JOINT EVALUATION OF MAJOR 5 IN RAHAD SCHEME

By

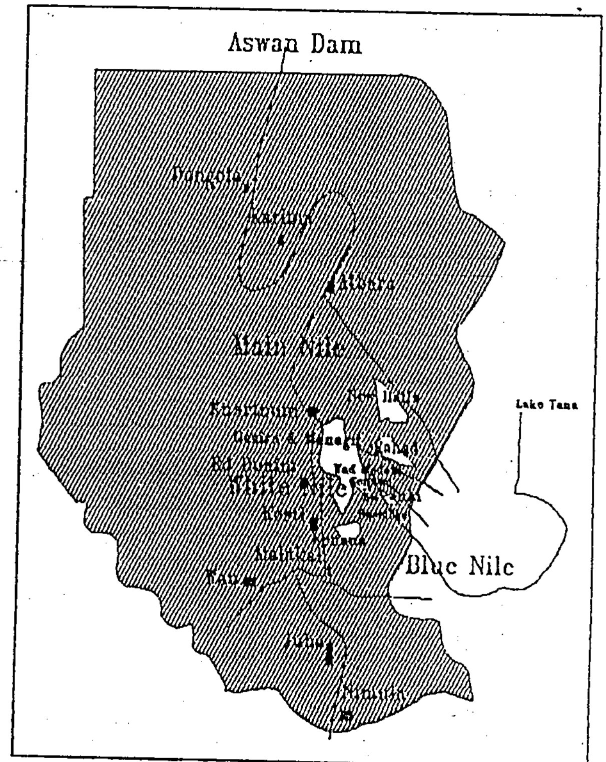
M. S. Shafique[1], Abdel Bagi A. Yousaf Elgam[2], Magdi E. Tawadrous[3]

I. Background:

1. Rahad Irrigation Scheme

As shown in Map 1., Rahad Irrigation Scheme lies in the southeast of Wad Medani town. The project area of the scheme is approximately 25 km wide and 160 km long. It is situated at the eastern bank of the Rahad river. The town of El Fau is the headquarters of the project which is about 280 km from Khartoum along Khartoum-Gedaref highway. There is another asphalt road, locally called as spine road, which runs through the command area of the scheme. This road makes most of the project area easily accessible.

The first phase of the Rahad Irrigation Scheme was completed in 1981. At present, the total command area is reported to be 126,000 ha (300,000 feddans). With the completion of second phase, the total area may increase to 344,400 ha (820,000 feddans). The soils of the project area similar to those of the Gezira Scheme i.e., very deep, cracking, self-mulching clays, with high water holding capacity but low permeability.



Map 1. Rahad and other main irrigation schemes of Sudan

2. Main Irrigation Infrastructure

The main irrigation water source for the scheme is the Blue Nile. About 200 km downstream of Roseires Dam, near the village of Meina on the Blue

[1] Head, Sudan Field Operations, IIMI

[2] Director, Rahad Irrigation Operations, MOI

[3] Research Coordinator, IIMI-Sudan

Nile river, the Meina pumping station is located. This pumping facility is considered to be one of the largest in the world. The 79 meter long superstructure of the station houses 11 pumps, each with a capacity of 9.55 m^3/second (337.20 $ft.^3$/second or cusecs), to lift a maximum discharge of 105 m^3/second (3707.6 cusecs) into a supply canal.

From the pumping station the supply canal, about 84 km in length, runs northwest toward the Dinder River where it passes under the bed of the river in an inverted siphon. It continues on to the Rahad river where it discharges at a point 7 km downstream of Mufaza town.

The Rahad river is the second source of irrigation supply to the project area. However, its supplies are seasonal in nature. The flow in the river starts from mid-July with flood period in late September and dries out by the end November.

One kilometer from the out-fall of the supply canal, there is the Rahad barrage located. It serves to regulate flow into the main Rahad canal. The barrage also functions to control seasonal discharges from the Rahad river to supplement the irrigation supplies pumped from the Blue Nile river.

The capacity of the main Rahad canal is 100 m^3/second (3531 cusecs). The main canal, about 101 km long, feeds 215 km of Major canals, 780 km of Minor canals, 350 km of Sub-secondary canals (Double Abu Ashreens), and 4,500 km of tertiary canals called Abu Ashreens (Abu XX). To deal with the drainage of the project, a network of 1140 km long drains is established.

There are 10 Majors (sub-main canals) including those with same numbers but letter A or B added to them. Major 5 is the middle sub-main selected for a joint evaluation by all parties concerned: Rahad Agricultural Corporation (RAC), Rahad Irrigation Operations (RIO) and the International Irrigation Management Institute (IIMI). The schematic layout of the Major is shown in the following display (Map 2).

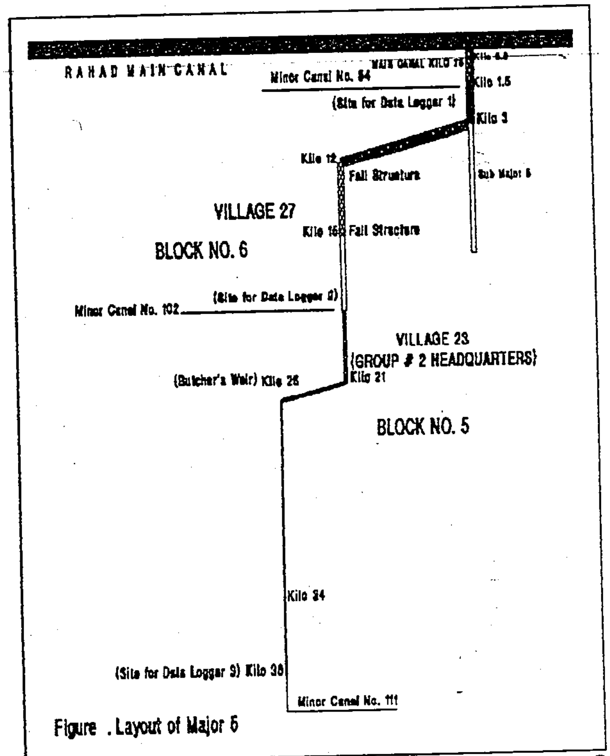


Figure . Layout of Major 5

Map 2. Schematic layout of Major 5 in Rahad Scheme

3. Nature of Research

IIMI initiated a research activity in the Rahad Irrigation Scheme in 1991. The research study entitled as " *Forces, Constraints and Interactions of Water Users, the Rahad Agricultural Corporation and the Ministry of irrigation in the* *operation and Maintenance of the Rahad Irrigation Scheme"* was aimed to achieve the following objectives:

(a) *To document the water indents, deliveries at Minor heads, and Abu Ashreens in the head, middle and tail sections of the Scheme.*

(b) *To document and understand the process by which water indents are determined by the Rahad Agricultural Corporation (RAC), and delivery responses to the indents by the Ministry of Irrigation (MOI).*

(c) *To evaluate the equity of water delivery among Abu Ashreens in the selected Minors.*

(d) *To document and understand water users response to water deliveries.*

The main principle of IIMI's strategy for its international field operations is to secure maximum involvement of relevant local agencies. In doing so, the Institute seeks to strengthen the national capacity in the field of irrigation management. Under this desirable setting, at IIMI we do acknowledge the important contributions of: (a) the Hydraulic Research Station (HRS) of MOI for taking leading role in the local calibration of irrigation control structures in the project area, and (b) the Department of the Rahad Irrigation Operations (RIO) & the Rahad Agricultural Corporation in extending full cooperation for undertaking the study.

The above stated objectives are important building blocks of an overall objective: *" to assist the relevant managing agencies and cultivators to field test practical tools for monitoring and assessing irrigation performance of the Rahad Irrigation System."* It is the context in which IIMI-Sudan has undertaken two *rapid appraisals of irrigation water distribution in Rahad.* On 3rd of November 1992, first such exercise was conducted for the field managers of the Rahad Agricultural Corporation (RAC). One day was spent in explaining the use of a manual for flow measurements (Shafique, 1992). On the following day, the managers collected data and quick analysis of the flow data about main, Major, Minor and field canals was then done to compare the findings with indents placed by RAC to MOI for the selected sub-system.

The second rapid appraisal exercise was designed for the staff of MOI responsible for irrigation operations in Rahad. Almost entire staff of the department, from director to section engineers, participated in this exercise held on 25 February 1993. The level of interest can be judged from the fact that the monitoring took place on a hot day in Ramadan and all the participants of the agency were fasting. On this day, the main canal (one control point only) and Major 5 (8 control points) were monitored.

This paper is based on the data collected by the staff of RAC on 3 November 1992 and officials of RIO / MOI on 25 February 1993. As the data collected represents only the performance of Major 5 on the above stated two days, IIMI's contribution of long term collected information about Major 5 makes the evaluation a meaningful "joint venture." IIMI's data collected on daily basis during the referred months will be used to support or suggest caution about the findings of the two rapid appraisals undertaken jointly with RAC and MOI.

The findings of the first exercise were discussed with members of IIMI's consultative committee in a meeting held at the end of November 1992. The members showed keen interest in the evaluation and acknowledged many opportunities identified for improvements.

The results of the second exercise were discussed with the participants of RIO on 3 March 1993 at headquarters of "El Ain" Subdivision in Village 23 of the Rahad Scheme. This gathering was aimed: (i) to share findings of the exercise with the officials, (ii) to interpret results, and (iii) to draw conclusions jointly. Next step will be to repeat similar exercise for monitoring the performance of the Minor and field canals.

Another very important party, which is also responsible for the management of the irrigated agriculture in the scheme, consists of farmers in the project. They have also been invited to undertake similar rapid appraisal of the system and then join with above mentioned managers of two agencies to analyze & interpret the existing irrigation performance. We hope that such joint efforts should help to develop and field test a package of improvements.

The main role of IIMI in these exercises was as follows: (i) to provide all the necessary support as an international neutral body to bring all the parties together, (ii) to help in developing consensus about the problems, and (iii) to present potential management innovations to be tried. We feel that such efforts were very rewarding for all the parties having stake in the scheme.

II. Literature Review

For this evaluation study, the review of literature will be limited to the following topics:

1. Concept of performance.

2. Design objectives.

3. Variables required in the control of a conveyance and distribution system of the Rahad scheme.

4. Performance indices which can use selected water control variables to determine the extent to which design objectives are achieved.

1. Concept of Performance

" Performance is the degree to which a system achieves its objectives. But objectives differ for individual systems and may be reset from time to time by a management decision. IIMI's concern is with absolute standards of performance, consistent definitions and measurements of components of performance, including productivity, equity, reliability, sustainability, profitability and quality of life (IIMI's Strategy for 1990s, fifth draft)." IIMI has opted this definition of performance as guideline in 1990s.

Abernethy (1989) has given following definition of performance:

" The performance of a system is represented by its measured levels of achievement in terms of one, or several, parameters which are chosen as indicators of system's goals."

Murray-hurst and Snellen (1991) have commented about the above definition (by Abernethy, 1989) as output oriented only. According to them the definition totally disregards the resources utilized, environmental impacts in achieving the level of outputs.

The definition given by Small and Svendsen (1992) does give due consideration to the points raised by Murray-hurst and Snellen (1991). This improved concept of performance is given as follows: "*Performance of a system as encompassing the totality of both its activities - inputs and the transformation of the inputs into intermediate and final outputs - and the effect of these activities on system itself and on its external environment.*"

Perhaps the definition of performance as given by Abernethy (1989) is simpler and more practical. The points raised and additions proposed could be considered an essential tools at the time of performance assessment i.e., to determine whether the performance results are acceptable or not. However, performance as such appears to be more an output oriented phenomenon.

In this study, the monitoring of performance is restricted to a portion of subsystem - physical component - of an irrigation system. As dictated by the data collected during two rapid appraisal exercises, focus is only on reporting the operating status of the sub-main conveyance and distribution system.

2. Design Objectives

In the context of water control, Johnstone (1926) states that the design of the Gezira scheme was based to meet the following conditions:

> *1. No field irrigation at night was possible.*
> *2. Disposal of water in excess of actual requirements was not possible after it had left the main canal.*
> *3. Under the terms of agreement, actual requirement of the cultivating syndicate had to be satisfied.*
> *4. Measurements of water under varying conditions and levels was necessary.*

Similarly Taj el Din et. al. (197-?) also state that the design of the operating system is to deliver required quantities of water at proper time at the farm level. In order to achieve such design objectives, the authors emphasize: "It was necessary for the Ministry of Agriculture and Irrigation (MOAI) to ensure that water delivered in the main canals (Gezira and Managil canals) at Sennar (dam serving the canals) is adequate for crop water requirements and the effective control of the water ensures that sufficient water is delivered at correct time to the cultivators."

The above referred literature clearly points out about two design objectives: (i) adequate water supply, and (ii) dependable / reliable water supply irrespective of time and location in the scheme. Also, additional emphasis is on the operational performance of the managing agency to ensure that the design objectives are being achieved.

Johnstone (1926) reports that the scheme was designed originally for continuous irrigation, however, at the time of construction the difficulty of irrigation was raised which made necessary to adopt night storage system. A report entitled as *Field Water management* (name of author missing) further elaborates as follows: " ... block inspector and his staff have to operate the regulators between the successive reaches in such a way that distribution to tenants from head to tail in the minor is as equitable as possible irrespective of their locations on the minor. The equitable distribution can be obtained by relative opening of the gates in the night-storage weirs and the (partial) opening or closing of the FOPs (field outlet pipes)." It is also quite clear that in order to have equitable water distribution at minor level, main and major canals have to supply equitable water supplies to these minor canals.

The above discussion helps to identify following design objectives:

(1) adequacy;
(2) dependability;
(3) equity; and
(4) effectiveness of operations to achieve adequate, dependable and equitable water distribution.

Variables for Water Control

In the context of Sudan, a number of variables can be selected. According to a report prepared by HR, Wallingford and HRS, Wad Medani (1991), some relevant variables could be as follows:

1. Indents prepared by an agricultural corporation.
2. Crop water requirements.
3. Authorized releases as documented by the Ministry of Irrigation (MOI).
4. Actual deliveries as monitored by researchers.

Depending upon the demand of a planned study, certain variables can be selected for deriving performance indicators. It will be always a real challenge for researchers to limit the number of variables but make maximum use of the ones selected.

Performance Indices

In order to establish the extent to which design objectives are being achieved, some of the above stated water control variables can be used to derive performance indices. First set of such indices is taken from a report produced by HR & HRS (1991) as given below:

"1. **Indent/Requirement Ratio (IRR):** a measure of the accuracy of the indenting process and the assessment of demand.

2. **Authorized release/indent Ratio (AIR):** a measure of the adjustment of the indents.

3. **Actual delivery/Authorize release Ratio (SAR):** a measure of performance of the distribution system.

4. **Management Delivery Ratio, Actual delivery / Requirement:** a measure of the performance of the whole process.

5. **Reliability:** the portion of the season that performance is acceptable. This equivalent to the probability that a given performance parameter lies within an acceptable range.

However, in the referred report there is no mention of any measure for an equitable water distribution. As a matter of fact, this aspect of water distribution was not considered by the authors of the report.

Kuper and Kijne (1992) and Molden and Gates (1990) have proposed following performance parameters for adequacy, dependability and equity as follows:

Adequacy: A fundamental objective of irrigation systems in Sudan is to deliver right amounts of water required to crops. To quantify the adequacy achieved, the authors have defined P_A as

$$P_A = \frac{1}{T}\sum_T (1/R \sum_R P_a) \quad ---(1a)$$

$$P_a = \frac{Q_d}{Q_r} \quad If \quad Q_d \leq Q_r ------(1B)$$

and

$$P_a = 1 \quad otherwise --------(1c)$$

Where $P_a = Q_d/Q_r$ is the ratio of water supply over water required. In the context of Sudan, the water required is the water indented by the field officials of parastatal agencies. The Equation 1 implies that Q_d and Q_r are defined for discrete locations where water is conveyed within a region R, and finite time intervals within period T.

Molden and Gates (1990) also proposed that P_a value more than 0.9 is assumed to be good, between 0.8 to 0.9 fair, and below 0.8 poor.

Dependability: The performance measure indicates the uniformity of Q_d/Q_r over time. A system which achieves almost steady state is considered dependable. The parameter for dependability is defined:

$$P_D = \frac{1}{R}\sum_R CV_T \left(\frac{Q_d}{Q_r}\right) -----(2)$$

In this case CV_T (Q_d/Q_r) is the temporal coefficient of variation of the ratio Q_d/Q_r over discrete locations in a region R, in a time span T.

Molden and Gate (1990) presented performance standard for P_D as given below:

P_D 0.0 to o.1 — good,
P_D 0.11 to 0.2 — fair, and
P_D over o.2 — unsatisfactory.

(The authors have used term poor instead of unsatisfactory).

Equity: As defined by Mohamed (1987), it indicates the ability of a system to uniformly deliver water. After Molden and gate (1990), Kuper and Kijne (1992) have suggested the following parameter for equity:

$$P_E = \frac{1}{T}\sum_T CV_R \left(\frac{Q_d}{Q_r}\right) ----(3)$$

where $CV_r(Q_d/Q_r)$ is the spatial coefficient of variation of the ratio of delivered water to the required amount (Q_d/Q_r). This coefficient variation is defined for a specific time T over a region R.

In this case also Molden and gate (1990) have proposed that performance should be taken good if equity parameter is between 0.0 to 0.1, fair if it falls between 0.1 and 0.2 and unsatisfactory if it exceeds 0.2.

In the context of Sudan, another parameter SIR, Supply Indent Ratio, is proposed by Shafique (1992) and Shafique et. al (1993). For day to day operational management, SIR seems more convenient and practical measure. It can be derived at the spot without too many calculations. This parameter indicates how well the indents placed by one agency, RAC in case of Rahad, are matched or responded by say RIO / MOI. Perhaps this indicator can also be used for better management of interface between two or more managing agencies responsible for irrigation schemes.

For equitable water distribution, it is not essential to have adequate water supplies. Pakistan's irrigation system, for example, is not designed to deliver adequate supplies but still it aims for an equitable water distribution.

If equity is a main concern then a new concept based on relative water ratio (RSR) is proposed (Shafique, 1993). This requires to have in denominator the total available water per unit area (say per ha) for the entire selected system and similar information about canal segments in the numerator.

III. Methodology:

The Rapid Appraisal #2 (RA2), findings of which are used as basis for the interpretation of different data sets about Major 5, took place on 25 February 1993. The RIO- staff in cooperation with IIMI-Sudan, selected 9 control structures at the following points in the scheme: (i) Kilo 76 of the Main Rahad Canal, and (ii) Kilo 0.0, Kilo 1.5, Kilo 3.5, Kilo 12, Kilo 15, Kilo 18, Kilo 21, and Kilo 26 of Major 5. The main reason for the selection was that these control structures were calibrated by a specialized agency of the Ministry of Irrigation: the Hydraulic Research Station (HRS).

At all the selected points, there were 8 sluice gates and one Butcher's Weir installed for controlling flows. They all are in good condition. After the referred calibration, these control structures are also being used by IIMI as flow measuring devices. In close cooperation with HRS, IIMI facilitated to paint gauges to read directly gate openings. Similarly, at the gated control points upstream and downstream gauges were installed to determined head across the structures. Such existing arrangements did facilitate the job of Rapid Appraisal of irrigation water distribution in the selected part of the Rahad System.

The data collection started from Kilo 0.0 and ended at Kilo 26 of Major 5. At certain points where either the upstream and downstream gauges were stolen, a survey level was used to find out head across the sluice gates. As a matter of fact, the necessity to use the survey instrument also helped to correct certain bench mark errors which perhaps existed from the start of the scheme. This can be taken a side benefit of the exercise. The manager of the RIO immediately instructed the gauge readers to use new correct reference for recording hourly water levels at Kilo 76 of the main canal and the head of Major 5.

The irrigation staff were provided a manual for flow measurements based on field calibration conducted in 1991. This document helped the officials to know the status of irrigation water supplies along the Major 5 immediately. As the assistant divisional engineer of El Ain Subdivision, Major 5 is a part of the administrative unit, was also a member of the team, information about indents was readily available for comparison purposes.

The Rapid Appraisal #1 (RA1) was conducted with RAC-staff on 2 & 3 November 1992. All the above stated facilities helped the staff to get the first hand experience about the performance of one of their sub-main canal, Major 5. As the officials of RAC were also interested to monitor secondary canals (Minors) and tertiary channels (Abu Ashreens), to save time some control points such as those located at Kilo 3.5 and 15 were not monitored. The information collected during RA1 pertaining to Major 5 serves as second source for the evaluation.

IIMI-Sudan has also monitored last two irrigation seasons: 1991-92 & 1992-93. As the referred two appraisals only describe the status of performance on two particular days, "long-term" support comes from IIMI-Sudan's contribution in this context. This data-support concerns to the months in which the rapid appraisals were conducted: February and November 1992.

As almost all the irrigation systems in Sudan are designed for an adequate, dependable and equitable water supplies, the main aim of the rapid appraisals and other IIMI's related efforts was to evaluate if the design objectives were being realized. The data collection for the performance of the water distribution was shaped by the above stated design considerations.

Like in any country, the field managers of irrigated agriculture in Sudan also need simple and practical means and indices to have quick and cost-effective evaluation of their managed system. For daily canal operations, indices which need very little effort to have real potential for their best and regular use in the field. In authors' view the supply-indent ratio (SIR) is one such index. As the use of the ratio, SIR, to explain the performance of Major 5 was found practical, the same index will be used for this joint evaluation.

In spite of many reservations about the validity of practices related to irrigation water indenting (RAC's job) and acting in response (RIO's duty), the fact still remains that at present the indents are the quantities of water demanded at different points and water reaching to these points is the actual water delivered. One can also say that water demanded should be as determined by crop-water requirements and response as provided by authorized supplies. However, in a surface irrigation system the crop-water requirements, calculated using well known empirical relationships, represent mere part not entire irrigation demand. Similarly, the authorized supply may not be the same as actual water delivered to a point. In this context also, the supply-indent ratio (SIR) was adopted.

According to the above stated reasons, SIR was also used in Eqs. 1 to 3. This may not be exactly the same as reported by Kuper and Jackob (1992) and Molden and Gates (1990). However, the adaptation in the context of Sudan is useful as it makes the evaluation task easier. On the other hand, the evaluation-criteria used by the referred authors will be applied as such to categorize the performance of Major 5.

VI. Data Analysis:

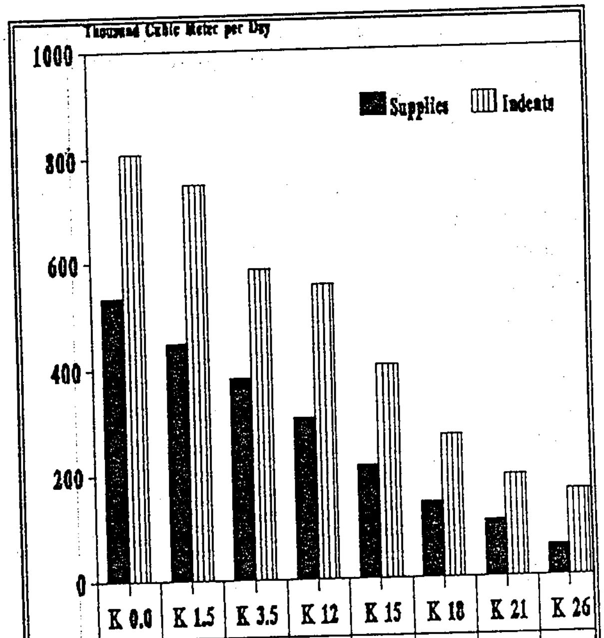
The analysis of the data collected is presented in Figures 1 through 8. As there are four different data sets, the figures follow the following scheme:

	Data Set No.	Figures No.
(i)	RA2 (Feb.25, 93)	1 to 8
(ii)	IIMI (Feb. 92)	1-a to 8-a
(iii)	RA1 (Nov.3, 92)	1-b to 8-b
(iv)	IIMI (Nov. 92)	1-c to 8-c

The data analysis will comprise of the following sub-headings: (a) Data Presentation and interpretation, (b) Ideas for Operating Systems for an adequate, Dependable and Equitable Water Distribution, (c) Comparison of Actual versus Projected Supplies, and (d) Status of Irrigation Performance. Wherever possible, responses of RIO-staff to the findings of RA2 are added. This insight was provided by the field staff on 3 March 1993 in response to the presentation of the RA2-findings.

Data Presentation & Interpretation:

Figure 1. shows a comparison of irrigation indents placed by RAC and supplies made available by RIO / MOI along Major 5 on 25 February 1993. For the purpose of interpretation and discussion, following questions were asked:



	K 0.0	K 1.5	K 3.5	K 12	K 15	K 18	K 21	K 26
Supplies	535	448	380	307	214	141	105	56
Indents	810	750	585	555	405	270	190	160

Fig. 1. Supplies & Indents along Major 5

(1) *The indents placed by the Rahad Agricultural Corporation (RAC) for Major 5 at each control point are drastically more than delivery responses determined by the officials of MOI of Rahad. What are the factors which cause such mismatch?*

(2) *In your opinion, what is the real use of placing or receiving indents on regular basis? Are there doubts about such requests to be irrelevant? How can such an existing institutional arrangement be utilized effectively?*

(3) *If the preparation of indents is a practice with no practical use, should not it be better to eliminate it?*

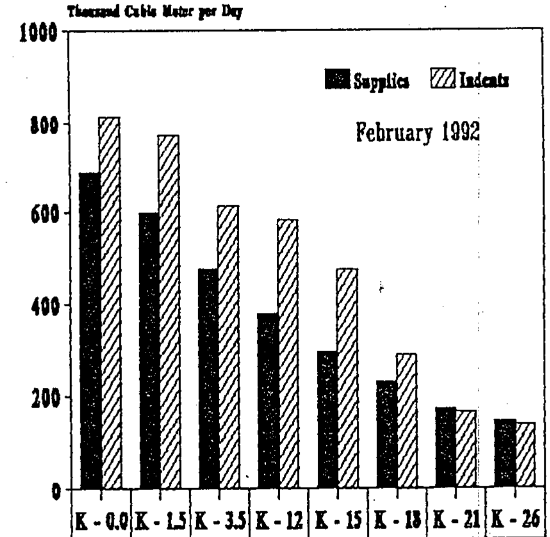
(4) *What are conscious efforts (if any) made to bridge the wide difference between supply and demand?*

(5) *If there have been no efforts to bridge the gap, do you have suggestions to remedy the situation?*

(6) *Under the new extended role of MOI for delivering irrigation water to the level of field*

outlet pipe (FOP), how will it help to address concerns regarding water distribution in the scheme?

As the above questions are based on only one day's data, it seems appropriate to present the monthly averages of February 1992 at various control points of the canal. Figure 1-a displays the data showing the similar trend but not too drastic as was the situation on the day of RA2.



	K - 0.0	K - 1.5	K - 3.5	K - 12	K - 15	K - 18	K - 21	K - 26
Supplies	689	598	475	380	297	228	173	145
Indents	816	773	614	582	474	288	167	139

Control Points (CP) of Major 5 in Rahad

Fig. 1-a. CP-wise monthly average supplies and indents

The above monthly average data almost confirm the validity of RA exercise. Perhaps it is appropriate now to summarize the response from RIO staff to the findings as below:

(1) *Drastic difference between demand and supply resulted partly an incorrect reduced level used to determine head differences across the first gated structure for Major 5.*

(2) *The block inspectors of the scheme place indents which are more than required. According to the RIO staff, the RAC officials think that MOI always delivers less than demanded and hence they try to indent maximum.*

(3) *The current procedure being used to determine indents needs to be revised. However, the practice is a useful institutional arrangement and it should not be eliminated.*

(4) *In order to overcome difficulties caused due to canal siltation and the dynamic nature of crop water requirements, indents should be placed daily. If indented amount stays constant, the RIO will assume that supplies are sufficient. If the daily suggested requests change, then supplies can be adjusted accordingly.*

(5) *The extension of RIO / MOI's role to FOP-level is expected to ensure supplies for intended Abu Ashreens only. This will also help to evaluate increases in demand with the design capacities of different channels.*

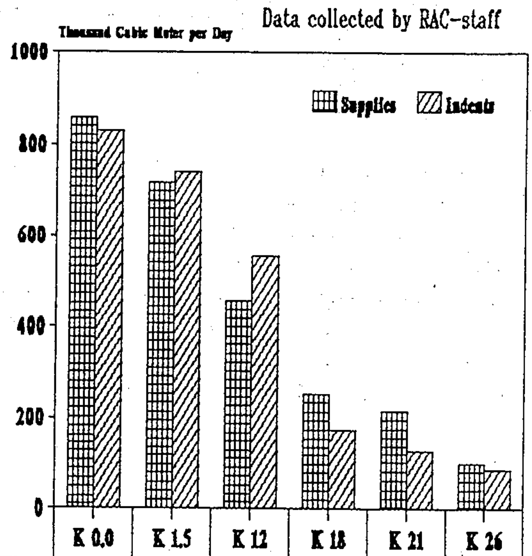
(6) *An interesting response about the adequate water supplies was based on the argument that no planted areas had been abandoned in Rahad as it happened for some other schemes in Sudan.*

Perhaps the RAC officials may like to argue over some of the responses given above. However, the responses merit due consideration in the process of explaining the water distribution in the Rahad Scheme. At the same time, there may more views and reasons to be added in this list.

Again, the above information is only for a particular period of an irrigation season. End of February is almost end of an irrigation season. Crops of ground-nuts and sorghum are already harvested. Cotton is also not a serious candidate for irrigation in this period. At this time, wheat is the only crop out in the field requiring irrigation. In this context, it is important to present data for a period when requirements are at peak or near to it.

For relatively higher demand, November could be considered as second period for comparison. Perhaps October would have even better, but RA1 was conducted a few days after the month and hence the choice resulted as the next to an ideal period. Figure 1-b provides information about the indents and supplies documented on 3 Nov. 92. In view of the fact that the figures only displays requests and corresponding responses of two concerned agencies on one day only, the Fig. 1-c is presented to look at monthly average of November 1992.

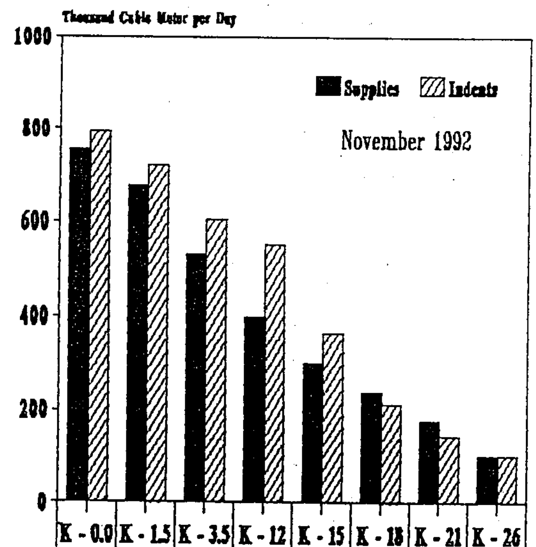
Figures 1-b and 1-c also show a close relationship between the findings of RA1 and average indents and supplies for entire November 1992. However, Fig. 1-b shows supply little more at head whereas Fig. 1-c depicts a slightly reverse case. At the next 3-4 control points (CPs), supplies are relatively lesser than indents. Again in both cases, the rest of tail CPs have supplies edging over indents. It obvious that at CP-basis the supplies and indents match better than those observed in February 1992 and 1993.



	K 0.0	K 1.5	K 12	K 18	K 21	K 26
Supplies	860	716	458	252	216	99
Indents	838	740	555	175	125	85

Control Points of Major 5 in Rahad

Fig. 1-b. CP-wise supplies & indents monitored on 3 Nov. 92



	K - 0.0	K - 1.5	K - 3.5	K - 12	K - 15	K - 18	K - 21	K - 26
Supplies	755	675	530	398	301	238	178	98
Indents	794	721	605	550	367	212	146	108

Control Points (CP) of Major 5 in Rahad

Fig. 1-c. CP-wise monthly average supplies and indents

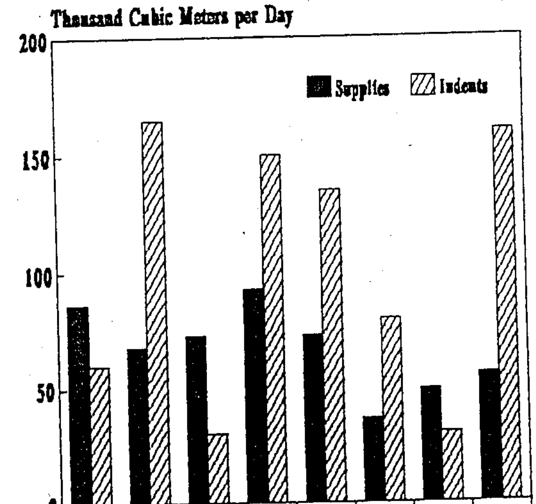
From the above presentation, there is an important observation to make about indents placed and supplies made available at two different stages of an irrigation season. In February, according to Figs. 1 & 1a the indents placed at the head of Major 5 are almost same to the ones concerning November as per Figs. 1b & 1c. Obviously, it is not very logical when crops and stage of an irrigation is considered. On the hand, even though supplies are also erratic but they are more in November as compared to the ones in February. Perhaps Response #2 explains the anomaly to some extent.

In order to share and improve understanding about the water distribution along Major 5, the attention of the RIO officials was drawn to second graphic presentation i.e., Fig. 2. The information about supplies and indents given in this figure is extracted from Fig. 1 and transformed according to each reach.

The concept reach is defined here as a stretch of a canal between two control points. As defined, Major 5 has following reaches:

R - 1 = K 0.0 to K 1.5
R - 2 = K 1.5 to K 3.5
R - 3 = K 3.5 to K 12
R - 4 = K 12 to K 15
R - 4 = K 15 to K 18
R - 6 = K 18 to K 21
R - 7 = K 21 to K 26
R - 8 = K 26 to K 38

By deducting the supplies and indents for each reach were determined by deducting supplies / indents at downstream control point of a reach from those monitored / reported at the upstream of the same reach. Fig.2 depicts reach-wise supplies and indents. All of a sudden, the distribution appears inconsistent.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
Supplies	87	68	73	93	73	36	49	56
Indents	60	165	30	150	135	80	30	160

Fig. 2. Reach-wise Supplies and Indents

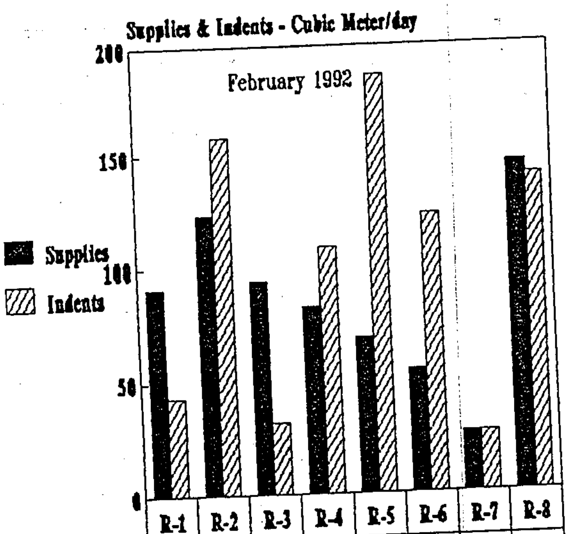
In view of the data displayed in Fig. 2, following questions were asked from RIO officials:

(1) *Fig. 1 shows a drastic difference between indents placed and supplies provided along each control point of Major 5 i.e., more quantities requested and low delivery responses. However, the reach-wise data presentation in Fig. 2 provides very erratic distribution. Reach Nos. 1, 3, & 7 are receiving more than amount indented. On the other hand, situation for the rest of the reaches is quite opposite. Why is it so?*

(2) *Do we make distinction between under and over supplies resulting on reach-basis and under and over supplies according to control points?*

(3) *Do we need to look at each individual reach? There are certain reaches which have more direct Double Abu Ashreens (D.A.XXs), Abu Ashreens (A.XXs) than Minors as compared to an opposite situation. It would also be important to discuss head-tail syndrome in this context.*

Before reporting the responses from the RIO officials, it seems proper to see if the distribution was a mere incident or a normal event. Figure 2-a provides average such reach-wise distribution for an entire month: February 1992. Ignoring slight changes, the display confirms the reach-wise erratic distribution established by RA2.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
Supplies	91	123	94	83	69	54	27	145
Indents	43	158	32	108	186	122	27	139

Reaches of Major 5 in Rahad

Fig. 2-a. Monthly average supplies & indents

Coming back to the referred response, the RIO-officials were a little bit surprised and taken aback. They did acknowledge the points raised. However, additional reasons for the depicted irregular water distribution were as follows:

(1) *Guards (Gaffirs) of control structures do contribute to this problem of inequitable water distribution. However, they do it in response to complaints from tails-sections of different Minor canals.*

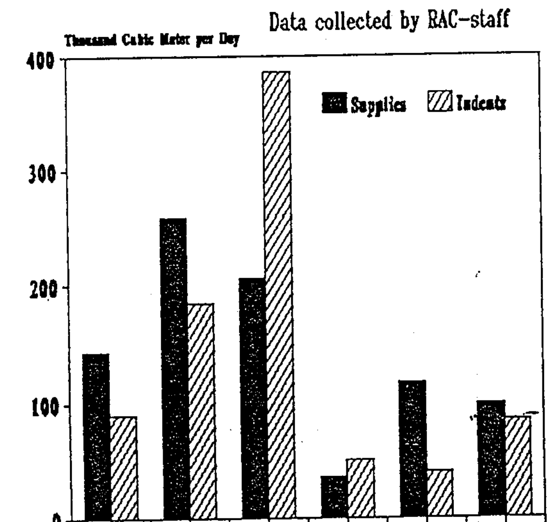
(2) *Changes in the water levels of main canal also contribute their share.*

(3) *Double gated Minor canals also have a potential to receive more water.*

The above factors may contributes some inequity or inconsistency but they definitely do not tell the whole story. Fact remains that the water distribution is very much off. The system needs to be monitored regularly for making and implementing appropriate decisions to deliver adequate, dependable and equitable supplies.

In order to establish the distribution over the season, additional information about November is presented in Figs. 2b and 2c. As can be seen, the situation is equally unsatisfactory if not worse.

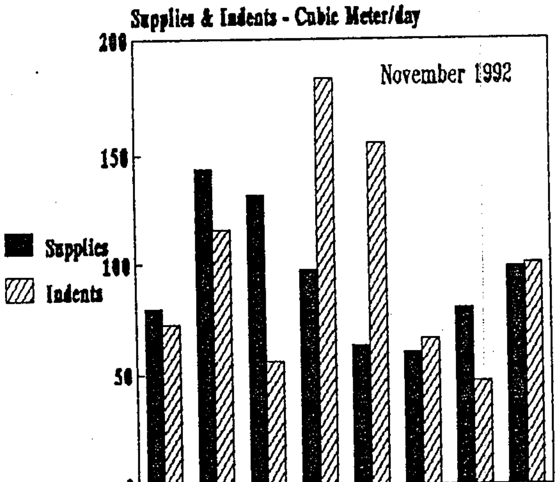
The above abnormal happening stays almost hidden when the bits of data monitored are arranged according to control points. In this case, information at each control point represent an average value for all the other points on the downstream of it. Such a "lump-summing" occurrence camouflage many ups and downs in the water distribution which might have happened in individual cases.



	R-1	R-(2+3)	R-(4+5)	R-6	R-7	R-8
Supplies	144	258	206	36	117	99
Indents	90	185	386	58	40	85

Reaches of Major 5 in Rahad

Fig. 2-b. Reach-wise supplies and indents on 3 Nov. 92

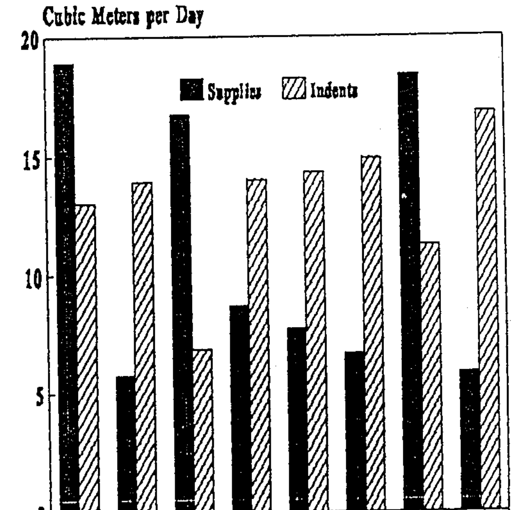


	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
Supplies	80	144	132	97	63	60	80	98
Indents	73	116	56	183	155	66	46	100

Reaches of Major 5 in Rahad

Fig. 2-c. Monthly average supplies & indents / day

For further discussion on the distorted water distributions, Fig. 3 is presented here to show the differences in indents and supplies per feddan of reach-command areas.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
Supplies	18.92	5.76	16.74	8.7	7.75	6.71	18.39	5.89
Indents	13.05	13.97	6.88	14.03	14.33	14.92	11.26	16.84

Fig. 3. Reach-wise Qs & Qi per Feddan

The unit reach-wise supplies and indents are derived using the following individual command areas (ha / feddans):

R – 1 = 1932 / 4599
R – 2 = 4960 / 11809
R – 3 = 1832 / 4361
R – 4 = 4492 / 10695
R – 5 = 3956 / 9418
R – 6 = 2252 / 5362
R – 7 = 1119 / 2664
R – 8 = 3990 / 9501

As the contribution of each reach toward overall distribution may vary according to the respective service areas, percent share is easy to visualize. So, Fig. "Reach-wise command areas" is a graphic presentation of percent share of each reach of Major 5.

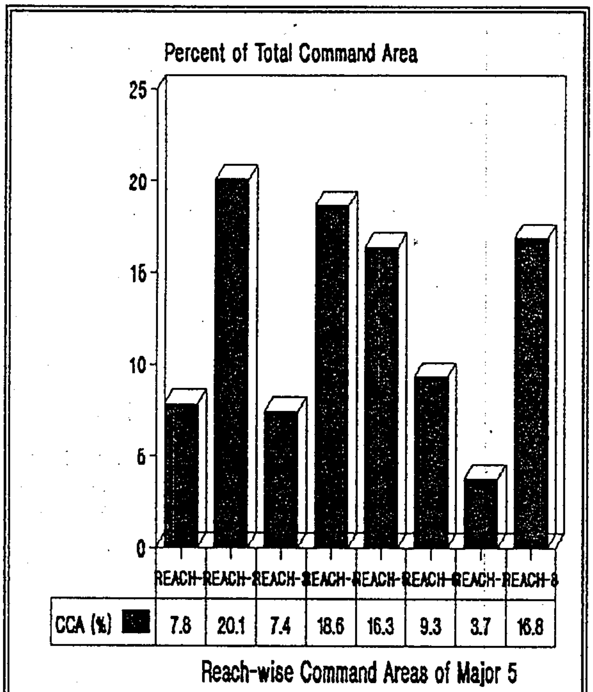


Fig. "Reach-wise command areas"

The reach-wise indents and supplies as shown in Fig. 3 were calculated by dividing the command areas of reaches as given above.

From the information presented above, it can be noticed that maximum supplies per unit command area were found in case of Reach Nos. 1, 3, and 7 having total command less than 20 percent. However, respective normalized supplies for rest of the reaches (area more than 80 percent) ranged half to one third of the above stated "lucky" reaches. Similarly when we look at the indents per unit command area of each reach, except Reach No.3 the indents per feddan are within a narrow range. Some difference might have resulted because of some difference in the ratios of cropped areas to the commanded areas of different reaches.

For the data interpretation, following questions were asked:

(1) Why the supplies/feddan of Reach Nos. 1, 3, and 7 are two or three times as compared to the rest.

(2) Why the indent per unit command area is very low in case of Reach No. 3 ?

In line with adopted scheme of data presentation, again it is appropriate to provide long-term support to the findings. Monthly averages of supplies and indents per feddan are presented in Fig. 3-a. It verifies the pattern identified by RA2 exercise.

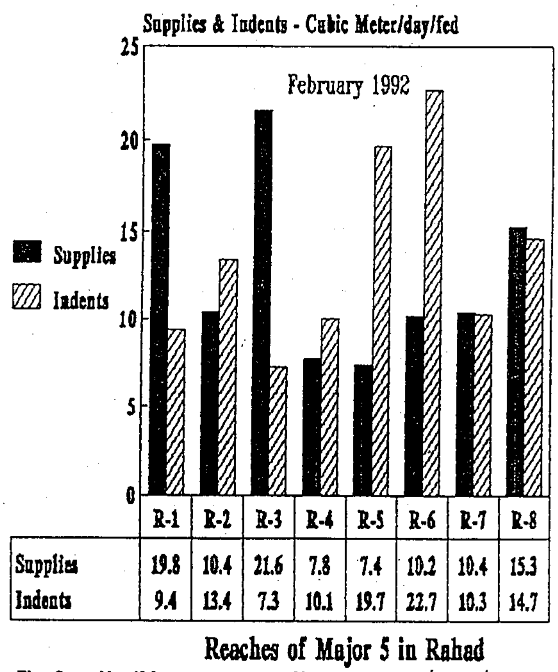


Fig. 3-a. Monthly average supplies & indents / day / feddan

Back to RIO-response, it was recognized that a drastic discrepancy existed among reaches. The most significant outcome of the RA exercise was the fact the RIO staff showed courage to confront by accepting its very existence.

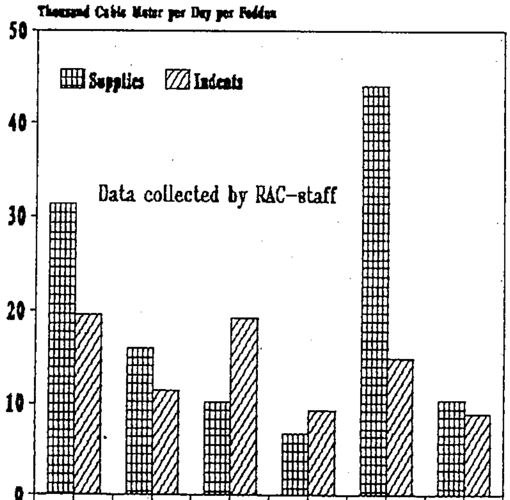
In addition to the obvious opportunities for improving the canal operational practices, following other contributing factors were also mentioned:

(1) *In case of Reach 1, its location at the head-end was considered to be an important factor. Also, the head Minor is the only Minor of Major 5 with two gates. Excess supplies can also result due to the operation of such unique structure.*

(2) *Reach 3 has a unique feature: it has more direct double Abu Ashreens from Major 5. As the operations of such canals at this time are not strictly controlled, farmers are getting more share of water supplies as compared to the rest. Additional factor in such commands is the presence of influential farmers with a flexible cropping pattern. As the RAC is not responsible for the operations of such direct field canals, the indents placed are generally low - call it a " futile step-treatment."*

(3) *Reach 7 has also more direct Abu Ashreens and Double Abu Ashreens and shares the same fortunate features as described for Reach 3.*

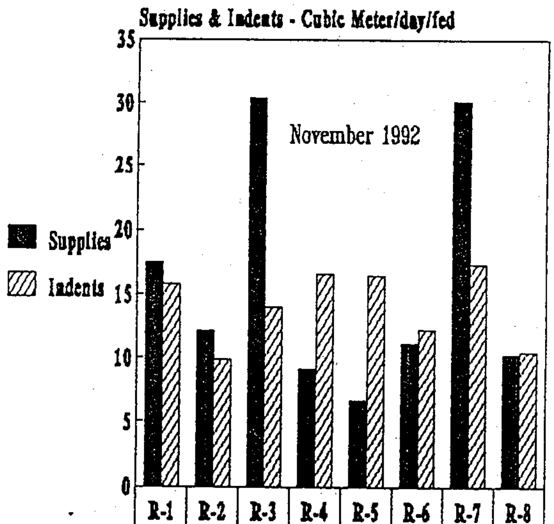
In order to generalize, similar data for November is provided in Figs. 3-b and 3-c. First display is about the data collected on 3 November 1992 by RAC staff. Based on data collected by IIMI-Sudan, second presentation gives monthly averages of unit supplies and indents. As clear from the figures, "lucky" and "unlucky" reaches are almost same and they refuse to trade places.



	R-1	R-(2+3)	R-(4+5)	R-6	R-7	R-8
Supplies	31.28	15.98	10.24	6.64	43.98	10.42
Indents	19.57	11.44	19.19	9.32	15.02	8.95

Reaches of Major 5 in Rahad

Fig. 3-b. Reach-wise supplies and indents on 3 Nov. 92



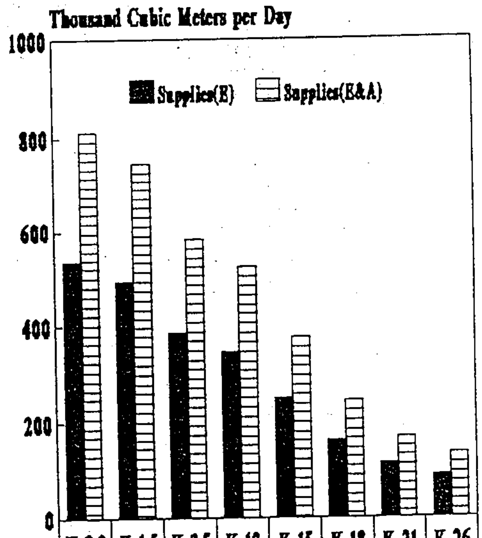
	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
Supplies	17.48	12.21	30.35	9.08	6.65	11.15	30.13	10.33
Indents	15.83	9.81	14.03	16.59	16.46	12.23	17.34	10.5

Reaches of Major 5 in Rahad

Fig. 3-c. Monthly average supplies & indents / day / feddan

Ideas for Operating System for an Equitable and Adequate Water Distribution (based on RA2 data only):

Like many other irrigation systems in Sudan, the Rahad System is also designed for an adequate, dependable and equitable water distribution irrespective of time and location considerations. Even if the supplies are not adequate as compared to the ones requested / indented, for example on 25 February 1993, one can still operate the system such a way to achieve an equitable water distribution based on an agreed criterion. If we agree to an equitable water distribution on command area basis, the supply received at the head of a canal be divided by its total command area and then calculations can be made for respective supplies at each control point down the line. Similar exercise can also be repeated for adequate and equitable water supplies by assuming that indents indicate the total irrigation water requirements. If so, then projected adequate and equitable supplies for Major 5 will result as shown in Fig. 4.



	K 0.0	K 1.5	K 3.5	K 12	K 15	K 18	K 21	K 26
Supplies(E)	535	493	385	345	247	161	111	87
Supplies(E&A)	810	746	582	522	374	243	169	132

Fig. 4. Projected Water Supplies

In the context of Fig. 4. following questions are for discussion:

(1) *In order to distribute the projected supplies, how should we proceed?*

(2) *What kind of facilities do we need for implementing the potential options for equitable or equitable and adequate (as defined above) water distribution?*

The above approach may not be applicable in those environments where cropping pattern is not fixed. In such cases, perhaps crop-based estimates for adequate and equitable water distribution can be considered.

The response to these questions resulted into a brainstorming exercise. A summary of views expressed is given below:

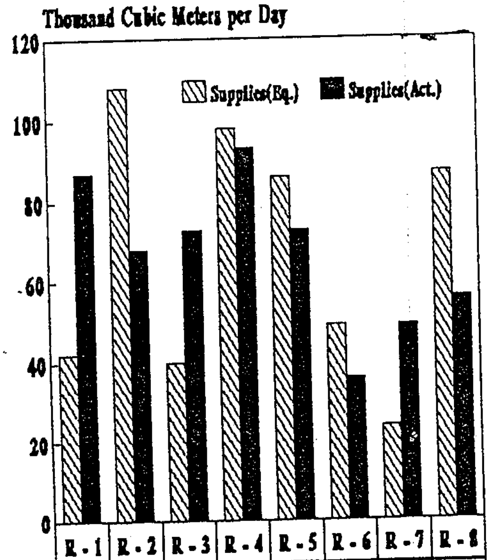
(1) *Using the "Decision Support Manual for Flow Measurements (Shafique, 1992), the weirs and gates can be set or adjusted to match the projected supplies. In case of gate-structures, gate openings may have to be readjusted when water levels on upstream and downstream stabilize. However, gate setting will have dominating effect as compared to changes in the operating head across a structure.*

For delivering pre-determined supplies at different control points along Major 5 will *require close monitoring and adjustments of Minors and other direct canals. Such a simple methodology, if agreed, is recommended to be tested for a selected Major in Rahad Scheme.*

(2) *For pilot testing the suggested operational scheme, improved communication system such as "walkie-Talky hardware" will be of immense help.*

Comparison of Actual versus Projected Supplies (based on RA2-data only):

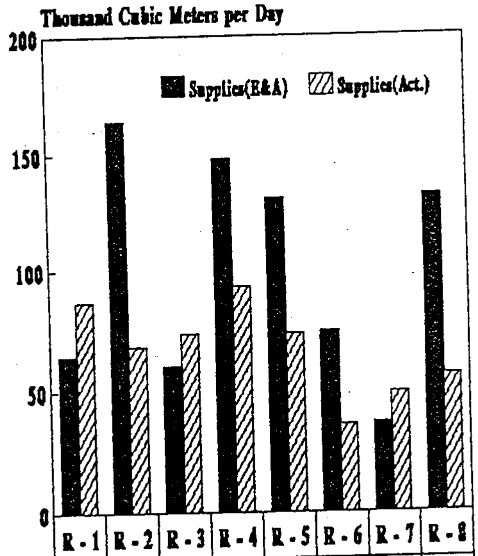
Fig. 5 presents almost similar information as shown in case of Fig. 4. However, the latter is intended to show differences in actual supplies as compared to the ones projected for an equitable



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
Supplies(Eq.)	42	108	40	98	86	49	24	87
Supplies(Act.)	87	68	73	93	73	36	49	56

Fig. 5. Projected (E) & Actual Supplies

water supplies of different reaches of the Major 5. Similarly, Fig. 6. presents a comparison between actual and equitable & adequate water supplies for different reaches. One has to note that in either case, actual supplies in case of Reach Nos. 1, 3, and 7 are still higher than projected supplies. Naturally such phenomenon should effect others reaches adversely under short supply situation as monitored on 25 February 1993.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
Supplies(E&A)	64	164	60	148	131	74	37	132
Supplies(Act.)	87	68	73	93	73	36	49	56

Fig. 6. Projected (E&A) & Act. Supplies

In this context, the discussion was focussed around following questions:

(1) *What makes Reach Nos. 1, 3, and 7 so lucky ? Is it a mere chance or there are some other factors which favor this situation?*

(2) *How can appropriate management decisions help to distribute this abundance of luck to relatively unlucky reaches of the same system equitably?*

In response to the above questions, similar factors were narrated as before. It was hoped that pilot testing of new methodology for canal operations should minimize difference between the referred reaches of Major 5.

Status of Irrigation Performance:

Irrigation performance has been evaluated in relation with the three design criteria stated earlier: adequacy, dependability and equity. Following Molden and Gates (1990) and Kuper and Kijne (1992), the three parameters for Major 5 were derived as described in the next section.

Modified Adequacy Parameter

The concept of adequacy is to deliver the required amount of water over the command area of a system such as Major 5. In the local setting of Sudan, indents are perceived to be required amounts. If it is accepted that the indents do represent water requirements, the adequacy index can be defined as supply-indent ratio or SIR. With this explanation in mind, a measure of performance in terms of adequacy can be modified as follows:

$$P_A = \frac{1}{T}\sum_T \left(\frac{1}{R}\sum_R P_a\right) \text{--}(4a)$$

$$P_a = \frac{Q_S}{Q_I} \text{ if } Q_S \leq Q_I \text{--}(4b)$$

$$P_a = 1 \text{ if } Q_S \geq Q_I \text{---}(4c)$$

Where in the above equations, Q_s / Q_I (SIR) is ratio of water supplied in response to water indented. Here Q_s and Q_I are defined for discrete locations n within a region R and for finite time-intervals t over a period T. Overall measure is denoted by P_A and individual measures as P_a.

Before deriving P_A, it is also important to assess adequacy by using SIR. Such a discussion will also help to interpret differences in the values of adequacy provided by SIR and P_A. After all, SIR serves as input to derive P_A. In a case, however, if SIR for all reaches or control points is less than 1, SIR will be same as P_A.

Figs. 7 & 8 provide information about supply-indent ratios (SIRs) concerning to Major 5 on 25 February 1992 (RA2). Fig. 7. presents these ratios for all control points of Major 5. It is interesting to note that the range of SIRs was 0.35 to 0.66. This implies that supplies were all the way less than what was indented at each control point along the system. In this case using Eqs. 1a, 1b, and 1c, P_A is found as 0.55 (same as average SIR). This should be evaluated with tentatively suggested standard of performance by Molden and Gates (1990). The authors describe that P_A value of more than 0.9 is assumed to be good, between .9 and .8 fair, and below .8 poor. This implies an unsatisfactory value in terms of adequate water supplies.

However, the Fig. 8 demonstrates that even under short-supply situation, the command areas of some reaches get supplies more than what was indented. In this case, reach-wise SIRs range 0.35 to 2.43 with aa average of 0.99. Here again it can be observed that "lucky" reaches are doing much better than others - perhaps at the expense of others.

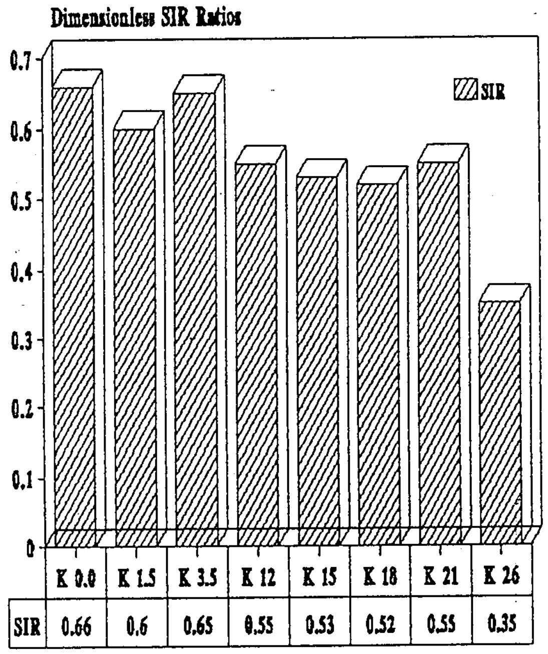


Fig. 7. SIRs at Control Points

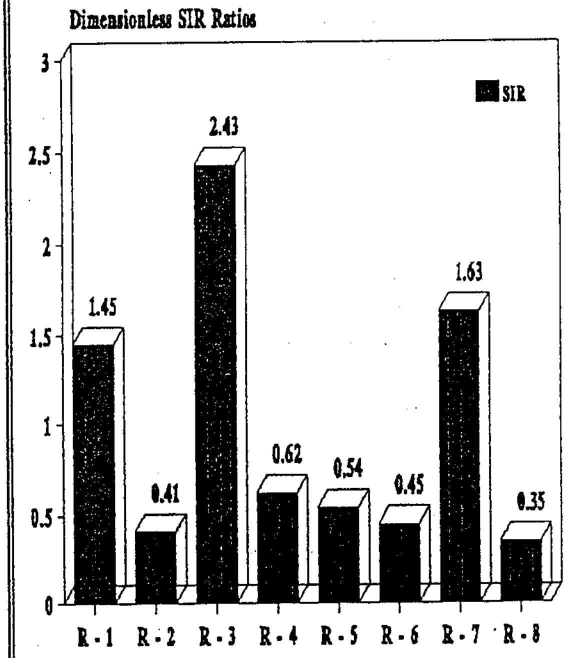


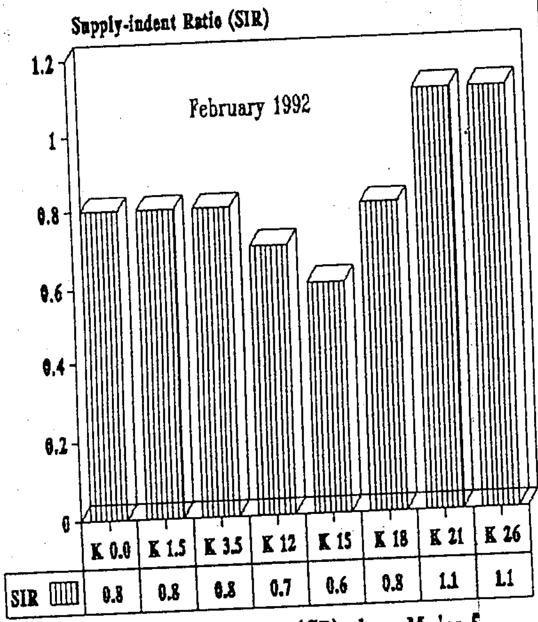
Fig. 8. Actual Reach-wise SIRs for Major

P_A for reach-wise case comes to 0.67 (area based on weighted average is 0.58). Either case, the chosen index shows that the performance falls well below 0.8. It also indicates that the system which was designed for an adequate water supplies was not performing well on the day it was monitored.

Again the example quoted above only represent one particular day. It seems appropriate, as was done earlier, to provide more data before giving any general state about the status of adequacy in the system.

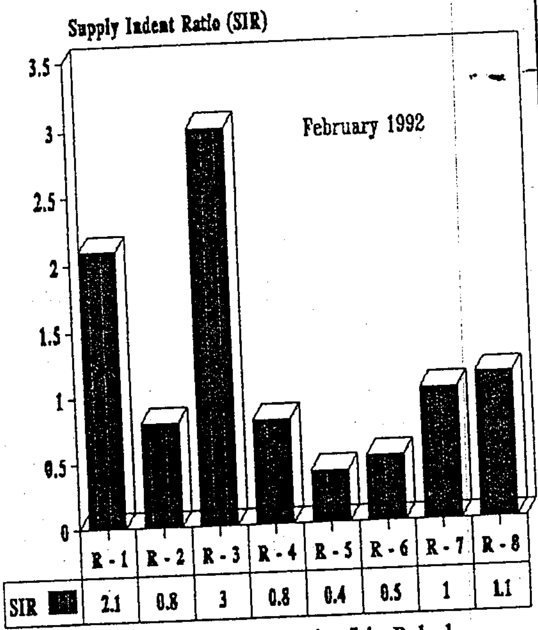
Monthly average values of SIR in February 1992 are exhibited in Fig. 7-a. The resulting CP-based ratios range 0.6 to 1.1 with an arithmetic average of 0.84. Equations 4a to 4c define P_A. The parameter on Cp-basis is 0.79. This indicates in response to water requested, water supplies were marginally fair. However, it does not tell if the crop water requirements were adequately met or not. In this context, one can remind that water requests from RAC to RIO / MOI hardly changed in February when compared with those placed in November.

Figure 8-a shows the same monthly average data but treated for water distribution at reach-basis. Here average SIR comes equal to 1.2. However, simple average and weighted average values of P_A are found to be 0.75 and 0.79 respectively. The difference between SIR and P_A is due to over-supply to certain reaches in this system. Such an excessive supply either causes ponded conditions at the farm level and / or often finds its way back to river through a network of drains. It should be, however, noted that the drainage system is not designed for such function at first place.



Control Points (CP) along Major 5

Fig. 7-a. Average CP-wise supply-indent ratios



Reaches of Major 5 in Rahad

Fig. 8-a. Average reach-wise supply-indent ratios

The second set of data concerns to November 1992. This month was chosen to represent a period of relatively higher crop water requirements and more crops in the field (On the lower demand side, monitoring results of February have already been discussed).

Figures 7-b and 8-b are based on data collected by RAC-staff on 3 November 1992 (RA1). The first figure shows water distribution according to control points and second one displays on reach-basis.

According to CP-distribution, an average Sir value is 1.2. As period T in this case is 1, performance parameter P_A comes 0.97 showing good distribution in terms of adequacy.

Water distribution based on reaches (Fig. 8-b) gives an average value of SIR as 1.39 (weighted average being 1.09). For a period of one day, P_A is found to be 0.87 which means highly fair supply in response to indents placed.

As RA1 presents data for one day in November, Figs. 7-c and 8-c are produced to display monthly average information for the month. CP-analysis based on SIR is given in Fig. 7-c and reach-wise distribution is provided in Fig. 8-c.

According to CP-data, an average value of SIR is 1 as compared to P_A being 0.89. There is very slight difference when similar analysis is repeated for individual reaches of the Major. The resulting average SIR and P_A are 0.99 and 0.86 respectively. Weighted averages are also very similar to the above values. This supports the findings of Ra1 which show highly fair adequacy level in November 1992.

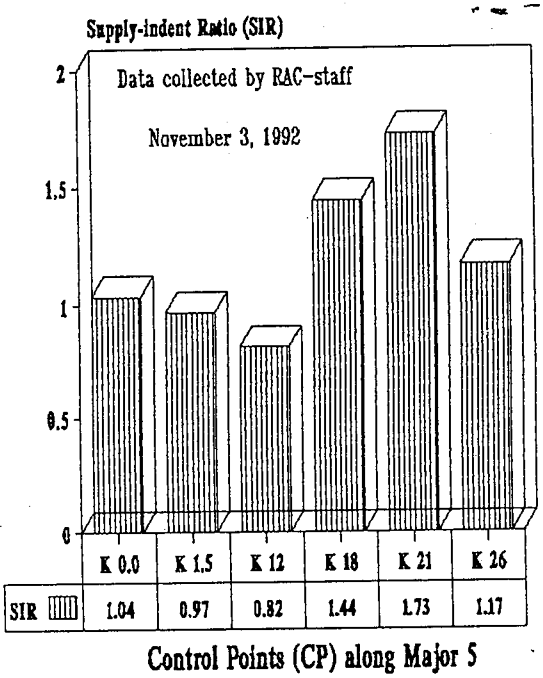


Fig. 7-b. CP-wise supply-indent ratios

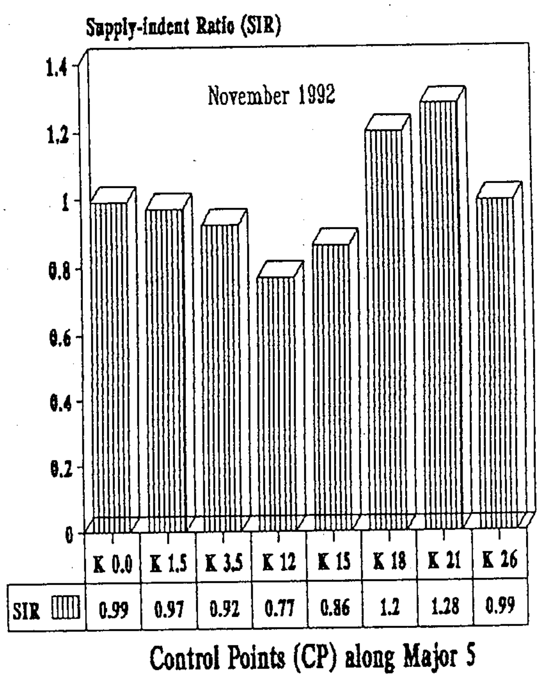


Fig. 7-c. Average CP-wise supply-indent ratios

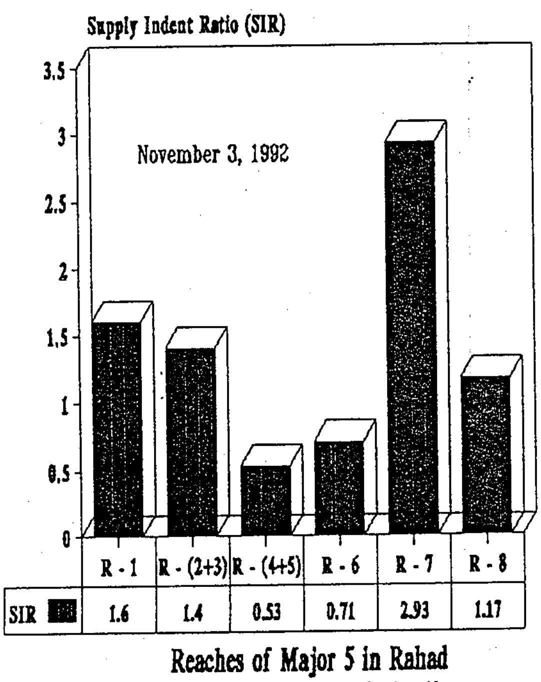


Fig. 8-b. Reach-wise supply-indent ratios

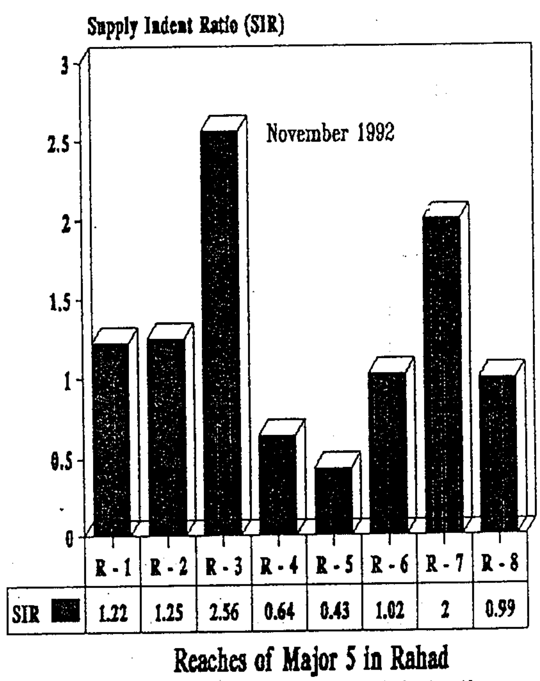


Fig. 8-c. Average reach-wise supply-indent ratios

Discussion about the status of adequacy levels concerning water supplies in response to requests / indents can not get fair treatment at this stage. There are many who strongly think that indents are not realistic demands. On the other hand, there are people who feel that due to siltation and absence of regular maintenance, it is difficult to match supplies with indents. However, everyone acknowledges that situation has improved significantly over the last couple of years.

Although it is difficult to give a categorical general statement about the entire scheme, it is possible to provide some data-based trends about Major 5. Summary of such observations about adequate water distribution is as follows:

(a) The relevant performance parameter , P_A, suggests that the overall water distribution at the Major is fairly adequate. It was in the upper half of the fair range in November and lower half in February. One might have thought it to be the other way around but this resulted mainly due a logical reduction in supplies and correspondingly almost no reduction in quantities demanded. This also hints that indent-based distribution, as it aught to be the case, may not be the fact on ground.

(2) Even under short-supply situations, there were three reaches (R-1, R -3 and R -7) which always got more than their due share demand. However, the area served by these reaches is slightly less than 20 percent of total command. There again three reaches (R -4, R -5 and R -6) which consistently got less than what was requested and they serve about 44 percent of the total area of Major 5. The supplies for the remaining two reaches (R -2 and R -8) fluctuated between the above extreme case. The command area belonging to these reaches is about 36 percent.

(c) Analysis according to control points should be interpreted carefully as it refers to average conditions for an entire section on the downstream. On the other hand, reaches are natural and logical basic units for water distribution and they provide better insight what happens along a conveyance or distribution system.

Modified Parameter of Dependability:

The second performance measure is modified to indicate the uniformity of Q_S/Q_I (SIR) over time. This adapted parameter of dependability is redefined as follows:

$$P_D = \frac{1}{R}\sum_{R} CV_T \left(\frac{Q_S}{Q_I}\right) \text{-----} (5)$$

In this case CV_T (Q_S/Q_I) is the temporal coefficient of variation of the ratio Q_S/QI(SIR) over discrete locations in a region R, in a time span T.

As the referred rapid appraisals had time interval limited to only to one day each, information collected during such exercise can not be used to derive P_D (the parameter of dependability). However, the said limitation does not apply to data collected during February and November 1992. The parameter of dependability, P_D, for the months changes with the treatment of data either on control point basis or according to the reaches of Major 5. Following is the summary of the resulting values of P_D (by the use of Eq. 5):

Month	CP-based	Reach-based
Feb. 1992	0.20	0.40
Nov. 1992	0.23	0.51

The performance parameter, P_D, in all cases lies in an unsatisfactory range. However, it is much worse if the dependability index is derived on reach-basis. As explained earlier, CP-analysis hides many deviations due its built-in averaging nature, the average coefficient of variation over time appears less serious and hence it does not tell the whole truth in this context.

Modified **Equity Parameter**

The equity water of distribution is defined as the ability of a system to uniformly deliver water over the system (Mohammed, 1987). According to Molden and Gates (1990), the equity parameter was defined in the section of review of literature. On the same pattern, the parameter is slightly modified and adapted for Sudan as given below:

$$P_E = \frac{1}{T}\sum_{T} CV_R\left(\frac{Q_S}{Q_I}\right) \text{---}(6)$$

In the above equation, $CV_R(Q_S/Q_I)$ or $CV_R(SIR)$ is the spatial coefficient of variance (standard deviation / mean) for specific period T over a Region R.

In case of the rapid appraisals, time T was taken as one. The resulting values of P_E based on two RA data-sets, as presented in Figs. 7 and 7-b, are reported as follows (by making use of Eq. 6):

Event	CP-base	Reach-base
RA1 (3 Nov.)	0.18	0.77
RA2 (25 Feb.)	0.28	0.62

Similarly, it will be interesting to compare above values of P_E with monthly averages of daily data collected by IIMI staff in February and November 1992. On the above pattern, the P_E-values are reported below:

Event	CP-base	Reach-base
Nov. 92	0.20	0.62
Feb. 92	0.20	0.80

As explained before, P_E determined on CP-basis are not appropriate because of its built-in averaging property. So, relatively lower values of P_E are misleading. For understanding real distribution inequities one may prefer to use reach-base analysis. According to the proposed criteria of Molden and Gates (1990), the reach-wise performance in terms of equity based is pretty unsatisfactory.

V. CONCLUSIONS

A part of Rahad Irrigation System was assessed to see if it was meeting its design objectives i.e., an adequate, dependable and equitable water distribution. Based on above stated

criteria, following can be concluded about the water deliveries in response to indents placed:

A. Overall average adequacy level can be characterize as fair, however, this does not hold for individual reaches of Major-5,

B. The dependability of water deliveries fall under unsatisfactory category, and

C. It is also clear that water distribution is also not satisfactory in terms of equity.

VI. RECOMMENDATIONS

(1) At least one irrigation system should be monitored on regular basis for evaluating its performance.

(2) On pilot level (for example Major 5), the generated information from the above proposed activity should be used for proper gate-setting for adequate, dependable and equitable water distribution.

(3) For improving the operations of a selected system, the relevant agency staff should be equipped with better communication facilities.

(4) In order to bridge gap between indents placed and actual supplies made available in response to the indents, some independent financial mechanism has to be devised. For example, if the indented amounts (m^3 /day) are used as basis for water charges, all concerned parties will take this existing and useful practice very seriously. In an indirect but cost-effective way, performance of irrigation systems in Sudan will jump up in a big way.

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