Chapter 4

WATER AND YIELD DISTRIBUTION PERFORMANCE OF THE RAHAD IRRIGATION SCHEME

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4.1 INTRODUCTION

4.1.1 Rahad Irrigation Scheme

Rahad Irrigation Scheme (Map #1) lies in the southeast of Wad Medani town. The project area of the scheme is about 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[12]). When the second phase is completed, 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.

4.1.2 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 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 (337.2 $ft.^3$/second or cusecs), to lift a maximum discharge of 105 m^3/second (3707 cusecs) into a supply canal.

From the pumping station the supply canal (about 84 km in length) runs northwest towards 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.

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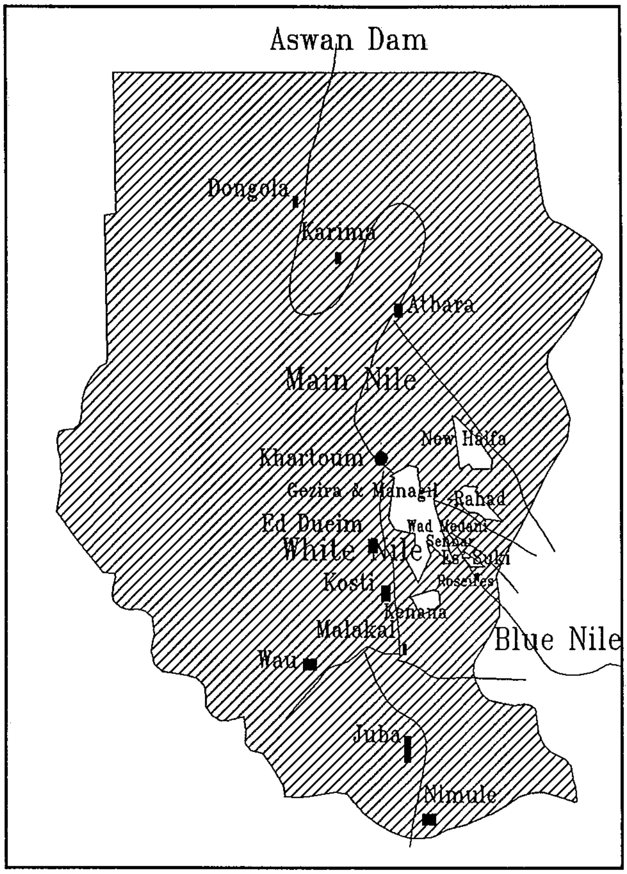
[12]A traditional unit for area, one feddan is equal to 0.42 ha.

Map 1. Rahad and other main irrigation schemes of Sudan.



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

The Rahad barrage is located one kilometer from the outfall of the supply canal which regulates flow into the 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 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 drains, 1140 km in length, is established.

There are 10 Majors (sub-main canals) including those with same numbers but the letter A or B added to them. Major 5 is the middle sub-main which is assumed to be a representative canal for performance evaluation of the scheme. The schematic layout of the Major is shown in the following display, Map #2. As the performance water distribution is more dependent on canal reaches (Shafique 1993), the hydraulic and agronomic aspects are also studied along such basic canal units shown in map #2.

4.1.3 Nature of Research

IIMI initiated a research activity in the Rahad Irrigation Scheme in 1991. The research study was entitled "*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, IIMI does acknowledge the important contributions of: (a) the Hydraulic Research Station (HRS) of MOI for taking the leading role in the local calibration of irrigation control structures in the project area; and (b) the Department of the Rahad Irrigation Operations (RIO) and the Rahad Agricultural Corporation for extending full cooperation in undertaking this study.

Map 2. Schematic layout of Major 5 in Rahad Scheme.

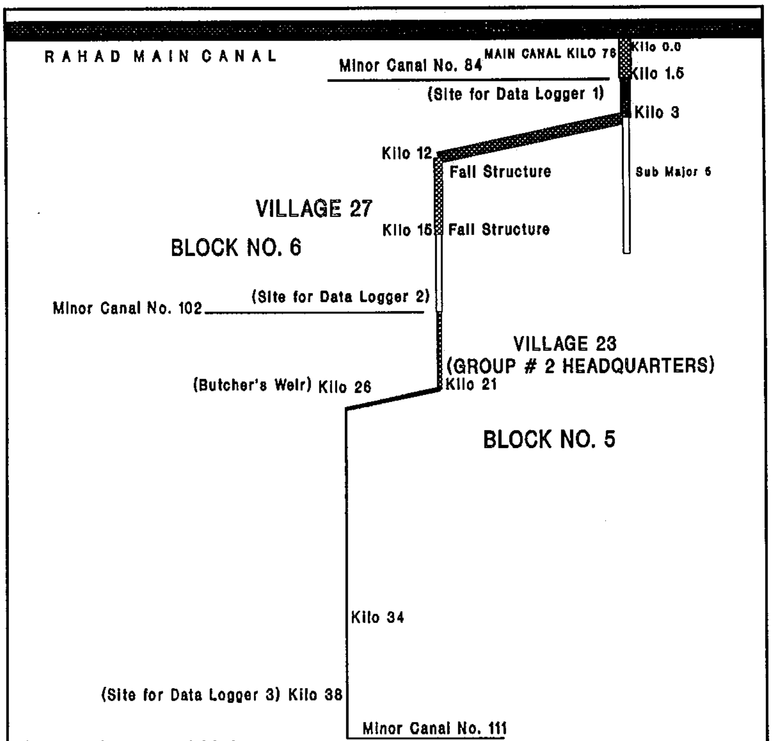


Figure . Layout of Major 5

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."* In this context, the performance of two important components, hydraulic and agronomic subsystems, of the irrigation system has been analyzed and reported herein. At the same time, this is only a portion of the main study conducted during the last three irrigation seasons.

4.2 LITERATURE REVIEW

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

(a) *Concept of performance;*

(b) *Design objectives;*

(c) *Variables required in the control of a conveyance and distribution system of the Rahad scheme; and*

(d) *Performance indices which can use selected water control variables to determine the extent to which design objectives are achieved.*

4.2.1 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 a guideline in 1990s.

Abernethy (1989) has given the 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-Rust 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 and the 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-Rust 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 the 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 two subsystems - physical and agronomic components - of an irrigation system. As dictated by the data collected during the last three irrigation seasons, focus is only on reporting the operating status of the sub-main conveyance and distribution system and agricultural productivity within the selected canal command.

4.2.2 Design Objectives of water delivery system

In the context of water control, Johnstone (1926) states that the design of the Gezira scheme (and almost all other irrigated schemes follow the same design considerations) was based on meeting 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; and*

4. *Measurements of water under varying conditions and levels was necessary.*

Similarly, Taj el Din et. al. (1984) also stated that the design of the operating system is to deliver the required quantities (always expressed in terms of indents placed) of water at the 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 the time to the cultivators."

The above referred literature clearly points out 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 Gezira scheme was designed originally for continuous irrigation. However, at the time of construction the difficulty of irrigation at night was raised which made necessary to adopt a night storage system. A report entitled as *Field Water management* (consultant report 1982) 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 opening or closing of the FOPs (field outlet pipes)."

It is also quite clear that in order to have equitable water distribution at the minor level, the main and major canals have to supply equitable water supplies to these minor canals. In other words, an equitable water distribution at all levels of the irrigation system is an important design objective.

The above discussion helps to identify the following design objectives for most of the irrigated schemes in Sudan:

(a) *adequacy;*
(b) *dependability;*
(c) *equity; and*
(d) *effectiveness of operations to achieve adequate, dependable and equitable water distribution.*

4.2.3 Variables for Water Control

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

(a) *Indents prepared by an agricultural corporation;*
(b) *Crop water requirements;*
(c) *Authorized releases as documented by the Ministry of Irrigation (MOI); and*
(d) *Actual deliveries as monitored by researchers.*

Agricultural performance generally uses variables based on yields. However, the crop yield variables can take different forms: *(i) actual yields; (ii) planned or target yields; (iii) potential yields; (iv) average project yields; etc.*

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

4.2.4 Performance Indices

4.2.4.1 Hydraulic Performance

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 and 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/Authorized release Ratio (SAR): a measure of performance of the distribution system;

4. Management Delivery Ratio (MDR), Actual delivery/Requirement: a measure of the performance of the whole process; and

5. Reliability: the portion of the season that performance is acceptable. This is 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 performance parameters for adequacy, dependability and equity as described below.

Adequacy. A fundamental objective of an irrigation system in Sudan is to deliver the right amounts of water as required for the crops. To quantify the adequacy achieved, the authors have defined P_A which is slightly modified to make it comparable with other two parameter as

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

$$P_a = \frac{Q_d}{Q_r} \quad If \; Q_d \leq Q_r$$

$$P_a = 1 \qquad otherwise$$

Where $P_a = Q_d/Q_r$ is the ratio of water delivered over water required. In the context of Sudan, the water required can be considered either the water demanded (indented) by the field staff of parastatal agencies or the water needed to meet crop water requirements. 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.

The above proposed change in Equation 1a requires to translate irrigation evaluation criteria suggested by Molden and Gates (1990). After such adjustment, the P_A value from 0 to 0.1 is assumed to be good, between 0.11 to 0.20 fair, and over 0.20 is assumed to be unsatisfactory.

Dependability. This 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 as:

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.

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

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

P_D 0.0 to 0.1 --- good,
P_D 0.11 to 0.2 -- fair, and
P_D over o.2 ----- unsatisfactory.

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

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

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 considered good if the 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 to be more convenient and practical measure. It can be derived without too many calculations. This parameter indicates how well the indents placed by one agency, say RAC in the case of Rahad, are matched or responded by say RIO / MOI. Perhaps, this indicator can also be used for better management at the 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.

4.2.4.2 Agricultural Performance

Bos et al. (1993) have categorized indices for agricultural performance into two groups: (i) area indicators, and (ii) production indicators. Following is a brief description of such indices:

Area Indicators. These indicators are based on those proposed by Mao Zhi (1989) are recommended for assessing one aspect of agricultural performance:

$$\text{Irrigated Area Performance} = \frac{\text{Actual Area}}{\text{Target Area}}$$

and

$$\text{Cropping Intensity Performance} = \frac{\text{Actual Cropping Intensity}}{\text{Target Cropping Intensity}}$$

In the context of Sudan, the indicator suggested for irrigated area performance seems more appropriate because of the familiarity of the planners with irrigated schemes.

Production Indicators. The indicators for agricultural performance in terms of production, as proposed by the referred authors, are as follows:

$$\text{Production Performance} = \frac{\text{Total Production}}{\text{Target Production}}$$

$$\text{Yield Performance} = \frac{\text{Actual Yield}}{\text{Target Yield}}$$

$$\text{Water Productivity Performance} = \frac{\text{Actual Water Productivity}}{\text{Target Water Productivity}}$$

$$\text{Yield-Target Ratio (YTR)} = \frac{Y_a}{Y_t}$$

The authors have also proposed the following ways to develop targets: (i) an increase in percent over existing levels; (ii) national targets or norms; and (iii) a target which represents an actual performance of the top ten or twenty percent of farmers in a selected system.

4.3 METHODOLOGY

4.3.1 Water Distribution Performance

4.3.1.1 Site Selection and Data Collection

The evaluation of hydraulic performance is mainly based on the data collected over the last three irrigation seasons, 1991-94, in the scheme. For this on-hands study, Major 5 which serves the middle group[13] of the system was selected on an assumption that the canal was a representative component of the irrigation system. There are people who think that Major 5 and its command are the best in the scheme; however, the resulting yields support the assumption made for this study.

Another reason for the selection of Major 5 was that the Hydraulic Research Station (HRS), with assistance from IIMI-Sudan, did calibrate all of its nine control structures which made it possible to use these control points as flow measuring structures.

At all the nine selected points, there were 8 sluice gates and one Butcher's Weir installed for controlling flows. They all are in good condition. In close cooperation with HRS, IIMI facilitated the painting of gauges to directly read gate openings. Similarly, gauges were installed upstream and downstream of the gated control points to determine the head across the structures (however, all such gauges have now been stolen). These arrangements did facilitate documenting the irrigation water distribution in Major 5.

[13]An administrative unit of Rahad Agricultural Corporation.

IIMI-Sudan has monitored three irrigation seasons: 1991-92, 1992-93 and 1993-94. Almost daily manual measurements were made for the most part during the monitoring period. However, during the first period, these measurements could only be taken for 10-20 days each month. On the other hand, data were also collected by data loggers and stage recorders at three to four points. But the data recorded on continuous basis are not used in this analysis.

The data regarding water indents placed during the all three seasons were retrieved from the records of the RIO and RAC in the project area. This information was then processed according to control points and canal reaches.

Actual irrigation requirements are based on crop water needs calculated by using an empirical relationship (Pennman Equation) with appropriate adjustments made for Sudan. Meteorological information gathered in Wad Medani, rainfall data collected from the command area of Major 5, and relevant crop factors were used to obtain the net crop water requirements of each reach of the major canal. By opting an overall irrigation efficiency of 70 percent, reach-wise irrigation requirements for the cropped area were derived. As the distribution of irrigation supplies and indents is studied according to canal reaches and control points, irrigation requirements were also arranged according to the control points of Major 5.

The required depths of irrigation water in mm/day were calculated on monthly basis from October to November during each season. Also, these depths were normalized, as was done with indents and supplies, over the entire area under four main crops i.e., if these quantities (estimated irrigation requirements) are multiplied by the total seasonal cropped area, planted or not planted at a particular point and time, the resulting quantity would represent total irrigation requirement for a canal reach or cropped area below a control point. It is because of this averaging technique that the irrigation requirements appear to be very low. However, the opted approach was found convenient for comparison purposes.

As almost all of the irrigation systems in Sudan are designed after the Gezira scheme, which aims at delivering adequate, dependable and equitable water supplies, one purpose of the study was to evaluate if the design objectives are being realized. So, the data collection has been targeted for assessing the performance of the water distribution in the scheme.

The hydraulic performance of the system is assessed based on the data collected during October to February in the referred three irrigation seasons. This choice is made because of the fact that during the selected period it hardly rains and all field crops totally depend on irrigation supplies.

4.3.1.2 Selected Indices for Water Distribution Performance

Like the field managers of irrigated agriculture in any country, Sudan also needs 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 have real potential for regular use in the field. In the author's view, the supply-indent ratio (SIR) is one such index. However, indices such as management delivery ratio (MDR) and irrigation requirement/indent ratio (IIR) are also used to explain the performance of Major 5 from different angles.

In spite of the many reservations about the validity of practices related to irrigation water indenting by the Rahad Agricultural Corporation (RAC) and as a consequence the response from the officials of the Rahad Irrigation Operations (RIO), the fact still remains that the indents are the quantities of water demanded at different points, while the water reaching to these points is the actual water delivered. The index SIR measures the degree of responsiveness between these two agencies.

One can also say that water indented should be as determined by crop-water requirements and deliveries as established by authorized releases. However, in a surface irrigation system, the pure crop-water requirements (calculated by using the best known empirical relationships) represent a mere part not the entire irrigation demand. Similarly, the authorized supply may not be the same as actual water delivered to a point.

For assessing the status of irrigation water required, supplied and indented at the major canal, relevant quantities can be expressed in two ways: (i) on volume basis such as cubic meters of water delivered or demanded on a daily and per cropped / commanded area; and (ii) in terms of depth per day given as mm/day. Although the volumetric notation is commonly used in Sudan, but for the convenience of wider audience the above referred quantities will be expressed in mm/day[14] (calculated based on cropped area instead of command area within each canal reach).

4.3.2 Agricultural Performance

4.3.2.1 Data Collection

Yield data are collected from the Accounts Department of the Rahad Agricultural Corporation (RAC). In order to retrieve such information from the records, the block inspectors of Blocks 5 and 6 were contacted. From these officials, a list of randomly selected farmers for each of the eight reaches of the Major was prepared. This selection included 8 Minors[15]; one Minor for each canal reach. It was assumed that the selected Minors represented the other two to three minors taking off from the same reach. Similarly, along a selected Minor, Abu Ashreens[16] were selected to choose four farmers for each such channel. Based on the groundwork, yield data about cotton and wheat from the official records were gathered.

The choice of cotton and wheat was based on the following factors: (i) as compared to sorghum and ground-nut, cotton and wheat are relatively more dependent on irrigation; and (ii) because of the mode of harvest and procurement of these "official" crops from the farmers, the yield information is quite accurate. The yield estimates for sorghum and ground-nut ("farmers' crops") are mainly based on an interview method and hence the yield estimates are not as reliable as is the case with cotton and wheat. Crop cut surveys were organized for the two farmers' crops at three Majors, but due to some intentional or otherwise procedural delays, the exercise could not be extended to Major 5. So, the reach-wise agricultural performance is based only on two of four crops grown in the scheme. However, the information relates to three irrigation seasons: (i) 1991-92; (ii) 1992-93; and (iii) 1993-1994.

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[14]multiplication by a factor of 4.2 will convert mm/day to m^3/day/feddan.

[15]secondary canal.

[16]*tertiary canals.*

For all four crops, scheme level yield and cropped area information for the above stated three years was gathered from the records of AUAC.[17] Also, the target / planned and average project yields were obtained from the same source. However, the information about potential yields for each of the four crops was provided by the Rahad Agricultural Research Station, El Fau.

4.3.2.2 Selected Indices for Agricultural Performance

For the evaluation of agricultural performance, the yields for cotton and wheat will be expressed in terms of Kantars[18] and sacks[19] per feddan respectively. Again, the status of the cotton and wheat yields within the command area of Major 5 will be studied according to its eight canal reaches. This effort is intended to compare temporal and spatial yield variations with those of water supplies and indents analyzed in the same manner.

For the cropped area performance, the first indicator suggested by Bos et al. (1993) will be used. In order to quantify the agricultural production performance, the basic relation to be used is the same as proposed by the authors:

$$\textit{Yield-Target Ratio (YTR)} = \frac{Y_a}{Y_t}$$

where Y_a and Y_t represent the actual yield and target yield respectively. In this study, however, the target yields are slightly different than the ones recommended by the authors. The chosen target yields are: (i) planned project target-yields; (ii) achievable project target-yields; and (iii) mean project yields for different crops in the Rahad Irrigated Scheme.

The ratio YTR is then used in a manner similar to SIR in order to study the yield distribution performance along the major canal. Actual cotton and wheat yields for each of the eight canal reaches are divided with the above selected target yields to obtain different production performance indicators for the three irrigation seasons, 1991-1994 (the same period considered for water distribution). Based on these intermediate indices, the following yield distribution parameters are calculated as described below:

A Parameter for Acceptable Distribution of Yields, $P_A(DY)$ is proposed that is comparable with the parameter for adequacy of water distribution, which is determined by Equations 1a to 1c. The only

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[17] *Advisory Unit for Agricultural Corporations.*

[18] A traditional measure for cotton, one kantar weight is equal to 143 (142.88) kilograms of seed cotton.

[19] A traditional measure for wheat, one sack weighs 100 kilograms.

change proposed here is to replace MDR with YTR (i.e, instead of the ratio Q_d/Q_r, Y_a/Y_t is used). Depending upon the target yield chosen, various indices for the yield distribution will result.

For assessing the performance, each parameter will need a different set of standards. As there is no such criterion available at the present time, the following yardstick for each case is proposed at this stage:

When the target yield is considered to be an average project yield, the resulting range of values for $P_A(DY)$ from 0 to 0.05, 0.06 to 0.1 and more than 0.1 are suggested to assess the representative level of a selected region being good, fair and unsatisfactory within a system. The proposed close range is based on the fact that the target yield is an average actual yield for the project. As the average project yield is an actual output, not a target yield in any sense, its use is not recommended for determining the acceptability of yield distribution. However, after quantifying the representative nature of a study area in the context of the whole scheme. The next two standards can be used to classify acceptable yield distributions.

In case the target yield is taken as the planned project yield, which is a management decision made in view of the available resources and system capacity to produce, the range of parameter $P_A(DY)$ for evaluating the level of acceptability of yield distribution is increased. It is proposed that if the values of the parameter are within 0.0 to 0.1, 0.11 to 0.20 and more than 0.20, the distribution will be evaluated as good, fair and unsatisfactory, respectively.

For a situation when the target yield is considered to be the potential project yield, the assessment criterion is further relaxed. This is mainly due to the fact that potential yield only results under an ideal environment, which does not exist under field conditions. On the other hand, the potential yields proposed by the researchers of a scheme are not an impossible target either. In the given context, the following assessment guide is proposed: (i) good acceptable yield distribution if P_A values range from 0.0 to 0.15; (ii) fair if the range is 0.16 to 0.30; and (iii) unsatisfactory when the parameter values are more than 0.30.

A Parameter for Dependable Distribution of Yields, $P_D(DY)$, which is temporal parameter, is similar to the one suggested for determining the dependability of water distribution. In this case, the relationship given by Q_d/Q_r is replaced with Y_a/Y_t in Equation 2 used for estimating the value of dependability of water distribution. The parameter for dependable yield distribution, P_D, provides a sound basis for the evaluation.

Just like the dependability of water distribution, the steadiness of yield distribution will also be considered good, fair or unsatisfactory if the resulting value of the parameter lies in either of the following ranges 0.0 to 0.1, 0.11-0.20 or more than 0.20, respectively.

A Parameter for Even Distribution of Yields, $P_E(DY)$, which is a relationship similar to that suggested for quantifying the equity of water distribution, can also be used for determining the index for even yield distribution. The only change required to be made is the same as discussed above (i.e., Y_a/Y_t exchanged with Q_d/Q_r in Equation 3). The index has spatial characteristic and depicts variations from point-to-point like canal reaches.

For assessing the even yield distribution along Major 5, the following yardstick is opted as per the resulting values of P_E:

Range of P_E	Assessment
0.0 to 0.1	Good
0.11 to 0.20	Fair
More than 0.20	Unsatisfactory

4.4 DATA ANALYSIS AND DISCUSSION

Does Major 5 represent the Rahad irrigation scheme as a whole? This is an appropriate question. The answer to such query is "yes" -- but only to an extent. As there are some who do dispute its representative character, an effort has been made to establish its relative position in the scheme.

Tables 4.1 and 4.2 provide ratios of actual to average project yields for cotton and wheat over a period of three years. The information is tabulated according to eight reaches of Major 5.

Table 4.1. Actual to average yield ratios for cotton along Major 5.

Year	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8	W.Mean
91-92	1.28	1.34	1.16	1.20	1.01	1.05	0.89	0.77	1.10
92-93	0.98	1.27	1.36	1.13	1.15	1.15	1.00	0.69	1.09
93-94	1.31	1.11	1.21	1.09	1.22	1.03	1.17	0.72	1.08

Table 4.2. Actual to average yield ratios for wheat along Major 5.

Year	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8	W.Mean
91-92	0.65	0.85	1.21	1.00	1.06	1.20	1.31	0.83	0.97
92-93	1.00	0.91	0.72	1.08	0.72	1.34	1.25	0.77	0.94
93-94	0.84	0.94	0.45	0.67	1.16	0.88	1.61	1.23	0.95

An average ratio for cotton over the three years of the monitoring period is 1.09. This means that cotton yields within the command area of Major 5 are 9 percent above the project average; a slightly better position. On the other hand, the same average yield ratio for wheat is 0.95 which is very close to a good representative standing for Major 5. Based on this analysis, one can claim that the site fairly exemplifies the Rahad Scheme.

4.4.1 Distribution of Irrigation Water

4.4.1.1 Irrigation Requirements

Actual irrigation requirements according to canal reaches and control points are displayed in Figure 4.1. As evident from the exhibited data, the differences between the maximum and minimum values are very small. However, the ratios between the maximum and minimum numbers are higher in case of reach-wise data as compared to the ones derived according to control points (CPs).

The above reported irregularity occurs due to the lumping effect while arranging the reach-based irrigation requirements according to CPs. During the first two seasons, these deviations are only about 5 percent but they increase to 14 percent in 1993-94. In the later case, the change is mainly due to a reach which has a flexible cropping pattern. Similar trend is also observed when spatial coefficients of variation are compared i.e., 0.01 to 0.05 and 0.07 to 0.15 for the irrigation requirement data organized according to CPs and reaches, respectively.

The high or low temporal variability in the context of irrigation requirements is beyond human control. Its knowledge, however, is essential in the evaluation and understanding of the water distribution.

Obviously in case of the irrigated schemes in Sudan, if the indent placing and irrigation supplies are also controlled to vary in time with the same proportions as the irrigation requirements do, the resulting water distribution performance will be good. However, if the agencies responsible fail to exercise such controls, then the outcome is not going to be very heartening.

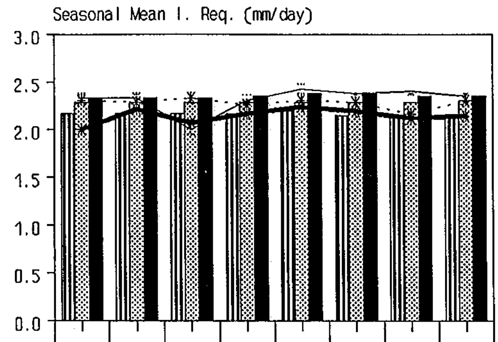
For the Rahad Irrigation Scheme, Figure 4.2 provides comparison between the reach-wise irrigation requirements during two months: (i) October; and (ii) February. There are some exceptions, but in general the reach-wise requirements in October are about three times higher than those estimated for February. This is also evident from the temporal coefficient of variation during the selected irrigation seasons which ranges from 0.46 to 0.56. These variations when compared with those of indents and supplies will help to understand the status of water distribution at Major 5.

The temporal coefficient of variation from season to season is only 0.04 which implies that with the fixed cropping pattern in the area, there is hardly any change in irrigation requirements. This is also evident from overall seasonal requirement being 2.2 mm/day which fluctuated by only 0.1 mm/day during the three seasons. Such a phenomenon of fixed cropping pattern and invariable climatic conditions during the selected period suggests that even the data based on historic irrigation requirements can provide a good scientific base for placing indents in the scheme.

4.4.1.2 Irrigation Water Indents

Indents are essentially the perceived irrigation requirements which may or may not be very accurate. So, the controversy between the Ministry of Irrigation (MOI) and Agricultural Corporations (ACs) over the matter is understandable. Till to-date, however, the practice is the only formal basis for estimating the demand for irrigation supplies. But if the estimates deviate from the actual irrigation requirements to an unacceptable degree, then the agency responsible (RAC) has to take a very serious notice of such anomaly. This is even more important as the water delivering agency (RIO/MOI) is required to respond only to the indents placed irrespective of actual irrigation requirements.

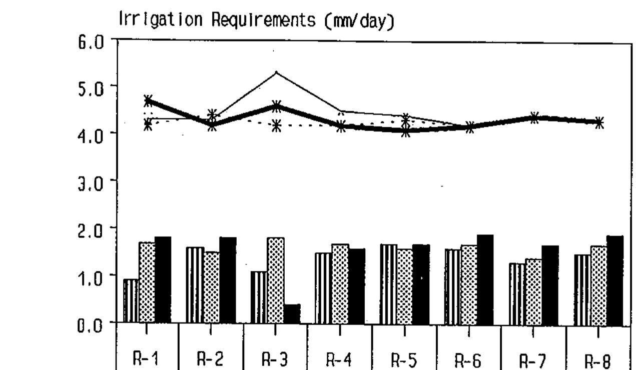
Figure 4.1. Mean irrigation requirements.



	R1&K0	R2&K1	R3&K3	R4&K12	R5&K15	R6&K18	R7&K21	R8&K26
R-I.Req. 91-92	2.0	2.2	2.1	2.2	2.2	2.2	2.1	2.1
C-I.Req. 91-92	2.2	2.2	2.2	2.2	2.2	2.1	2.1	2.1
R-I.Req. 92-93	2.3	2.3	2.3	2.3	2.3	2.3	2.2	2.3
C-I.Req. 92-93	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
R-I.Req. 93-94	2.3	2.3	2.0	2.3	2.4	2.4	2.4	2.4
C-I.Req. 93-94	2.3	2.3	2.3	2.4	2.4	2.4	2.4	2.4

Reaches & Control Points of Major 5

Figure 4.2. Comparison of irrigation requirements during October and February.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
10-91	4.7	4.2	4.6	4.2	4.1	4.2	4.4	4.3
02-92	0.9	1.6	1.1	1.5	1.7	1.6	1.3	1.5
10-92	4.2	4.4	4.2	4.2	4.3	4.2	4.4	4.3
02-93	1.7	1.5	1.8	1.7	1.6	1.7	1.4	1.7
10-93	4.3	4.3	5.3	4.5	4.4	4.2	4.4	4.3
02-94	1.8	1.8	0.4	1.6	1.7	1.9	1.7	1.9

Reaches of Major 5

Leaving aside the controversy about indents, the current status of the practice is given in Figure 4.3 which illustrates the seasonal irrigation water indents in terms of mm/day. For comparison purposes, the indents are arranged according to canal reaches and control points. Although, the seasonal averages are quite similar, but the coefficients of variation for CP and reach based data are very different.

During the study period, the spatial coefficient of variation for reaches, based on monthly requests, varies from 0.22 to 0.27 as compared to 0.07 to 0.12 associated with CP-wise indents. This again shows a "smoothing" effect as a result of aggregating indents according to control points. In order to avoid such masking effect associated with CP data, discussion about water distribution will be more supported by reach-analysis.

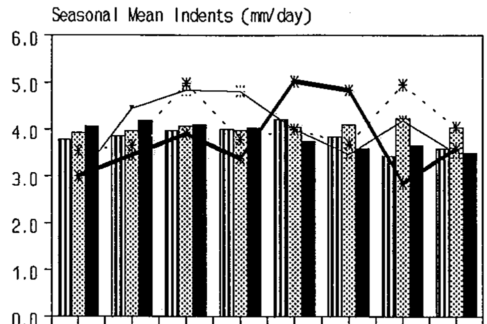
Changes in indent placing within a season, on monthly basis, are quantified by taking temporal coefficient of variation. This measure shows that the temporal variability ranges from 0.26 to 0.34 during the study period. This variability is only 46 to 74 percent of the corresponding change in irrigation requirements. However, if the data were analyzed as per seasons, the same variation drops to 0.12 due to the averaging effect.

But, the seasonal time-related variability should not be confused with the drastic change that should occur from month to month within a season corresponding to irrigation requirements. For example, on an average the temporal coefficient of variation based on monthly data for irrigation requirements is 0.51 as compared to 0.04 (one-third when compared with indent placing) when the same data are analyzed with seasonal means. In the first instance, the temporal variation is restricted within a season whereas the second case points to a change from season to season instead. The both situations leave a lot of room for improvement in indenting practices.

Nevertheless, even the time-based coefficient of variation does not help enough. It does not identify if the change in indent placing is occurring in the same quantity and direction as is the case with irrigation requirements. For example, irrigation requirements from October to February always change in one direction i.e., the maximum in October and then they reduce from that point onward. However, this is not always true in case of the indents placed during the corresponding periods. In order to avoid the stated problem, an alternative approach is proposed next.

According to the option, each season is divided into three phases: (i) October; (ii) November; and (iii) December to February. By taking the mean irrigation requirements (over the study period) in October as a scaling reference quantity, dimensionless numbers for the irrigation requirements and indents corresponding to the three phases are derived. These transformed quantities are presented in Table 4.3. It is obvious from the table that the time-based changes within seasons in the two types of irrigation demand are far from being compatible. Comparison shows that the irrigation requirements during second and third phase are about 60 and 40 percent of the corresponding indents. Moreover, the reductions in the irrigation requirements are predictable whereas it is difficult to speculate the same for water indents.

Figure 4.3. Mean irrigation indents places.



	R1&K0	R2&K1	R3&K3	R4&K12	R5&K15	R6&K18	R7&K21	R8&K26
R-Indent 91-92	3.0	3.5	3.9	3.4	5.0	4.8	2.9	3.6
C-Indent 91-92	3.8	3.9	4.0	4.0	4.2	3.8	3.4	3.6
R-Indent 92-93	3.5	3.7	5.0	3.8	4.0	3.7	5.0	4.0
C-Indent 92-93	3.9	4.0	4.1	4.0	4.0	4.1	4.2	4.0
R-Indent 93-94	3.0	4.5	4.8	4.8	4.0	3.5	4.2	3.5
C-Indent 93-94	4.1	4.2	4.1	4.0	3.7	3.6	3.7	3.5

Reaches and Control Points of Major 5

Table 4.3. Normalized irrigation requirements and indents.

Year	Irrigation Requirements			Indents		
	October	November	Dec-Feb	October	November	Dec-Feb
91-92	0.98	0.57	0.31	0.39	1.08	0.84
92-93	0.98	0.55	0.35	1.26	0.85	0.86
93-94	1.03	0.57	0.36	1.51	0.96	0.72
Mean	1.00	0.57	0.34	1.15	0.96	0.81

This is clear that the indent-placing within a season along Major 5 has at least two times higher spatial and about half the temporal variability when compared with that of irrigation requirements. However, these irregularities imply that either the current indenting practice is meant to give additional consideration to the field difficulties being experienced in meeting the crop water needs or simply it is a "ritual" which has to be performed. In the author's opinion, perhaps there is truth in both statements.

Simple seasonal averages of the indents placed for all the reaches during 1991-92, 1992-93 and 1993-94 are 3.8, 4.1 and 4.0, respectively. During the three irrigation seasons, the ratio between the maximum and minimum amounts demanded for different canal reaches is 1.7 and the average standard deviation is 0.6 mm/day. On an average, the indented amounts are about 80 percent more than the estimated irrigation needs during the study period.

Figure 4.4 gives information about the indents placed in October and February during each irrigation season for the selected eight reaches along Major 5. It is surprising to note that during the first two irrigation seasons, for the different canal reaches indent-placing does not follow any trend - for the different reaches the indents placed during the two extreme months crisscross each other. In the last season, there is visible reduction from October to February. However, the reduction for some reaches is too little and for other being too much. In short, there is no evidence that the indents are placed in a systematic way to meet crop-water requirements.

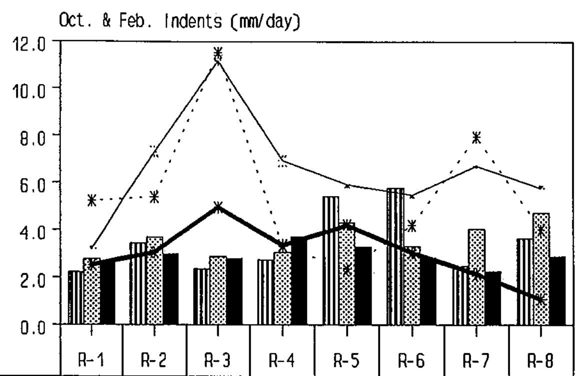
4.4.1.3 Irrigation Water Supplies

In principle, the irrigation deliveries at different locations along a canal are the responses provided by the MOI to the water indents placed by an agricultural corporation (Rahad Agricultural Corporation, RAC, in this case). As per the indented quantities, the MOI officials adjust gate-settings at each control point.

Figure 4.5 depicts the annual irrigation supplies delivered to each selected reach and control point of Major 5 during the study period of three years. As can be seen, the water delivery according to canal reaches is rather erratic.However, when data are arranged according to control points, the water deliveries appear to be fairly uniform. This strengthens the author's view that the study of water distribution according to control points paints a rosy picture whereas the reality may be very different.

As the masking effect due to the aggregation of data in the case of CPs hides sharp deviations from reach to reach, status of water supplies can be studied better by arranging and analyzing data according to canal reaches. On this premise, the rest of analysis and discussion are based on the primary water distribution units i.e., canal reaches.

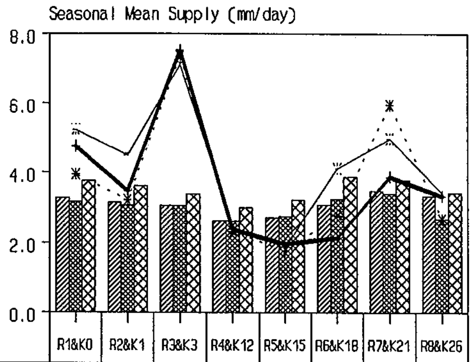
Figure 4.4. Mean irrigation indents placed during October and February.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
10-91	2.5	3.0	5.0	3.4	4.2	3.0	2.1	1.1
02-92	2.2	3.5	2.4	2.7	5.4	5.8	2.5	3.6
10-92	5.2	5.4	11.5	3.3	2.4	4.2	8.0	4.0
02-93	2.8	3.7	2.9	3.0	4.3	3.3	4.0	4.7
10-93	3.2	7.3	11.2	7.0	5.9	5.5	6.7	5.8
02-94	2.6	3.0	2.8	3.7	3.3	2.8	2.2	2.9

Reaches of Major 5

Figure 4.5. Mean irrigation supplies delivered in response to indent placed.



	R1&K0	R2&K1	R3&K3	R4&K12	R5&K15	R6&K18	R7&K21	R8&K26
R-Supply 91-92	4.8	3.5	7.5	2.4	2.0	2.1	3.9	3.3
C-Supply 91-92	3.3	3.1	3.0	2.6	2.7	3.1	3.5	3.3
R-Supply 92-93	4.0	3.2	7.3	2.3	1.8	2.8	6.0	2.7
C-Supply 92-93	3.2	3.1	3.0	2.6	2.7	3.2	3.4	2.7
R-Suupy 93-94	5.2	4.5	7.1	2.5	1.9	4.1	5.0	3.4
C-Supply 93-94	3.8	3.6	3.4	3.0	3.2	3.9	3.8	3.4

Reaches and Control points of Major 5

As exhibited in Figure 4.5 and 4.6, about half of the reaches receive irrigation supplies relatively more than the other half.

These are "lucky" reaches, as termed by Shafique et al. (1993) of Major 5. There could be many reasons for the lopsided water supplies from reach to reach, but the following appear to be the main factors:(i) location; (ii) topography; (ii) influence, and (iv) perhaps the inbred belief and experience of the canal gate operators to keep flows and levels within "all weather tested" safe ranges. These factors may explain why did the reach-wise water supplies follow a consistent pattern.

The reach-wise annual data given in Figure 4.5 show that the maximum and minimum ratio is 3.9 as compared with the indents where the same ratio was only 1.7.
Also, the mean standard deviation for the three seasons is 2.8 times higher than the similar variation associated with the corresponding indents placed. Similarly, when the monthly means are considered, as displayed in Figure 4.6, the ratio between the maximum and minimum supplies rises to 13. This means that seasonal averages bring down the difference to one-third only.

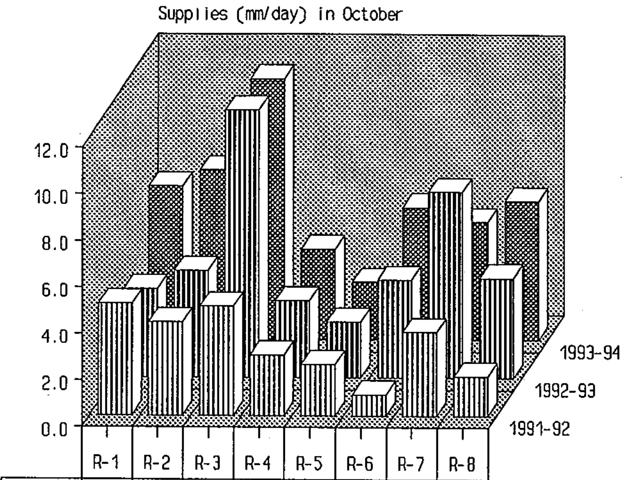
The above stated differences imply that the variations are going to be higher for delivering water supplies from reach to reach as compared with indent placing during the selected period. The spatial coefficient of variation based on monthly supply data varies from 0.45 to 0.52 as compared to the indents where the similarly variability along the major canal was found to be in a range from 0.22 to 0.27. This indicates that the water deliveries along Major 5 fluctuate two times more than the similar variability in the indent placing.

An excessive uneven spatial distribution of water supplies is not a desirable occurrence in any irrigated scheme. However, some degree of the higher abnormality is expected as the both operations are different in nature: (i) indents are prepared on a fixed rate (say, 5000 m^3 / tertiary command) for an almost fixed cropping pattern, enabling officials to be consistent if they wish or try to ; and (ii) delivery of supplies is a physical process which also requires an intensive management process in order to minimize such changes.

Another point to note is that the temporal variability based on monthly data within each season for delivering irrigation supplies and placing indents is almost same. It shows that either the indents placed by the RAC are responded well by the RIO/MOI, or the both agencies have reached to an *equilibrium* in opting a standard types of requests and responses. In the author's view, the experience based indenting and delivering irrigation water supplies may make the both interpretations sound right.

But, it is also true that the water supplies are not in agreement with the irrigation requirements in the project area. This is explained by normalizing the periodic supplies and irrigation requirements which is achieved by taking the mean of the October irrigation requirements over the study period (three seasons) as the scaling reference parameter. The transformed quantities are presented in Table 4.4 which confirm the author's assertion about the lack of compatibility between irrigation requirements and supplies.

Figure 4.6. Reach-wise irrigation supplies.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
1993-94	6.6	7.3	11.2	3.9	2.5	5.7	5.1	6.0
1992-93	3.8	4.6	11.5	3.3	2.4	4.2	8.0	4.3
1991-92	4.8	4.0	4.7	2.6	2.2	0.9	3.6	1.7

Reaches of Major 5

Table 4.4. Normalized irrigation requirements and supplies.

Year	Irrigation Requirements			Irrigation Supplies		
	October	November	Dec-Feb	October	November	Dec-Feb
91-92	0.98	0.57	0.31	0.71	1.08	0.82
92-93	0.98	0.55	0.35	1.21	0.80	0.76
93-94	1.03	0.57	0.36	1.37	0.98	0.82
Mean	1.00	0.57	0.34	1.10	0.95	0.80

Simple averages of irrigation supplies for all the reaches during the first, second and third monitoring seasons are 3.7, 3.7, 4.2 mm/day, respectively. During the study period, the ratio between the maximum and minimum amount of irrigation water delivered is 4.3 which is 2.5 times higher when it is compared with the similar spread associated with the corresponding indent placing. This is another example which points to a relatively more skewed distribution of the reach-wise water supplies.

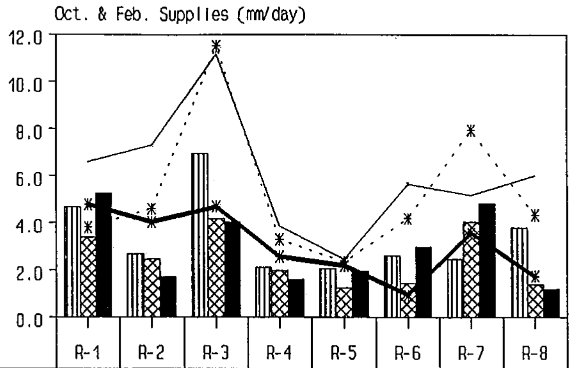
As shown earlier in Figure 4.2, the irrigation requirements reduce drastically from October to February. It seems proper to compare irrigation supplies for the same months during the study period. The main purpose of presenting such information is to observe if the irrigation supplies follow the same trend established by the irrigation requirements in the area. Figure 4.7 displays the data regarding the reach-wise irrigation supplies for October and February during the three monitoring periods.

It is important to note that during the first season, 1991-1992, there are three reaches which received more supplies in February as compared to October which is contrary to the reported reduction irrigation requirements. For the rest of the five reaches, the October supplies are more that those monitored during February but by only a small margin. These reductions range from 2 to 33 percent.

During the remaining two seasons, the october supplies for different reaches are always more than those in February, a trend which shows positive signs. However, these reductions do not mean that these supplies match with the irrigation requirements. During February, only the middle reaches (R-4 to R-6) received supplies almost according to the estimated irrigation requirements. However, their supplies during October were mostly about half of the required amounts.

Comparison of the information about indents and supplies given in Figure 4.4 and 4.7 is also worthwhile. An important point to note is that the middle three reaches (exception being Reach No. 6 during the last season), R-4 to R-6, consistently received relatively less supplies whereas the indents placed for these reaches are generally more than the corresponding supplies. Reverse is also true in case of Reach No. 1. The operational control of two reaches, R-3 and R-7, in reality lies with the influential farmers of the corresponding commands served by direct tertiary channels from the major canal. Although, Reach No. 7 is near the tail but it is also helped by the presence of a moveable weir as control structure. All such factors explain why there are two "mountain peaks" in the both figures. In case of Reach No. 2, the indents placed are usually higher than supplies delivered. For the tail reach, Reach No. 8, it is difficult to give a general statement except this that the supplies are quite erratic throughout the study period.

Figure 4.7. Mean irrigation supplies delivered during October and February.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
10-91	4.8	4.0	4.7	2.6	2.2	1.0	3.6	1.7
02-92	4.7	2.7	7.0	2.1	2.0	2.6	2.5	3.8
10-92	3.8	4.6	11.5	3.3	2.4	4.2	8.0	4.3
02-93	3.4	2.5	4.2	2.0	1.2	1.4	4.0	1.4
10-93	6.6	7.3	11.2	3.9	2.5	5.7	5.2	6.0
02-94	5.2	1.7	4.0	1.6	2.0	3.0	4.8	1.2

Reaches of Major 5

The above given details suggest that the water supplies and indents which match on an overall basis do not correspond at the level of canal reaches. In the author's opinion, the RIO/MOI has managed to deliver irrigation supplies according to the indents placed by the RAC during the last two seasons. But such good control on canal operations has only been applied at the head of Major 5 as the supplies and indent at Kilo 0.0 do not deviate too much. Still, there is a lot more to be done to improve erratic water distribution along the canal.

4.4.1.4 Status of Water Distribution

The discussion about the water distribution is presented by reviewing interrelationships among its three key components: (i) irrigation requirements; (ii) irrigation water indents; and (iii) irrigation supplies. Based on these basic elements, additional explanation will be provided by interpreting the ratios such as MDR, IIR and SIR at different levels of the selected system.

A summary of the irrigation requirements, indents and supplies is provided in Tables A-1 to A-15 in the appendix. These data have been tabulated according to the eight canal reaches of Major 5. This information spans from October to February during the three monitoring periods / years. These tables provide a good comparative overview about the status the water distribution.

Also, it is important to point out that the referred elements are the product of physical as well as management conditions, processes and results. So, they indicate the performance of both the physical as well as the management systems.

Figure 4.8 provides a visual comparison of the key elements of water distribution. The information, means over the entire study period, portrays contrast among these components from October to February.

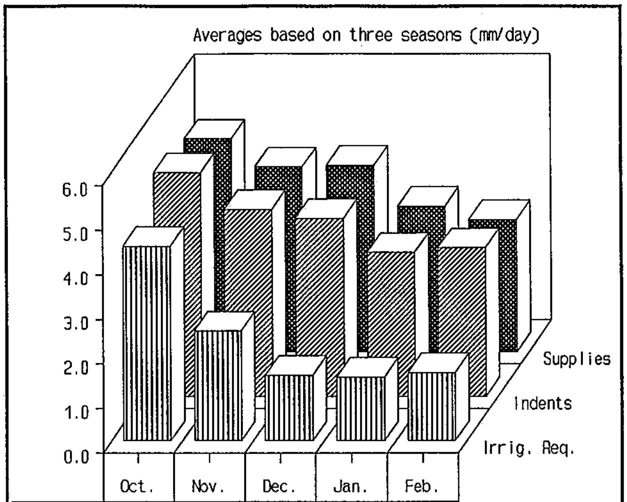
By looking at the aggregated data displayed in Figure 4.8, the three statements which can be made about the interrelationships among the key elements are as follows: (i) they appear to be in an acceptable range during October; (ii) mean irrigation supplies and indents are almost same through out the period selected; and (iii) neither supplies nor indents match with the corresponding irrigation requirements from November to February.

In order to quantify the relative position of each element from October to February, the average values of three seasons are transformed into dimensionless numbers by using the mean irrigation requirement in October as a scaling reference parameter. The resulting normalized information is presented in Figure 4.9. It shows that during the study period the irrigation supplies and indents are 70 to 125 percent more than the irrigation requirements. However, the only exception was that during October all elements were within an acceptable range.

The above discussion suggests that the indents and supplies match very well throughout the selected period from October to February. It is, however, only right if the comparison is restricted to the overall mean values on monthly basis. This harmony falls apart when the distribution of these elements is analyzed according to the reaches of Major 5.

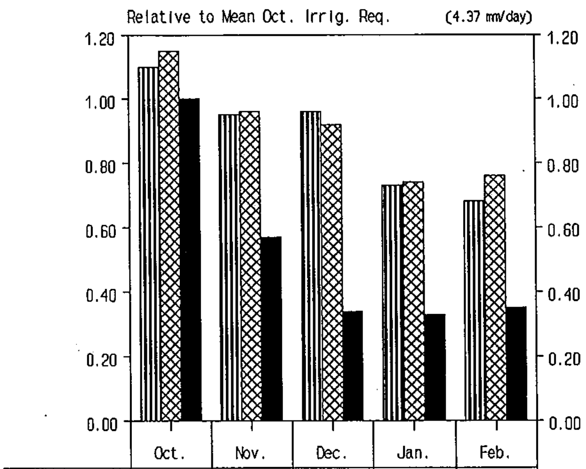
Figure 4.10 again presents normalized irrigation supplies, indents and requirements according to the canal reaches. For this purpose, the mean of the irrigation requirements over three seasons was considered as a reference parameter.

Figure 4.8. Comparison of three key elements: Irrigation supplies, indents and requirements.



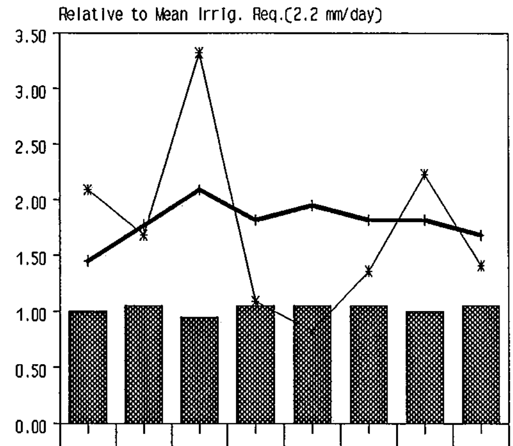
	Oct.	Nov.	Dec.	Jan.	Feb.
Supplies	4.8	4.2	4.2	3.3	3.0
Indents	5.0	4.2	4.0	3.2	3.3
Irrig. Req.	4.4	2.5	1.5	1.4	1.5

Figure 4.9. Normalized irrigation supplies, indents and requirements.



	Oct.	Nov.	Dec.	Jan.	Feb.
Supplies	1.10	0.95	0.96	0.73	0.68
Indents	1.15	0.96	0.92	0.74	0.76
Irrig. Req.	1.00	0.57	0.34	0.33	0.35

Figure 4.10. Comparison of the normalized quantities on reach-basis.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
Supplies	2.09	1.68	3.32	1.09	0.82	1.36	2.23	1.41
Indents	1.45	1.77	2.09	1.82	1.95	1.82	1.82	1.68
Irrig. Req.	1.00	1.05	0.95	1.05	1.05	1.05	1.00	1.05

Based on the resulted reach-wise normalized information, the following observations can be made: (i) because of the fixed cropping pattern, there is hardly any change in the irrigation requirements; (ii) even being the long-term average indents and supplies, they differ widely from each other at all reaches except for Reach 2; and (iii) relative to other two components, the distribution of supplies is very erratic. It appears that there is an ample room for the improvement of canal operations along the major canal.

Next the water distribution is studied with the help of the following ratios: (i) management delivery ratio (MDR); (ii) indent-irrigation requirement ratio (IIR); and (iii) supply-indent ratio (SIR). Although these ratios are used to quantify the performance of water distribution for an irrigated area, but they can also be utilized to compare the status of water distribution at two different times.

The management delivery ratio is employed to see if the supplies are adequate to meet irrigation requirements. However, the same ratio when determined on reach basis, it can also show if the reach-wise water distribution is right to meet crop water needs.

By plotting this ratio according to the canal reaches at two times periods when the irrigations requirements are either maximum or minimum, a good understanding about the water distribution can be drawn. Figure 4.11 presents such a contrast by diagraming MDRs of October and January.

As evident from the data presented, the reach-wise distribution during October and January is very erratic to say the least. Depending upon the reaches under consideration, there exist all three possibilities: (i) under supply (MDR < 1.0); (ii) over supply (MDR > 1.0); and (iii) right irrigation (MDR = 1 or around 1.0). In october, the current water distribution does all. During January, on the other hand, over supply is prevalent which might be suppressing yields due to surface waterlogging for the most reaches.

The second ratio, IIR, when applied on reach-basis, it indicates the kind of water distribution which will result to meet crop water needs for each reach of a selected system. Hence, the main aim to study the water distribution with IIR is to visualize the consequences if the indented amounts were met as such.

As shown in Figure 4.12, the situation is still far less than satisfactory. During October 1991-92, the water indents for the most reaches, except Reach Nos. 3 and 5, were less than irrigation requirements which would have not resulted into desirable water distribution. During January, if the requested indents were met then serious over supply would have occurred also. However, a reasonable water distribution would have followed, had the supplies been delivered according to the reach-wise indents in October, 1992 and 1993.

As the indents placed are the only formal irrigation requirements received by the officials in the Ministry of Irrigation, other indices may not be considered appropriate for judging the current status of water distribution. In this context, supply-indent ratio (SIR) seems a better measure.

As a matter of fact, the ratio (SIR) determines a formal degree of responsiveness that exists for the distribution of water in the scheme. According to the overall average supplies and indents presented in Figure 4.8, the distribution based on the SIRs would result fairly uniform. But to see if this was true even according to the canal reaches, SIRs are plotted in Figure 4.13.

Figure 4.11. Management delivery ratios during October and January.

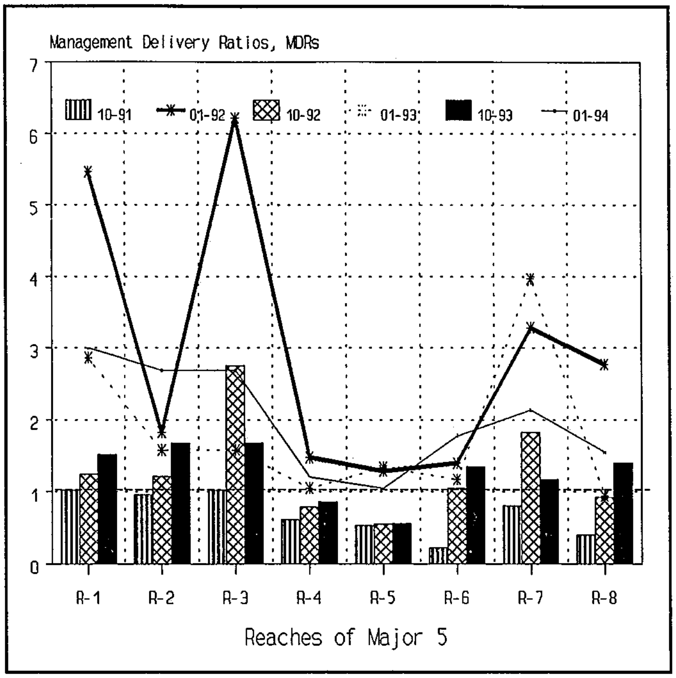
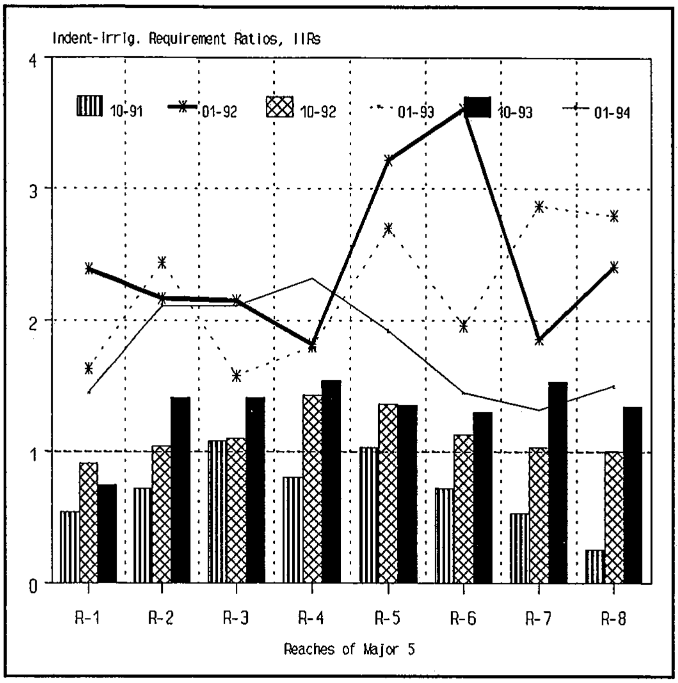


Figure 4.12. Indent-irrigation requirement ratios during October and January.



A casual look at the data displayed in Figure 4.13 does not support the earlier impression about the water distribution based on SIRs being adequate. It is true that the overall monthly averages of the supplies and indents fairly match each other but only in terms of total quantities at the level of Major 5. However, the water apportionment from reach to reach results into an uneven distribution. However, the data presented in Figures 4.8 and 4.13 indicate that with the better management of the canal operations along the system, there would be no difficulty in meeting all indents placed for each reach.

So far, the water distribution is studied according to the canal reaches by taking monthly averages over the study period. The analysis has helped to identify the reaches which receive in particular month over, under or right amounts of water. Like the monthly analysis of the water distribution, one can study the same on seasonal basis too.

Obviously, there has to be expected a significant lumping effect hidden in a seasonal evaluation but the information given in Table 4.5 still confirms most of the views expressed about the status of water distribution at Major 5.

Table 4.5. Seasonal mean values of MDR, YORE and SIR.

Year	Canal Reaches									
	Index	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8	MEAN
91-92	MDR	3.7	1.8	5.1	1.3	1.0	1.2	2.4	2.2	2.3
	IIR	2.2	1.9	2.4	1.8	2.6	2.8	1.8	2.3	2.2
	SIR	1.8	1.0	2.3	0.8	0.4	0.5	1.6	1.0	1.2
92-93	MDR	2.0	1.6	3.5	1.1	0.9	1.3	3.1	1.2	1.8
	IIR	1.6	1.8	1.7	2.1	2.3	1.9	2.4	2.1	2.0
	SIR	1.4	1.0	2.2	0.7	0.5	0.8	1.4	0.8	1.0
93-94	MDR	2.5	2.2	2.2	1.1	0.8	1.8	2.3	1.5	1.8
	IIR	1.4	2.2	2.2	2.3	1.8	1.5	1.7	1.6	1.8
	SIR	2.0	1.1	1.1	0.5	0.5	1.3	1.5	1.0	1.1

Reach Nos.4, 5 and 6 generally received relatively lesser supplies throughout the study period as compared to the indents placed. Consequently, MDRs and SIRs remained lower than others. Reach Nos. 1, 3 and 7 received more supplies with better MDRs. Remaining two reaches fall in the middle of these two groups.4.4.2 Distribution of Crop Yields

4.4.2.1 Status of Yields

The cropping pattern in the scheme includes four crops: (i) cotton; (ii) ground nut; (iii) sorghum; and (iv) wheat. As the yield data for ground nuts and sorghum are not very accurate, the discussion about the yield status within the command area of Major 5 is based on cotton and wheat only.

Figure 4.13. Supply-indent ratios during October and January.

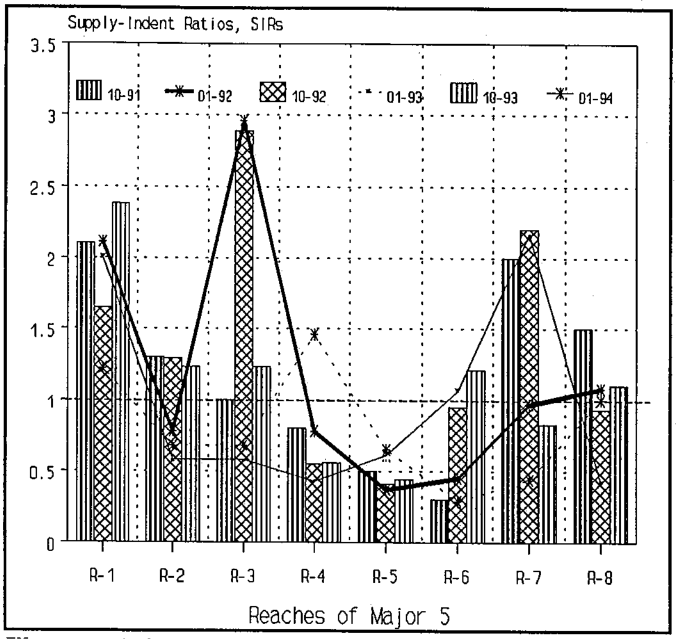


Figure 4.14 and 4.15 pertain to cotton. The first figure illustrates the cotton yields over three years according to various reaches of the Major. When a trend line is drawn based on the mean for the study period, it indicates that the cotton yields decline from head to tail. This trend confirms the general thinking about the location-based advantages and disadvantages particularly during the critical period of October . During October 1991-92 (year of maximum cotton yield), the first three reaches had enough supplies to meet irrigation needs. But, the rest of the reaches received too little supplies. Such a water delivery pattern partly explains the reported trend.

The second figure (Figure 4.15) depicts overall cotton yields associated with the monitoring period. Surprisingly, there is a sharp decline (about 30 %) after 1991-92.

Some people link this decline in cotton yields with decreased water supplies, the adverse weather conditions, and management changes in the scheme. This may or may not be entirely incorrect. However, one thing is sure that there was no reduction in water supply. Contrary to the impression, the quantity of water delivered in M^3/day/feddan increased by about 16.5 percent from 1991-92 to 1993-94. It appears that surface waterlogging could have suppressed yields to some extent.

In the author's opinion, the main factors in this yield reduction are as follows: (i) uncertainty about the future of the scheme's management mode; (ii) uncertainty by the staff regarding their future role and its demoralizing effects; (iii) some back and forth changes in the water control at different levels of the irrigation system; (iv) a phenomenon of surface waterlogging; (v) difficulties associated with financial support; and (vi) problems related with the availability of machinery, inputs and other support services on an "as, when and where" basis, etc.

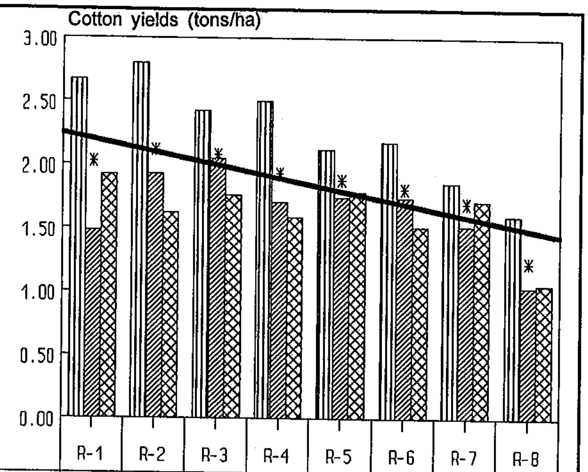
Figure 4.16 displays reach-wise wheat yields over the study period. Contrary to the cotton case, the trend line drawn based on three years of mean yields exhibits a slight decline from tail to head. This runs against a general perception related to head versus tail.

Moreover, the data show that higher yields belong to those reaches which have been termed as "not so lucky" because of low deliveries at such localities. One explanation for this abnormal situation lies perhaps in the availability of water at the critical period for wheat growth in January. As given in Tables A-10 to A-12, the middle three reaches, R-4 to R-6, generally received less but enough supplies to meet the irrigation requirements. The lavish water deliveries to the rest of the reaches might have effected yields due to the resulting surface waterlogging.

Only exception in this case are the two "lucky" reaches i.e., R-3 and R-7, which serve their respective command areas with a flexible cropping pattern and managed by the knowledgeable agricultural graduate farmers. These areas have also good functional facilities for surface drainage. It is, therefore, possible that not all of the excess supplies delivered to these commands turned to wheat fields but perhaps diverted to the main crop of vegetables and / drained off.

The above given explanation is based on the assumption that wheat may be less sensitive to slightly short supplies as compared with cotton and, hence, the yields at the referred locations are better. However, it does not explain why the wheat yields are lower where there is plenty of water available. Again, one can speculate that wheat may be more sensitive to the surface waterlogging as compared with cotton, which is usually grown on ridges and has longer roots. Considering the nature of the heavy clay soils, the mentioned problem is a normal thing to occur.

Figure 4.14. Average cotton yields according to canal reaches.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
1991-92	2.67	2.80	2.42	2.50	2.12	2.18	1.86	1.60
1992-93	1.48	1.93	2.05	1.70	1.74	1.74	1.52	1.04
1993-94	1.92	1.62	1.76	1.59	1.78	1.51	1.71	1.05
Mean	2.02	2.11	2.08	1.93	1.88	1.81	1.70	1.23

Reaches of Major 5

Figure 4.15. Average cotton yields for the entire command of Major 5.

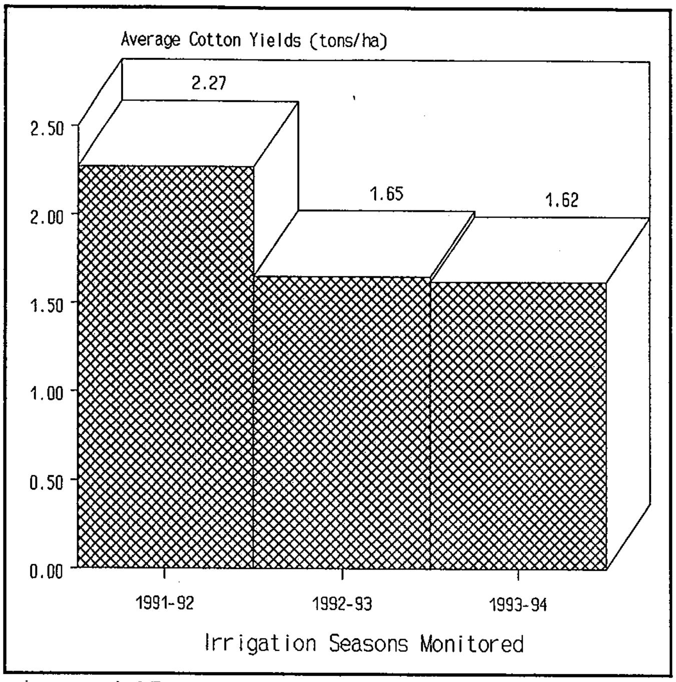
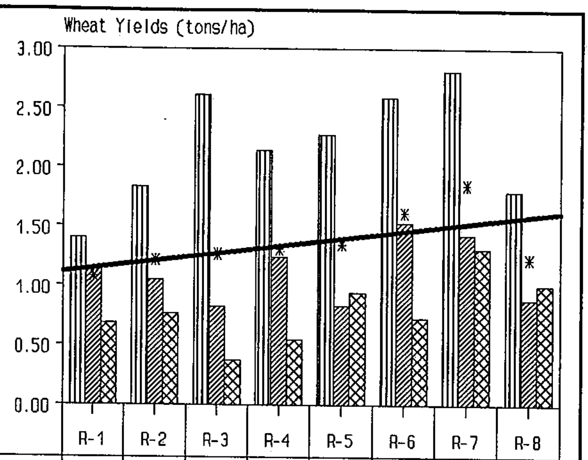


Figure 4.16. Average wheat yields according to canal reaches.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
1991-92	1.40	1.83	2.61	2.14	2.28	2.59	2.81	1.79
1992-93	1.15	1.05	0.82	1.24	0.83	1.53	1.43	0.88
1993-94	0.69	0.77	0.37	0.54	0.95	0.72	1.31	1.00
Mean	1.08	1.22	1.27	1.31	1.35	1.61	1.85	1.22

Reaches of Major 5

Figure 4.17 illustrates the situation of wheat yields within the command area of Major 5 from 1991-92 to 1993-94. Like the cotton yields, wheat also follows the same diving pattern. However, the decline in wheat yields during the last two years is even sharper. When compared with 1991-92, the wheat production per hectare in 1993-94 has dropped by a factor of 2.75. This decline points to a shocking event. The reasons for these reductions in wheat yields may be very similar to those described above while explaining the corresponding decline for cotton yields.

4.4.2.2 Status of Yield Distribution

The yield distribution is explained by deriving the yield-target ratios (YTRs) for cotton and wheat. The reach-wise analysis portrays the relationship of actual yields with respect to target yields along the Major. The selection of target yields depends on the type of evaluation under consideration.

In this study, two target yields are used: (i) target being a planned yield; and (ii) target being a potential yield. Planned yields[20] for cotton and wheat are taken as 2.2 tons (6.5 Kantars) and 1.9 tons (8 sacks) per hectare (feddan), respectively. The potential yields[21] are considered as 4.1 tons (12 Kantars) and 4.3 tons (18 sacks) per hectare (feddan) for cotton and wheat in the same order.

Based on the above given target yields, the YTRs for cotton and wheat are presented in Figure 4.18 and 4.19. In both cases, for YTR equal to one, a line is drawn to see if the resulting actual yields meet the targets for both crops.

In the first year, 1991-1992, almost all with few exceptions achieved the referred planned targets for cotton and wheat. In the case of cotton, the last two reaches should not meet their set target. Similarly, the head reach was almost the only one which did not accomplish the yield goal for wheat. For the remaining monitoring seasons, the production of cotton and wheat remained well below the set targets. The sharp drop in the cotton and wheat yields kept the values of these ratios (YTRs) below one.

While comparing the distribution of cotton and wheat, it is important to note that the maximum and minimum YTRs range from 0.47 to 1.26 as compared with wheat, which has the similar range but with more spread i.e., 0.19 to 1.48. Even the average over three years is better for planned YTR of cotton than of wheat - 0.84 and 0.72, respectively.

A similar trend is detected when potential YTRs are compared. For cotton, the average ratio over the study period is 0.45 and for wheat it is only 0.30. The spread between the maximum and minimum YTR (potential) is 0.25 to 0.7 for cotton and 0.10 to 0.65 for wheat. Even in this comparison, cotton shows better distribution.

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[20]provided by AUAC.

[21]information provided by the scientists of the Agricultural Research Station, El Fau.

Figure 4.17. Average wheat yields for the entire command of Major 5.

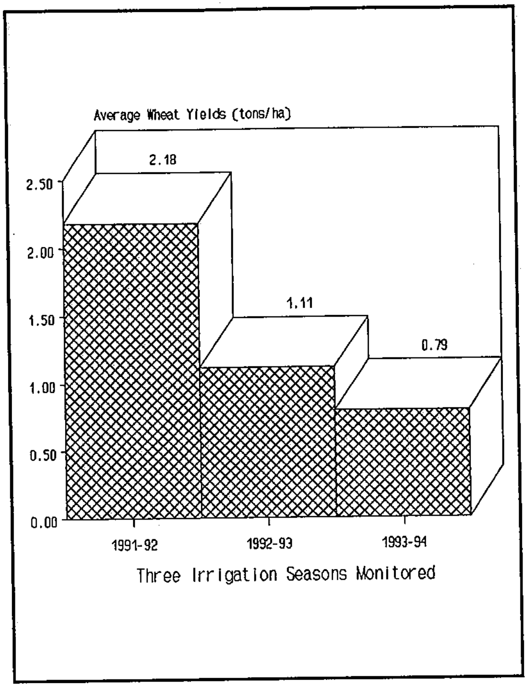
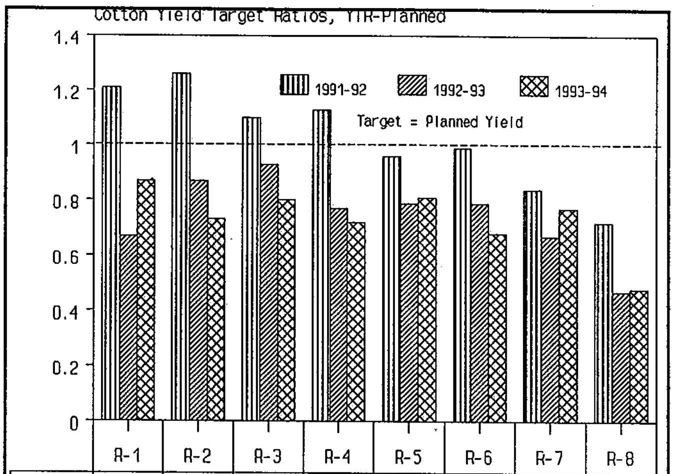


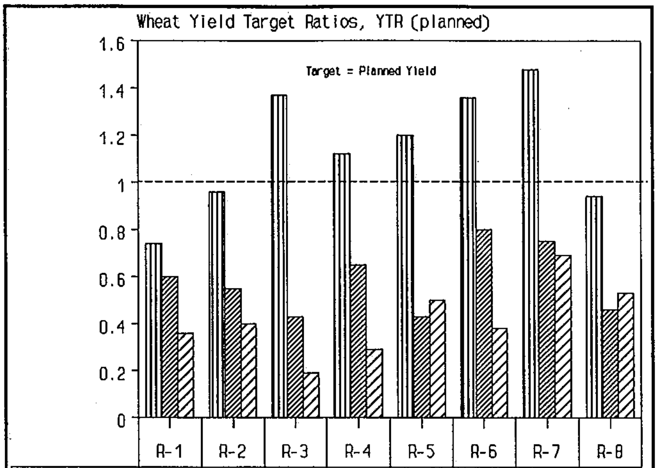
Figure 4.18. Cotton yield distribution status in the command area of Major 5.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
1991-92	1.21	1.26	1.1	1.13	0.96	0.99	0.84	0.72
1992-93	0.67	0.87	0.93	0.77	0.79	0.79	0.67	0.47
1993-94	0.87	0.73	0.8	0.72	0.81	0.68	0.77	0.48

Reaches of Major 5

Figure 4.19. Wheat yield distribution status in the command area of Major.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
1991-92	0.74	0.96	1.37	1.12	1.2	1.36	1.48	0.94
1992-93	0.6	0.55	0.43	0.65	0.43	0.8	0.75	0.46
1993-94	0.36	0.4	0.19	0.29	0.5	0.38	0.69	0.53

Reaches of Major 5

4.4.3 Water Distribution Performance

As a matter of fact, an earlier discussion in this paper about the irrigation supplies, indents, requirements and water distribution is given to provide proper setting for assessing the existing performance of water distribution along Major 5. This evaluation is based on the following two sets of indicators: (i) ratios such as MDR, IIR, and SIR; and (ii) parameters for water adequacy, dependability, and equity. The first set of indicators, referred as ratios, has been discussed in details under the section about the water distribution. The second set consists of the parameters which have been described by Equations 1, 2, and 3.

In the contest of Sudan, one would like to know about the following : (i) status of water supply in relation to irrigation requirements; (ii) relationship between indented amounts and irrigation requirements; and (iii) extent of water availability to the indented amounts. These aspects have been already deliberated in this paper. However, Figure 4.20 is presented to describe the seasonal results about the resulting water distribution during the study period.

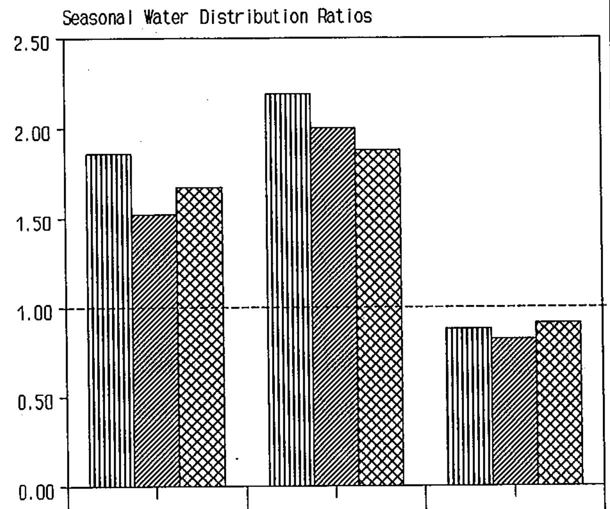
It is important to note that virtually there is no significant change in the seasonal average values of the MDR, IIR, and SIR from year to year. These data imply the following: (i) there was about 70 percent more water delivered than the corresponding irrigation requirements; (ii) indents placed were approximately 100 percent in excess of the amounts required; and (iii) the supplies delivered almost 90 percent of the indents placed.

The above described situation at Major 5 indicates to a serious problem of oversupply and over-indenting in the scheme. There could be many reasons for these surplus supplies and indents. In the author's opinion, the following are some important factors which may have caused the oversupplies: *(i) prevalent practice of over-indenting; (ii) intentional or unintentional effort to reduce the required management input by minimizing operational controls along the major canal; (iii) compensation for the absence or lack of the operational controls along the major canal by releasing excess supplies; and (iv) convenience of the gate-operators and dependence on the their "all weather tested" safer ranges for gate operations.* Similarly, possible determinants for the over-indenting, in the author's view, could be listed as: *(i) erratic distribution of water supplies along the major canal; (ii) established pattern of short supplies for some reaches; (iii) absence of the operational controls along minor canals; (iv) "will-based" disorderly water distribution at the tertiary level; and (v) disturbed field levels and large basins necessitate prolonged irrigations.*

However, the phenomenon of oversupplies over-indenting is only true on overall basis as the distribution according to reaches (Figures 4.11 and 4.12) points to both over and under supply and indenting cases. Similarly, the matching prospects of the supplies and indents exist, to some extent, only at the head of Major 5 as the apportionment of the supplies and indents from reach to reach leaves a lot of room for improvement (Figure 4.13).

A positive aspect of this situation is that the canal operations performed to meet indents by the RIO / MOI at the head of the major canal are quite reasonable. However, there is a need and opportunity to extend the same control along the channel also.

Figure 4.20. Seasonal water distribution ratios for the entire command of Major 5.



	Supply/Req. (MDR)	Indent/Req. (IIR)	Supply/Indent (SIR)
91-92	1.86	2.19	0.88
92-93	1.52	2.00	0.82
93-94	1.67	1.88	0.91

As illustrated in this paper, it is not enough to judge the performance of an irrigation system only at macro-level. This caution is necessary to avoid misleading conclusions. For example, overall mean MDR, IIR, and SIR suggest that there being more than enough water available to meet irrigation needs. But Figures 4.11 to 4.13 reveal that the distribution at reach-basis was causing serious over or under supply conditions. Moreover, the reach-based evaluation helps to pinpoint the bottlenecks which effect water distribution performance within the command area of a system. On this premise, the following discussion about the parameters for adequacy, dependability and equity is based on the overall as well as reach-base analyses:

(a) Parameter for Adequacy. The parameter for adequate water distribution is calculated as given by Equations 1 to 3. Figure 4.21 exhibits the resulting values over the last three years. These averages are based on the data for five months: October to February during each irrigation season.

Figure 4.21 presents information on individual reaches basis during the study period. The values ranging from 0.0 to 0.1 indicate a good water distribution in terms of adequacy. Reach Nos. 1, 2, 3, and 7 consistently perform better. Reach Nos. 4 and 8 fall in the fair category (0.11-0.20). Reach 6 have shown progress during the study period: (i) unsatisfactory in the first season; (ii) fair in the second season ; and (iii) good level of adequacy during the last season. However, the performance of Reach No. 5 remained unsatisfactory throughout the study period.

Figure 4.22 illustrates seasonal averages of the over supply fractions. In the author's opinion, these are the "price tags" for various adequacy levels achieved at Major 5. Such a performance, therefore, should be judged by considering the parameter for adequacy and the resulting over supply fraction together.

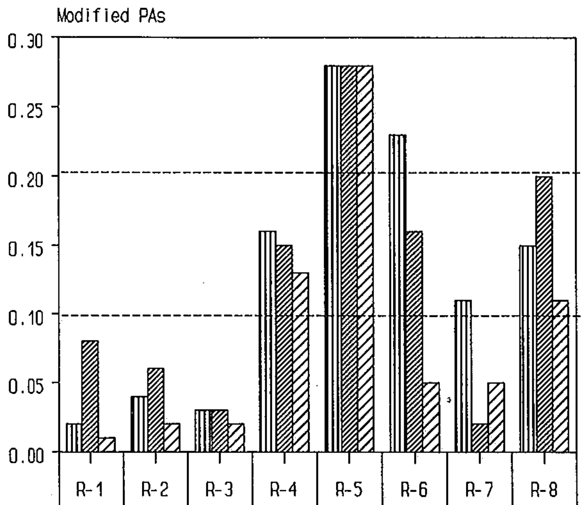
For the entire Major 5 system, the overall performance of the system in terms of adequacy, as per original criteria proposed by Molden and Gates (1990), is described as fair and good during 1991-93 and 1993-94, respectively. Of course, this broad classification hides the fact that the overall adequacy level for reach No. 5 remained within unsatisfactory range throughout the study period.

In the author's opinion, however, a season may be a too long period to base judgements on the adequacy levels as indicators for a good or poor performance. It is suggested that these levels should be restricted to critical months when the resulting adequacy levels effect yields of certain crops in a significant manner. Also, the two adequacy related indices, P_A and over supply fraction, should be used together to evaluate performance.

(b) Parameter for Dependability. This parameter is derived by using Equation 2. Figure 4.23 presents the results for the study period of three years. This temporal coefficient of variation over discrete locations (i.e., eight reaches) is used to evaluate the reliability of water distribution.

Figure 4.23 displays different values of the parameter according to eight reaches of Major 5 over three irrigation seasons. There is difficulty in establishing any special trend based on the resulting information; however, the dependability of water distribution is found unsatisfactory according to an opted standard. There is not even a single reach which has a value of less than 0.2 to qualify either for the fair or good category. Although, during the last season some reaches, R-1 to R-3, have made significant improvement and almost qualify for a marginally fair performance.

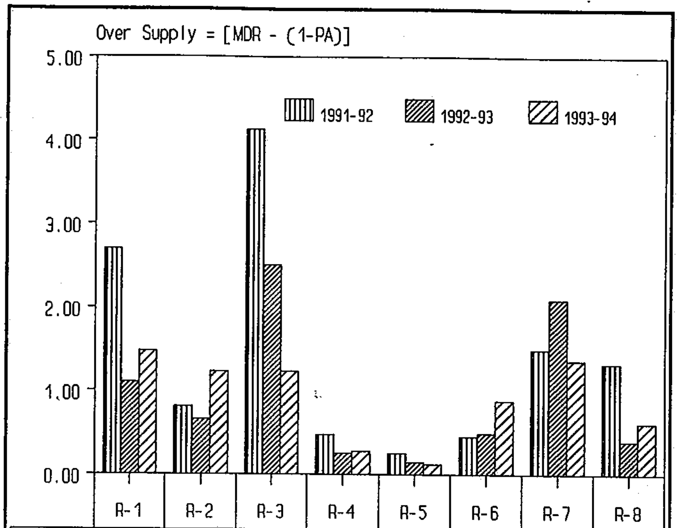
Figure 4.21. Parameters for adequacy derived on reach basis.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
1991-92	0.02	0.04	0.03	0.16	0.28	0.23	0.11	0.15
1992-93	0.08	0.06	0.03	0.15	0.28	0.16	0.02	0.20
1993-94	0.01	0.02	0.02	0.13	0.28	0.05	0.05	0.11

Reaches of Major 5

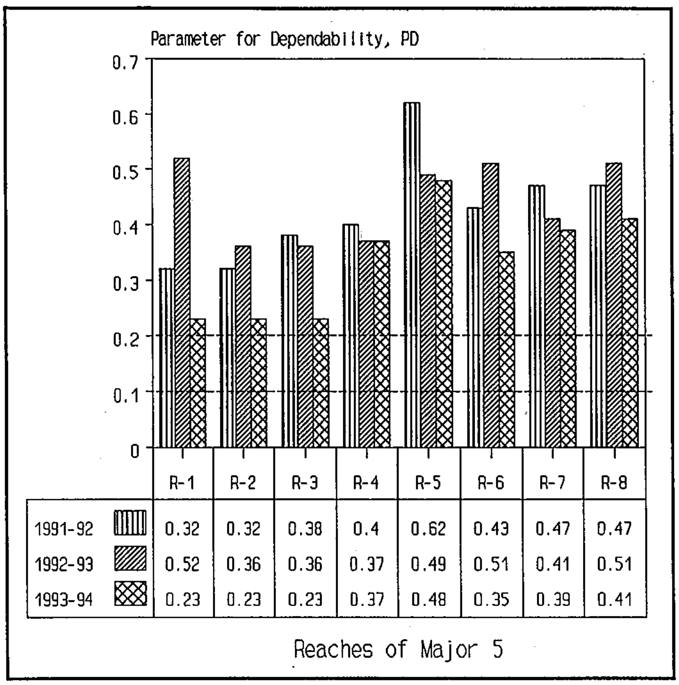
Figure 4.22. Over supply fractions.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
1991-92	2.69	0.81	4.12	0.47	0.25	0.45	1.49	1.32
1992-93	1.10	0.66	2.50	0.25	0.14	0.49	2.09	0.39
1993-94	1.48	1.23	1.23	0.27	0.12	0.88	1.36	0.61

Reaches of Major 5

Figure 4.23. Parameter for dependability derived on reach basis.



	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
1991-92	0.32	0.32	0.38	0.4	0.62	0.43	0.47	0.47
1992-93	0.52	0.36	0.36	0.37	0.49	0.51	0.41	0.51
1993-94	0.23	0.23	0.23	0.37	0.48	0.35	0.39	0.41

The seasonal values of the dependability parameter during the first, second, and third seasons are 0.43, 0.44 and 0.35, respectively. These average parameters all indicate that the distribution of water over time has been well below the desired levels. However, it is encouraging to note that there has been an improvement in the performance of certain reaches during the last monitoring season. With some additional attention, these very high levels of unreliability can be reduced.

The parameter for dependability, in the author's view, is more relevant for those locations where the irrigation systems are designed to deliver a fixed amounts but generally short-supplies without giving any consideration to the changing climatic conditions or the stage of crop growth. If a system is designed to meet irrigation requirements, supplies are usually more than needed, water is almost always available in the feeder canals which can be extracted at convenience, and the choice of crops does not rest with farmers; the low or high values of the parameter for dependability may not be very critical. In such settings, as is the case in Sudan, it is natural to expect such variations over time. In the later case, if the temporal variations in water delivery match in quantity and direction with those corresponding to the irrigation requirements, it should indicate a more dependable pattern for water supplies.

(c) Parameter for Equity of Water Distribution. The last index chosen is the parameter of equity (P_E) in the distribution of irrigation supplies. Figure 4.24 depicts different values of the parameter according to five selected months.

The above referred figure displays changes in the indicator over three years on a monthly basis. In each month, the parameter of equity, like the parameter for dependability, shows an unsatisfactory level of water distribution. The seasonal averages range from 0.49 to 0.67 which also confirm the same low performance levels. As a matter of fact, the spatial water distribution is worse than the performance indicated by the parameter for dependability.

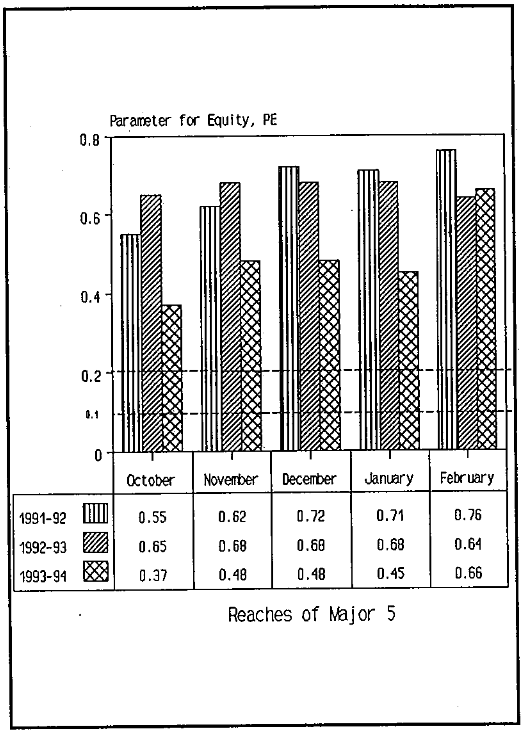
4.4.4 Agricultural Performance

Agricultural performance is described in two ways: (i) Production performance; (ii) irrigated area performance. The findings under both categories are presented as below:

(a) Yield Distribution Performance. The yield distribution performance is discussed under three categories: (i) acceptable distribution; (ii) dependable distribution; and (iii) even distribution. Parallel with water distribution, each category of the yield distribution parameters for production performance are derived as discussed in the methodology section. The results as displayed in Figures 4.25 and 4.26 are briefly discussed below:

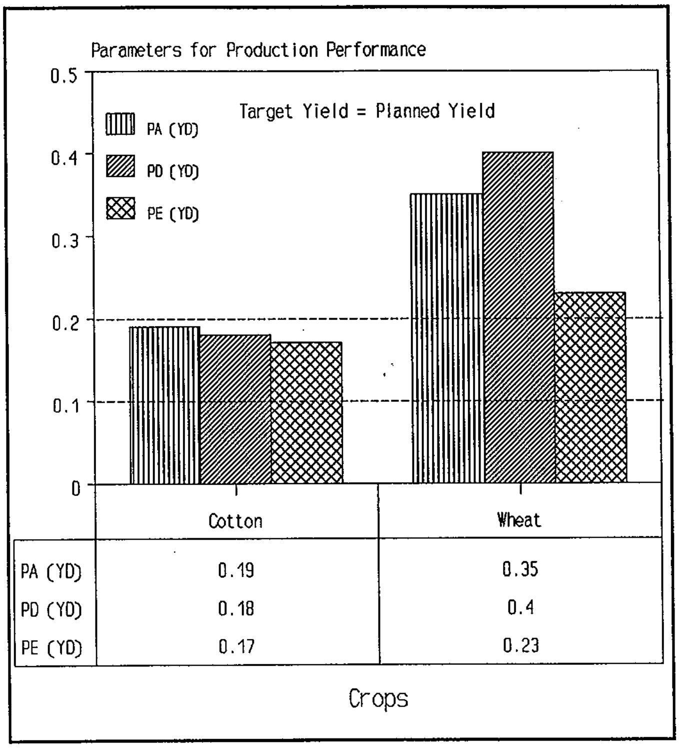
(b) Parameter for acceptable distribution of yields, $P_A(DY)$. When the target is taken as planned yields, the parameter values for cotton and wheat are found to be 0.19 and 0.35 respectively (Figure 4.25). According to the proposed standard, the acceptability level of the distribution of cotton yields falls in the fair category, whereas the same parameter for wheat indicates an unsatisfactory performance.

Figure 4.24. Parameters for equitable water distribution.



	October	November	December	January	February
1991-92	0.55	0.62	0.72	0.71	0.76
1992-93	0.65	0.68	0.68	0.68	0.64
1993-94	0.37	0.48	0.48	0.45	0.66

Figure 4.25. Agricultural production performance based on cotton and wheat crops.



	Cotton	Wheat
PA (YD)	0.19	0.35
PD (YD)	0.18	0.4
PE (YD)	0.17	0.23

The yield acceptability parameter is also derived by setting the target as potential instead of planned yields. In this case, the parameter for acceptable distribution of yields drops to an unsatisfactory level for both crops. However, as shown in the figure, the performance of cotton is relatively better than wheat.

(c) Parameter for dependable distribution of yields, $P_D(DY)$. This is a temporal coefficient of variation averaged over a selected region or locality. As the planned and potential yield remained the same during the study period, the parameter $P_D(DY)$ results are the same in both cases.

As shown in Figure 4.25, the parameter for cotton and wheat is 0.18 and 0.40, respectively. When these values are evaluated according to a proposed criterion, the performance for cotton is found to be fair, whereas wheat falls into an unsatisfactory category. This means that over a period of three years, variations in the cotton yields within the command area of Major 5 were not as drastic as was the case with wheat yields. The difference in the rate of change is more than double.

(d) Parameter for even distribution of yields, $P_E(DY)$. The parameter $P_E(DY)$ is selected to evaluate the spatial variability of cotton and wheat yields over the selected period of three years. Such a variability is quantified by using Equation 3 with appropriate changes as proposed in the methodology section. The resulting values of the parameter are exhibited in Figure 4.25, which are the same with either type of proposed target yields.

The difference in the values of $P_E(DY)$ for cotton and wheat is not much (i.e., 0.17 and 0.23) when compared with the resulting values for the other two parameters of yield distribution. Still, the performance of cotton is better than wheat.

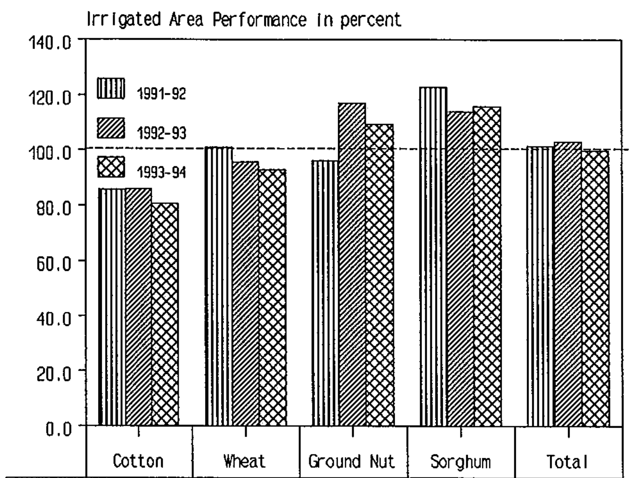
(ii) Irrigated Area Performance:

As recommended by Zhi (1989), the irrigated area performance for the Rahad scheme is simply outstanding. During the study period of three irrigation seasons, the index of area performance was either very close to 100 or more than 100 percent. An average for three years is 101.4 percent, which is higher than even planned. As all the crops are grown once in an irrigation season, the stated result also matches with the cropping intensity performance.

However, if the recommended area index is slightly adjusted to provide a relationship between the area irrigated under each crop and the target or allocated area for each crop, there are certain interesting trends to report. Figure 4.26 presents the irrigated area performance according to individual crops grown in the scheme.

In the scheme, cotton and wheat crops are perceived to be "official crops", whereas sorghum and ground nuts are considered to be "farmers crops". It is clear from the information exhibited in Figure 4.26 that there does exist a clear trend regarding the two categories of crops. Obviously, both cotton and wheat are well below their allocated share as against sorghum and ground nuts, which are grown over and above their due share. The only exception in this general statement is the allocated area under ground nuts during 1991-92, which was not fully availed. Perhaps it happened because of the introduction of wheat as a new crop in the scheme.

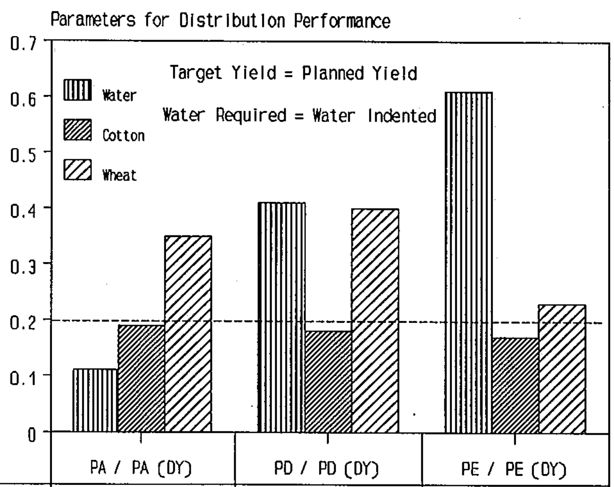
Figure 4.26. Irrigated area performance of the Rahad Scheme.



	Cotton	Wheat	Ground Nut	Sorghum	Total
1991-92	85.8	100.9	96.1	122.7	101.4
1992-93	86.0	95.7	116.9	113.8	103.1
1993-94	80.7	92.9	109.3	115.7	99.7

Irrigated Area under Crops

Figure 4.27. Comparison of water and yield distribution at Major 5.



	PA / PA (DY)	PD / PD (DY)	PE / PE (DY)
Water	0.11	0.41	0.61
Cotton	0.19	0.18	0.17
Wheat	0.35	0.4	0.23

Type of Performance Indicators

4.4.3 Comparison of Water and Yield Distributions

Figure 4.27 displays indices for water distribution and the corresponding yield distribution. These are average values of the selected parameters over the study period for the entire command of Major 5.

In the case of water, the parameter of adequacy (P_A) has minimum values when compared with other two parameters: P_D and P_E. However, they all indicate an unsatisfactory level of water distribution performance.

When the corresponding parameters for yield distribution are considered, cotton presents very encouraging results. All three parameters depict that the yield distribution of cotton is fair for all three aspects of performance. On the other hand, the same performance for wheat is not as promising as is the case with cotton. Moreover, parameters for acceptable yield distribution for both crops are categorized as unsatisfactory.

Spatial variability for water distribution is higher than the temporal variability or adequacy levels. On the contrary, the spatial variability in the distribution of cotton and wheat yields (P_E(DY) is the lower (although, the difference does seem to be significant) relative to the other two parameters.

From the above comparison, it is evident that no empirical conclusion can be drawn. However, it can easily be hypothesized that controlling the spatial and temporal variability in water distribution should improve adequacy in case of water and may help to achieve acceptable levels of the target yields in the scheme.

4.5 CONCLUSIONS

4.5.1 Water Distribution

(a) *Irrigation requirements, indents and supplies if arranged and analyzed according to control points mask sharp irregularities present in their actual distribution on reach basis. These deviations are very minimum in the case of irrigation requirements and maximum with irrigation deliveries. The variations associated with the indent placing fall in between the two extremes.*

(b) *The irrigation requirements vary with time in a very explicit manner: (i) maximum in October; (ii) about two-third of the October requirements in November; and (iii) almost one-third of the October requirements from December to February. Except for October, irrigation supplies delivered and indents placed are 0.6 to 2.4 times more than the irrigation requirements estimated for a period from November to February.*

(c) *If Reach Nos. 3 and 7 are dropped because of their flexible cropping pattern and a unique class of farmers, then the overall distribution of the water indents and irrigation supplies generally follow a reverse pattern.*

(d) *With the exception of 1991-92, irrigation supplies and indents during October are higher as compared to those recorded in February. However, this difference is almost half when compared with the changes in the irrigation requirements during the corresponding months.*

(e) *Averages over the study period on monthly basis suggest a reasonably good match between the water indents placed and irrigation supplies delivered. However, the same can not be said for the irrigation requirements.*

(f) *Averages over the study period on reach basis show that the distribution of indents, supplies and irrigation requirements widely differ from each other.*

(g) *When the water distribution patterns during October and January are considered according to the canal reaches, the MDRs and IIRs are distinctly higher during January as compared with those derived in October. This imply over supplies and over indenting during the later part of the season.*

(h) *There is no unique pattern followed if the water distribution during October and January based on SIRs is compared. However, these ratios are generally higher than 1 during the both periods except Reach Nos. 4, 5, and 6 commanding about 50 percent area of Major 5.*

4.5.2 Yield Distribution

(a) *Cotton yields are higher for the upper reaches and lower on the tail-end.*

(b) *Wheat yields have a slightly reverse trend as compared to one noted for cotton. In particular, the middle reaches have clearly higher yields than the rest.*

(c) *Yields of Cotton and wheat crops have dropped from 1991-92 onward. However, the drop in case of wheat is steeper than cotton.*

(d) *Planned YTRs for cotton indicate that, except for the last two reaches, the actual yields during 1991-92 met the planned targets. But during the last two seasons, there was not a single reach which was able to achieve the target yields.*

(e) *Planned YTRs for wheat also exhibit that, except for the three head and tail reaches, the target yields were accomplished during the first season (1991-92). Like cotton, during the last two seasons the actual wheat yields were far below the planned mark.*

4.5.3 Water Distribution Performance

(a) *The parameter for adequate water distribution, P_A, for almost all of the canal reaches fall in either good or fair category with the following exceptions: (i) Reach No. 5 throughout the study period; and (ii) Reach No. 6 only in 1991-92.*

(b) *The canal reaches which achieved fair to good adequacy levels also show higher over supply fractions implying a real potential for the surface waterlogging in the area.*

(c) *The parameter for dependable water distribution, P_D, suggest unsatisfactory performance throughout the study period for the all canal reaches. However, there is a trend for improvement from 1991-92 onward(it might have happened because of the on-going long-term monitoring activity).*

(d) *The traditional approach suggested for a dependable water distribution does not seem to be applicable in the context of Sudan. There is a need to modify the measure for one context to another.*

(e) *The parameter for equitable water distribution, P_E, exhibits a very unsatisfactory level of performance during the entire study period. Such a low performance in the context of an equitable distribution indicate a serious water distribution problem from reach to reach in the command area of Major 5.*

4.5.4 Yield Distribution Performance

(a) *All three parameters for the production performance based on planned YTRs; $p_A(DY)$, $P_D(DY)$, and $P_E(DY)$; show that the overall performance for the cotton yield distribution is better as compared with wheat. However, if the performance is based on potential YTRs, the resulting yield distribution is unsatisfactory in both cases.*

(b) *The irrigated area performance is termed to be excellent: almost 100 or more than 100 percent in the study period.*

4.6 RECOMMENDATIONS

4.6.1 Provisions for Improving the Water and Yield Distribution

(a) *Between the Rahad Irrigation Operations (MOI) and the Rahad Agricultural Corporation (RAC), a mutually accountable system of water distribution along major canal be devised and implemented.*

(b) *Between the Rahad Agricultural Corporation and farmers, a mutually accountable system for water distribution should be formulated and followed.*

(c) *Water distribution at the tertiary level should be systematized.*

(d) *A precision land levelling activity should be made a part of the activity of land preparation.*

(e) *Field reshaping should be considered to increase the working head of the advancing water front on the ground.*

(f) *Furrow irrigation should be reconsidered with a head dike by replacing siphons in order to reduce extra head requirement for diverting water from tertiary canal to furrows.*

(g) *The canal control structures should be calibrated to use them as tools for the flow measurement.*

(h) *The prevalent problem of the surface waterlogging must be recognized and addressed as soon as possible.*

(i) *The facility for the surface drainage should not be restricted to rain water only; it should be extended for draining of surplus water from the fields.*

(j) *Water indents and irrigation supplies should be made to correspond with the irrigation requirements.*

4.6.2 Facilities for improving the Water and Yield Distribution

(a) *In order to provide accountability in delivering and receiving irrigation water at different control points along canals, the following arrangements may assist:*

(i) *all the gated control structures should have gauges to monitor gate openings, upstream, and downstream water levels; and*

(ii) *simple and practical guides such as nomogram (like the one exhibited by IIMI-Sudan at the head of Major 5) should be provided at different control points. This should help to improve the quality of canal operations and to provide a common ground for a meaningful dialogue between the RAC and MOI.*

(b) *Communications along major canals should be strengthened by providing suitable equipment, such as walkie-talkies, to the gate operators.*

(c) *logistical problems of the field staff should be addressed.*

(d) *A financial incentive system should be considered for improving the water and yield distribution in the area.*

4.7 REFERENCES

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APPENDIX

Table A-1. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during October, 1991.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	4.7	4.2	4.6	4.2	4.1	4.2	4.4	4.3
Indents	2.5	3.0	5.0	3.4	4.2	3.0	2.1	1.1
Supplies	4.8	4.0	4.7	2.6	2.2	0.9	3.6	1.7

Table A-2. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during October, 1992.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	4.2	4.4	4.2	4.2	4.3	4.2	4.4	4.3
Indents	5.2	5.40	11.5	3.3	2.4	4.2	8.0	3.9
Supplies	3.8	4.6	11.5	3.3	2.4	4.2	8.0	4.3

Table A-3. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during October, 1993.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	4.3	4.3	5.3	4.5	4.4	4.2	4.4	4.3
Indents	3.2	7.3	11.2	6.9	5.9	5.5	6.7	5.8
Supplies	6.6	7.3	11.2	3.9	2.5	5.7	5.1	6.0

Table A-4. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during November, 1991.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	2.5	2.5	2.6	2.4	2.5	2.4	2.5	2.4
Indents	4.2	3.7	5.2	5.0	6.0	6.0	3.6	4.3
Supplies	4.5	4.5	11.8	2.5	2.3	3.3	4.6	4.0

Table A-5. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during November, 1992.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	2.5	2.5	2.4	2.3	2.5	2.4	2.3	2.4
Indents	3.6	2.6	4.4	4.5	4.4	3.2	4.1	2.6
Supplies	4.0	3.2	4.2	2.5	1.8	2.9	7.2	2.6

Table A-6. Crop water irrigation requirements, indents, and supplies according to eight reaches of Major 5 during November, 1993.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	2.4	2.4	2.6	2.5	2.6	2.4	2.6	2.4
Indents	3.0	4.2	4.2	5.0	3.9	3.6	6.8	2.7
Supplies	5.1	5.7	4.1	2.9	1.7	4.7	6.9	3.6

Table A-7. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during December, 1991.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	1.1	1.4	1.1	1.3	1.4	1.3	1.2	1.2
Indents	3.3	4.5	4.1	3.8	5.0	5.6	4.2	5.3
Supplies	5.5	3.6	8.0	2.6	1.3	2.0	4.9	4.2

Table A-8. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during December, 1992.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	1.6	1.5	1.6	1.5	1.6	1.5	1.4	1.6
Indents	3.4	3.5	3.3	4.7	4.3	3.9	4.1	4.8
Supplies	3.7	3.4	10.8	2.1	1.5	3.6	5.0	3.5

Table A-9. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during December, 1993.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	1.6	1.6	1.1	1.5	1.8	1.7	1.7	1.6
Indents	3.3	4.0	3.2	4.4	3.5	2.9	3.4	3.2
Supplies	4.5	4.3	10.5	2.2	1.4	4.2	4.6	3.8

Table A-10. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during January, 1992.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	0.8	1.4	1.0	1.4	1.5	1.4	1.2	1.3
Indents	2.7	2.6	2.9	2.0	4.4	3.8	2.0	3.7
Supplies	4.4	2.6	6.2	2.1	1.9	2.0	3.9	3.0

Table A-11. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during January, 1993.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	1.6	1.5	1.7	1.6	1.5	1.6	1.3	1.6
Indents	2.7	3.2	2.8	3.4	4.5	3.9	4.6	4.1
Supplies	4.8	2.4	6.08	1.7	1.9	1.8	5.6	1.5

Table A-12. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during January, 1994.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	1.6	1.6	0.6	1.4	1.6	1.7	1.7	1.6
Indents	2.6	3.8	2.8	4.0	3.3	2.6	1.7	3.0
Supplies	4.8	3.5	5.8	1.7	1.7	3.0	3.4	2.5

Table A-13. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during February, 1992.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	0.9	1.6	1.1	1.5	1.7	1.6	1.3	1.5
Indents	2.2	3.5	2.3	2.7	5.4	5.8	2.4	3.6
Supplies	4.7	2.7	6.9	2.1	2.0	2.6	2.5	3.8

Table A-14. Irrigation requirements, indents, and supplies according to eight reaches of Major 5 during February, 1993.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	1.7	1.5	1.8	1.7	1.6	1.7	1.4	1.7
Indents	2.8	3.7	2.9	3.0	4.3	3.3	4.0	4.7
Supplies	3.4	2.5	4.2	2.0	1.2	1.4	4.0	1.4

Table A-15. Irrigation requirements[22], indents, and supplies according to eight reaches of Major 5 during February, 1994.

Crop water Requirements (CWR), Indents and Supplies (mm/day)								
Reaches	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8
CWR	1.8	1.8	0.4	1.6	1.7	1.9	1.7	1.9
Indents	2.6	3.0	2.8	3.7	3.3	2.8	2.2	2.9
Supplies	5.2	1.7	4.1	1.6	2.0	3.0	4.8	1.2

[22]Irrigation requirements and crop water requirements are used interchangeably in this paper.