and freshwater fish. Sugarcane is by far the predominant crop, accounting for 67% of the cultivated area.

Field data were collected from primary and secondary sources. Primary data included measured or observed data on canal discharges and gauge readings, cropping patterns, crop yields and daily evaporation and rainfall. Secondary data were gathered from the National Irrigation Commission’s records on gauge readings, canal discharges, cropping patterns, evapotranspiration and rainfall. From data collected certain additional data were derived or estimated, this included canal seepage losses, irrigation efficiencies and crop yields.

Fig. 1 shows the discharge entering the Main Canal as measured at the rating station at the intake and the summation of all allocations made to canal offtakes throughout the system (excluding Main Canal conveyance losses). The canal offtake figures are derived from measurements made by RCIW staff at canal offtake measuring structures twice per day.

4. Modelling actual performance

Actual cropping, operational and weather data were read into the IRMOS database and analysed to produce values for selected scheme performance indicators. The available field data on crop yields and soil water balance for the RCIW were incomplete for the study period and so missing data had to be generated through an IRMOS sub-routine. In particular, the harvest records kept by farmers did not always include both the harvest date and the quantity harvested for each field, so the IRMOS sub-routine was used to generate estimates of crop yield were necessary. IRMOS also monitors the soil moisture content for each time period, using available data for each period to estimate the irrigation demand for the following period.
The actual water supply and irrigation demand weekly hydrograph for the scheme, as determined at the river intake, are presented in Fig. 2, together with a plot of the potential evapotranspiration requirement (taken as a simple proxy for total demand), also determined at the river intake. The actual water supply hydrograph (supply) is derived

![Fig. 1. RCIW Main Canal supply discharge vs summation of allocations at canal offtakes.](image1)

![Fig. 2. Actual RCIW supply, demand and potential evapotranspiration data for 1992.](image2)
from discharge measurements at the Main Canal intake, whilst the irrigation demand hydrograph (demand) is obtained by summing the irrigation demand for each crop based on its soil moisture status and allowing for application and conveyance losses up the system. The evapotranspiration requirement (ETmax) is calculated from the crop’s potential evapotranspiration requirement and allowance made for application and conveyance losses. From Fig. 2 it can be seen that the total volume supplied is very close to the potential evapotranspiration demand, indicating that there is generally sufficient water available to match crop water needs. However, as can be seen from Fig. 1, only 50% of the water available at the river intake can be accounted for as having been allocated at the offtakes; for this reason the irrigation water demand (as derived from the crops’ soil moisture status) remains higher than the water supplied for most periods.

The values of the performance indicators calculated by IRMOS using the actual data are presented in Table 1, column 1. A discussion of some of these indicators, and their values, follows.

4.1. **Total volume allocated and total effective rainfall**

The total volume allocated and the total effective rainfall summate to 99.23 MCM which exceeds the potential evapotranspiration demand by 15.52 MCM (18%), indicating a degree of over-allocation.

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance of the RCIW Scheme: values of actual and optimal water allocation (calendar year)</td>
</tr>
<tr>
<td>Performance indicator</td>
</tr>
<tr>
<td>Potential evapotranspiration demand at offtake (MCM)</td>
</tr>
<tr>
<td>Total volume allocated at intake (MCM)</td>
</tr>
<tr>
<td>Total effective rainfall (MCM)</td>
</tr>
<tr>
<td>Relative water supply</td>
</tr>
<tr>
<td>Over-supply ratio</td>
</tr>
<tr>
<td>Unsatisfied demand ration</td>
</tr>
<tr>
<td>Relative evapotranspiration (Eta/Etm)</td>
</tr>
<tr>
<td>Total crop yield loss</td>
</tr>
<tr>
<td>Gross crop value at maximum yield</td>
</tr>
<tr>
<td>Pre-harvest cost of crops</td>
</tr>
<tr>
<td>Net crop value at maximum yield</td>
</tr>
<tr>
<td>Potential net value at present yield</td>
</tr>
<tr>
<td>Relative yield (gross)</td>
</tr>
<tr>
<td>Relative profitability</td>
</tr>
<tr>
<td>Specific yield ($/MCM)</td>
</tr>
<tr>
<td>Conveyance efficiency</td>
</tr>
</tbody>
</table>
4.2. Relative water supply

The relative water supply (RWS) is a measure of the supply to demand at any point in the system. The figure given in Table 1 (1.19) is the average of the RWS values at each Water Management Unit intake for each time period during the study period. This measure is deceptive as a performance indicator when applied at the scheme level over a long period. Although it gives an indication of the overall level of water availability, the availability of water may fluctuate from one location to another and one time period to another. Consequently wastage and over-supply are not separately accounted for and a “good” RWS may disguise a situation in which there were severe shortages of water over several time periods, and excesses in other time periods. IRMOS provides visual representation of RWS values (Fig. 3) which show the spatial variation of the RWS values for each Water Management Unit (WMU) within the scheme. Fig. 3 shows that the total water allocation over the study period for some WMUs is excessive whilst others receive very little water.3

4.3. Supply:demand ratios

To overcome the difficulties expressed above with the RWS the over-supply ratio (O-SR) and the unsatisfied demand ratio (UDR) performance indicators are used. The values presented in Table 1 indicate that the water supply was not matched to the demand throughout the study period. During periods of limited supply only 38% of demand was met, whilst during periods when supply exceeded demand 13% more water was allocated than was necessary. This was due to large rainfall events not having been anticipated, as well as a failure to match supply with demand.

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3 Fig. 3 shows the RWS values for the study period, IRMOS calculates, and can display, values for each time period if required.
4.4. Relative yield

The IRMOS estimated actual evapotranspiration rate was 74% of potential for the study period, indicating an appreciable shortage of water to the crop root zone. Most crops would have experienced soil moisture stress at some time during the study period resulting in loss of yield. The total scheme relative yield (actual to potential yield) estimate made by IRMOS was 0.72, which represents a crop loss valued at some US $3.7 million. Actual crop yield data was not available for all fields, but actual yield data collected during the study period from farmers and sugar estate’s showed close agreement with IRMOS values calculated for individual fields.

4.5. Relative profitability

Whilst the relative yield indicates how much of the potential harvest will actually be harvested, the relative profitability (potential net value at present yield/net crop value at maximum yield) measures how the losses affect the net income of the scheme’s farmers. The relative profitability also indicates whether the scheme as a whole is operating at a loss, a negative figure indicating that establishment and operating costs exceed income derived from the crops.

For the study period this indicator reveals that only 59% of the potential net income from the scheme was realized. As will be discussed later the optimal water allocation pattern raises this figure to 85%.

4.6. Specific yield

The specific yield shows the value of production per unit of water abstracted. For the actual performance the value is US $126 880 per million cubic metres of water supplied, or 12.7 cents per cubic metre.

This indicator is perhaps one of the most useful since all factors affecting scheme performance such as irrigation efficiency, water supply, water demand, rainfall utilization or water allocation policy, will affect its value.

5. Modelling optimal performance

As outlined earlier the IRMOS model incorporates an Optimization Sub-Model which seeks to maximize the net income to the scheme (though not necessarily to individual farmers). Relevant actual data for the RCIW Scheme during the study period was used to generate an optimal return to the scheme. The primary actual data used included the supply available to the scheme taken from the daily discharges measurements at the Main Canal intake, the actual rainfall and the actual cropping pattern. It is important to note that the IRMOS model was run in the Water Management mode, in which water allocations are calculated for each time period based on the season’s data to date and predictions of future patterns using historical data. This is the mode that is used by scheme managers to make their regular in-season plans for water allocations. Thus for
these runs the IRMOS model was modelling the actual decisions that would have been made by the Scheme Manager during the 1992 season if they had used the IRMOS model.

The following sections discuss the optimal allocation performance figures presented in Table 1, column 2.

5.1. **Total volume allocated and total effective rainfall**

The total volume allocated and the total effective rainfall summate to 88.86 MCM which exceeds the potential evaporation demand by 6.78 MCM (8%), indicating a degree of over-allocation. This over-allocation is considerably less than is the case for the actual allocation.

5.2. **Relative water supply**

The relative water supply for optimal water allocation during the study period was 1.08, in comparison with 1.19 for the actual allocation implying a better overall match between supply and demand for Water Management Units (WMUs). The difference stems from better water allocation resulting in higher actual evapotranspiration and lower water allocation. The RWS map for the study period (Fig. 4) shows a more equitable water allocation, though supplies remain limited resulting in some WMUs having RWS values <0.8.

5.3. **Supply:demand ratios**

The over-supply ratio is, surprisingly, higher under the optimal water allocation policy. This is due to the optimization process under-estimating following period rainfall and over-estimating evaporation (i.e. getting the planned water allocations “wrong”). When operating under the optimal water allocation policy IRMOS uses the actual data from previous time periods to update the model to the current period but uses predicted and planned data over the planning horizon. The mean evaporation and mean rainfall are used
to predict evapotranspiration and rainfall respectively. As actual values of evapotranspiration were generally less than the mean whilst actual rainfall was generally more, IRMOS over-allocated water to some fields, resulting in some wastage.

Considering the unsatisfied demand ratio in the optimal mode during periods of water shortage only 30% of demand was not met, in comparison with 38% for the actual allocation.

5.4. Relative yield

The actual evapotranspiration increased from 74% to 86% of potential under the optimal allocation. This represents a 25% improvement in the relative yield for the optimal over the actual allocation. The estimated crop loss correspondingly declined from the actual estimate of US$3.7 million to US$1.4 million. This significant decline in total crop loss underlines the benefits that can be derived from attempting to allocate water in response to irrigation demand. In the case of the Rio Cobre Scheme this can be achieved without making any changes to the physical infrastructure. The real change that is required to implement this policy is a change in managerial and operational procedures as a result of the need for more data collection, processing and analysis. The IRMOS model greatly facilitates the necessary data processing and analysis.

5.5. Relative profitability

Under the optimal water allocation policy there is a significant improvement in the relative profitability to 0.85 (from 0.59 for the actual allocation). Despite the fact that the optimization procedure was constrained by having small holders with under 2.5 ha receiving all their water requirements, the optimal policy showed a relative increase of 42% over the actual allocation.

5.6. Specific yield

The optimal allocation policy increased the value of specific yield by some 45% over the actual allocation. This reflects more efficient use of water as the optimal allocation policy allocates less water where it is least required and more water where it will have a more telling impact on crop production. This figure (US$181 557 per MCM) sets an upper boundary to the level of crop production that can be achieved from the available water supply. Any measures to further improve the specific yield (without changing the cropping pattern) would involve making more water available to the crops at certain times during the season.

6. Identification of constraints to performance on the RCIW Scheme

From an analysis of the data generated for the RCIW Scheme for the actual and optimum allocation runs several areas were highlighted as requiring further investigation. These were:
• Conveyance efficiency.
• High crop losses due to under-irrigation.
• Over-supply of water to some crops.
• Existing water allocation policy.

Each of these issues is discussed in turn in the following sections.

6.1. Conveyance efficiency

In analyzing the performance of the RCIW Scheme one of the areas of poor performance which quickly became apparent was the low conveyance efficiency. The conveyance efficiency measures the percentage of discharge entering the system that is recorded as having been allocated to the Water Management Units. For the study period the actual conveyance efficiency determined from the discharge measurements was only 50%. The apparent low conveyance efficiency needed to be investigated further if the cause was to be identified, and if necessary, remedial action taken.

Several factors which might account for the loss of water in the system were identified:

• High seepage or spillage losses.
• Errors or discrepancies in measuring discharges at control points.
• Tampering with measuring devices or control structures.
• Unauthorized diversion of water.
• Unrecorded diversion of water.
• Errors in recording Main Canal discharges.
• Water allocation for non-agricultural use.

1. High seepage or spillage losses. The high conveyance losses could be accounted for by high seepage or spillage losses. During the study period the seepage losses were measured at several locations within the system (Table 2). Using these figures the total

Table 2
Measured seepage rates on RCIW canals (January–March 1992)

<table>
<thead>
<tr>
<th>Canal</th>
<th>Predominant lining type</th>
<th>Length (km)</th>
<th>Seepage rate a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hartlands</td>
<td>Concrete</td>
<td>6.34</td>
<td>0.51</td>
</tr>
<tr>
<td>Port Henderson</td>
<td>Concrete</td>
<td>7.01</td>
<td>0.48</td>
</tr>
<tr>
<td>Turners Pen</td>
<td>Concrete</td>
<td>5.03</td>
<td>0.50</td>
</tr>
<tr>
<td>Cumberland Pen</td>
<td>Masonry</td>
<td>4.27</td>
<td>1.01</td>
</tr>
<tr>
<td>Old Harbour</td>
<td>Masonry</td>
<td>3.78</td>
<td>0.98</td>
</tr>
<tr>
<td>Old Harbour</td>
<td>Earth</td>
<td>9.63</td>
<td>1.98</td>
</tr>
<tr>
<td>Sydenham</td>
<td>Concrete</td>
<td>2.97</td>
<td>0.50</td>
</tr>
<tr>
<td>Main</td>
<td>Earth</td>
<td>4.70</td>
<td>2.08</td>
</tr>
<tr>
<td>Lower Main</td>
<td>Earth</td>
<td>2.50</td>
<td>2.10</td>
</tr>
<tr>
<td>Little Hartlands</td>
<td>Earth</td>
<td>3.59</td>
<td>1.95</td>
</tr>
<tr>
<td>Lawrence Field</td>
<td>Earth</td>
<td>2.50</td>
<td>1.85</td>
</tr>
<tr>
<td>Caymanas</td>
<td>Earth</td>
<td>4.79</td>
<td>1.97</td>
</tr>
</tbody>
</table>

aMeasured as percent of flow ($Q$) per kilometre.
seepage losses were estimated for the canal network and an overall conveyance efficiency, using daily and weekly discharge values, of 79–83% calculated. The indication therefore was that high seepage losses were not responsible for the low conveyance efficiency. From field observations of irrigation practice during the fieldwork programme no signs were seen of significant spillage losses. It is concluded that these factors are not the cause of the low overall conveyance efficiency.

2. Errors or discrepancies in measuring discharges at control points. On the RCIW Scheme there are Parshall flumes and rectangular weirs at control points. Discharge measurements are made twice a day by field staff, and errors are possible in the gauge readings associated with the structure, or in conversion of the gauge readings to discharge. During the fieldwork programme random readings were discretely taken and checked against readings taken by the field staff; good agreement was found (Table 3). There were some instances where the field staff had entered the discharge as being zero when there was water flowing through the offtake. Whether this was due to the field staff recording zero because they had not been to the field to take the actual reading, or due to deliberate under-recording could not be ascertained.

3. Tampering with measuring devices or control structures. It is possible that farmers had tampered with control structure or measuring structure gauges in order to obtain more water than they were charged for. This can be done in several ways — farmers can change gate settings from those set by field staff, or they can raise the measuring structure water level gauge so that it under-records the actual discharge. These measures are generally, however, detectable by vigilant field staff.

4. Unauthorized diversion of water. Unauthorized diversion of water in the RCIW Scheme occurs when water users who have no contract for water supply, or whose contract has been suspended, continue to divert water. In some cases portable pumps are used to abstract water — this is difficult to detect as it may take place at night and the perpetrators take action to avoid being detected by RCIW staff. The amount clandestinely abstracted in this way though is likely to be small.

Table 3
Monitoring of discharges at Notch 29, Old Harbour Canal

<table>
<thead>
<tr>
<th>Date</th>
<th>Gauge reading (cm)a</th>
<th>Discharge</th>
<th>Discharge reported by field staff (l s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.12.92</td>
<td>13.5</td>
<td>81</td>
<td>80</td>
</tr>
<tr>
<td>21.12.92</td>
<td>13.0</td>
<td>77</td>
<td>80</td>
</tr>
<tr>
<td>22.12.92</td>
<td>6.5</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>23.12.92</td>
<td>14.0</td>
<td>85</td>
<td>80</td>
</tr>
<tr>
<td>24.12.92</td>
<td>13.0</td>
<td>77</td>
<td>80</td>
</tr>
<tr>
<td>25.12.92</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>26.12.92</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average for period</td>
<td>49.7</td>
<td>49.3</td>
<td></td>
</tr>
</tbody>
</table>

a Readings were taken in the morning, shortly before or after readings taken by RCIW staff.
5. **Unrecorded diversion of water.** Water may be diverted with the knowledge of field staff but not recorded. During the fieldwork programme no evidence was found that this might be the case.

6. **Errors in recording Main Canal discharges.** The discharge entering the Main Canal is recorded from a gauge in a rated section of the canal. Unfortunately the rating curve is very dependent on the downstream canal conditions, as a consequence of which several rating curves have been produced and are used according to the downstream conditions. The accuracy of the measurements for the Main Canal discharge depend on the accuracy of these rating curves and the skill of the gauge reader in selecting the correct rating curve to use.

7. **Water allocation for non-agricultural use.** The scheme allocates some 5 million cubic metres per year for industrial and domestic use. These abstractions are gauged and measured, though there are some small communities of domestic users residing alongside the Main Canal who abstract water without measurement or charge. Their consumption rate is low and the total quantity abstracted negligible.

   The above investigations are, unfortunately, inconclusive, they do not identify where the “missing” water is and further, more detailed, study is required. The field measurements of canal seepage indicate that the losses are not caused by high seepage from the canals themselves, thus “management” losses are the more likely cause.

6.2. **High crop losses due to under-irrigation**

   Through the application of the performance orientated water allocation policy it was found that the high crop losses could be significantly reduced, indicating that, given the existing supply situation, water was being incorrectly allocated using the actual allocation policy.

6.3. **Over-supply of water to some crops**

   Despite the limited water supply in most periods, several Water Management Units were supplied, at times, with more water than they required. This reduces water availability to other users and adversely affects scheme performance. The performance orientated policy demonstrates how such over-supply can be reduced and performance enhanced.

6.4. **Existing water allocation policy**

   The problems identified in Sections 6.2 and 6.3 above are a consequence of inadequate monitoring and planning of irrigation water allocations within the RCIW Scheme. At present the calculations for water allocation are carried out by hand, though the IRMOS model could be used to facilitate these calculations. However, as has been demonstrated in Sections 4 and 5, the current water allocation policy constrains the agricultural potential of the RCIW Scheme. As has been shown consideration should be given to adopting the optimum allocation water allocation policy for the RCIW Scheme.
7. Recommendations to improve performance

The analysis of the scheme’s performance and its comparison with the optimal water allocation policy reveal the following four specific areas of low performance:

1. The current water allocation policy results in inequitable distribution of water, water wastage and lower than optimum crop production;
2. The quantity of water supplied to Water Management Units is insufficient to meet the needs of the crops even when optimally allocated;
3. The discharge available at the system’s intake does not always match the demand for water within the system;
4. The irrigated area is lower than potential as a consequence of the system operating below capacity.

The recommended actions to improve the scheme’s performance should thus be aimed at addressing these four areas. From a number of runs of the model the following progressive actions are recommended:

- **First**: to improve the water management by changing the water allocation policy;
- **Second**: to improve the operation to reduce conveyance losses;
- **Third**: to modify the capacity of the operation of the intake to match supply to existing demand;
- **Finally**: to increase the irrigated area by operating the system at its full capacity.

Model runs in which the conveyance losses are reduced first resulted in lower returns than changes to the water allocation policy.

One key feature of phasing the implementation of actions needed to improve performance is that management and operational improvements precede infrastructural modifications so that when the water supply is increased the scheme will have the water management procedures in place to benefit most from such changes.

The actions taken to relieve identified performance constraints must first be shown to improve the net benefits of the scheme before being recommended for implementation. In the following sections the benefits and costs of actions identified to relieve water management constraints are examined.

7.1. Changing water allocation policy

The performance summary (Table 1) shows that optimal water allocation could improve the net value of crop production, using existing water supplies, by as much as US $2.4 million. However, adopting an optimal water allocation policy would involve changes in water management which would impose additional costs on the system. The changes include acquisition of computer hardware and software, employment of a Water Manager and additional clerical, technical and field staff. The costs of these items are presented in Table 4.

The total annual cost of implementing these changes is estimated at $189 000, which represents a potential benefit:cost ratio of 12.5.
7.2. Improving the operational procedures to reduce losses

Only 50% of the water diverted from the Rio Cobre is accounted for as having been allocated to the Water Management Units (Fig. 1). As previously outlined using seepage rates for individual canals, seepage losses at the discharge levels encountered during the study period were estimated at between 16% and 18%. It is therefore reasonable to expect that seepage losses can be reduced to 20% of total intake discharge. Running the IRMOS model again with these reduced loss figures shows that the supply would be better matched to demand (Fig. 5), and equity and adequacy of supply would be improved (Fig. 5, compared to Fig. 3, and Table 1, column 3, compared to columns 1 and 2).

Table 1, column 3 shows that, with only 20% losses and with optimal water allocation, the Potential Net Value would be US$8,452,961, representing a further increase in net value of US$649,451 over optimal allocation at the existing conveyance efficiency.

Table 4
Costs of changing to an optimal water allocation policy

<table>
<thead>
<tr>
<th>Item</th>
<th>Annual cost US($)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical assistant</td>
<td>10,000</td>
<td>Assist the Water Manager coordinate information transfer between Head Office and local offices</td>
</tr>
<tr>
<td>Field supervisors</td>
<td>10,000</td>
<td>Receives instructions from Water Manager. Monitors the field staff</td>
</tr>
<tr>
<td>Field staff (12)</td>
<td>60,000</td>
<td>Support existing field staff with data collection and operation of system</td>
</tr>
<tr>
<td>Equipment maintenance</td>
<td>30,000</td>
<td>Insurance, petrol for vehicles, servicing, etc</td>
</tr>
<tr>
<td>Total recurrent costs</td>
<td>135,000</td>
<td></td>
</tr>
<tr>
<td>Equivalent annual cost of initial items</td>
<td>22,500</td>
<td>Assuming investment in equipment and training will be repeated after 5 years</td>
</tr>
<tr>
<td>Sub-total</td>
<td>157,500</td>
<td></td>
</tr>
<tr>
<td>Overhead costs (20%)</td>
<td>31,500</td>
<td>Additional administrative costs incurred by NIC as a result of changes</td>
</tr>
<tr>
<td>Total costs</td>
<td>189,000</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5. RWS map for optimal water allocation and 80% conveyance efficiency (total for study period).
Actions taken to reduce losses should, therefore, cost <$649 451 to justify taking them. Such actions include improved monitoring of canal activities to avoid spillage and prevent unauthorized diversion of water and better monitoring of the discharge measuring process along the canals. In order to motivate staff to strive for better scheme performance and to improve individual performances, it is proposed that part of their salary be in the form of a performance related incentive. Table 5 lists the costs of carrying out such changes. The total cost is estimated at US$100 300, representing a potential benefit:cost ratio of 6, fully justifying the changes.

### Matching discharge at the intake to water requirement

The supply:demand hydrographs for the scheme operating at 80% efficiency with the current cropping pattern show that the maximum potential evapotranspiration in any one week is 2.24 MCM. The discharge at the intake with an 80% conveyance efficiency required to meet this demand is 2.28 MCM, and the corresponding average discharge is 4.6 m³ s⁻¹. This is just within the capacity (5 m³ s⁻¹) of the pumping plant supplying the Main Canal, therefore no additional pumping plant is required.
7.4. Increasing irrigated area

The Main Canal has a design capacity of 7.5 m$^3$ s$^{-1}$. Following major rehabilitation studies on the canal system, however, tests by the National Irrigation Commission (Barak, 1989) showed that the safe maximum operating capacity was only 6.5 m$^3$ s$^{-1}$. Due to the high rate of silt deposition it has been difficult to maintain operational capacity at this level.

In 1992 the dam on the Rio Cobre which provided command for the scheme intake was damaged and a temporary pump station had to be installed. The repair of the dam allows scheme managers and farmers more flexibility in the operation of the scheme. At present more than 3000 ha of land lie idle, so there is scope for increasing the cropped area. By having more water in the scheme and increased crop area, the positive impact of the measures to improve performance outlined above will be more pronounced. Conversely, failure to adequately manage and operate the scheme will result in continued underperformance, and loss of productive potential.

8. Application to other schemes

The IRMOS model and the approach outlined above can be applied to other irrigation schemes to quantify performance, identify performance shortfalls and develop action plans for performance enhancement. Care has to be taken with the type of irrigation scheme to which this approach is applied. Chambers (1988) very usefully categorized points of entry to improve irrigation management as:

- rights, communications and farmers’ participation;
- operational plans;
- performance monitoring and computer analysis.

Chambers argued that interventions in respect of rights, responsibilities and farmers’ participation are the domain of social scientists and scheme managers, and are applicable for small scale or small holder schemes where performance is low. Interventions to improve operational plans are the domain of scheme managers and are applicable to medium to large scale schemes which have a low to moderate level of performance. Performance monitoring and computer analysis are the domain of management scientists and scheme managers and apply to all scales of scheme which have moderate to high levels of performance.

The use of IRMOS and the analytical procedures outlined above thus relate to schemes in the categories where improvements to operational plans and performance monitoring and computer analysis apply. Priority requirements are control and measurement at primary, secondary and tertiary level, and an established organizational structure to collect, process, analyse and use management data. Where these criteria are met the IRMOS model can be effectively used, either (i) as a day-to-day operational tool with diagnostic capability, or (ii) as a diagnostic tool for performance assessment and identification of measures for performance enhancement. In the first case IRMOS is set up and used by the scheme manager, in the second IRMOS would be set up and used by
those interested in scheme performance assessment. This might include irrigation consultants involved in scheme rehabilitation, management consultants involved in identifying management improvements, or researchers interested in how systems are performing and identifying production constraints.

9. Conclusions

The paper has described the use of the IRMOS model to analyse the performance of an irrigation scheme, identify achievable levels of performance and develop approaches for performance enhancement.

The study of performance has been carried out by comparison to an analysis of the optimum performance of the scheme, given the same cropping pattern, rainfall, climatic conditions and water supply. This comparison with the output derived from the optimal water allocation has been valuable in setting targets against which the actual performance can be assessed. Performance indicators have been used which reflect the need to satisfy objectives, the main ones of which in this instance are the net value of the agricultural production and the specific yield (production per unit of water).

From the analysis practical steps can be identified which can lead to enhanced performance. In the case of the RCIW Scheme relatively easy-to-apply measures can be taken which do not require investment in infrastructure, rather they relate to better management of the existing infrastructure. The measures proposed can be costed and potential net benefits quantified. In the case of the RCIW Scheme the potential net benefits are significant, even if the full benefits are not realized the margins are such as to merit serious consideration of the proposals.

Detailed analysis of the kind outlined in this paper would not be possible without a computer-based model such as IRMOS. The study outlined has involved determining and then simulating the allocation of irrigation water supplies to 103 Water Management Units and within these a total of 246 fields, maintaining soil moisture balance data for each field and tracking the yield response to the soil moisture conditions for each field. The next step is for the model to be adopted as part of the management process for the RCIW Scheme and for further refinements to be made to the model and to the management practices.

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References


