36

Chapter 3

MAJOR CANAL PERFORMANCE EVALUATION OF RAHAD IRRIGATED SCHEME

Christopher Gideon[8], Amir B. Saeed[9], Hassan I. Mohammed[10]

3.1 INTRODUCTION

The major constraints to producing more food for meeting the demands of an increasing world population is land and water scarcity. One possible approach to conserve these scarce resources may be through improving the performance of the existing large scale irrigation projects. Other means to conserve these resources is to improve their management and utilization level. A key factor in better management is the performance of human resources. As such, the development of performance indicators and a rigorous evaluation methodology for helping managers to improve their systems is critically needed. An evaluation exercise is useful for establishing whether or not to make improvements (e.g., to employ an intervention such as a rehabilitation program or not), on existing projects compare performance of different sections within a project, or between different projects.

However, performance was conceptually approached by two models. The goal-oriented model (Scott 1979; and Seashore 1983) and system or contingency theory model (Murray-Rust and Snellen 1993).

A field multi-objective evaluation of the performance of irrigation systems are limited. Due to this inadequate understanding of field conditions, magnitudes and causes of priority problems were not fully identified, especially in less developed countries. However, most studies and reports were based on rapid appraisals, or concentrating on one part of the system.

For the purpose of evaluating the performance of a multi-objective irrigation project for rural development, the Rahad irrigated project was selected as a case study.

The Rahad case study may serve as a model to evaluate large agricultural projects in the central clay plains of Sudan. Hence, this study is directed towards proposing and testing a set of quantitative performance indicators for water delivery at the major canal level. As such, this study is expected to establish standards and guidelines for the agencies managing the project.

[8]Research Student, Department of Agricultural Engineering, Faculty of Agriculture University of Khartoum.

[9]Acting Dean, Faculty of Agriculture, University of Khartoum.

[10]Head of Agricultural Engineering Department, Rahad Agricultural Corporation.

3.2 INDEX SYSTEM FOR EVALUATION

Routine monitoring of an irrigation system is essential in providing the basic data for performance assessment (Bos et al. 1993). On the basis of a goal-oriented model the following sets of indicators were chosen to express the actual and planned values in term of a ratio:

(3.2.1) quality of irrigation service
(3.2.2) water scheduling indicator
(3.2.3) agricultural indicator
(3.2.4) overall index

3.2.1 Quality of irrigation services

Following approach of Molden and Gates (1990), this index conceptually addresses the system physical capability for operating the system to deliver water as per the schedule. Major state variables to evaluate the water delivery system in terms of amount (Q) at point (X) and time (t) may be defined as:

$Q_{ac}(X,t)$ = actual amount delivered by the system;
$Q_{cwr}(X,t)$ = amount of crop water requirement at the downstream delivery point X;
$Q_i(X,t)$ = amount of demand or indent in the delivery schedule; and
$Q_d(X,t)$ = amount designed for perfect operation according to the given schedule.

Hence, twelve performance measures are defined relative to four water delivery system objectives (adequacy, efficiency, dependability and equity). Each measure is a function of selected state variables of the system and is related to either actual field performance, performance relative to structural contributions, or performance relative to management contributions. The adequacy objective relates to the desire to deliver targeted amount of water needed for crop growth to delivery points in the system. Efficiency is the conservation of water resources in the delivery process (prevention of over-delivery). Dependability is the achievement of temporal uniformity in the ratio of delivered amounts of water to targeted amounts. Equity is defined as the spatial uniformity of the ratio of the delivered water to the targeted or potentially deliverable amounts.

The twelve output performance measures are summarized in Table 3.1 in the form of average discrete functions of comparative ratios of state variables over a region or subregion, R, served by the delivery system for a time period, T. Molden and Gates (1990) suggested a performance standard or scale to judge the level of performance achieved (as good, fair, or poor) according to Table 3.2.

Table 3.1. *Matrix of water delivery system performance measures relative to system objective.*

Delivery System Objective	Actual	Structural Contribution	Management Contribution
Adequacy	$P_{Aac} = \frac{1}{T}\sum_{T=1}^{T=n}(\frac{1}{R}\sum_{R=1}^{R=m} P_a)$	$P_{AS} = \frac{1}{T}\sum_{T=1}^{T=n}(\frac{1}{R}\sum_{R=1}^{R=m} P_{as})$	$P_{AM} = \frac{1}{T}\sum_{T=1}^{T=n}(\frac{1}{R}\sum_{R=1}^{R=m} P_{am}$
Efficiency	$P_{Fac} = \frac{1}{T}\sum_{T=1}^{T=n}(\frac{1}{R}\sum_{R=1}^{R=m} P_{Fac})$	$P_{FS} = \frac{1}{T}\sum_{T=1}^{T=n}(\frac{1}{R}\sum_{R=1}^{R=m} P_{fs})$	$P_{FM} = \frac{1}{T}\sum_{T=1}^{T=n}(\frac{1}{R}\sum_{R=1}^{R=m} P_{fm}$
Dependability	$P_{Dac} = \frac{1}{R}\sum_{R=1}^{R=n} CV_T(\frac{Q_{ac}}{Q_{cwr}})$	$P_{DS} = \frac{1}{R}\sum_{R=1}^{R=n} CV_T(\frac{Q_d}{Q_i})$	$P_{DM} = \frac{1}{R}\sum_{R=1}^{R=n} CV_T(\frac{Q_{ac}}{Q_d})$
Equity	$P_{Eac} = \frac{1}{T}\sum_{T=1}^{T=n} CV_R(\frac{Q_{ac}}{Q_{cwr}})$	$P_{ES} = \frac{1}{T}\sum_{T=1}^{T=n} CV_R(\frac{Q_d}{Q_i})$	$P_{EM} = \frac{1}{T}\sum_{T=1}^{T=n} CV_R(\frac{Q_{ac}}{Q_d})$

Notes: $P_a = Q_{ac}/Q_{cwr}$ if $Q_{ac} \le Q_{cwr}$, otherwise = 1 $P_{as} = Q_d/Q_i$ if $Q_d \le Q_i$, otherwise = 1
$P_{am} = Q_{ac}/Q_d$ if $Q_{ac} \le Q_d$, otherwise = 1 $P_{fac} = Q_{cwr}/Q_{ac}$ if $Q_{cwr} \le Q_{ac}$, otherwise = 1
$P_{fs} = Q_i/Q_d$ if $Q_i \le Q_d$, otherwise = 1 $P_{fm} = Q_d/Q_{ac}$ if $Q_d \le Q_{ac}$, otherwise = 1
CV_T = Temporal coefficient of variation over time period T. CV_R = Spatial coefficient of variation over the region R.

n = number of time (weeks, months) m = number of regions (reaches, sections)

Table 3.2. Performance standards for indicators of quality of irrigation service.

Indicator	Scale		
	Good	Fair	Poor
P_A	0.90-1.0	0.8-0.89	<0.80
P_F	0.85-1.0	0.70-0.84	<0.70
P_D	0.00-0.1	0.11-0.20	>0.20
P_E	0.00-0.10	0.11-0.25	>0.25

Source: Molden and Gates (1990).

3.2.2 Water scheduling indicator (WDP)

The index of water delivery performance as defined by Bailey and Lenton (1984) is used to reflect the process of scheduling through time and space. Hence, it monitors productivity and equity and combines the effects of adequacy and timeliness with appropriate weights attached to critical periods of crop growth (Mohammed 1992; Rao 1993). Water delivery performance (WDP) can be defined as follows:

$$WDP_i = \frac{1}{n} \sum_{t=i}^{n} K_{ti} P_w$$

$$\sum_{i}^{n} K(t_i) = 1$$

$$P_w = \frac{Q_{ac_{ti}}}{Q_{cwr_{ti}}} \; if \; Q_{ac_{ti}} \leq Q_{cwr_{ti}}$$

$$otherwise P_w = 1$$

where:

$Q_{ac_{ti}}$ = the total volume of water entering a minor (i) during the period (t)

$Q_{cwr_{ti}}$ = Total crop water requirement to be supplied to a minor (i) during period (t).

K = Weighting factor indicating the relative importance of the different types of crop growth in a physiological or economic sense.

n = Crop growth stage.

3.2.3 Agricultural indicator

Crop productivity may be evaluated either by area utilization (land conservation), yield categories as per unit of area or per unit of water (Mohammed 1992; Rao 1993). In this study irrigated area utilization is considered only which is taken as:

$$Area\ Performance = \frac{Actual\ Crop\ Area}{Target\ Crop\ Area}$$

3.2.4 The overall performance index (O.P.I.)

The overall performance index for water allocation in the system varies in the view of different decision makers or users. However, it is suggested here to express the views of each of the evaluators by expressing their relative weight for each indicator. Hence, OPI can be defined as:

$$OPI = \sum_{i=1}^{n} W_i \, S_i$$

$$i = 1, \ldots \ldots n$$

where:

OPI	=	overall performance index;
W_i	=	relative weight of (i) indicator;
S_i	=	the performance index scores for the (i) indicator; and
n	=	number of performance indicators.

3.3 APPLICATION TO SYSTEM EVALUATION

3.3.1 THE CASE OF RAHAD IRRIGATED PROJECT

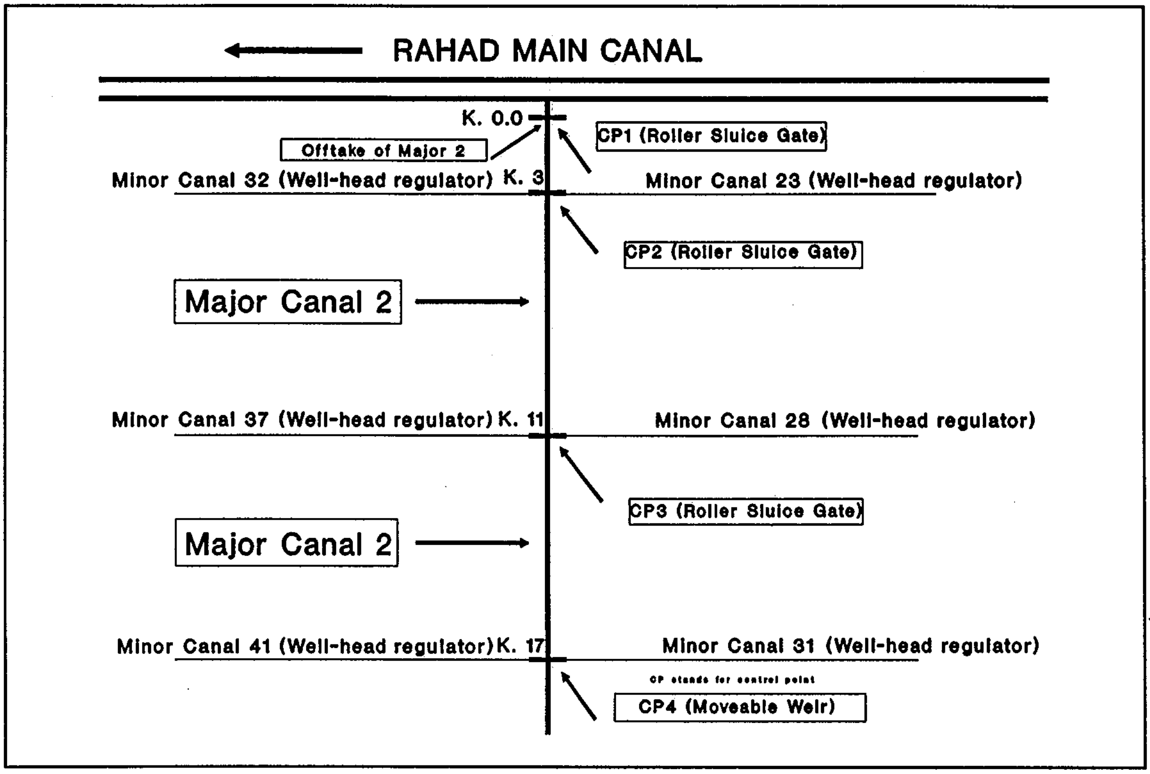
The Rahad irrigated project, which is approximately 25 km wide and 160 km long, is situated along the eastern bank of the Rahad River. The first phase of Rahad was put under production in 1981 (300,000 feddans), and its second phase is expected to increase its area up to 820,000 feddans. The soils, layout and management of the Rahad are also like the Gezira Scheme (Elawad and Hamid 1993). Hence, the development of a diagnostic analysis in Rahad may serve as a model to evaluate other large-scale projects.

In addition, Rahad is a new and developing project; thus, it is selected as a case study on the assumption that good bookkeeping and reliable data are available. This may serve to document its existing practices and provide a warning system to any signs of failures not to be repeated in its second phase. Elawad and Hamid (1993) reported that due to the lack of established standards and guidelines for the two managing agencies (Ministry of Irrigation, MOI and Rahad Agricultural Corporation, RAC) there is conflict and disagreement between them. A system to resolve this conflict and measure the services rendered by both agencies is needed.

An extensive set of field measurements were made during the 1992/1993 season to monitor Major No. 2 (head major) water flows. Four control points (CP) and six minor canals (m.c.) offtakes were sampled to represent the major head, middle and tail conditions as shown in Figure 1. Primary and secondary data are reported in Gideon (1994).

The data collected in the field allowed a determination of the state variables defined before (i.e. Q_{ac}, Q_i, Q_{cwr}, Q_d). Crop water requirements were calculated using Farbrother's Tables (1976).

Figure 1. Schematic layout of Major Canal 2 displaying monitoring points.



3.3.2 Evaluation according to control points (CP - evaluation)

Adequacy: Adequacy is based on the Molden and Gates scale (2). Table 3.3 shows that the actual adequacy (P_{Aac}) and the structural adequacy (P_{AS}) can be considered good. On the other hand a poor management adequacy (P_{AM}) was indicated. This is attributed mainly to the fact that the management agency (MOI) always operates the system within safety limits to avoid canals overflowing.

Efficiency: As shown in Table 3.4, the efficiency indicator due to actual (P_{FAC}) and management (P_{FM}) ranges between good and fair. However, the structural efficiency (P_{FS}) can be classified as poor. This may be due to the fact that indents tend to be far less than the design discharges.

Dependability: Dependability is within the acceptable limits as shown in Table 3.5. However, dependability of water distribution along the major canal tends to decrease slightly towards the tail end of the canal which agrees with the findings of Elawad and Hamid (1993).

Equity: Table 3.6 shows good water distribution with respect to actual (P_{Eac}) and management (P_{EM}) equity measure irrespective of location. However, equity due to hydraulic structure (P_{ES}) can be marked as poor during the early and late seasons, whereas equity during the mid season is fair.

3.3.3 Evaluation according to Minor canal offtakes (M.C. - evaluation)

3.3.3.1 Adequacy

Following the Molden and Gates Scale (1990), Table 3.7 indicates good actual and structural adequacy, irrespective of location or crop growth stage. However, management adequacy was poor in general. This may be due to:

(a) Lack of communication (late response to the indents, or closing and opening the gates;

(b) The management seems to be based on personal experience and judgement, specially in manipulating the gate opening rather than the proper use of existing and functioning structures; and

(c) Water allocation by MOI in most cases is based on quota rationing on an area basis and strict adherence to the rule not to run any canal near its maximum capacity (too safety conscious).

3.3.3.2 Efficiency

Table 3.8 shows a decrease in actual efficiency from head to tail minors and from early through late season.

Management efficiency. Is within the design limits (rule of safety is always kept).

Structural efficiency. Although the selected structures were all functioning, the poor efficiency index is perhaps due to improper use, poor gate setting, and manipulation of the gates by the ghaffirs (gate-operators).

There is no variation due to location or during season with respect to management and structural efficiency.

3.3.3.3 Dependability

In Table 3.9, the following may be observed with respect to dependability:

(a) Actual dependability

- Seasonal performance: For head being near to the source of supply, its dependability is generally fair at the head, but poor in the middle and tail.

- Early season performance: dependability of the head and tail was found to be fair, while it was poor in the middle. Results at the head are following the general trend observed by Elawad and

Hamid (1993), while the tail situation is because of hydraulic position (movable weir) and not the distance position.

- Mid and late seasons performance: The tail shows fair results due to the fact that the structure is a movable weir which gives a positive head-flow relationship.

(b) *Management dependability:* Generally it can be described as fair irrespective of location along the major with respect to the whole system. These results are in agreement with those given by Shafique (1993).

- The variation was found to be due to hydraulic location rather than distance location.

- Results at the head may be described as good, but the middle displayed an inconsistent trend, while the tail was good (due to moveable weir).

(c) *Structural dependability:* The operation of structures was poor, although the structures selected were in good condition. This result likely occurs because they are operated without precise measurement.

3.3.3.4 Area Index

Table 3.10 showed the irrigated area performance (IAP). The ideal values of IAP should be unity. In this table, the values are less than one, which means that the cropped area was a fraction of the target or planned area. This was likely due to a lack of maintenance on the main drains due to the disposal of excessive rainfall or surplus irrigation water.

3.3.3.5 Water delivery performance (WDP) indicator

Bailey and Lenton (1984) proposed WDP which varies between 0.0 - 1.0 and 1.0 is good. Following this measure, Table 3.11 indicates that;

- The operation of the head and middle minor canals, with respect to WDP was found to be within a good range throughout the early, middle and late seasons. However, the WDP distribution decreased from head to tail minors, which in general indicated a common behavior of large irrigation schemes.

3.3.4 Evaluation of overall performance index (OPI)

3.3.4.1 Control points - O. P. I.

When the control points were ranked according to their overall performance index as listed in Table 3.12, they showed inconsistent and fluctuating results. These results are similar to Kab El Gidad Major in the Gezira Scheme (Shafique 1993). The above stated situation indicates three probable explanations:

(a) Actual and demand supplies are mismatched and the management tends to over indent at the tail sections of the major;

(b) The type of hydraulic structure at the tail control point (movable weir) creates a positive head condition; or

(c) The on-going monitoring exercise made some officials go abroad.

Whatever the case may be, the process of water distribution needs a detailed and corrective review.

3.3.4.2 Minor canal - O. P. I.

With reference to Table 3.13, the following may be observed:

- results are in agreement with those reported for CP;
- head-tail variation are reported as common phenomena in large canal system (Rao 1993); and
- The results indicate that hydraulic position, rather than the spatial position only, has an effect in altering the head-tail postulation.

3.4 CONCLUSIONS

Although the analysis is approximate as rainfall and other losses were not explicitly considered, yet the set of indicators chosen and the results achieved indicate fairly well the trends in performance:

(1) As the delivery system is based on a demand mode, the block inspectors tend to over demand water, while the operating engineers are conservative in supplying water within the canal safety limits. Operation generally is based on personal experience, this calls for more training and proper communication facilities.

(2) Analysis of operating CP generally indicates good performance, but with limited structural efficiency and poor management adequacy. This is may be due to manual operation of the system based on experience.

(3) Operation of minor canals in the Rahad irrigated project may be described as having good performance, with the exception being the structural dependability performance.

In particular, the middle and tail ends indicate a poor dependability level at mid and late seasons, while the overall seasonal dependability is fair. This indicates the importance of analyzing the inter-seasonal variation in diagnosing each of these indicators.

On the other hand consistency was reflected by a measure of less than one (1) in the irrigated area performance.

The WDP measure of minor canal off-takes showed a general tendency of decreasing from head to tail; nevertheless, offtakes lying at the head and middle of the major were in the good range of operation measure irrespective of seasonal variation.

As anticipated in a large scheme such as Rahad, the overall performance indicators for the minor offtakes were inconsistent.

Hence future studies are needed to consider new methodologies for improving system operation.

Table 3.3. Adequacy performance according to control points (Seasonal).

Control Points Indicators	CP_1	CP_2	CP_3	CP_4
$P_{Aac}=Q_{ac}/Q_{cwr}$	1.0	1.0	.89	.86
$P_{AM}=Q_{ac}/Q_d$	0.43	0.81	0.38	0.43
$P_{AS}=Q_d/Q_i$	1.0	1.0	1.0	0.63

Table 3.4. Efficiency performance according to control points (Seasonal).

Control Points Indicators	CP_1	CP_2	CP_3	CP_4
$P_{Fac}=Q_{cwr}/Q_{ac}$	0.95	0.52	0.30	1.0
$P_{FM}=Q_d/Q_{ac}$	1.0	1.0	1.0	1.0
$P_{FS}=Q_i/Q_d$	0.62	0.52	1.0	0.63

Table 3.5. Dependability performance according to control points (Seasonal).

Control Points Indicators	CP_1	CP_2	CP_3	CP_4
$P_{Fac}=CV_T\ (Q_{ac}/Q_{cwr})$	0.17	0.23	0.18	0.22
$P_{DM}=CV_T\ (Q_{ac}/Q_d)$	0.08	0.07	0.08	0.11
$P_{DS}=CV_T(Q_d/Q_i)$	0.18	0.23	0.22	0.26

Table 3.6. Equity performance according to control points (Seasonal).

Control Points Indicators	CP_1	CP_2	CP_3	CP_4
$P_{Eac}=CV_R\ (Q_{ac}/Q_{cwr})$	0.25	0.51	0.21	0.17
$P_{EM}=CV_R\ (Q_{ac}/Q_d)$	0.06	0.14	0.06	0.06
$P_{ES}=CV_R\ (Q_d/Q_i)$	0.32	1.0	0.36	0.23

Table 3.7. Adequacy performance according to minor canals.

Evaluating indicators	Time or season	Location		
		Head Minors	Mid Minors	Tail Minors
$P_{Aac} = Q^{ac}/Q_{cwr}$	E	.99	.90	1.0
	M	1.0	1.0	1.0
	L	1.0	1.0	.79
	S	1.0	1.0	1.0
$P_{AM} = Q_{ac}/Q_d$	E	.64	.47	.39
	M	.48	.68	.44
	L	.39	.41	.22
	S	.50	.45	.35
$P_{AS} = Q_d/Q_i$	E	1.0	.99	1.0
	M	1.0	.92	1.0
	L	1.0	1.0	1.0
	S	1.0	1.0	1.0

E = Early season, M = Mid season, L = Late season, S = Whole season (seasonal)

Table 3.8. Efficiency performance according to minor canals.

Evaluating indicators	Time or season	Location		
		Head Minors	Mid Minors	Tail Minors
$P_{Aac} = Q^{ac}/Q_{cwr}$	E	.90	1.0	.83
	M	.84	.59	.63
	L	.57	.48	1.0
	S	.79	.65	.83
$P_{FM} = Q_d/Q_{ac}$	E	1.0	1.0	1.0
	M	1.0	1.0	1.0
	L	1.0	1.0	1.0
	S	1.0	1.0	1.0
$P_{FS} = Q_i/Q_d$	E	.68	.57	.68
	M	.54	.72	.68
	L	.48	.45	.55
	S	.56	.62	.64

E = Early season, M = Mid season, L = Late season, S = Whole season (seasonal)

Table 3.9. Dependability performance according to minor canals.

Evaluating indicators	Time or season	Location		
		Head Minors	Mid Minors	Tail Minors
$P_{Dac} = CV_T(Q^{ac}/Q_i)$	E	.20	.25	.19
	M	.19	.24	.21
	L	.18	.26	.05
	S	.20	.21	.21
$P_{DM} = CV_T\ (Q_{ac}/Q_d)$	E	.12	.07	.12
	M	.10	.23	.14
	L	.09	.12	.02
	S	.11	.14	.13
$P_{AS} = (CV_T(Q_d/Q_i)$	E	.23	.34	.33
	M	.22	.25	.33
	L	.24	.31	.13
	S	.23	.31	.38

E = Early season, M = Mid season, L = Late season, S = Whole season (seasonal)

Table 3.10. Irrigated area performance - Minor Canals.

Location	Canals	Actual Area	Target Area	%	Average
Head Minor	MC23	1,053.5	1,378	76	80
	MC32	739.5	880	84	
Mid Minor	MC28	959.0	1,176	82	78.5
	MC37	699.0	959	73	
Tail Minor	MC31	857.0	987	86	86
	MC41				

M.C. = Minor Canals

Table 3.11. Water delivery performance indicator for minor canals.

Time or Season	Location		
	Head Minors	Mid Minors	Tail Minors
Early	1.0	.90	.56
Mid	1.0	1.0	96
Late	1.0	.92	.43
Seasonal	1.0	.94	.65

Table 3.12. Overall performance index control points.

Evaluation Indicator	Location of control points			
	CP_1	CP_2	CP_3	CP_4
Equal weight	6.06	7.03	5.18	5.97
Rank	2	1	4	3

Table 3.13. Overall performance index Minor Canals.

Evaluating Agency	Minor Canal Location		
	Head	Mid	Tail
RAC	44.90	38.75	42.26
Rank	1	3	2
MOI	47.15	45.81	47.94
Rank	2	3	1

3.5 REFERENCES

Bailey, C. and Lenton, R. (1984). A Management tool for the Gezira irrigation scheme. In Fadl O. A. and Bailey C. eds., Water distribution in Sudanese irrigated agriculture productivity and equity.

Bos, M.G.H., Murray-Rust, D. J. Merrey, H. G. Johnson, and W. B. Snellen (1993). Methodologies for assessing performance of irrigation and drainage management. Rahad workshop (No. 1), H.R.S., Medani, June 1993.

Elawad, O. M. and Hamid, S. H. (1993). Evaluation of water supply at the main irrigation system of the Rahad Scheme. Rahad workshop (No. 1), HRS, Medani, June 1993.

Gideon, C. (1993). Major and minor canals performance evaluation, Rahad irrigated Project. MSc. Thesis to be presented at the University of Khartoum.

Mohammed, H. I. (1992). Analytic and optimization decision - making models for multi-objective on-farm irrigation improvement strategies. Unpublished Ph.D Thesis, University of Khartoum.

Molden, D. J. and Gates, T. K. (1990). Performance measures for evaluation of irrigation water-delivery systems. ASCE, Volume 116, No. 6.

Murray-Rust, D. H. and W. B. Snellen (1993). Irrigation system performance assessment and diagnosis. IIMI, ILRI, and IHE. Forthcoming IIMI research monograph. Colombo, Sri Lanka: IIMI.

Rao, P.S. (1993). Review of selected literature on irrigation performance. Forthcoming IIMI research paper. Colombo, Sri Lanka: IIMI.

Scott, W. R. (1979). Effectiveness of organizational effectiveness studies, in Paul S. Goodman and Johannes M. Pennings, eds. New perspectives on organization effectiveness. Jossey-Bass Publishers, Chapter 4 (pp. 63-95).

Seashore, S. E. (1983). A framework for integrated model of organizational effectiveness, in Kim S.C. and David A. W., eds., organizational effectiveness: a comparison of multiple models. New York. Academic Press, Chapter 3 (PP 55-70).

Shafique, M. S. (1993-94). Field outlet pipe news of IIMI volume 2 through volume 8.

ACKNOWLEDGEMENT

1. This work is part of an on-going MSc research program by the University of Khartoum.
2. Facilities offered by IIMI-Sudan are greatly acknowledged.