CHAPTER 2

Performance of the Gezira Canals

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2.1 BACKGROUND

2.1.1 Sudan

In terms of area, Sudan is the largest country in Africa (Figure 1). Its population in 1992 was estimated around 26.7 million and its total area is 250.6 million ha (EIU and FAO). The annual rate of population growth is 2.8 percent (Zaki 1992), annual GDP growth is 2.0 percent (EIU) and per capita annual income is estimated at $300 (PCGLOBE Software 1989).

The agriculture sector of Sudan accounts for 38 percent of GDP and provides employment to about 80 percent of the country's population. The sector contributes about 98 percent of total foreign exchange. According to Zaki(1992), the sector has the following four sub-sectors: (1) irrigated agriculture-1.68 million ha (FAO source reports 1.89 million ha is a better estimate); (2) mechanized rain-fed agriculture-2.52 million ha; (3) traditional rain-fed agriculture-4.2 million ha; and (4) livestock. After excluding livestock, the estimated contributions of the irrigated and rain-fed sub-sectors are about 45 and 55 percent, respectively.

2.1.2 Irrigation Schemes

At present, the total area within the irrigated sub-sector is about 1.89 million ha. The Gezira-Managil scheme alone occupies 0.882 million ha. Other major public sector schemes are New Halfa (0.151 million ha), Rahad (0.126 million ha), and Blue and White Nile Schemes (0.269 million ha). There are five sugarcane schemes with a command area of about 0.1 million ha. Other small irrigated public schemes are Es Suki (33.6 thousand ha), Abu Nama (12.6 thousand ha), and Northern Agricultural Production (NAPC) schemes (38.6 thousand ha). There are two main schemes outside of the Nile system: Gash and Tokar.

The private sector consists mainly of pump schemes, which are concentrated in the north. The estimated irrigated area in this sector is about 0.19 million ha (pre-mission working paper of the World Bank office in Khartoum, 1988).

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2.1.3 The Gezira Scheme

The Gezira Scheme is huge in size and dominates the entire irrigated sector of Sudan. It is approximately 47 percent of the entire total irrigated area of Sudan and also the largest single management scheme in the world. It has been the backbone of the Sudanese economy: its share to total agricultural GDP is estimated to be 35 percent (Plusquellec 1990).

The Gezira Irrigation Scheme (0.882 million ha) is mainly gravity fed and lies between the Blue and White Niles south of Khartoum (Levine and Baily 1987). As shown in Figure 2, the irrigation system of the scheme is a huge network of main, major, minor and tertiary canals[4].

According to Plusquellec (1990), the following are the main features of the conveyance and distribution system of the scheme:

- *2 main canals of total length of 261 km with conveyance capacity ranging from 168 and 186 m^3/s at headwork to 10 m^3/s at the tail;*

- *11 branch canals of total length of 651 km with conveyance capacity ranging from 25 to 120 m^3/s;*

- *107 major canals of total length 1,652 km with a carrying capacity ranging from 1.5 to 15 m^3/s;*

- *1,498 minor canals of total length of 8,119 km with a delivery capacity ranging from 0.5 to 1.5 m^3/s;*

- *29,000 water courses called "Abu Ashreens" (Abu XX) of total length of 40,000 km with 116 l/s capacity; and*

- *350,000 field channels called "Abu Sitta" (Abu VI) of total length of 100,000 km with 50 l/s capacity.*

All canals have cross-regulators[5] which serve as *control points* (*CPs*) for off-taking canals. The stretch of canal between two regulators is called a *reach*. A segment of a canal comprising two or more reaches is defined as a *section*.

The above conveyance and distribution system is the one which is targeted here for assessing and quantifying the hydraulic performance in comparison with its design objectives. This paper, therefore, only deals with a selected portion of the physical system of Gezira Scheme. By making use of reliable existing secondary data, an effort is made to evaluate the system.

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[4]In Sudan, major, minor and tertiary canals are called Majors Minors and Abu Ashreens respectively.

[5]Cross-regulators are of the following kinds: (i) Sluice gates, (ii) Pipe-regulators, and (iii) Butcher's weirs.

2.1.4 Why the Gezira Canal System?

The International Irrigation Management Institute (IIMI) established its field office in Sudan in the middle of 1989. Over the last more than four years, the Institute has brought the national and international experience to the doorstep of policy-makers and managers responsible for irrigated agriculture. To achieve this objective, dozens of seminars and workshops have been organized at different locations.

Field research is being conducted at two main locations: (1) the Rahad irrigation scheme where the performance of a selected canal system has been monitored over the last two years; and (2) the White Nile pump schemes with a focus on the comparison of different management modes introduced after the privatization of many pump irrigated schemes. Limited technical assistance has also been provided to the Kenana Sugar Company near Kosti.

For the Gezira Scheme, which is the largest and the forerunner of all major schemes in this country, IIMI's contribution was confined to the level of on-farm water management only. A senior advisor from IIMI remained associated with the Water Management Advisory Unit (WMAU) from 1990 to 1992. His main responsibility was to establish the Unit and provide training and technical assistance to the field staff of the scheme. According to the terms and conditions of his job, he concentrated more on water management issues below the field outlet pipe (F. O. P).

It is also well known that over the last 68 years of its existence, the Gezira scheme has been studied more than many schemes in the world. There is a long list of research papers, theses, reports and books written about the scheme. In other words, there exists a rich source of secondary data which can be exploited. The main irrigation system, however, did not receive enough attention till the 1980's.

2.1.5 Importance of Secondary Data

At many occasions, the management of IIMI and its many supporters have stressed the importance of making use of existing data in the field of irrigated agriculture. The proponents of this view feel that in many developing countries there exists a lot of data and literature which can easily be analyzed and reviewed to learn useful lessons. Also, reports based on such information provide cost-effective and faster means of knowledge generation and dissemination to many stakeholders.

In certain cases, financial difficulties hinder proper dissemination of generated information to all parties concerned. Due to such factors, information generated and reports written by national agencies, with or without outside help, stay confined to a few deep pockets. This restricted circulation of research findings deprives many researchers their due share of reward and recognition and others to benefit from it.

2.1.6 Source of Secondary Data

Although the Gezira scheme has been studied extensively, the main focus always remained on the on-farm activities. Farbrother, an FAO consultant, who spent more than a decade and half in Sudan is considered to be an authority on soils, crops and on-farm water management practices in the scheme. He contributed dozens of research papers, technical notes and reports. Farbrother's work is very much acknowledged and appreciated in Sudan. There are countless other researchers who contributed their share to enrich the knowledge about the scheme. However, in the past, the main conveyance and distribution subsystem attracted very little attention from many of the researchers and the focus remained on the on-farm subsystem.

In the 1980s, there came a pleasant change. The policy-makers and researchers started undertaking studies about the main conveyance and distribution system of the scheme. Partly, this change can be attributed to the rehabilitation program for the Gezira and Managil scheme which was initiated at that time.

After securing necessary research funds from the Gezira Rehabilitation Project, the Hydraulic Research Ltd, Wallinford, and Hydraulic Research Station, Wad Medani (MOI) conducted a collaborative research study in the scheme. The secondary data which will be used in this paper comes from a report entitled as *"Research for Rehabilitation: Study of the Reliability of Water Supply to Minor Canals."*

From this point onward, the report about the reliability of water supply to minor canals will be referred to as the *Main Data Source Report (MDS-Report 1991).* The data used in this paper is mainly tabulated in the second volume of the report.

2.1.7 Objectives

The design considerations for the Gezira canal system were to convey and distribute adequate, equitable and reliable water supplies regardless of time and location in the scheme. In line with the design criterion, the objective of this study is to *quantify the extent to which design objectives are achieved by assessing the hydraulic performance of the Gezira irrigation system under the following three categories: (i) Conveyance of Water Supplies, (ii) Utility of Water Supplies, and (iii) Maintenance of the Irrigation System.*

2.2 LITERATURE REVIEW

In this section, the following topics will be briefly covered:

1. Concept of performance.
2. Design objectives.
3. Variables required in the control of a conveyance and distribution system of the Gezira scheme.
4. Performance indicators which can use selected water control variables to determine the extent to which design objectives are achieved.

2.2.1 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 for this definition of performance as a guideline for the 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-Rurst and Snellen (1992) have commented that the above definition (by Abernethy 1989) is output oriented only. According to them, the definition totally disregards the resources utilized, and the environmental impacts in achieving the level of outputs.

Perhaps 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 system itself and on its external environment."*

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

In this study, the performance monitoring is restricted to a component of an irrigation system generally called the main system. As dictated by the availability of secondary data, the focus is only on reporting the operating status of the main conveyance and distribution system. By no means was there any intention to ignore the importance of the on-farm part of the subsystem.

2.2.2 Design Objectives

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

1. No field irrigation at night was possible.

2. Disposal of water in excess of actual requirements was not possible after it had left the main canal.

3. Under the terms of agreement, actual requirement of the cultivating syndicate had to be satisfied.

4. Measurements of water under varying conditions and levels were necessary.

Similarly, Taj el Din et. al. (1982) also stated that the design of the operating system is to deliver the required quantities 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 (the dam serving the canals) is adequate for (satisfying) crop water requirements and the effective control of the water ensures that sufficient water is delivered at the correct time to the cultivators."*

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

Johnstone (1926) also reports that the scheme was originally designed for continuous irrigation. However, at the time of construction, the difficulty of irrigation by night was raised, which made it necessary to adopt a night storage system. A report by Euroconsult (1982) further elaborates on the irrigation management practices as follows: " ... *block inspector and his staff have to operate the regulators between the successive reaches in such a way that distribution to tenants from head to tail in the minor is as equitable as possible irrespective of their locations on the minor. The equitable distribution can be obtained by relative opening of the gates in the night-storage weirs and the (partial) opening or closing of the FOPs (field outlet pipes)."* It is also quite clear that in order to have equitable water distribution at the Minor level, the main and major canals have to supply equitable water supplies to these minor canals.

The above discussion helps to identify the following design objectives:

(1) adequacy;

(2) dependability;

(3) equity; and

(4) operational effectiveness to achieve adequate, dependable and equitable water distribution.

2.2.3 Variables for Water Control

The selection of the variables is based on the data presented in the original report. According to this report, the variables are as follows:

1. Indents prepared by the SGB.

2. Crop water requirements.

3. Authorized releases (as determined by officials).

4. Actual deliveries.

As this paper is based on the referred MDS-Report (1991), the above variables will be used in deriving performance indicators for the selected Gezira canals.

2.2.4 Performance Indices

2.2.4.1 Hydraulic Performance Indicators

In order to establish the extent to which design objectives are being achieved, the above stated water control variables will be used to identify performance indices. The first set of such indices is taken from the Main Data Source Report(MDS-Report 1991) as given below:

1. Indent/Requirement Ratio (IRR): a measure of the accuracy of the indenting process and the assessment of demand (R1 in MDS-Report 1991).

2. Authorized Release/Indent Ratio (AIR): a measure of the adjustment of the indents (R2 in MDS-Report 1991).

3. Actual Delivery/Authorized Release Ratio (SAR): a measure of performance of the distribution system (R3 in MDS-Report,1991).

4. Management Delivery Ratio, Actual Delivery/Requirement (MDR): a measure of the performance of the whole process (MDR in MDS-Report 1991).

5. Reliability: the portion of the season during which performance is acceptable. This is equivalent to the probability that a given performance parameter, for example R3, lies within an acceptable range."

However, in MDS-Report (1991) there is no mention of any measure for an equity parameter. As a matter of fact, this aspect of water distribution was not considered in the report referred to at all.

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

Adequacy: A fundamental objective of irrigation systems in Sudan is to deliver the amount of water required to crops. To quantify the adequacy achieved, the authors have defined P_A[6] as

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

and

[6]Attached figures show P_A as PA.

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

$$P_a = 1 \quad otherwise\text{--------}(1c)$$

Where $P_a = Q_d/Q_r$ is the ratio of water delivered over water required. In the context of Sudan, the water demand can be either crop water requirements or indents placed. Equation 1 implies that Q_d and Q_r are defined for discrete locations where water is conveyed in a region R at finite time intervals within a period T.

Molden and Gates (1990) also proposed that a P_a value more than 0.9 is assumed to be good, between 0.8 to 0.9 fair, and below 0.8 poor (unsatisfactory as used in this paper).

When requirement provides the basis for a target discharge, the *Management Delivery Ratio (*MDR) is the same as the *Delivery Performance Ratio (DPR)* as defined by Bos et al. (1993) and Rao (1993). *Water Delivery Performance, WDP,* also provides similar information. Baily and Lenton (1984) described WDP as:

$$WDP = \frac{1}{n}\sum_{t=1}^{t=n} \frac{V(t)}{V^*(t)}$$

where V(t) is the total volume of water entering the headworks of the irrigation system during period t, $V^*(t)$ is the total target volume to be supplied in period t, and n is the number of periods in the cropping season. The authors have suggested the following condition for the above equation of WDP:

$$V(t) \leq V^*(t)$$

Supply-Indent Ratio (SIR) is another indicator presented by Shafique et. al (1993) for assessing adequacy in the context of Sudan. As the indented water quantities are the targets to be achieved, *SIR* also quantifies the conveyance or delivery performance of an irrigation system such as the Gezira System.

It is important to note that *MDR / DPR or SIR* are basically Q_d/Q_r where Q_d stands for an actual delivery and Q_r being a target discharge defined as per plan. Obviously, either such indicator can be an input to derive P_a and P_A as described by Eqs. 1a to 1c.

Levine (1982) has described the *Relative Water Supply (RWS)* as the most complete indicator for adequacy. The measure can be explained as below:

$$RWS = \frac{Irrigation + Rainfall}{Evapotranspiration + Seepage + Percolation}$$

As used in the MDS-Report (1991), the same parameter, RWS, is stated as *the ratio of irrigation and effective rainfall to canal water requirements.* The slight deviation from the standard definition of the index appears to have happened because seepage and percolation losses in Sudan are considered to be almost negligible. In the same context, when the measure is calculated for the normal growing period with very little rainfall, the resulting values are almost the same as given by MDR. Sakthivadivel et al. (1993) have proposed a cumulative relative water supply indicator (CRWS) with special reference to systems irrigating rice. Its usage for upland crops is yet to be tried.

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

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

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

Molden and Gates (1990) presented a performance standard for P_D[7] as given below:

P_D 0.0 to o.1--good,

P_D 0.11 to 0.2--fair, and

P_D over o.2--unsatisfactory.

Bos et al. (1993) have selected the following indicator of *Overall Reliability (O.R)*:

$$O.R = \frac{Volume\ Delivered}{Target\ Volume} \times \frac{Actual\ Duration\ of\ Supply}{Target\ Duration\ of\ Supply}$$

The above equation implies that if actual and target values are the same, then the parameter becomes one. This should also mean that the best indication of an overall reliable or dependable supply is the unit value of the index. However, the index would also become one if, for example, the actual volume is half of the target volume and the actual duration is double that of the target duration. For example, the Gezira Irrigation System is supposed to irrigate a total area of 37.8 ha (called ***Number*** or field of 90 feddans in the scheme) at a rate of 5000 M^3/day for 7 days. However, under an inequitable water distribution scenario, the same area gets irrigated within 14 days due to a low supply rate of only 1250 M^3/day. In such a case, the index of reliability may give a misleading indication.

Equity: As defined by Mohammed (1987), it indicates the ability of a system to uniformly deliver water. Molden and Gates (1990), and Kuper and Kijne (1992) have suggested the following performance indicator, P_E[8], for equity:

[7]Attached figures show P_D as PD.

[8]Attached figures show P_E as PE.

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

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

In this case, Kuper and Kijne (1993) have proposed that the performance should be taken to be 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.

Abernethy (1986) has proposed a relatively simple indicator, *Modified Inter-quartile Ratio (Modified IQR)*, for a quick view of overall equity. The index is based on DPR (or MDR) with the following interpretation:

$$ModifiedIQR = \frac{Average\ DPR\ of\ best\ 25\%\ of\ the\ system}{Average\ DPR\ of\ worst\ 25\%\ of\ the\ system}$$

For assessing equity of water distribution at canal levels, Vander Velde (1991) has suggested looking at the head-tail differences. The *Head:Tail Equity Ratio* (HTER) is expressed as:

$$Head\!:\!TailEquityRatio = \frac{Average\ DPR\ of\ upper\ 25\%\ of\ the\ system}{Average\ DPR\ of\ Tail\ 25\%\ of\ the\ system}$$

2.2.4.2 Maintenance Indicators

Bos et al. (1993) have described the following measures for maintenance performance:

$$Efficiency\ of\ Infrastructure = \frac{Number\ of\ Functioning\ Structures}{Total\ Number\ of\ Structures}$$

Another important indicator suggested by the same authors is aimed at assessing the impact of sedimentation and erosion on the physical irrigation system. The index, *Water Surface Elevation Ratio (WSER)*, relates actual and target water surface elevations at full supply level (FSD):

$$WSER = \frac{Actual\ Water\ Surface\ Elevation\ at\ FSD}{Target\ Water\ Surface\ Elevation\ at\ FSD}$$

2.3 METHODOLOGY

2.3.1 Measurement Locations

The main data source report is based on information collected during two irrigation seasons: 1988-89 and 1989-90. The HRS and HR Wallingford decided to monitor a network of sites across the Gezira scheme.

Three major canals were chosen to document performance levels at the head, middle and tail areas of the Gezira main canal. Zanda (abbreviation of Zananda), Gamusia and Kab El Gidad (KEG) are the head, middle and tail Majors, respectively. The head Major obtains water from the main pool at Kilo[9] 57 (main pool) and not the Gezira main canal, which has the same source. The middle major canal has its offtake at Kilo 114 of the main Gezira canal. The tail Major receives its share from the main canal at Kilo 194. On each major canal, three minor canals located at the head, middle and tail sections were selected. Figure 1-C provides a schematic layout of the selected canals.

2.3.2 Data Collection

During the two irrigation seasons, 1988-89 and 1989-90, monitoring started on 1 July and ended on 10 March. This exercise included direct measurements, such as monitoring of sluice gates, movable weirs, fixed crest weirs and well head regulators; and indirect information about indents, authorized supplies and planting dates and areas of crops. The latter information was needed to calculate crop water requirements for the selected command areas. Using head-discharge relationships, the direct measurements were converted into actual supplies at different selected control points.

The entire information is tabulated in the MDS-Report (1991) by averaging the values of the selected variable on a bi-weekly basis (total of 19 readings each season i.e., 38 weeks). The Volume 2 of the MDS-Report (1991) presents a set of monitored data about the Gezira main canal and its 3 Majors and 9 Minors. Also, actual and authorized discharges at the heads of four Managil canals were recorded regularly.

2.3.3 Use of the Secondary Data

As the recording of actual supplies of the Gezira main canal started from 28 August during the first irrigation season, the monitored data for all of the selected canals were considered only from that date onward. This implies that the information from 1 July to 28 August 1988 recorded at other canals was not included in the analysis of the secondary data. As the irrigation requirements are abnormally low and unpredictable just after the planting time (July and August) due to minimum crop-water needs and rains, ratios such as MDR become too high to be used in determining an average trend during the normal growth period anyway.

Towards the maturity stage of the main crops (mid-February to March) water demand drops causing MDR to become explosive, so that the last two bi-weekly readings during both seasons were also dropped (i.e. only normal growth periods were considered). During the second irrigation season (1989-90), as the rainfall was very low and actual supplies to the main canal were monitored from 1 July, only the first bi-weekly information was dropped.

Although during the second season, the bi-weekly information was considered from 15 July 1989-90, still a couple of MDRs for the Minors at the head of the Major became too abnormal in the third week of August due to rain. These corresponding data points were also ignored. However, the stated difficulty

[9]Km in Sudan is commonly referred as Kilo.

suggests that MDR is an erratic ratio which should be used carefully to avoid misleading results. In this context, perhaps the Supply-Indent Ratio proposed by Shafique et al. (1993) seems a relatively safer index in the context of Sudan.

2.3.4 Indicators Selected for Analysis

The following indicators as presented in the literature review can be adopted either as such, or with some modifications, for evaluating the hydraulic performance of the selected Gezira irrigation system according to the following three categories:

A. *Conveyance of Water Supplies*
(1) Management Delivery Ratio (MDR)
(2) Supply-Indent Ratio (SIR)
(3) Supply-Authorized Release Ratio (SAR)

B. *Utility of Water Supplies*
(1) Parameter for adequacy, P_A (Eqs. 1a to 1c)
(2) Parameter for dependability, P_D (Eq. 2)
(3) Parameter for equity, P_E (Eq. 3)
(4) Modified Inter-quartile Ratio
(5) MDR and SIR

C. *Maintenance of System*
(1) Water Surface Elevation Ratio (WSER)

Also, there are some additional indicators that could be adopted, which would further help to develop an understanding for the performance of the Gezira Irrigation System. These measures are either being proposed for the first time, or derived from the ones listed above. These indices are also grouped into three categories:

A. *Conveyance of Water Supplies:*

A general conveyance indicator is used to evaluate the conveyance performance of the Irrigation Operation Department of MOI responsible for the Gezira Scheme as:

$$Conveyance\ Index\ (CI) = [MDR\ /\ SIR\ /\ SAR]_{period} - 1$$

In this case, the ratio of actual and target supply could be either of the following indicators: MDR, DPR or SIR, etc. The selection of any particular indicator will depend on the way that the target supply is defined. In this report, the following arbitrary criteria based on CI is used to describe the level of conveyance performance in the Gezira Scheme:

0.0 to 0.1 = Excellent
0.11 to 0.2 Or 0.0 to-0.05 = Good
0.21 to 0.3 Or-0.06 to-0.10 = Fair
> 0.3 or less than-0.10 values = Not satisfactory

B. *Utility of Water Supplies:*

(1) Parameter for adequacy concerning an individual locale (PAI). The value of the index is derived by taking
R = 1 in Eq. 1a. Two other equations, Eqs. 1b and 1c, will be used as such for calculating PAI[10]. It is interesting to note that PAI becomes similar to WDP.

(2) Parameter for dependability regarding an individual locale (CVt). The index is derived by considering R = 1 in Eq. 2.

(3) Depending upon the choice of conveyance indicators, an *equity ratio for head and tail (ERHT)* components of a distribution sub-system is defined as:

$$ERHT(MDR) = \frac{\frac{1}{n}\sum_{t=1}^{t=n} MDR_{Head}}{\frac{1}{n}\sum_{t=1}^{t=n} MDR_{Tail}}$$

$$ERHT(SIR) = \frac{\frac{1}{n}\sum_{t=1}^{t=n} SIR_{Head}}{\frac{1}{n}\sum_{t=1}^{t=n} SIR_{Tail}}$$

$$ERHT(SAR) = \frac{\frac{1}{n}\sum_{t=1}^{t=n} SAR_{Head}}{\frac{1}{n}\sum_{t=1}^{t=n} SAR_{Tail}}$$

where t is the time period and n is the number of periods monitored. The choice of conveyance indicator may depend on availability of data and preferences, etc.

[10] PAI is quite similar to WDP (Baily and Lenton, 1984).

It is desirable that researchers and irrigation managers of a particular irrigation system should jointly decide some ranges for ERHT to categorize results as excellent, good, fair or unsatisfactory. However, for this paper, an arbitrary set of such limits is proposed:

0.9-1.1	Excellent
0.8-0.89 and 1.11-1.20	Good
0.70-0.79 and 1.21-1.3	Fair
Less than 0.7 or more than 1.3	unsatisfactory

Note: In some cases, it is possible to expect ERHT less than 1 at certain stages of an irrigation season. Such a situation may be unique but possible. For example, tail reaches of many systems in Sudan, contrary to the official position, are used to dispose of excess water.

C. *Maintenance of System:*

(1) *Water Surface Status (WSS)*: The index is defined by measuring actual water surface at peak discharge, or mean water level recorded in a period from a reference point fixed at a unit depth below the full supply level. A value of the measure less than one is likely to indicate an erosion problem or over-capacity of a canal resulting from imprecise dredging or cleaning activity. If, on the other hand, WSS is more than one, then it is possible to have a rise caused by siltation and / or weed infestation in a canal.

(2) *Supply-Designed Capacity Ratio (SDR):* This measure can be used to determine the extent to which seasonal or periodic actual supplies compare with designed canal capacities. If the ratios for two or more seasons, along with those determined during maximum demand periods, stay low, it may indicate a maintenance problem. As actual supplies at the heads of many canals are usually recorded, the proposed measure seems a very convenient and cost-effective tool.

(3) *Authorized Release-Designed Capacity Ratio (ADR):* In some countries, information regarding authorized releases may not be available. However, for a country like Sudan, such practice is an essential part of canal operations. If ADR values are low, it may indicate a possibility of excessive siltation or vegetative growth in a canal. This assertion is based on the hypothesis that field officials responsible for canal operations usually give serious consideration to the existing canal capacities in determining authorized releases for different canals.

2.4 DATA ANALYSIS AND DISCUSSION

This section provides results by analyzing the secondary data in the form of indicators about the hydraulic performance of the selected canals of the Gezira scheme. These indicators are presented under the three performance categories described earlier. Under each grouping of indicators, a discussion furnishes the author's explanation of the results. At first, each component of the main system is discussed separately by analyzing the data based on: (I) control points (CPs); and (ii) sections. In the case of Gamusia, middle Major, the analysis is also extended to different canal reaches. This follows with a comparison of different levels of the system. At the end, these results for the Gezira main canal system are compared with one in Pakistan studied by Kuper and Kijne (1992).

2.4.1 Conveyance of Water Supplies

2.4.1.1 Conveyance Index (CI)

A. Main Gezira Canal

Table 2.1 below presents a summary of results for the main Gezira canal. The conveyance index, CI, is calculated based on MDR values collected at the head, middle and tail control points. The data are also analyzed based on head middle and tail sections.

Table 2.1. The Conveyance Index for the Main Gezira Canal.

Location/ Position	Type of Values	1988-89		1989-90	
		CP-based	Section	CP-based	Section
HEAD	Maximum	0.16	0.78	1.17	2.80
	Minimum	-0.38	-0.39	-0.30	-0.26
	Seasonal	-0.05	0.12	0.10	0.47
MIDDLE	Maximum	0.09	0.10	0.63	0.66
	Minimum	-0.41	-0.40	-0.45	-0.45
	Seasonal	-0.20	-0.19	-0.15	-0.16
TAIL	Maximum	0.10	0.10	0.31	0.31
	Minimum	-0.61	-0.61	-0.47	-0.47
	Seasonal	-0.34	-0.34	-0.09	-0.09

Note: CP stands for control point.

The main canal serves a total command area of about 414,400 ha. As the information collected at a control point pertains to the entire downstream stretch of a canal, the seasonal result at the head control point, Kilo 57, gives an average CI of -0.05 and 0.10 during 1988-89 and 1989-90, respectively, for the whole Gezira main canal. These values, as per the proposed criteria for evaluation, suggest that the conveyance performance is good to excellent. This also implies that the actual releases at the head gate quite well match with crop-water requirements.

As one moves away from the head to the middle and tail control points, the seasonal conveyance performance deteriorates. At the middle, Kilo 114, and the tail, Kilo 194, the canal supplies are aimed to serve their respective command areas which are 51 and 3.4 percent, respectively. The seasonal Conveyance Index indicates an unsatisfactory performance at these CPs during both seasons, with the only exception being an improvement at the tail in 1989-90.

Other presented information relates to the differences between maximum and minimum values of the conveyance index. As the data for the tail CP and section are the same, the resulting numbers are obviously going to be the same. But, it is interesting to note that the spread determined by maximum and minimum CIs based on CP and section analysis is almost the same at the middle and tail during the respective monitoring periods. However, the same cannot be said for the head CP and head section where the referred difference is more than double. It implies that the head section received excess supplies relative to a command-average determined by the head control point.

Moreover, when the above stated differences during 1988-89 are compared with the related outcome of 1989-90, there is also a doubling trend except for the tail where the range is almost the same. It points to an increase in supply in the second season, which has improved seasonal averages at different control points. However, analysis based on section suggests that the conveyance performance deteriorated for the head section as the CI increased from 0.12 to 0.47. There is a slight improvement at the middle, but the index is still within unsatisfactory limits. However, the excess supply which trickled down to the tail contributed to improving the conveyance performance from unsatisfactory to marginally fair. As a matter of fact, the saving of 1 percent from the middle section representing 47.6 area pushed the performance up for the tail section from -0.34 to -0.09 because of the area being only 3.4 percent of the total canal command.

Before initiating a discussion about the conveyance performance for the selected Majors, it is important to keep in mind the results of the main canal. Following are the main points to be remembered:

(1) As per data collected at the head control point, the conveyance index for the entire command of the Gezira main canal is within the excellent range.

(2) Seasonal average for the head section was good in the first season, but declined in the second due to excessive supplies.

(3) Actual supplies for the middle and tail sections were less than target supplies during both seasons. The conveyance performance remained unsatisfactory for the two sections during both seasons except for an improvement to a marginally fair level in the tail section (having only 3.4 percent of the total command) during the second season.

B. Major Canals

The head, middle and tail Majors have command areas of 8520, 19002 and 5817 hectares, respectively. The head Major and the main canal have a common source, whereas the middle and tail Majors receive their supplies from the head and middle sections of the Gezira main canal. There was no Major selected from the tail section of the main canal.

Table 2.2 presents results about the conveyance index for the head Major. In 1988-89, the Major received supplies for its entire command of about 17 percent more than targeted amounts. This percentage does not change at the middle control point. However, it drops to 5 percent at the tail control point. During the first season, the analysis on CP-basis indicates that the performance at the first two control points was fair and at the tail control point it became excellent.

Table 2.2. The Conveyance Index for the Head Major (Zananda).

Location/ Position	Type of Values	1988-89		1989-90	
		CP-based	Section	CP-based	Section
HEAD	Maximum	0.91	0.97	2.52	2.24
	Minimum	-0.12	-0.14	-0.12	-0.31
	Seasonal	0.17	0.07	0.56	0.74
MIDDLE	Maximum	0.89	1.74	3.23	2.80
	Minimum	-0.17	-0.20	-0.25	-0.34
	Seasonal	0.17	0.48	0.50	0.54
TAIL	Maximum	0.88	0.88	3.43	3.43
	Minimum	-0.35	-0.35	-0.43	-0.43
	Seasonal	0.05	0.05	0.51	0.51

The ICs derived from section-data shows that the performance of head and tail sections lies in the excellent range. However, the middle section received 48 percent more supplies than required; hence, its performance is classified as unsatisfactory. One explanation for the drastic difference lies in the fact that estimated crop-water requirements for the head section were 22.5 and 6.5 percent more than for the middle and tail sections, respectively. During 1989-90, the conveyance performance based on both types of analyses can be termed unsatisfactory. This is mainly due to actual supplies on the average being 56 percent more than target supplies. Also, the differences between maximum and minimum values are about 2.5 times more in the second period as compared to the first one. This is another indication for the stated deterioration.

The middle Major has about 33 percent more command area than that of the head and tail Majors combined. It gets its supplies from the first section of the main canal at Kilo 114 from Sennar Dam.

The results of the data analyzed based on control points and sections are displayed in Table 2.3A. The analysis shows that the conveyance index lies in an excellent range at all control points during 1988-89. As the actual deliveries at the tail CP serve the tail section only, the performance index is obviously going to be the same. The results of two analyses at the middle point show similar performance (i.e., excellent as per the arbitrary suggested limits). However, the head section extracts a relatively greater share of water as compared to an average determined at the head control point.

Table 2.3A. The Conveyance Index for the Middle Major (Gamusia).

Location/ Position	Type of Values	1988-89		1989-90	
		CP-based	Section	CP-based	Section
HEAD	Maximum	0.47	1.44	2.50	1.61
	Minimum	-0.31	-0.67	-0.21	-0.63
	Seasonal	0.05	0.21	0.29	-0.06
MIDDLE	Maximum	0.54	0.99	2.79	3.87
	Minimum	-0.27	-0.30	-0.13	-0.55
	Seasonal	0.02	0.04	0.42	0.43
TAIL	Maximum	0.99	0.99	2.72	2.72
	Minimum	-0.34	-0.34	-0.41	-0.41
	Seasonal	0.01	0.01	0.43	0.43

During 1989-90, the Major follows the trend set by the head Major with few exceptions. An average CI derived at the head CP and for the head section indicates performance within a fair range, which is better than the head Major. However, the performance at the middle and tail CPs and sections is similar to the first Major (i.e., unsatisfactory), but CIs are slightly on the lower side. Another similarity is that the differences between maximum and minimum values of the index for 1989-90 are 2 to 3 times higher than those monitored in 1988-89. This measure also shows the extent to which the responsible agency is serious about matching actual supplies with target quantities. As the spread widens, so does the gulf between *what it is* and *what it ought to be.*

In case of the middle Major, data were available to extend the analysis on a reach basis, the only exception being the last reach, Reach-5, which cannot be termed a reach as it is, rather, a tail section instead. So, data related to the tail-CP and the resulting indices are the same for the tail section and Reach-5.

According to the author's opinion, canal reaches are the basic units of water distribution. Any data set analyzed either on CP or a section basis may hide many unpleasant features of water distribution because of so called *averaging* or *lumping* effects.

Table 2.3B presents information about conveyance performance of the middle Major based on data analyzed on a reach basis. As discussed earlier, the Major received on average 5 percent (at head CP) more supplies than targeted for its entire command during 1988-89. The distribution which appeared to be excellent as per CP-data has turned out to be marginally good in one case and marginally fair in three other cases. The tail reach / section, however, received supplies almost matching those required.

Table 2.3B. *The Conveyance Index for Middle Major.*

SEASON	TYPE	REACH-1	REACH-2	REACH-3	REACH-4	REACH-5
1988	Maximum	1.48	3.33	1.71	0.75	0.99
to	Minimum	-0.63	-0.94	-0.72	-0.95	-0.34
1989	Seasonal	0.26	0.18	0.22	-0.10	0.01
1989	Maximum	1.04	2.26	5.53	5.05	2.72
to	Minimum	-0.89	-0.98	-0.71	-0.97	-0.41
1990	Seasonal	0.18	-0.31	0.84	0.21	0.43

Note: Tail Control Point, Tail Section, and Reach-5 have common data.

During the monitoring period of 1989-90, the reach-base analysis shows the conveyance performance being good to fair for Reach-1 and Reach 4, respectively. However, the other reaches either received too much or too little supply against their targets and performance is classified as unsatisfactory. As the first two reaches (Reach-1 and Reach-2) form the first section and the second two reaches (Reach-3 and Reach-4) make up the second section, which shows that with CP or section-base analysis, one would not be able to identify short supplies for Reach-2 and fair conveyance performance at Reach 4.

Another interesting comparison relates to the spreads-the difference between maximum and minimum CIs-derived using analyses based on CPs, sections or reaches. By dropping the common tail results, the following are the spreads during 1988-89: (i) 0.78 to 0.81, (ii) 1.2 to 2.11 and (iii) 1.7 to 4.27 for CPs, sections and reaches, respectively. Similarly, the differences for CPs, sections and reaches during 1989-90 are: (i) 2.71 to 2.92, (ii) 2.24 to 4.42, and (iii) 1.93 to 6.24 in the same order. This clearly supports the earlier statement about the averaging effect. This may provide sufficient justification for considering the analyses done on aggregate levels (Baily and Lenton 1984; Levine and Baily 1986) insufficient for evaluating an irrigation system.

The off-take of the tail Major is located at Kilo 194 of the main Gezira canal. It is interesting to note that the tail Major receives its supplies from the middle section of the main canal which, as discussed before, did not perform well during 1988-1990. The middle section of the main canal managed only 19 and 16 percent less deliveries against its targeted amounts during the two monitored irrigation seasons.

Table 2.4 provides different values of the conveyance index about the tail Major during the two years, 1988-90. Contrary to the short supply situation at the source section of the main canal, it is interesting to note that the tail Major received excess supplies as compared to its target amounts. Whether it be a coincidence, a routine occurrence or a deliberate effort, the fact remains that the tail Major provides a trend of extra supplies. It is also contrary to a general belief the tails are usually bound to receive lower supplies because of obvious location- or position-related disadvantages.

Because of the long monitoring periods, it is difficult to support the premise that the excess supply situation resulted from mere coincidence. Perhaps there are other more significant factors to be considered.

The premise of routine occurrence is also very logical. The proponents of this idea argue that the agricultural officers of SGB[11] over-indent their requirements. The MOI officials adjust these indents quite often according to their perception of water requirements, status of sedimentation, potential threat of rains, availability of water, and the current capacities of their canals. If for some reason, upstream managers do not take his or her requested share, the excess supply ends up at the tail.

Table 2.4. The Conveyance Index for the Tail Major.

Location/ Position	Type of Values	1988-89		1989-90	
		CP-based	Section	CP-based	Section
HEAD	Maximum	0.56	0.38	1.27	1.21
	Minimum	-0.14	-0.60	-0.02	-0.27
	Seasonal	0.17	-0.06	0.47	0.16
MIDDLE	Maximum	0.66	0.62	1.67	1.23
	Minimum	-0.19	-0.39	-0.10	-0.31
	Seasonal	0.29	0.07	0.67	0.24
TAIL	Maximum	1.38	1.38	2.54	2.54
	Minimum	0.08	0.08	0.17	0.17
	Seasonal	0.61	0.61	1.40	1.40

On the other hand, it is also possible that there was a deliberate effort to effect the supply situation for the tail Major. In this context, there could be two reasons for the effort:
(i) there is a common belief, which is informally used as an indicator of the system performance, that if the tail is satisfied, then the entire system should have been performing well; and (ii) knowing the nature of the study, there might have been an effort in this direction to influence the outcome.

The above stated relatively excess supply at the tail Major is shown by different values of the conveyance index in Table 2.4. It is evident that during 1988-89 the Major received on an average 17 percent more water than was required at the head control point. The amount increases at the middle point to 29 percent, indicating that the head section did not extract proportional supply (6 percent less than target). The index further went up at the tail CP (0.61) to mean that the middle section also drew relatively less by having actual deliveries 7 percent more than targeted quantities.

[11] Sudan Gezira Board , a parastatal agency for the Gezira Scheme.

According to the chosen criteria, the conveyance performance for the head and middle section falls in the good and excellent ranges, respectively. This can be compared with CP-based values which show good and fair conveyance levels according to head and tail control points. When the tail CP and section are the same, the performance is unsatisfactory due to 61 percent supplies over the required targets.

During 1989-90, the CP-data shows the index being always in the unsatisfactory range. However, as the index increases from head to the tail (0.47 to 1.4), most of the excess supplies are delivered to tail and conveyance performance results are fair for both head and middle sections. This is another example how the head, middle and tail CP-analysis can hide the actual performance of different sections. It is the author's opinion that the section analysis similarly has the potential to hide the actual situation in the reaches because of the so called averaging phenomenon.

Before discussing the conveyance performance at the level of Minors, it seems appropriate to list the main findings about major canals. Following is a summary of the results:

(a) Based on CP-analysis, the average conveyance performance (derived at the head control point) during 1988-89 for the head and tail Majors is found good and excellent for the middle Major.

Similarly, during 1989-90, the average performance results are unsatisfactory for the head and tail Majors, but marginally fair for the middle Major.

The above statements also signal that the head and tail Majors received more supplies relative to the Middle Major when deliveries are compared with their respective targets.

(b) The conveyance performance during 1988-89 at the level of tail CPs / sections of the head and middle Majors falls in the excellent range, but the tail of the tail Major shows unsatisfactory performance due to oversupply.

During 1989-90, the tails of all three Majors indicated an abundance of actual supplies being 43 to 140 percent more than their requirements and hence the performance is unsatisfactory.

(c) With one exception, the head and middle sections of all Majors have shown the conveyance index doing very well during the first monitoring year. However, the performance of these sections is mixed in the following year.

C. *Minor Canals*

There were a total of nine Minors selected for the study. At each Major, three Minors were chosen to represent the head, middle and tail positions. The command areas of these canals range from 375 to 1150 ha, with the average being 760 ha.

In the case of Minors, the data collection was not extended to all control points or reaches along the canals. Rather, the heads of all Minors along three Majors were monitored. This implies that the data collected can only provide information about overall average conditions at this secondary canal level. The analogy of such measurements can be drawn with the information represented at head control points in the cases of main and major canals. As found from the above discussion, indices derived from such data may conceal many discrepancies that occur along a canal. As a matter of fact, it is even more important to study the Minors on a reach basis as these canals serve as the interface between the MOI and SGB, and for all practical purposes, such a network of 1498 secondary channels lies in *no man's land*.

Table 2.5 furnishes different calculated values of the conveyance index for all nine Minors over two monitoring periods: (i) 1988-89; and (ii) 1989-90. In spite of the above comments, the current data set and related results are still very helpful in presenting the following observations:

Table 2.5. The Conveyance Index for the Selected Minors and Majors.

Source	Type of Values	1988-89			1989-90		
		Head Minors	Mid. Minors	Tail Minors	Head Minors	Mid. Minors	Tail Minors
HEAD MAJOR	Maximum	2.80	2.32	0.60	3.03	2.40	3.61
	Minimum	-0.53	-0.62	-0.49	-0.30	-0.34	-0.38
	Seasonal	0.24	0.12	-0.11	0.56	0.36	0.34
MIDDLE MAJOR	Maximum	0.70	0.95	0.98	1.92	3.27	3.68
	Minimum	-0.42	-0.34	-0.72	-0.63	-0.43	-0.58
	Seasonal	0.15	0.26	0.14	0.03	0.60	1.28
TAIL MAJOR	Maximum	1.30	2.82	1.93	1.74	1.77	5.00
	Minimum	-0.89	-0.14	-0.13	-0.36	-0.43	0.15
	Seasonal	0.09	0.63	0.83	0.69	0.23	2.09

(a) During 1988-89, all Minors of the head and middle Majors performed well and the resulting values of CI are in either the good or fair categories. On the other hand, performance of the head Minor of the tail Major is excellent, but the other two secondary canals-middle and tail Minors-indicate unsatisfactory conveyance performance.

(b) Almost contrary to (a), all Minors show unsatisfactory performance (with only two exceptions) during 1989-90.

(c) Maximum oversupply occurs at the tail Minor of the tail Major, about 83 and 209 percent more than required for the first and second year, respectively. This occurrence also indicates that unutilized deliveries are pushed to the tails.

(d) Another interesting piece of information relates to the difference between maximum and minimum values of the conveyance index for the nine Minors. During 1988-89, the average differences corresponding to each set of three Minors of head and tail Major are equal and almost double when compared to the Minors of the middle Major. In the following period, the average differences of Minors located at the head, middle and tail Majors are almost the same. However, when compared to the results of the previous year, they are 50 to 100 percent more.

D. *Comparison of Conveyance Performance at Different Levels*

The comparison is mainly based on results given in Table 2.6. However, some information from the preceding discussion will also be used. The CI values of the table below are the average of CPs, sections and reaches. Such an aggregation is bound to level off many sharp differences because of the averaging of values calculated for head, middle and tail positions.

However, for comparison purposes, it seems prudent to have one value for each level to avoid confusion. This has been done by using the seasonal average of the *Management Delivery Ratio (MDR)* in deriving an average conveyance index for each canal level. But this does not exclude utilizing relevant results for each component of the Gezira canal system discussed so far in detail. This is the setting in which the following statements for comparison are made:

(1) During 1988-89, the results based on CP-analysis present on the surface a baffling anomaly: on the one hand, the conveyance performance of the main canal is unsatisfactory because actual supplies are 20 percent less than target ones, while on the other hand, the conveyance performance of the tail Major and its Minors is also unsatisfactory but the reason is reversed i.e., 36 and 52 percent excess supply for the Major and Minors. Moreover, all the other major and minor canals show performances from excellent to fair and no average conveyance index indicates any instance of short supply. A similar trend is found based on section analysis. However, in the latter case, the performance of the tail Major is slightly improved to a fair level, but still shows a situation of excess supply.

(2) During 1989-90, the derived values of the conveyance index follow the trend established in the first monitoring period (i.e., abundance of water supply for almost all Majors and Minors) but relatively less supply at the primary source. In the second monitoring period, conveyance performance of all major and minor canals is unsatisfactory when CP-based results are considered. However, the performance of the Middle Major on average improves to a fair level when calculations are based on sections or reaches. *A point to be noted is that the selected Majors and Minors were receiving lavish supplies at a time when the main canal was barely meeting its targets.*

The situation described above may appear to be puzzling, but in reality it is not. It should be borne in mind that it is possible to manage excess supplies for only 3 out of 107 Majors and a mere 9 out of 1498 Minors from the huge Gezira scheme? The same can also be said about the Gezira main canal, but the difficulty lies in the fact that there are only two main canals in the scheme.

Table 2.6. An Average Conveyance Index for Different Canal-levels of the Gezira Canal System.

CANALS	CP/ Section	1988-89			1989-90		
		Max.	Min.	Mean	Max.	Min.	Mean
Main Canal	CP	0.06	-0.39	-0.20	0.70	-0.41	-0.05
	Section	0.08	-0.31	-0.14	1.26	-0.34	0.08
Head Major	CP	0.78	-0.18	0.13	3.06	-0.26	0.52
	Section	1.08	-0.13	0.20	2.48	-0.17	0.59
Mid. Major	CP	0.56	-0.24	0.03	2.42	-0.25	0.38
	Section	0.59	-0.33	0.09	2.48	-0.24	0.26
	Reach	0.65	-0.35	0.11	2.62	-0.35	0.27
Tail Major	CP	0.84	-0.07	0.36	1.73	0.02	0.85
	Section	0.57	-0.10	0.21	1.37	0.01	0.60
Head Major	Minors (HMT)	0.90	-0.37	0.08	2.55	-0.28	0.42
Mid. Major	Minors (HMT)	0.82	-0.22	0.19	2.23	-0.27	0.64
Tail Major	Minors (HMT[12])	1.65	-0.16	0.52	1.97	0.0	1.0

(3) In general, the difference between maximum and minimum values of CI increases from the main canal to Majors and Minors. These difference are maximum at Minors: 3 to 5 times more when compared with majors and 6 to 11 times with respect to the main Gezira canal. *It appears that these differences have an inverse relationship with the management-level of canal operations.*

[12]HMT stands for head, middle and tail locations.

2.4.2 Utility of Water Supplies

2.4.2.1 Parameter for Adequacy (PAI)

The parameter for adequacy concerning an individual location, PAI, is first applied to find the adequacy status from location to location (i.e., control points, sections or reaches of a selected canal). This indicator is adopted from Molden and Gates (1990) with minor adjustment. Later on, the original indicator, P_A, suggested by the authors will be used to compare different levels of the Gezira canal system.

A. Main Canal

Adequacy of water supplies should not be a problem in Sudan as its irrigated sector, at the present stage, is only able to utilize 70 percent from its share of the Nile waters (Zaki 1992). However, it is possible to expect inadequacy at certain locations due to problems concerning the distribution of irrigation supplies.

Results derived at a control point represent average conditions below that point. It implies that values based on data collected at the head control point of the Gezira main canal represent average conditions below that point (i.e., the entire command of the main canal). So, with reference to Figure 3 (A and B) and performance criteria suggested by Molden and Gates (1990), it is evident that the average adequacy level during the two irrigation seasons (1988-89 and 1989-90) for the entire command of the main canal is good.

However, during both seasons, the adequacy parameter for about 51 percent of the canal command (below the middle CP) indicates a slightly unsatisfactory adequacy level. In case of the area below the tail CP, the parameter shows a very unsatisfactory situation during the first season, but reaches the fair category in the second season.

The command area, actual supplies and water requirements below the tail control point are the same as for the tail section. Therefore, adequacy levels will obviously be the same in both cases during the monitoring periods. The head and middle sections have a similar performance as discussed for the head and middle CPs, with slight improvements as section-bases parameters are derived only for their respective actual supplies and requirements.

The distribution which creates some location specific changes in the adequacy levels can be understood better by comparing management delivery ratios (MDR) with relevant PAIs. For example, the differences between MDR and PAIs (oversupply fractions) are minimal at the middle and tail sections. However, these differences for the head section are 0.16 and 0.49 during the first and second periods and caused slight inadequacy for the other sections.

B. Major Canals

Head Major: According to Figures 4A and 4B, the parameter of adequacy at all control points and sections during the monitoring periods is generally more than 0.9; thus, there is a good adequacy level at the head Major. Only the head section in the first period has a slightly less than good level.

The oversupply fractions have higher values than observed at the main canal and they are quite consistent for all CPs and sections. In case of abundant supply, these fractions only point to mismanagement of available irrigation supplies which could have been effectively used at other deprived locations.

Middle Major: According to results presented in Figures 5A, 5B and 5C, average values of PAI at the head control point during the two periods show that actual supplies were enough to achieve a good adequacy of water distribution for almost the entire command of the middle Major. The CP-based data does not show any localized inadequacy very clearly because of the prevailing oversupply and averaging effects. However, the section and reach-base data point to some shortcomings regarding adequate water distribution.

For example, the adequacy level during 1988-89 for all sections (values for all tail segments are to be the same) is fair, but Reach # 2 and Reach # 4 show unsatisfactory performance. Again, in 1989-90 the parameters for the head section indicate a barely fair level, with the remaining sections falling in the good category. However, it is interesting to note that Reach # 2 and Reach # 4 again are distinguished by very unsatisfactory performance. Perhaps, it is difficult to identify trouble spots with the other two procedures used for data analysis.

The oversupply fractions are almost the same as in the case of the head Major. However, the reach-based values show sharp variations, signaling mismanagement of water supplies at the reach levels.

Tail Major: Figures 6A and 6B present values of PAI and MDR based on CP and section data. The CP-analysis indicates that the adequacy level is within the good range irrespective of location and monitoring period. A similar trend is found in the case of section-wise water distribution, with the only exception being the head section which secured a fair instead of good level of performance.

The most interesting point is the oversupply fractions. As evident from the figures referred to, these fractions explode toward the tail of the Major. Such a consistent sharp increase toward the tail of the tail Major does not seem to be a mere case of mismanagement of available water supplies-it appears more to be an informal management style for canal operations.

C. Minor Canals

The results in terms of MDR and PAI for the Minors of the head, middle and tail Majors are shown in Figures 7A, 7B and 7C. In general, the values of all PAIs indicate either fair or good adequacy levels of water distribution. This pattern persists irrespective of time and place.

As expected, PAIs of all Minors of the tail Major fall in the good classification. However, the oversupply fractions, especially for the tail Minor of the tail Major, indicate trends similar to those established at its source. This further supports the earlier statement about the informal management style.

D. Comparison of Adequacy of Water Distribution at Different Levels

In order to compare different levels of the Gezira main canal system, values of adequacy at each level are derived using a *Parameter of Adequacy,* P_A, as defined by Eqs. 1a to 1c (Molden and Gates 1990). As the proposed method results in a single average value for each component of the system (i.e., main canal, Majors and Minors), it is helpful in getting a distinct picture about the performance at different levels.

The resulting values of the above mentioned parameter of adequacy, P_A, are displayed in Figure 8A. These values are derived according to control points, sections, reaches and heads of minor canals. In order to demonstrate the kind of differences which could appear just by analyzing data based on different arrangements, adequacy levels for the middle Major are plotted according to control points, sections and reaches (Fig. 8B).

The values of P_A for the main canal show that the adequacy level during 1988-89 can be described as either marginally fair or marginally unsatisfactory. For the same year, the adequacy of water distribution at the Major and Minors is generally good, with a few cases of performance near the top of the fair range. During 1989-90, the adequacy level is improved at the main canal level due to an average annual increase of water supply of 5.2 percent at the head. The performance for the main canal falls in the upper half of the range chosen for fair distribution. During the period, adequacy levels for all the Majors and Minors, without exception, lie in the range termed as good.

However, it is interesting to look at data presented about the middle Major. As given by Figure 8B, based on CP-data, the adequacy level is at the top of the fair range or good; as per section data the adequacy is at the top of the fair range or marginally good; and data analysis based on reaches reveals that the level is marginally fair and unsatisfactory for the first and second seasons, respectively. This change can also be attributed to the *averaging* effect on the resulting parameters. For example, if one section has two reaches with MDR being 1.6 and 0.4 for say every time interval t. Using Eqs. 1a to 1c, the average adequacy level for the two reaches will come to 0.70 and the section will have a perfect value of P_A as 1. A similar argument can be made to an additional *lumping* effect from sections to control points.

Going back to the comparison among different components of the system, one can draw a parallel with the findings discussed under the section on *Conveyance of Water Supplies*. If the selected segments of the system are not the *best* among all, the former explanation under the referred section is also applicable in this case.

However, it has to be noted that in the MDS-Report (1991) the crop water requirements were transformed into canal water requirements only by considering canal water losses due to evaporation. Seepage losses were assumed to be negligible for the heavy clay soils of the scheme. There is no mention of evaporation losses from the water which stands in fields for days, unofficial but widely practiced surface drainage, water which is turned to the field roads, conveyance and application losses.

2.4.2.2 Parameter for Dependability (CVt)

The parameter **CVt** is adopted from Molden and Gates (1990) to determine an indicator for dependability of irrigation supplies at one particular location along a system over a time period t. The main parameter for dependability, P_E, proposed by the authors will be used to get single performance values for each component of the system.

A. Main Canal

Figures 3C and 3D provide values of **CVt** at different control points and sections, respectively. The analysis based on CP-data illustrates that the dependability levels at the head and middle control points are in the (marginally) fair range during the first monitoring period. However, while the tail control point shows unsatisfactory performance in this respect, the area below this point is only 3.4 percent of the total command. The same performance during the following period drops to an unsatisfactory level with some improvement at the tail control point.

The analysis based on data related to sections shows that during both of the monitoring seasons, the values of **CVt** for the head and middle sections indicate an unsatisfactory level, with the exception that the value of **CVt** for the middle section during the first period falls in a marginally fair range. Because the data set is the same, the values of **CVt** for the tail control point, or tail section, are going to be same. In the latter case, during the first period, the performance is low (unsatisfactory level) but it improves in the following monitoring season.

B. Major Canals

The resulting levels of the parameter for dependable water supplies for all three Majors are presented in Figures 4 to 6. The values of **CVt** are derived by basing analyses on data collected at control points, sections and / reaches.

Generally, all Majors show unsatisfactory levels of performance in the context of dependable water distribution. The **CVt** values are very high in the case of head and middle majors, but relatively lower for the tail Major. Again, the **CVt** values for the first season are relatively lower when compared with those of the second season. This may result because the management practices are less intensive at Majors as compared to the level of main and branch canals.

Figure 5F illustrates the resulting values of the parameter when data analysis is done according to canal reaches. As is evident from the figure, Reach #2 and Reach # 4 produce the maximum values of **CVt**. It is interesting to note that the highest values correspond to the lowest values of **PAI** for the same reaches. This may have happened due to erratic supplies to these segments of the Major and less attention being paid to these trouble spots.

C. Minor Canals

The parameter **CVt** is derived for the selected 9 Minors described before. Based on the data about actual supplies and their respective water requirements, **Management Delivery Ratios** for the two monitoring periods have been used to derive the seasonal values of the parameter at each head of the minor canal. These results are presented in Figures 7A, 7B, and 7C. Each figure displays information for three Minors of each Major for two periods - - 1988-89 and 1989-90.

As is evident from the referred figures, the values of parameters in each and every case indicate an unsatisfactory level of performance in terms of dependable water distribution. The results also show that the unsatisfactory levels of **CVt** are higher for the Minors of the head Major as compared to the Minors of the middle and tail Majors. Had the evaluation been planned according to CPs, sections or reaches of each Minor, the resulting levels of the parameter might have been even higher.

D. *Comparison of Dependability of Water Distribution at Different Canal Levels*

Instead of looking at the results for specific locations, as is done by calculating values of **CVt** at different points, a **Parameter of Dependability (P_D)** as suggested by Molden and Gates (1990) is applied to derive only one value for the selected three Minors of each major canal. Figure 9A exhibits the results for each component of the Gezira canal system.

The performance in terms of dependable water distribution is unsatisfactory at each level. However, each component of the system has its position based on the corresponding value of P_D either high or low. A comparison of the results indicates that the parameter has its relatively low values for the following canals: (i) main canal; (ii) tail Major; and (iii) Minors of tail Major. The rest of the canals show a higher level of undependable water distribution.

In the case of the main canal, the relatively low values of the parameter, P_D, or in other words, the better performance in terms of dependability can be attributed to the higher level of attention paid and efforts directed to the management of canal operations. It seems quite possible that if some more attention is paid at the level of the main canal, at least fair water distribution can be secured.

The tail Major and its Minors also have relatively lower values of P_D within an unsatisfactory range. While it is true that the Majors get relatively less attention for their operations as compared to the main canal and that the Minors lie in *no man's land* anyway, the above mentioned trend toward the tail appears to be surprising. However, when the abundance of actual supplies throughout the monitoring periods at the tail Major and its Minors is compared with other corresponding canals, it appears to be possible to have such results.

Figure 9B provides a visual display about the differences in the resulting values of the parameter for dependability based on data collected according to control points, sections and canal reaches. The P_D values based on reach data are 50 to 100 percent more than those based on CP data while section-related results lie in the middle. However, these numbers, more or less, all indicate that water distribution over time is quite unsatisfactory.

Bos et al. (1993) have mentioned that if supplies are undependable, farmers may be less efficient in water use and also reluctant to apply optimal quantities of other inputs. Perhaps, the scale of the impact referred to may vary from one context to another. For example, undependability of water distribution can result under two obvious circumstances: (1) short and fluctuating supplies over time; or (2) excess and fluctuating supplies over time. The third context would be a case where a government or semi-government agency provides and or applies inputs. It may mean that while reliability is a crucial concern for a country like Pakistan, it is of less importance for the Gezira scheme in Sudan.

2.4.2.3 Parameters for Equity

In order to assess the ability of a system, or any part of the system, three types of indicators have been selected: (i) **Parameter for Equity, P_E,** as proposed by Molden and Gates (1990); (ii) **Modified Inter-quartile Ratio, Modified IQR,** suggested by Abernethy (1986); and (iii) **Equity Ratio for Head and Tail, ERHT.** All three parameters are used to understand different aspects of the status of water distribution within the command of the main canal.

(a) Parameter for Equity, P_E

This parameter describes an equity concept in terms of the spatial coefficient of variation of a selected ratio such as MDR. It gives an average situation over the selected region but does not pinpoint the *pockets* within a region which may need special attention to improve the equity of water distribution.

Based on this concept, Figures 10A and 10B display results for different components of the Gezira canal system. The values of P_E for all components either fall in the fair or unsatisfactory ranges depending upon the way data were collected, arranged and analyzed.

The CP-based data analysis shows that the equity of water distribution for the main and major canals can generally be classified as fair (Fig. 10A). It is also evident that there is very little difference between the parameters corresponding to the two monitoring periods - - 1988-89 and 1989-90. This aspect is contrary to the findings discussed earlier about adequacy and dependability of water distribution.

The section-based data analysis, however, shows the values of the parameters, indicating that relevant performance is unsatisfactory for the main and major canals (Fig. 10A). These results are almost the same during the two monitoring seasons.

The above stated differences in the resulting values of the parameter, P_E, extend further support to the earlier findings in this context. Another example for the trend is given in Figure 10B. This is a case of the middle Major exhibiting striking differences in values of the same parameter, with the only difference being the way the data are analyzed based on selected segments of water distribution (i.e., control points, sections and canal reaches).

In the case of Minors, the performance is found unsatisfactory as expected. This may result due to *unattended* operations and the generally bad condition of control structures along these canals.

(b) Modified Inter-quartile Ratio

The Modified IQR, on the other hand, quantifies the extent to which data averages of the top and lower quarters of a system vary. In many cases, these differences can be associated with the head and tail of a system. However, in a country like Sudan, this may not always be true.

Table 2.7 provides **Modified Inter-quartile Ratios** for all the selected components of the main canal network of canals.

These ratios are derived from CP and section data. The ratios are found with a range of 1.5 to 3.0 for the entire system. As is evident from the table, these ratios are relatively low during 1988-89 for the following canals: (i) main canal; (ii) tail Major; and (iii) the Minors of the tail Major. Except for the main canal, when the ratio is derived from section analysis, the same trend is repeated during 1989-90. Other canals have relatively higher values of the ratio.

At present, there are no criteria set to evaluate the equity of water distribution based on these ratios. However, as a first cut, the following ranges for good, fair and unsatisfactory performance can be considered: (i) 1.0-1.5; (ii) 1.5-1.75; and (iii) 1.75 or more, respectively.

If the above arbitrary criteria are accepted, then the performance in terms of equity of water distribution of the main canal and tail Major can be categorized as fair. The rest of the canals fall in the last performance category.

(c) Equity Ratio for Head and Tail (ERHT)

The third parameter has its main focus on the equity for head and tail at different levels of a system. This indicator can help to identify head and tail differences at each level of the system or subsystem, and hence, to address problems accordingly.

Table 2.7. Inter-quartile Ratio for the Gezira Canals.

CANALS	CP/ Section	1988-89	1989-90
Main Canal	CP	1.55	1.89
	Section	1.62	2.78
Head Major	CP	1.86	3.06
	Section	1.88	2.70
Mid. Major	CP	1.84	2.76
	Section	1.89	2.76
	Reach	1.95	3.00
Tail Major	CP	1.72	1.79
	Section	1.52	1.59
Head Major	Minors	2.54	2.86
Mid. Major	Minors	2.02	3.08
Tail Major	Minors	1.96	2.21

Table 2.8 present **Equity Ratios for Head and Tail** corresponding to different canals of the system. It is interesting to note that there are 10 numbers in the table which are less than 1. These numbers imply that MDR ratios of the tails are higher than their respective heads. These results are contrary to a general concept about the head and tail syndrome. This phenomenon is not indicated by the values presented in Table 2.7.

There is a clear trend from 1988-89 to 1989-90; the values of ERHT generally decrease during the second season. This may have happened due to 5.2 percent extra supply provided at the head of the main canal. Also, the ERHT values derived from section data are generally higher than those related to control points.

Table 2.8. Equity Ratios for Head and Tail for Different Canals.

CANALS	HEAD and TAIL DATA	1988-89	1989-90
Main Canal	CP	1.44	1.21
	Section	1.70	1.48
Head Major	CP	1.13	1.03
	Section	1.02	1.15
Mid. Major	CP	1.04	0.90
	Section	1.20	0.66
	Reach	1.25	0.83
Tail Major	CP	0.72	0.61
	Section	0.58	0.48
Head Major	Minors	1.39	1.16
Mid. Major	Minors	1.01	0.45
Tail Major	Minors	0.60	0.55

The performance of the main canal is unsatisfactory, particularly during the first period as the head received relatively more water than the tail. On the other hand, the unsatisfactory level of the tail Major and its Minors results from reverse reasons. During 1989-90, the middle Major and its Minors follow a similar trend. It is, however, quite possible that the excess supply at the identified tail-ends may end up in surface drains.

2.4.3 Maintenance of System

Bos et al. (1993) have suggested that maintenance should accomplish the following three purposes: *(i) Safety; (ii) keeping water control infrastructure in working condition; and (iii) keeping canals in sufficiently good condition to minimize losses and sustain designed discharge-stage relationships.* Recently, the researchers, like the authors referred, to above and Mao Zhi (1989) have proposed some indicators to assess performance in terms of maintenance of irrigation infrastructure. But, at the current level of the activity, a lot more remains to be done.

In the context of the Sudan Gezira Scheme, the type of available data does not allow discussion of all maintenance related aspects of the Gezira canal system. Moreover, the main concern for the main system managers is the rapidly decreasing canal capacities due to a serious problem of siltation and weed infestation in the channels. As the phenomenon has a direct bearing on the water distribution in the scheme, the selection of the maintenance indicators is intended to address this identified concern only.

2.4.3.1 Water Surface Status (WSS)

The first indicator selected in this case is **Water Surface Status (WSS).** The values of the indicator are presented in three tables (Tables 2.9 A to C). The resulting numbers are based on mean and peak levels measured from a unit depth from full supply levels (FSL) on the upstream of headgates of various canals in the Gezira scheme. This index can help to assess if the rise or drop in WSS indicates that maintenance measures are required.

At this stage, however, it is difficult to recommend a specific value of WSS to serve as a tickler for initiating a maintenance activity. It may require consultations with the main system managers, investigations based on long-term relevant data, timing of maintenance activity, and impacts of maintenance on mean and peak discharge levels. Once such threshold levels are determined, the indicator can become a useful tool for the main system managers as the needed information is usually recorded on a regular basis at different levels of many irrigation systems.

In the case of certain canals, with time and mainly because of siltation, the bed levels rise. For example, Niaz Beg distributary in Punjab (Pakistan) has its bed level either equal or higher than designed FSL for a section about 20 kilometers toward its tail end (WAPDA 1984). Similarly, the rise in bed levels of the head, middle and tail Majors in this study is reported to be 1.3, 1.2 and 0.6 meters, respectively (MDS-Report,1991). This implies that corresponding canal banks have also been raised to keep the system running. Under such circumstances, one needs to consider the indicator, WSS, with the existing bank and full supply levels before deciding to undertake a maintenance activity.

Tables 2.9A and 2.9B compare the values of WSS based on mean levels for the main canal, 3 Majors and 9 Minors. In general, the Minors need attention as the numbers in the tables are relatively on the higher side. The tail Major also shows a similar trend. However, these higher values do not necessarily point to a maintenance problem. There is a possibility that some such canals are receiving supplies beyond their design limits.

Table 2.9A. Water Surface Status (WSS) for the Main Gezira Canal and Head, Middle and Tail Majors (Mean Levels Basis).

CANALS	1988-89			1989-90		
	Head	Middle	Tail	Head	Middle	Tail
Main Canal	1.34	1.19	1.36	1.37	1.14	1.37
Head Major	1.34	1.01	0.75	1.37	1.04	0.90
Mid. Major	1.19	1.52	1.08	1.14	1.44	1.10
Tail Major	1.36	1.62	1.47	1.37	1.75	1.37

Note: Depth from the defined depth is taken in meters.

Table 2.9B. Water Surface Status (WSS) for the Minor Canals of Head, Middle and Tail Majors.

CANALS	1988-89 (Based on Mean Levels)			1989-90 (Based on Mean Levels)		
	Head Minors	Middle Minors	Tail Minors	Head Minors	Middle Minors	Tail Minors
Head Major	0.82	0.73	1.53	0.94	0.90	1.92
Mid. Major	1.47	1.45	1.45	1.37	1.49	1.40
Tail Major	1.70	1.55	1.00	1.80	1.49	1.05

Note: Depth from the defined reference is taken in meters.

Table 2.9C provides results from 4 Managil canals based on mean and peak discharge levels. Except for the Managil Old, all the numbers corresponding to other canals indicate siltation or weed infestation causing the water levels to rise. It is also reported that the peak discharge levels of Managil New and Fahal branch canals were either equal to, or higher, than their respective designed bank levels (MDS-Report 1991).

Table 2.9C. Water Surface Status (WSS) at the Head of Managil Branch Canals.

CANALS	1988-89		1989-90	
	Mean Level Basis	Peak Level Basis	Mean Level Basis	Peak Level Basis
Managil Old	0.57	1.02	0.63	1.02
Managil New	1.25	1.88	1.27	2.04
Shawal	1.23	1.51	1.03	1.57
Fahal	1.80	2.09	1.36	1.96

Note: Depth from the defined reference is taken in meters.

However, it is also possible to have these higher levels if diverted supplies are more than the design capacity of a canal. It implies that the above results should be studied, together with information about supplies diverted and intended, and design capacities of different canals being studied.

2.4.3.2 Supply-Design Capacity Ratio (SDR)

Figure 11 shows different **SDR** values for the Gezira and Managil canals. The data illustrate that the main Gezira canal (GMC), Managil New (M-New), Zanda Major (head Major), and Gamusia Major (middle Major) have almost identical average supply-design capacity ratios in a range of 0.70 to 0.80 for both the monitoring periods. The tail Major, however, has attained higher ratios of these parameters, than any other canal (i.e., 0.82 to 0.96 during 1988-89 and 1989-90). If October and November are selected as peak discharge periods, then the following are the resulting SDRs:

YEAR	GMC	MANAGIL	NEW ZANDA	GAMUSIA	KEG
1988-89	0.80	0.90	0.79	0.85	0.92
1989-90	0.80	1.04	0.86	0.90	1.12

The above high ratios partly explain the higher upstream levels as determined by WSS. However, as there are only two cases when SDR is found to be slightly more than 1, the high values of WSS still signal siltation and weed infestation to a degree in these canals.

Figure 11 also illustrates that the average SDRs (seasonal mean values) for the following three canals are very low: (i) Managil Old (M-Old); (ii) Fahal; and (iii) Shawal. The ratios for these canal lie within a range of 0.2 to 0.5. There could be three possible explanations for such low ratios: (i) too little supply was diverted; (ii) the carrying capacities of these canals were drastically reduced due to siltation and weed infestation; and (iii) a combination of both factors.

Even the SDRs of the above three canals, corresponding to the selected peak discharge months, are low. These values are tabulated below:

PERIOD	MANAGIL OLD	SHAWAL	FAHAL
Oct. and Nov. 1988-89	0.56	0.37	0.26
Oct. and Nov. 1989-90	0.64	0.40	0.30

When the SDRs of these three canals are compared with corresponding values of WSS, it appears that Managil Old may have some reason other than maintenance for these low ratios. However, Shawal and Fahal branch canals, which have high WSS levels with low SDRs (i.e., a combination of low deliveries with respect to their design capacities and higher water levels at their heads) provides a strong reason to suspect reduced carrying capacities and a need to consider corrective measures.

2.4.3.3 Authorized Release-Design Capacity Ratio (ADR)

This ADR is selected on the following hypothesis: *"the field managers of the main system base their decisions for authorized releases mainly on the existing capacities of various canals."* However, there could also be other reasons such as: (i) sediment load in canal waters; (ii) irrigation demand; (iii) availability of water at the source point; and (iv) intentional increases or reductions for certain locations such as tails, trouble spots, heads of canals, etc.

The ADRs and SDRs presented in Figure 11 for different canals follow each other very closely. So, the ADRs also support some of the tentative observations about such canals as Fahal and Shawal.

Although the proposed package of the above three indicators appears to be a reasonable selection, it is too early to suggest that it could be used as a tickler system for initiating a maintenance activity. Though it may be insufficient, it is surely a serious effort in the right direction.

2.4.4 Comparison with Other Countries

Comparisons across countries needs careful presentation of basic assumptions used to derive even similar indicators. Similarly, different climatic and soil conditions will also change the resulting performance indices. Moreover, the size of a main system, and the way data is arranged for analysis, may give different results. For example, the indices may differ if they are calculated based on data according to control points, canal sections, or reaches.

At this stage, data are not available for all types of hydraulic indices. However, Table 2.10 provides examples from three countries for indicators belong into the performance category: *utility of water supplies*. These countries are: (1) Sudan; (2) Pakistan; and (3) Sri Lanka. Both Sudan and Pakistan have large gravity irrigation main canals as compared to Sri Lanka. In the case of the latter, the selected main canals are very similar to the Minors in the irrigated schemes of Sudan. As compared to Sri Lanka, which is a humid country, Sudan and Pakistan are classified as arid / semi-arid regions.

Table 2.10. Comparison of the Water Utility Indicators for Performance at Main Canal Levels across Sudan, Pakistan and Sri Lanka.

Indicators	CPs / Sections	Year	GMC (SGB) (SD)	Fordwah Branch (Pak)	Minneriya (SL)	Kaudulla (SL)
P_A	CPs	1988-89	0.78	0.67 (91-92)	0.79 (1987)	0.85 (1987)
		1989-90	0.86			
	Sections	1988-89	0.80			
		1989-90	0.88			
P_D	CPs	1988-89	0.22	0.47 (91-92)	0.59 (1987)	0.55 (1987)
		1989-90	0.29			
	Sections	1988-89	0.25			
		1989-90	0.35			
P_E	CPs	1988-89	0.19	0.63 (91-92)	0.64 (1987)	0.76 (1987)
		1989-90	0.13			
	Sections	1988-89	0.25			
		1989-90	0.24			

From the table, it is evident that the performance in terms of adequacy of water distribution at the Gezira main canal is similar to the two systems monitored in Sri Lanka. It is better than the case of Fordwah Branch from Pakistan. However, it should be noted that the Pakistani irrigation system is not designed for adequate water distribution; it aims at equitable but short supplies.Moreover, the calculations related to the parameter of adequacy for GMC consider only evaporation losses to convert crop water requirements into water requirements, whereas in the case of Fordwah, a conveyance efficiency of 60 percent is used.

The other parameters such as P_D and P_E indicate relatively better performance of the Gezira main canal as compared to the examples chosen from the other two countries. Many factors could have contributed to achieving relatively better performance. In addition to Sudan's management style for its irrigated agriculture and factors such as tight heavy clay soils of the Gezira, as well as availability of needed irrigation supplies, a crop-based demand system (in spite of the weakness associated with the indenting procedure), etc.

Other components of the system are not compared because of the incompatibility of indices derived for Fordwah distributaries and the absence of secondary canals in the cases of the Minneriya and Kaudulla systems. In the first case, the parameters for adequacy and dependability are based on ratios of actual deliveries to designed discharges for the secondary canals.

2.5 CONCLUSIONS AND RECOMMENDATIONS

Based on the secondary data analyzed and discussed, plus the canal operations observed in the Gezira scheme, a set of practical recommendations is presented for implementation. The package is mainly based on making use of already available data, the current institutional provisions for routine data collections and canal operations, and some readjustments and redefined roles for the existing departments and institutions in the scheme. The following recommendations also identify important research and monitoring activities aimed at improving the hydraulic performance of the Gezira scheme:

2.5.1 Activities Recommended for Improved Hydraulic Performance

1. At present, water levels and gate-openings are routinely recorded at all control points along the main canals and heads of Majors. It is recommended that the same practice should also be extended to include all control points of majors canals. In order to improve the credibility of the daily information reported by the gate-operators, it is essential to have a serious mechanism for counter-checking the accuracy and reliability of the information recorded.

2. Even if the reporting of water levels and gate-openings is accurate and reliable, or made so with a little more attention, it is still not an end in itself. In the context of improving the water distribution performance, it is strongly recommended that the reports should be translated into actual deliveries daily at all control points to be compared with targeted quantities. If the distribution is not found as planned, instructions should be conveyed to the person concerned

on the same day. With the available telephone facility in the scheme, it is possible to exchange such information rapidly. For the main and branch canals, the two directorates of irrigation operations in the scheme can be made responsible. For Majors, the offices of relevant divisional engineers can be entrusted with the responsibility.

Based on the findings of this paper, it is strongly recommended that the evaluation of water distribution should be based on canal reaches as they are basic hydraulic units for water distribution for the main system.

(3) After a short time period of interruption, the responsibility for Minors is back with the agricultural administration of the Gezira scheme. The Water Management Advisory Unit (WMAU) of the SGB should train and assist the agricultural field staff of the scheme in monitoring, evaluation and taking corrective measures for improving the water distribution at Minors.

(4) The official schedule at a tertiary level is to have a *number* (37.8 ha) irrigated within a week. However, the existing unattended irrigation practices at this level are far from the formal procedure reported in the books. It may take 4 to 5 days in some cases and 20 to 25 days in other cases to irrigate a *number*[13]. Such a distorted water distribution at the end point needs immediate attention. It is, therefore, recommended that the WMAU / SGB should advise and provide necessary assistance to the tenants for ensuring proper distribution at the tertiary level.

(5) Canal siltation and weed infestation is a very serious problem in the irrigation schemes of Sudan. It is recommended that the field irrigation managers should make use of the suggested maintenance-related indices in this paper. Such an additional suggested use of the routine daily recorded information at control points along the main and branch canals would add another purpose to a *ritual* that is of little use at present.

(6) The Minors get silted faster than any other component of the main system. This phenomenon is the cause of serious problems of water distribution at the Minors as reported in this paper. At present, the maintenance responsibility of Minors lies with the Ministry of Irrigation. In addition to financial problems of the Ministry, there are inter- and intra-agency bureaucratic procedures. For such reasons, the desilting of the Minors suffers. It is, therefore, recommended that farmers should be made responsible for pursuing this activity. Farmers should be free to choose and pay directly for all options available to them for the desilting of Minors.

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[13]personal communication with Mr. Izzel din El Mekki, former managing director of the Gezira Scheme.

2.5.2 Recommended Facilities

2.5.2.1 Arrangements for Data monitoring

1. Generally, the control points of the main, branch and major canals are equipped with sluice gates. At present, there are no gauges installed to measure the head difference across these gates. For an effective monitoring of flows, it is strongly recommended that such gauges should be installed immediately as the provision of such convenient means does not require a large financial commitment from the Ministry of Irrigation.

2. The current practice to measuring gate opening is based on the number of screws turned up or down with respect to a reference point. Such *screw-based* measurements are difficult to make and may not be very transparent and accurate. In the context of canal operations, many supervisors hardly bother to count screws to verify their instructions were implemented or not. It is, therefore, suggested that either gauges should be installed or painted to read gate openings directly.

3. The gauges of structures, such as Butcher's Weir, should read flow in thousand m^3/day directly instead of the usual graduations in centimeters or meters. This should facilitate confirmation of whether the actual supplies are matching with requested indents at a particular point. This should also help the officials of SGB to verify if their water request / indents are being met when compared with actual deliveries.

4. For remote locations where the Gezira telephone link is not available, then *walkie-talkie* type equipment should be provided to the relevant staff.

5. For quick data analysis and record, computers should also be provided, at least to the two directorates for irrigation operations in the scheme.

2.5.2.2 Training of Relevant Staff

1. The agricultural officials of the Gezira scheme are not trained to undertake monitoring and evaluation of water distribution at the Minors. It is suggested that the Water Management Advisory Unit of SGB should offer short training programs for its field staff.

2. It is also recommended that The Ministry of Irrigation should organize local training programs for its staff. Such training activity should aim at providing necessary skills for the evaluation of the hydraulic performance of the main system and use of the proposed (and other) indices for such assessment.

2.5.2.3 Research

1. Sudan is an extremely flat country. Installation of flow measuring structures in the existing canals will be a difficult and expensive job. For most places, it may even be impossible. It is, therefore, suggested that a regular program for field calibration of irrigation control structures should be entrusted to the Hydraulic Research Station (HRS) of MOI. In order to have accurate information on which to base daily decisions about canal operations, it is also desirable to keep updating the older calibrations of structures in the scheme.

2. Due to the heavy clay nature of the soils of the Gezira scheme, the seepage losses are very low. However, it is considered appropriate for HRS to conduct a study aimed at identifying conveyance losses due to, say, evaporation, seepage and human interference, etc. Proper estimates of conveyance losses are expected to improve the ability of the Ministry to deliver appropriate water supplies at desired locations as per plans.

3. A considerable amount of irrigation water ends up in surface drains in the scheme. Although such *leakage* is usually denied by officials, it is a well acknowledged reality in the scheme. It is recommended that a study should be conducted in the scheme to quantify the drainage over time. Where surface drains are not available, water is disposed of to fallow fields and roads, etc. It will be useful to know the quantities in order to determine the net quantity delivered to the fields.

4. A study should be conducted to devise a tickler system for the maintenance of canals. A package of indicators is proposed which can be applied to the available long-term data with the Ministry. The resulting indices can show the maintenance-related conditions over time, as well as changes in the values of the indices which occurred after a maintenance activity. A detailed study in this context is recommended to further improve the suggested mechanism.

5. In order to encourage relatively more meaningful interaction between the officials of SGB and MOI at their inter-face (i.e., the level of minor canals), it suggested that researchers should devise and field test simple and practical management tools and interventions. This package should be targeted at the field staff and tenants of the scheme to verify if the deliveries are provided according to mutually agreed indents.

6. The secondary data used in this paper was collected from the main canal to the *headgates of minor canals only.* In other words, the effort was confined to a level which is relatively well supervised. However, the management controls for the canal operations below the headgates of Minors are hardly applied. From the analysis of data and absence of any serious management control at the Minors and Abu Ashreens, it is hypothesized that the hydraulic performance of the lower water distribution subsystem is expected to be extremely unsatisfactory. In order to document the current status of this performance, it is recommended that the water distribution at Minors and *Abu Ashreens* be studied in detail.

7. One of the most important finding of this report is that the traditional concept of performance evaluation based on head middle and tail conditions at different canal-levels is not satisfactory. It is strongly recommended that future research should base such evaluations on canal reaches instead.

8. The respective command areas should be used as weighting factors for determining seasonal averages for a component of a system.

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