EVALUATION OF HYDROULIC PERFORMANCE OF MAJOR CANALS IN THE RAHAD AGRICULTURAL SCHEME–SUDAN

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KEYWORDS: Rahad agricultural scheme, hydraulic performance, Major canals.

ABSTRACT

Diagnosis and evaluation of irrigation projects is complex and often neglected subject, in spite of its important role which plays if the declining output of the large scale irrigated projects in Sudan is to be improved.

A package of goal- oriented performance indicators (quality of irrigation services, water scheduling and area utilization) was used to quantify the hydraulic performance of the main canal water delivery system in Rahad irrigated scheme. As a result, an overall evaluation index is formulated to reflect the irrigation system multiple objectives. Stratified sampling procedure adopted to extensively monitor and quantify water flows at four control points and six Minor canals of Major (No.2). Secondary data was obtained from the various canal operating agencies.

The results generally reveal considerable seasonal variability in the performance of the indicators used and maloperation of canal structures. They indicate that water delivery performance in the Minor canal is decreased towards the tail end. Therefore, new operational methodologies are needed to solve these problems.

الملخص:

تشخيص وتقويم المشاريع المروية موضوع معقد ومهمل ولكنه يلعب دوراً حيوياً في تحسين الإنتاجية المتدنية في المشاريع المروية الكبرى بالسودان.

تم استخدام حزمة من مؤشرات الأداء الموجهة نحو تحقيق الأهداف (جودة خدمات الري وبرمجة المياه واستغلال الأراضي) لأغراض التحديد الكمي للأداء الهايدروليكي لشبكة قناة رئيسية لتوزيع المياه في مشروع الرهد الزراعي. وبناء عليه تم بناء مؤشر تقويم كلي ليعكس الأهداف المتعددة لنظام الري. استخدمت طريقة العينات على أساس الطبقات لأغراض المتابعة المكثفة لتصرفات المياه في أربع نقاط تحكم وست قنوات ثانوية في القناة الرئيسية نمرة (2) تم التحصل على البيانات الثانوية من مختلف الهيئات العاملة في تشغيل القناة.

أوضحت النتائج عموماً اختلافات موسمية في قيم مؤشرات الأداء المستخدمة واستخدام خاطئ لمنشآت القناة. كما أوضحت النتائج أن مؤشر توزيع المياه في القنوات يتناقص نحو نهاية القناة . ولهذا هناك احتياج لاستخدام طرق تشغيل جديدة لحل هذه المشكلة.

INTRODUCTION

The major constraint to produce more food to meet the increasing world population demand is water security. One possible approach to conserve this scarce resource may be through improving the performance of the existing large-scale irrigation projects and improving its management and utilization level. A key factor in better management is the performance of human factor. As such development of performance indicators and rigorous evaluation methodology is needed to help managers to improve their system. Evaluation exercise is useful tool to aid scheme manager to compare and the efficiency of alternative system and operating procedures to improve existing projects (to employ intervention or rehabilitation programmed or not, and to compare performance of different sections within a project or different projects).

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

A field multi- objective evaluation of performance of irrigation systems is limited. Due to this inadequate understanding of field conditions, causes and magnitudes of priority problems were not fully identified especially in less developed countries. Most studies and reports are either based on rapid appraisals or concentrating on one part of the system (Mohamed, 1992).

Rahad irrigation scheme is selected as a case study for the purpose of evaluating the performance of multi-objective irrigation project for rural development. Rahad case study may serve as a model to evaluate large agricultural projects in the Central Clay Plains of the Sudan. As reported by (Elawad and Hamid, 1993) development of an index system of evaluating performance of irrigated project can be used as a tool to resolve conflict and measure the service rendered by the operating agencies. Hence, the objective of this study is to develop a systematic and comprehensive procedure for evaluating seasonal performance of irrigated projects and also to propose and test a set of quantitative performance indicators for water delivery at Major level.

MATERIALS AND METHODS

Development of Index System of Evaluation: On basis of goal oriented model the following sets of indicators are chosen to express the actual and planned values (in terms of ratio) to reflect the quality of irrigation service, water scheduling, agricultural indicators and over all system performance indexes(Bos *et al.,* 1993).

Quality of irrigation service conceptually addresses physical system capability and operation to deliver water per schedule and design. As given by (Molden and Snellan, 1993) twelve performance measures are defined relative to four objectives of water delivery system (adequacy, efficiency, dependability, and equity). The suggested performance indicators are depicted in (Table 1) and their respective scale to judge their attainment is given in (Table 2).

Water delivery performance (WDP) that reflects the scheduling process through time and space is measured according to (Bailey and Lenton, 1984, Mohammed 1992 and Rao, 1993). It varies from 0.0 to 1.0 where 1.0 is good and 0.0 is worst. It can be defined as:

$$WDP = \frac{1}{n} \cdot \sum_{t=i}^{n} k_{ti} \cdot P_W$$

$$\sum_{i=1}^{n} k(ti) = 1$$

$$P_W = \frac{Q_{ac.ti}}{Q_{CWI.ti}} \quad \text{if } Q_{ac_{ti}} \leq Q_{ac_{ti}}$$

Otherwise P_w =1

Where:

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

$Q_{CWI_{ti}}$ = total crop water requirement to be supplied Minor (i) during period (t).

K= weighting factor indicating the relative importance of the different types of crop growth in physical or economic sense (e.g yield response factor, Gideon, 1993). n = crop growth stage.

Table (1): Matrix of Water Delivery System Performance Measures Relative to System Objective

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

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

Agricultural Indicator: It is evaluated in terms of crop productivity per unit area or per unit water. Land conservation expresses agricultural performance as a ratio of land of actual cropped area to target area (Mao Zhi, 1989).

The overall performance index (OPI) of water allocation in irrigated agricultural schemes with respect to different decision makers and stalk holders is estimated according to (Mohammed 1992)

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

Where:

OPI = overall performance index, i = 1, 2, 3 **…,** n number of performance indicators Wi = relative weight of (i) indicator, Si = the performance index scores for the (i) indicators and.

Data Collection: Rahad irrigated scheme located along the Eastern bank of the Rahad River (Latitudes 13º 43 -14º.35N and longitudes 34º 22-35º 55E) is approximately 25km wide and 160 km long. The first phase of Rahad was to put under production in 1981 an area of 126,000 hectars, and its second phase is expected to increase its area up to 344,000hectars. The network of open flow canalization system in the project is composed of unlined Major, Minor and Water-courses in descending order of magnitude. Most of the Rahad area is covered by dark, heavy cracking clay soils. The average annual rainfall is 400mm and the mean daily temperature is 40ºc in Summer and 17ºc in Winter. The soils and canalization layout and management of the Rahad are typical to the Gezira Scheme.

An extensive set of field measurement were made to monitor Major No.2 (head Major in the project) water flows. Four control points (CP) and six Minor canals (MC) off takes were sampled to represent the Major head, middle and tail conditions. Data monitoring programme was initiated by calibrating ten hydraulic structures (Fig.1) using current meter and a dumpy level by following the procedure described by (Gideon, 1993). The flow rate passing each structure was measured four times a day (with an interval of three hours) for a complete agricultural season. Water indents, cultivated area, sowing dates were taken from Block 2 Head Inspector (BI). Authorized water flow releases, 10-day discharges and design discharges were taken from Ministry of Irrigation Engineer (ADE) at kilo 36. Crop water requirements were calculated using Farbrother tables of indents (Farbrother, 1977).

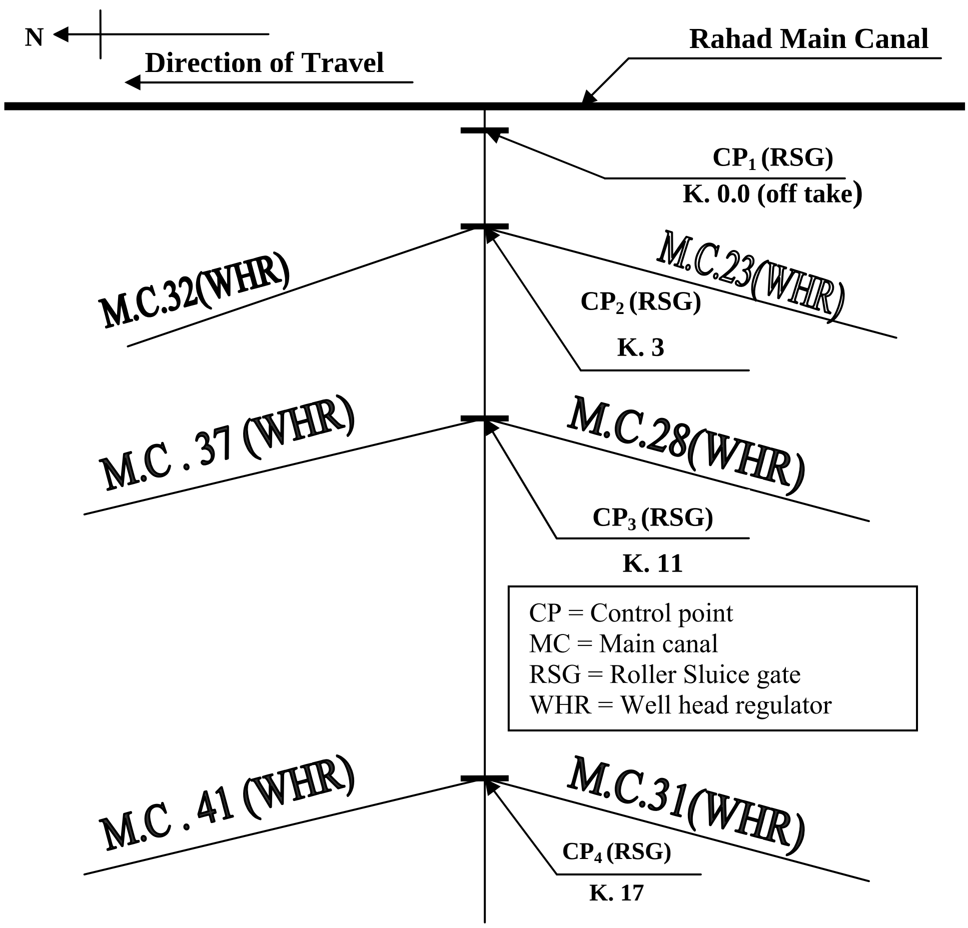

Fig. (1): Schematic layout of locations monitored along Major (No.2) Rahad Irrigation Project (not to scale)

RESULTS AND DISCUSSION

Evaluation According to control points (CP. evaluation):

Adequacy: based on the scale given in (Table 2) it is evident from (Table 3) that the actual adequacy (PAac) and the structural adequacy (PAS) can be considered well while a poor management adequacy (PAM) was indicated. According to (Francis *et al.*, 1988) this can be attributed to the fact that the irrigation management agency always operates the canal system within safety limits to avoid water overflow and damage.

Table (2): Performance standards for indicators of quality of irrigation service.

Indicators	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)

Table (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	0.89	0.86
$P_{EM} = Q_{ac} / Q_d$	0.43	.81	0.38	0.43
$P_{FC} = Q_d / Q_i$	1.0	1.0	1.0	0.63

Efficiency: as shown in (Table 4) the efficiency indicator due to actual (PFAC) and management (PFM) ranges between good and fair. However, the structural efficiency (PFS) can be classified as poor. This may be due to the fact that indents tend to be far less than the design discharges (Giden, 1993)**.**

The porr structural efficiency can be attributed to the low level of reliability, resiliency and vulnerability of hydraulic structures. Damage assess-ment of existing structures of Gezira and Rahad irrigated schemes in Sudan was made as part of rehabilitation and modernization programme reveled the need to urgently maintain the existing structures and replace some of them (roller shnice gates and field out let pipes)by installing more efficient ones such as hydro-mechanical gates (Francis and Elawad, 1986, Ahmed *et al.*,1986).

Dependability: it is within the acceptable limits (Table 5). However, dependabil-ity of water distribution along the Major canal tends to decrease slightly towards the tail end of the canal which agrees with the finding of (Elwad and Hamid, 1993) for Rahd main canal and for Gezira irrigation network (Mohamed, 1992).

Table (4): Efficiency 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	023	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	022	026

Equity: (Table 6) shows good water distribution with respect to actual (PEac) and management (PEM) equity measures irrespective of location. However, equity due hydraulic structure (PES) can be marked as poor during early and late seasons, where in the mid season it is fair.

Elowad and Hamid (1993) reported that there are two periods of peak demand for water at early and late season. Early season water shortage arise from low rainfall and the need to sow all crops at short time period.

While late season shortage is due to overlap of demand of all crops in the rotation for irrigation water after cession of rainfall. To meet variation in demand there is a need to use more in an up stream water level control made of operation flexible structures weirs as cross-regulator and to keep flow as steady as passable by sluice gates as off take structures (Burt, 1987).

For the case of Rahad weirs rather than orifices are used as canals off take structures (Mohammed, 1992).Hence, low level of structural performance (PES) is expected.

Table (5): Dependability performance according to control points (Seasonal)

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

Table (6): Equity performance according to control points (Seasonal)

Indicators \ Control Points	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

Evaluation According to Minor Canal off Takes (Mc- Evaluation):

Adequacy: (Table 7) indicates a good actual and structural adequacy irrespective of location or crop growth stage. However, management adequacy was poor in general. This may be due to lack of communication, late response time, and operation of hydraulic structures on basis of experience and quota rationing rather than on scientific rules (ELawad and Hamid, 1993).

Chembers (1988) identifies lack of communication as one of the causes of poor water scheduling and delivery in manually operated irrigation system such as Rahad.Although communication is required both upward to managers and downwords to farmers no such communication system is installed in Rahad project.Hence, information can not be collected, aprocessed, analysed and acted upon in order that water is delivered to the farm unit.

Table (7): Adequacy performance according to minor canals

Evaluation Indicators	Time or Season	Location		
		Head Minors	Mid Minors	Tail Minors
$P_{Ac} = Q_{ac} / Q_{cwr}$	E	0.99	0.90	1.0
	M	1.0	1.0	1.0
	L	1.0	1.0	0.79
	S	1.0	1.0	1.0
$P_{AM} = Q_{ac} / Q_d$	E	0.64	0.47	0.39
	M	0.48	0.68	0.44
	L	0.39	0.41	0.22
	S	0.50	0.45	0.35
$P_{AS} = Q_d / Q_i$	E	1.0	0.99	1.0
	M	1.0	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)

Efficiency: (Table 8) shows a decrease in actual efficiency from head to tail Minors and from early through late season but within canal capacity design limits (rule of safety). Similar results were reported for Gezira scheme (Fakki *et al.,* 1984).

Structural Efficiency: Although the selected structures were all functioning, the poor efficiency index is perhaps due to improper use, poor setting and manipul-ation of the gates by the gatekeeper. There is no variation due to location or within season with respect to management and structural efficiency.

Table (8): Efficiency performance according to minor canals

Evaluation Indicators	Time or Season	Location		
		Head Minors	Mid Minors	Tail Minors
$P_{Aac} = Q_{ac} / Q_{cwr}$	E	0.90	1.0	0.83
	M	0.84	0.59	0.63
	L	0.57	0.48	1.0
	S	0.79	0.65	0.83
$P_{FM} = Q_d / Q_{ac}$	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	0.68	0.57	0.68
	M	0.54	0.72	0.68
	L	0.48	0.45	0.55

	S	0.56	0.62	0.64

E = Early Season, M = Mid Season, L = Late Season, S = Whole Season (Seasonal)

As given before, the low level of structural efficiency is related to use of sluice gates as Minor canal cross regulator and to the complete damage of circular night storage weirs in Rahad scheme (Ahmed *et al.*, 1986).

Dependability: In (Table 9) the following may be observed:

Actual Dependability:

- Seasonal dependability: for head Major is generally fair in head reaches and poor in the mid and tail reaches. According to (Chember, 1988) this is a typical phenomenon in manually operated, upstream control, large irrigated schemes (Bos *et al.,*1993).
- Early in the season: dependability of head and tail Minors was found to be fair, while it was poor in the middle. This was observed by Elawad and Hamid (1993). Tail low dependability is due to use of movable weir rather than to location.
- At mid and late seasons performance: The tail Minors shows fair results due to the type of structure in use.

Management Dependability: It can be described as fair and varies with hydraulic location irrespective of spatial location along the Major. These results are in agreement with those given by (ELawad and Hamid, 1993).Location of off takes of tertiary and Minor canal at too great distance from the commanding cross–regulators affect the ability of these off takes to effectively divert the required flow under low flows (Bos *et al.,* 1993).

Table (9): Dependability performance according to minor canals

Evaluation Indicators	Time or Season	Location		
		Head Minors	Mid Minors	Tail Minors
$P_{Dac} = CV_T(Q_{ac} / Q_i)$	E	0.20	0.25	0.19
	M	0.19	0..24	0.21
	L	0.18	0.26	0.05
	S	0.20	0.21	0.21
$P_{AM} = CV_T(Q_{ac} / Q_d)$	E	0.12	0.07	0.12
	M	0.10	0.23	0.14
	L	0.09	0.12	0.02
	S	0.11	0.14	0.13
$P_{AS} = CV_T(Q_d / Q_i)$	E	0.23	0.34	0.33
	M	0.22	0.25	0.33
	L	0.24	0.31	0.13
	S	0.23	0.31	0.38

E = Early Season, M = Mid Season, L = Late Season, S = Whole Season (Seasonal)

Structural Dependability: The operation of structures was poor although the structures selected were in good condition. This is due to structure type rather than its maintenance level (Burt, 1987).

Area Index: (Table 10) showed irrigated area performance (IAP). In ideal case it should be unity. The obtained values are less than one. This is reported to be caused by water ponding in the field for larger periods due to lack of field drains and proper land leveling operation (Mohamed, 1993).

Water Delivery Performance (WDP): (Table 11) indicates that the operation of head and middle Minor canals, with respect to (WDP) was found to be within a good range throughout early, middle and late seasons. While (WDP) distribution decreased from head to tail Minors which is a common behavior in operating open channel large irrigation schemes (Faki *et al.,* 1984 and MaoZhi, 1989).

Table (10): Irrigated area performance of minor canals

Location	Canals	Actual Area	Arget Area	%	Average
Head Minor	MC23	1053.5	1378	76	80
	MC32	739.5	880	84	
Mid Minor	MC28	959.0	1176	82	78.5
	MC37	699.0	959	73	
Tail Minor	MC31	857.0	987	86	86
	MC41				

Table (11): Water delivery performance of minor canals

Time or Season	Location		
	Head Minors	Mid Minors	Tail Minors
Early	1.0	0.90	0.56
Mid	1.0	1.0	96
Late	1.0	0.92	0.43
Seasonal	1.0	0.94	0.65

Evaluation of Overall Performance Index (OPI):

For Control Points: When the control points ranked according to their overall performance index (Table 12) they showed inconsistent and fluctuating results. These results are similar to the Gezira- Kab El Gidad Major- (Francis *et al.,* 1988 and Francis and Elowod, 1989).

Table (12): Overall performance index for control points (Seasonal)

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 (13): Overall performance of index minor canals

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

This indicates three probable explanations**:**

Actual and demand supplies are mismatched and the management tends to make over indenting at tail sections of the major, The type of the hydraulic structure at tail control point (movable weir) creates positive head condition, The process of water distribution needs a detailed and corrective review.

For Minor Canal: With reference to (Table 13) the following may be observed:

Results are in agreement with those reported for control point, Head-tail variation is reported as common phenomena in large canal system (Mao zhi1989 and Rao, 1993).

The results indicate that hydraulic characteristics rather than spatial position from parent canal off take have the main effect in altering the head-tail postulation.

CONCLUSIONS

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

As the delivery system is based on 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 call for more training and proper communication facilities. Analysis of control point (CP) generally indicate good performance, but with limited structural efficiency and poor management adequacy. This is may be due to system manual operation by experience. Operation of minor canals in Rahad irrigated project may be described as good performance with exception to 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 interpersonal variation in diagnosing each of these indicators.

The (WDI) measure of canal off-takes showed a general tendency of decreasing from head to tail of the Minors. As anticipated in a large scheme such as Rahad, the overall performance indicator of Minor off takes was inconsistent. Hence, future studies based on the index system of evaluation given in this study are needed for determining the efficiency of alternative systems and operating procedures and the effect of improvement measures or water saving strategies to be evaluated.

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