Arba Minch University

Assessment of the Performance of Gezira Irrigation Scheme, Sudan

By

Jal Fnom Kojeaze Seach

A Thesis Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Science in Irrigation and Drainage Engineering

To

School of Post Graduate Studies

Arba Minch University

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CERTIFICATION

We, the undersigned, certify that we read and hereby recommended for acceptance by Arba Minch University a **thesis/dissertation** entitled, "**Assessment of the Performance of Gezira Irrigation Scheme, Sudan**" in partial fulfillment of the requirements for the degree of Masters of Science in Irrigation Engineering.

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(Co-Supervisor)	Signature	Date

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I, Jal Fnom Kojeaze Seach, declare that, this thesis is my own original work and that it has not been presented and will not be presented to any other university for a similar or any other degree award.

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A thesis Submitted in partial fulfillment of the requirements for the degree of Masters of Science in Irrigation Engineering.

Date defended: October 09, 2010

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DEDICATION

This study is dedicated to my dear mother, father, sisters and brother who have always encouraged me for higher studies. This achievement could not be possible without their sacrifices.

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Abstract

The objective of this study was to assess the performance of the Gezira Irrigation Scheme, Sudan. To assess the performance, water supply indicators (Overall consumed ratio, relative water supply, relative irrigation supply, water delivery capacity and water delivery performance); cropping intensity; land productivity indicators; output indicators (Output per cropped area, output per command area and output per unit irrigation supply) and economical indicators (water productivity, relative water cost and benefit cost ratio) have been used. For this purpose, relevant secondary hydrological data, land and crops data and information for the period from 1970/71 to 2008/09 were collected from Ministry of Irrigation and Water Resources and Sudan Gezira Board. Ten-day average meteorological data for the period 1971-2000 and the average monthly meteorological data for period 1989-2008 for Wad Medani station were collected from Ministry of Science and Technology-Meteorological Authority. CROPWAT 8.0 software was used for estimation of crop water requirement and irrigation water requirement and the performance indicates methods were employed to determine the selected indicators. The water supply indicators such as seasonal overall consumed ratio during the seasons 1989/90-2008/09 ranged from 0.3 to 0.8, seasonal relative water supply values during the seasons 1970/71-2008/09 ranged from 1.1 to 2.7 and seasonal relative irrigation supply during the seasons 1970/71-2008/09 ranged from 0.8 to 2.0. These results indicate that the water supply vary from adequate to excessive compare to estimated demand. The water deliver capacity during seasons 1970/71-2008/09 values varied between 0.7 and 2.4 and the seasonal water delivery performance during seasons 1999/2000-2008/09 ranged from 0.71 to 0.91showing that the water is not a constraint in the scheme level but issues of effective management. The cropping intensity during season 1970/71-2008/09 ranged from 35% to 86%. The main crops grown by the scheme are sorghum, wheat, groundnut and cotton. The Land productivity of sorghum ranged between 0.84 and 2.8 ton per hectare, wheat ranged from 0.6 to 2.4 tons per hectare, groundnuts ranged between 0.55 and 3.0 tons per hectare and cotton ranged from 0.8 to 1.9 ton per hectare. The land productivity of the main crops was low compared to the level of yield obtained at Gezira research station which is 4.75 ton per hectare, 3.57 ton per hectare, 5.24 ton per hectare and 3.1 ton per hectare for sorghum, wheat, groundnuts and cotton respectively. The low land productivity obtained from farmer's fields is due to many factors such as delay of sowing date and lack of fund for operation and maintenance and excess water supply. During the season 1995/96-2003/04, the output per cropped area of cotton ranged from 205.5 US$ per hectare to 700.618 US$ per hectare, wheat between 31.776 US$ per hectare to 625.251 US$ per hectare, groundnuts between 11.13 US$ per hectare and 145.25 US$ per hectare and sorghum between 21.85 US$ per hectare and 493.82 US$ per hectare. The output per command area ranged from per 51.3 US$ per hectare to 285.9 US$ per hectare and the output per unit irrigation supply ranged 7.7 US$/1000 m^3 to 37.9 US$/1000 m^3. The water productivity for sorghum ranged between 0.1 to 0.35 kg/m^3, wheat ranged between 0.06 to 0.29 kg/m^3, groundnuts ranged from 0.06 to 0.34 kg/m^3 and cotton ranged between 0.07 to 0.17 kg/m^3. The water productivity was low compared to international standard which is ranged between 0.20 to 2.5 kg/m^3. The low level of water productivity was due to lack of proper water management and hence excessive water losses and low inputs. The economical indicators used were Relative water cost (RWC) and Benefit cost ratio (B/C). During the seasons 1991/92-2006/07 the RWC value varied from 0.03 to 0.07. The upper limit indicates uneconomical production. The benefit-cost ratio during the seasons 1970/71-2008/09 ranged between 0.01 and 2.0. The Gezira Scheme was moved towards the lower side of the range indicate no improvement in the economical production due to low profitability. Improving the performance of the scheme can be attained through proper planning of agricultural seasons by adoption of scientific methods for estimation of crop water requirement such as FAO methodology, insure adequacy of water supply, operation water service, increase soil fertility by proper application of fertilizers for cotton and wheat and growing of a legume crop, establish sustainable finance policy for water pricing and introduce a performance assessment program for monitoring the operation services.

Keywords: Gezira, performance indicators, relative irrigation supply, relative water supply, water delivery capacity, water delivery performance, land productivity, agricultural output, water productivity, relative water cost, benefit cost ratio.

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Acronyms and Abbreviations

GS	Gezira Scheme
GOS	Government Of Sudan
GRS	Gezira Research Station
MOFNE	Ministry Of Finance And National Economy
MOIWR	Ministry Of Irrigation And Water Resources
SD	Sudanese Dinar
SDG	Sudanese Pound
SGB	Sudan Gezira Board
ARC	Agriculture Research Corporation
IWMI	International Water Management Institute
FAO	Food and Agriculture Organization of the United Nations
DIU	Dam Implementation Unit
UNCED	United Nation Conference On Environment And Development
IFPRI	International Food Policy Research Institute
SSA	Sub-Saharan Africa
Aquastat	FAO's Information System On Water And Agriculture
WUAs	Water Users Association
O and M	Operation And Maintenance
BI	Block Inspector
SDE	Sub Division Engineer
ADE	Assistant Sub Division Engineer
EMC	Earth Moving Corporation
ITCZ	Inter Tropical Convergence Zone
fed	Feddan
ha	Hectare

CHAPTER ONE

Introduction and Background

1. Introduction

1.1 Water for Agriculture

By the year 2025, 83% of the expected global population of 8.5 billion is expected to live in developing countries. Yet the capacity of available resources and technologies to satisfy demands of this growing population for food and other agricultural commodities remains uncertain. The world's food production depends on the availability of water, a precious but finite resource. The role of water as a social, economic and life-sustaining good should be reflected in demand management mechanisms and be implemented through resource assessment, water conservation and reuse (UNCED, 2002).

The water scarcity map in Figure 1.1 shows that all countries in Africa are projected to be either physically or economically water scarce in 2025. Given this scenario, imports are expected to increase and account for more than 10 % of total cereal consumption in Africa. In Sub-Saharan Africa (SSA), cereal imports are projected to triple from 9 million metric tons in 1990 to 29 million metric tons in 2020 (Rosegrant and Perez, 1995). In their business as usual scenario, International Water Management Institute (IWMI) and International Food Policy Research Institute (IFPRI) project an import requirement of 35 million metric tons for SSA by 2025 (Rosegrant *et al.*, 2002).

Countries that are physically water scarce, like South Africa and North African countries, may not have adequate water resources to meet their projected water needs in 2025; and yet more than a quarter of the world population will be living in these regions. A recent analysis using IWMI’s Podium Tool presents a more optimistic picture of the water and food nexus in South Africa, suggesting that absolute scarcity is an unlikely scenario (Kamara and Sally, 2002).

Economically water-scarce countries potentially have enough water resources to meet their future needs, but they will not be in a position to make the additional investments required to actually harness and use these resources. This is the situation confronting most countries in SSA. Country level situations and scenarios however mask significant differences within countries, both temporally and spatially. Some of these SSA countries have regions and river basins that already face serious physical water scarcity. An example is the Ewaso Ngiro North basin in Kenya (Gichuki, 2002).

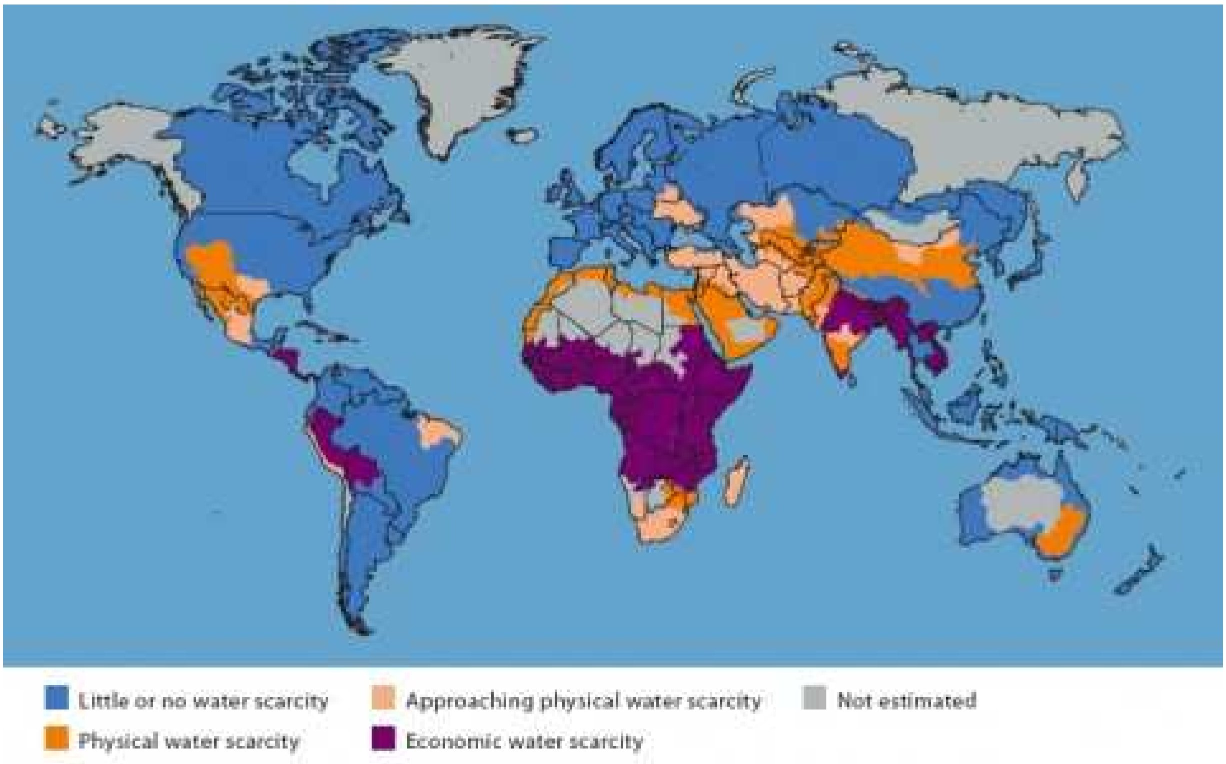

Figure 1.1 World water scarcity map (IWMI, 2007)

1.2 Sudan Water Resources

The successful negotiation of the 1959 Nile Water Agreement between Sudan and Egypt laid the foundations on which fundamental changes to the Gezira cropping patterns were eventually built. The immediate impact on the traditional irrigation regime of the scheme was, of course, almost nil as the 'stored-water' constraint physically imposed by the capacity of Sennar reservoir still remained in place. Similarly, lifting of the 4 billion cubic meters limitation in Sudan's gross consumption was not itself of immediate benefit to the Gezira, as annual diversion at Sennar dam in late 1950s were of the order of 1.6 billion cubic meters only (Farbrother, 1996). Nevertheless, the psychological impact of the Nile Water Agreement on morale in Sudan's Ministry MOIWR was incalculable. The hugely successful negotiations in Cairo in 1959 ensured an unassailable standing within

Government circles for the engineer/diplomats of MOIWR. Egyptian agreement with a figure of 18.5 billion cubic meters as Sudan's prospective share of the Nile Waters was widely regarded as a generous gesture, reflecting the desire of Egyptian Government for closer political ties, or failing that, assured good-neighbor relationships with the new Republic (Farbrother, 1996).

Egypt's share of the Nile Waters was 55.5 billion cubic meters. Ten billion m^3 were estimated as evaporation losses from the Aswan High Dam Reservoir. Currently the annual water avaial.ble to the Sudan from national and international sources is about 35.5 to 37 billion cubic meters as shown in Table 1.1. Agriculture sector consumes more than 90 % of this amount. Table 2.1 show that the Ministry of Irrigation and Water Resources (MOIWR) under the Long Term Agriculture Strategy (2002-2027) estimated that the irrigation water needs by the year 2027 will be about 42.5 billion cubic meters, human and animal usage and domestic and industrial needs are estimated to be about 10.1 billion cubic meters (Sirekhatim *et al.*, 2005).

1.3 Irrigation and drainage development

The GS Irrigation scheme in Sudan covers an area of some 2.1 million feddans (about 882,000 ha) fed principally by gravity irrigation. The GS plain is located in the triangle land between the Blue and the While Nile south of Khartoum. The original irrigation system comprised the Gezira main canal to serve approximately 300,000 feddans (126,000 ha) of cultivable land. Extensions to the initial scheme were carried out in the late 1920s and early 1930s and subsequent smaller extensions steadily increased the command area to around one million feddans (420,000 ha) by the early 1950s. In 1957, work commenced to bring the planned area of around 800,000 feddans (336,000 ha) of the Managil extension under irrigation. By the mid-1960s, the Managil was fully operational. At present, according to (Herve, 1990) after further small extensions, the irrigated area stands at 1.2 million feddans (504,000 ha) in Gezira and 0.9 million (378,000 ha) in Managil. The GS Scheme is Sudan's oldest and largest gravity irrigation system. It receives water from Sennar Dam on the Blue Nile and is divided into some

114 000 tenancies. Farmers operate the scheme in partnership with the government and the SGB, which provides administration, credit and marketing services.

Table 1.1: Summary of the available water to Sudan

Water Resources	Quantity (billion cubic meters)	Constraints
Sudan present share of Nile water agreement (at central Sudan)	20.5	Seasonal pattern coupled with limited storage vessels. Expected to be shared with riparian.
Wadies waters	5 to 7	High variable, short duration flows, which are difficult to monitor or harvest.
Renewable groundwater	4.0	Deep water entailing high cost of pumping. Remote areas of weak infrastructure
Present total	30.0	
Expected from reclamation of swaps	6.0	Capital investment needed with considerable social and environmental cost
Total	35.5 to 37	

Source: MOIWR (2010)

Table 1.2: Water Demand projected to 2027 (billion cubic meters)

Year	Irrigation	Domestic supply	Animal and others	Total
2010	27.1	1.1	3.9	32.1
2020	32.6	1.9	5.1	39.6
2025	40.3	2.5	5.3	48.0
2027	42.5	2.8	7.3	52.6

Source: MOIWR (2010)

The scheme has played an important role in the economic development of Sudan, serving as a major source of foreign exchange earnings and of Government revenue. It has also contributed to national food security and in generating a livelihood for 2.7 millions of people who now live in the command area of the scheme (FAO Aquastat, 2005). The GS scheme was designed in the 1920s after prolonged experiments had been carried out on a prototype scale. It was designed with the main objective of producing cotton, a single cash crop. It was thus a non-perennial scheme with monoculture. Other crops were initially grown to provide food for the tenant farmers, and to help in the maintenance of soil fertility (Herve, 1990).

In the post-colonial period, it was assumed that the only sound way to bring about development would still be through large irrigation developments. The increase in Nile water allocation through the 1959 Nile Waters Agreement with Egypt led for example to the construction of the Managil extension of the Gezira Scheme and of the New Halfa Scheme. The New Halfa Scheme is located on the upper Atbara River in the east of the country. It was partly financed by Egypt after the construction of the Aswan High Dam that created Lake Nasser, which flooded the Sudanese town of Wadi Halfa in 1964. Since then the inhabitants have been relocated to the new irrigated agricultural al.nds where they have been growing a variety of crops (FAO Aquastat, 2005).

In the 1970s, Sudan was expected to become the "bread basket" of the Arab world, and with large investments from oil-rich Gulf nations, irrigation schemes such as the Rahad Scheme, which receives its water from the Rahad River and the Blue Nile, were established. Large-scale irrigated agriculture expanded from 1.17 million ha in 1956 to more than 1.68 million ha by 1977. The 1980s were a period of rehabilitation, with efforts to improve the performance of the irrigation sub-sector. In the 1990s, some smaller schemes were licensed to the private sector, while the four large schemes of Gezira and Managil, New Halfa, Rahad and Suki remained under government control because they were considered strategic schemes. In 1995, surface water was the water source for 96 percent of the total irrigated land area, and the remaining 4 percent were irrigated from groundwater (small tube-wells). The irrigated area where pumps are used to lift water was 346,680 ha in 2000. Most irrigation schemes are large-scale and they are managed by piratical organizations known as Agricultural Corporations, while small-scale schemes are owned and operated by individuals or cooperatives. In 2000, the total area equipped for irrigation was 1,863,000 ha, comprising 1,730,970 ha equipped for full or partial control irrigation and 132,030 ha equipped for spate irrigation. FAO Aquastat (2005) stated that only about 800,000 ha, or 43 percent of the total area, are actually irrigated owing to deterioration of the irrigation and drainage infrastructures. In 2005 the Gezira Act of 2005 was established for institutional reforms in GS.

1.4 Gezira Scheme Act of 2005

Gezira Act of 2005 was established to introduce the institutional reforms in the scheme and accordingly specify the process of creating WUAs. The Act refers to WUAs as farmers' organizations undertaking actual tasks with regard to water management, operation and uses. The Act specifically stated that: "*the water user associations shall be established under supervision of the Board at the scheme level. They shall be legal entities representing the farmers' self management system. They shall also undertake actual responsibilities in managing water uses through entering into a contract with the Ministry of Irrigation and Water Resources (MOIWR) in the area of supply of water and technical consultation*". Parts of the Act objectives are to ensure farmers right to effectively participate, at all administrative levels, in planning and implementation of projects and programs that affect their production and livelihoods. Also to ensure farmers right to manage irrigation operations at the field canal level through WUAs. The Act specified the responsibilities of MOIWR, Ministry of Finance and National Economy (MOFNE) and the WUAs. The MOIWR shall be responsible for operation and management of the primary irrigation and drainage canals and pumps in the scheme, and for providing sufficient water for WUAs at the intake of the respective field canals, and MOFNE shall be responsible for financing maintenance, rehabilitation and operation of water canals in return for water charges to ensure provision of such services. The WUAs shall maintain, operate and manage field canals and internal drainage (Bashier, 2009).

1.5 Problem statement

The irrigation system was originally designed for continuous system (day and night irrigation), but due to practical difficulties regarding irrigation during night, mainly social, the system was converted to the present night storage system (NSS) in the early 1930s. The cropping pattern and type of crops changed many times until 1975 when the rotation changed from eight-course rotation (cotton, fallow, fallow, cotton, fallow, sorghum, groundnut, and fallow) with nominal cropping intensity of 50% to the four course rotation (cotton, wheat, sorghum/groundnut, fallow) with 75% cropping intensity until 1989, then the main Gezira scheme changed to the present five course rotation (cotton, sorghum, groundnuts, wheat and fallow) with 75% cropping intensity, while the Managil extension had 100 percent with no fallow. At present, however, fallow has also been introduced in Managil where the target cropping intensity is 75 % throughout, although various problems have kept the actual intensity well below that figure in recent years (Abdulal, 1989). The main irrigated crops are sorghum, cotton, wheat, groundnuts and vegetables. Irrigated agriculture has been Sudan’s largest economic investment, yet returns have been far below potential. A study by the World Bank (2000) showed that, during the period 1976-1989, yields were low and extremely variable and cultivated areas suffered a gradual decline. In the Gezira Scheme, a complex mix of financial, technical and institutional problems resulted in a serious fall in the productivity of the scheme and a corresponding drop in farm incomes. The management of the Gezira Scheme ran into problems since the early 1970's, shortly after the scheme reached its present extension. The studies done by Ishag and Ageeb (1987) showed that the average yield of the crops in the rotation for seasons (1964/64 to1987/88) had decreased dramatically. The relative yields for the main crops cotton, wheat, groundnuts, and sorghum were 32%, 29 %, 21% and 18% compared to potential yields respectively. Many factors are responsible for such low yields. Shortage of irrigation water particularly during the critical period (October to November) is due to overlapping of water requirement of various crops, silting of canals, weed growth in canals and financial problems. Cropping intensity dropped from 80 % in season 1991/92 to 40 % in season 1998/99. About 126,000 ha were taken out of production owing to sedimentation and water mismanagement, leading to a reduced availability of water. Because of bad water management, water supply is about 12 % below crop water requirements at crucial stages in the growth cycle, while at the same time, as much as 30 % of the water delivered is not used by crops. However, an initiative aimed at "broadening farmer's choices on farm systems and water management" by FAO in part of the scheme, caused that productivity of sorghum, cotton and wheat to be increased to 112 % for 2000/01, compared to the Gezira average of 42 %. Since then, the performance of the irrigation sector has consistently fallen short of expectations due to low levels of productivity of the irrigated crops in the irrigation scheme. Therefore, it is important to assess the performance of the existing irrigation schemes. To improve the irrigation system, management requires feedback to discover the strong and weak aspects of the irrigation system. This can be measured by carrying out a performance assessment. Bos *et al.* (2005) stated that performance is measured through the use of indicators for which data are collected and recorded. The analysis of the indicators then informs us on the level of performance.

1.6 Objectives

The main objective of this study was to assess the performance of Gezira large-scale irrigation scheme and make recommendations for improvements, if any.

The specific research objectives of this study are

- to evaluate the performance of Gezira irrigation scheme based on determined performance indicators
- to make recommendations for improvements of the performance of Gezira irrigation scheme.

1.7 Significance of the study

The result of this study will show the level of the performance of the scheme. Hence, it will help the decision-makers to take the necessary measures to improve the performances of the scheme. Water managers of an irrigation scheme should monitor the performance of key operations closely to identify shortcomings and take corrective measures at the right time. Performance assessment provides relevant feedback controls to the management, where as performance indicators provide necessary information about the level of performance relative to the objective.

CHAPTER TWO

Literature Review

2.1 Background

In recent years there has been a growing concern that performance in the context of irrigated agriculture is significantly less than had been anticipated. The anticipated potential through irrigation of land earlier dependent on unpredictable and unreliable rainfall has not always been achieved, and in some respects, irrigation has lost much of its purpose as an investment strategy for developing countries (Murray *et al.*, 1993).

The shortfalls in performance can be cited at almost every level of the irrigation sector. Those concerned with major lending programs for irrigation, notably the banks and certain bilateral funding agencies, have begun to feel that the return on investment is not really justified. According to Murray *et al.* (1993), greater emphasis has been placed on other sectors at the expense of new investment in irrigation, or in the rehabilitation or modernization of existing systems.

Similarly, at system level, there is disappointment in levels of cropping intensity, irrigation intensity and yields from many irrigated areas. The economics of irrigated agriculture are such that many farmers have not been able to achieve a more prosperous and healthy life.

At the level of water distribution there are innumerable references to inequity of water distribution leading to major disparities between head and tail areas, to deficit water supplies and loss of production in some locations, or to excess water delivery and development of water logging and salinity in others. Water supplies at any given location are often poorly matched to crop needs, highly variable in both timing and discharge, and are, sometimes, of increasingly poor quality.

These comments serve to highlight two aspects of irrigated agriculture. The first is easily forgotten without the investments in irrigation over the past hundred years, and especially in the last thirty years in conjunction with agricultural technologies such as high yielding varieties, cheap pumps, and huge increases in fertilizer use, famine would still be the major threat in Asia as much as it is in parts of Africa at the present time. It may be true that the efficiency of water and land resource use for irrigated agriculture is low, but it is a technological package that feeds billions of people according to Murray *et al.* (1993).

The second aspect is perhaps more topical. The great increase in awareness in environmental issues, particual.rly for the conservation of natural resources in the context of a still increasing population, means that the sense of living in a finite world has become increasingly dominant.

Gezira Scheme (GS) is large-scale gravity irrigation started during the British colonial period (1898-1956) and the colonial agricultural policy was characterized by the promotion of cotton production in the Nile Basin. Irrigation by pumping water began at the beginning of the 20th Century, substituting traditional flood irrigation and water wheel techniques. GS is Sudan's oldest and largest gravity irrigation system only about 70,000 feddans not under gravity irrigation, located between the Blue Nile and the White Nile. Started in 1925 and progressively expanded thereafter, it covers about 2.1 million feddans (882,000 ha). It receives water from Sennar Dam on the Blue Nile and is divided into some 114,000 tenancies. Farmers operate the scheme in partnership with the government and the Sudan Gezira Board, which provides administration, credit and marketing services. The scheme has played an important role in the economic development of Sudan, serving as a major source of foreign exchange earnings and of Government revenue. It has also contributed to national food security and in generating a livelihood for millions of people who now live in the command area of the scheme (FAO Aqua stat, 2005).

2.2 Performance assessment of irrigated agriculture system

2.2.1 General

Developing countries have made huge investments in infrastructure for irrigation in the form of irrigation schemes over the last half century, realizing its importance for food production for the growing population. This investment, together with improved crop production technologies such as use of fertilizers, hybrid varieties, plant protection techniques, etc. has enabled many countries to move towards achieving self-sufficiency in food production. Nevertheless there is also a perception that many irrigation schemes do not perform up to expectations or achieve the goals (Bos *et al.*, 2005). Irrigation performance is the result of a large number and variety of activities such as planning, design, construction, operation of facilities, maintenance and application of water to the land (Small and Svendsen, 1990) or agricultural production, irrigation, land settlement, maintenance, construction, water users' organization (Nijman, 1992).

Management of the application of water to land or "Irrigation Water Management" is important within each irrigation scheme for achieving the benefits of the earlier activities and investment in creating the irrigation potential. It is also important at the catchment/basin and national levels, where increasing attention is being focused on efficient management of water resources to meet growing challenges: the increasing demand for irrigation to meet the growing food demands of the population; the competition for water allocation from high priority non-agricultural sectors; the limitation to the development of new water resources due to rapidly increasing cost, technical infeasibility and environmental concern (Bos *et al.*, 2005).

Performance assessment of irrigation and drainage can be defined as the systematic observation, documentation and interpretation of the management of an irrigation and drainage system, with the objective of ensuring that the input of resources, operational schedules, intended outputs and required actions proceed as planned (Molden, 2004).
Performance assessment is an activity that supports the planning and implementation process. The ultimate purpose of performance assessment is to achieve an efficient and effective use of resources by providing relevant feedback to the management at all levels. As such, it may assist the project management in determining whether the performance is satisfactory and, if not, which and where corrective or different actions need to be taken in order to remedy the situation. It should provide insights into the process of irrigation and drainage so that managers, farmers, and planners can do business in new, more productive and efficient ways (Boss *et al.*, 2005).

2.2.2 Application of Performance Assessment

Performance assessment can be used in a variety of ways, including:

- Operational performance assessment is concerned with the routine implementation of the agreed (or pre-set) level of service. It specifically measures the extent to which intentions are being met at any moment in time, and thus requires that actual inputs and outputs are measured on a regular basis (Molden, 2004).
- Strategic performance assessment is a longer term activity that assesses the extent to which all avaial.ble resources have been utilized to achieve the agreed service level efficiently and whether achieving this service also meets the broader set of objectives. Time-series of the indicator and its rate of change commonly are used in this activity. An avaial.ble resource in this context refers not merely to financial resources: it also covers the natural resource base and the human resources provided to operate, maintain and manage irrigation system. Strategic management involves not only the system manager, but also higher level staff in agencies and at national planning and policy level (Molden, 2004).
- Diagnostic performance assessments are performed to gain an understanding how irrigation functions, to diagnose causes of problems, and to identify opportunities for performance improvements in order that action can be taken to improve irrigation water management. Diagnostic assessments are carried out when difficult problems are identified through routine monitoring, or when stakeholders are not satisfied with the existing levels of performance achieved and desire a change. Diagnostic assessment supports both operational performance monitoring and strategic planning (Molden, 2004).
- Comparative performance assessment and benchmarking. Benchmarking can be described as “a technique which enables organizations to compare performance to relevant and achievable standards and thus help secure continual improvement” (Miller, 1992). Benchmarking is used in both the private and public sectors as a means for organizations to assess their performance-internally against organization norms and standards, and externally against key competitors or

organizations standards. A benchmark can be an historical reference point or a future goal to be achieved (Wild, 1999).

2.2.3 Phases of irrigation performance assessment

Irrigation schemes are planned and operated for multiple objectives. These objectives often coincide with each other. Therefore, it is necessary to have a proper trade off amongst these objectives and this call for an appropriate system to quantify these performance objectives. As many irrigation schemes are characterized by variability in soils, cropping patterns, irrigation efficiencies and climate, multiple users, water scarcity and complex network of canals, it is necessary to know the temporal and spatial variation in these performance measures over each irrigation scheme. Pointing out that the main function of the irrigation scheme is to provide irrigation, Abernethy (1986) argued that the yardstick for the evaluation of the irrigation management must be whether it fulfills its function, i.e. the delivery of water where and when it is wanted, reliably and in the right quantities (Gorantiwar and Smout, 2005).

There are three phases (planning, operation and evaluation) in irrigation water management during which the performance should be measured, so as to know and continuously improve the performance of the irrigation water management according to the set objectives.

2.2.3.1 Planning

The allocation plan and corresponding water delivery schedule need to be prepared to achieve the set objectives of the irrigation scheme during the planning phase of irrigation water management and then these needs to be followed during the operation. It is possible to estimate all the performance measures at the planning stage except reliability and efficiency. But if the allocation plans and water delivery schedules are prepared without considering the heterogeneity in the scheme, the characteristics of the water delivery schedules and the appropriate efficiencies at several levels and pal.ces, then this will reduce the reliability (Gorantiwar and Smout, 2005).

2.2.3.2 Operation

The chosen allocation plan is put into the operation and the manager then needs to monitor the performance of this plan when in operation, to allow for continuous assessment and improvement of performance of irrigation water management of the irrigation scheme. Allocation plans and schedules are prepared for historical data or synthetic climatologically data series on various assumptions. In practice however the irrigation scheme may not behave according to these plans, because of spatial and temporal variation in climate, secondly because of the inappropriate consideration of complexity and variability in the physical aspects of the scheme (different characteristics of the water distribution network, variable soils) and managerial aspects (on demand/continuous/rotational water supply) while developing the allocation plan and thirdly due to different types of interventions.

The performance assessment under simual.ted and actual operation will enable the irrigation manager to review the allocation plan of the same irrigation year or subsequent irrigation years (Gorantiwar and Smout, 2005).

2.2.3.3 Evaluation

The comparison of the planned performance (or during simual.ted operation) and the actual performance at the end of the irrigation season will enable the irrigation authorities to diagnose whether the deviation from the expected performance is due to climatologically variability, inappropriate considerations to different aspects of the scheme, management aspects or combinations of these, and will provide the management with insight to improve the performance. During evaluation the manager needs to measure the performance measures such as irrigation efficiency which cause the expected performance to deviate from the actual. Actual measurement of these parameters will enable the authorities to know the trend of variation and whether deviation of actual performance from the anticipated during the planning is due to their improper consideration. The inclusion of actual measurements will also enable these parameters to be included appropriately during further planning (Gorantiwar and Smout, 2005).

2.2.4 Framework for performance assessment

All performance assessment programmers require a framework to define and guide the work. Several frameworks have been proposed in the past, in some cases these have been specific to a particular scheme and in other cases they have been more generic. The framework described herein Figure 2.1 builds on this previous work, and work by (Burton and Muttra, 2002). The framework serves to define why the performance assessment is needed, what data are required, what methods of analysis will be used, who will use the information provided. Without a suitable framework the performance assessment programmed may fail to collect all the necessary data, and may not provide the required information and understanding (Bos *et al.*, 2005). The framework is based on a series of questions. The first stage, purpose and scope, looks at the extent of the performance assessment, who it is for, from whose viewpoint it is undertaken, who will carry it out, its type and extent. Once these issues are decided, the performance assessment programmed can be designed, selecting suitable criteria for the performance assessment, performance indicators and the data that will be collected. The implementation of the planned programmed follows, with data being collected, processed and analyzed The final part of the programmed is to act on the information provided, with a variety of actions possible, ranging from changes to long-term goals and strategy, to improvements in day-to-day procedures for system management, operation and maintenance (Bos *et al.*, 2005).

2.2.4.1 Purpose and Scope of performance assessment

The initial part of formulating a performance assessment programmed is to decide on the purpose and scope of the performance assessment. Key issues relate to who the assessment is for, from whose viewpoint, the type of assessment and the extent/boundaries. It is important that adequate time is spent on this part of the work as it structures the remaining stages (Bos *et al.*, 2005).

As with any project or task, it is essential that the purpose and objectives of the performance assessment be defined at the outset. Three levels of objective-setting can be identified by rationale; overall objective and Specific objectives. The rationale outlines the reason for which a performance assessment programmed is required. The overall objective details the overall aim of the performance assessment programmed. Establishing the rationale and identifying the overall and specific objectives of the performance assessment programmed is not always straightforward; care needs to be taken at this stage of planning to ensure that these objectives are clearly defined before proceeding further (Bos *et al.*, 2005). The performance assessment can be carried out on behalf of a variety of stakeholders. These include government; funding agencies; irrigation and drainage service providers; irrigation and drainage system managers; farmers and research organizations. Who the assessment is for is closely linked to the purpose of the assessment. The assessment may be carried out on behalf of one stakeholder or group of stakeholders, but may be looking at performance assessment from the perspective of another stakeholder or group of stakeholders. Government may commission a performance assessment (Bos *et al.*, 2005). Different organizations or individuals have different capabilities in respect of performance assessment, and different types of performance assessment will require different types of organization or individuals to carry out the assessment. A government agency might employ a consultant to carry out performance assessment of a scheme with a view to further investment, while a university research team might carry out a research programmed to identify and understand generic factors that affect system performance (Bos *et al.*, 2005). Small and Svendsen (1992) identify four different types of performance assessment, to which a fifth, diagnostic analysis can be added:

1. Operational.
2. Accountability.
3. Intervention.
4. Sustainability.
5. Diagnostic analysis.

The type of performance assessment is linked with the purpose; in fact Small and Svendsen refer to these categories as the rationale for performance assessment. Operational performance assessment is relates to the day to day, season to season monitoring and evaluation of scheme performance (Bos, 1990).

Accountability is an important aspect of any management model, and this type of assessment provides information on the basis of which accountability can be judged. There are at least three different cases in which information from accountability assessments can be employed. These are:

- in the internal processes of the organization managing the irrigation system,
- in the relationship between the irrigation agency and its supervising board or body, and
- in the relationship between the farmers of the system and the agency.

In many countries, a national irrigation agency is responsible for the operation of the physical facilities of most or all of the large irrigation systems in the country. Comparative information on the performance of the various systems can assist the top management of such an agency in evaluating the performance of individual project managers. Careful thought needs to go into the choice of the dimensions and measures of performance that are used, since project managers can be expected to respond to this choice by modifying the way in which they fulfill their jobs as they attempt to enhance their performance ratings (Bos, 1990).

Those who supply resources as inputs into the irrigation system generally have a vested interest in its performance. Routine performance assessments on a seasonal, annual or multi-year basis allow the suppliers of resources to evaluate not only the effectiveness with which these resources have been used, but also the appropriateness of requests for additional resources. A requirement for regular accountability assessments can strengthen accountability linkages between the operating and funding agencies. The knowledge that such assessments are to be undertaken is likely to cause the irrigation operating agency to modify its behavior in ways that will cause the assessments to be more favorable. In a financially autonomous operating agency, the need for such accountability assessments is largely replaced by the internal incentives resulting from the agency's need to remain financially viable. This has the potential to simplify significantly the government's task of monitoring and controlling the operation of the irrigation agency (Bos, 1990).

There is increasing awareness that developing superior levels of performance in large irrigation systems depends in important ways on the existence of a healthy and mutually respectful relationship between operators of the physical facilities and the farmers. A key mechanism both for helping create this type of relationship and for utilizing it to maintain strong system performance is a provision for regular accountability assessments of system performance at the interface between the two (Bos, 1990).

All accountability assessments need to be designed to provide objective information on agreed-upon dimensions of performance. In some cases they may need to be undertaken by an external agency in an effort to ensure objectivity in the collection, analysis and presentation of the data. In the case of joint assessments of irrigation service to farmers, the involvement of farmers and system operators together in the assessment process establishes countervailing interests that may help to ensure the objectivity of the information. In other cases, primary responsibility for undertaking the assessment could lie with the irrigation agency, but with some external agency having oversight responsibilities to monitor the process and vouch for its validity (Bos, 1990).
A desire to improve some aspect of irrigation performance underlies a wide variety of irrigation system interventions made by managers and government agencies. These interventions may range from modest changes in water distribution procedures to major rehabilitation of physical facilities.

Many individuals and organizations including government planning agencies, external donor agencies, managers within an irrigation agency, and professional irrigation researchers will want both ex ante assessments to evaluate the desirability of or need for a proposed intervention, and ex post assessments to assess the results of the intervention. Such assessments generally require data for one or more complete seasons. Lags between the initiation of an intervention and the resulting changes in performance may make it necessary for ex post assessments to cover a multi-year period. Annual variability in conditions may also make it prudent for a study designed to evaluate an intervention to incorporate data from several years into the analysis (Bos, 1990).

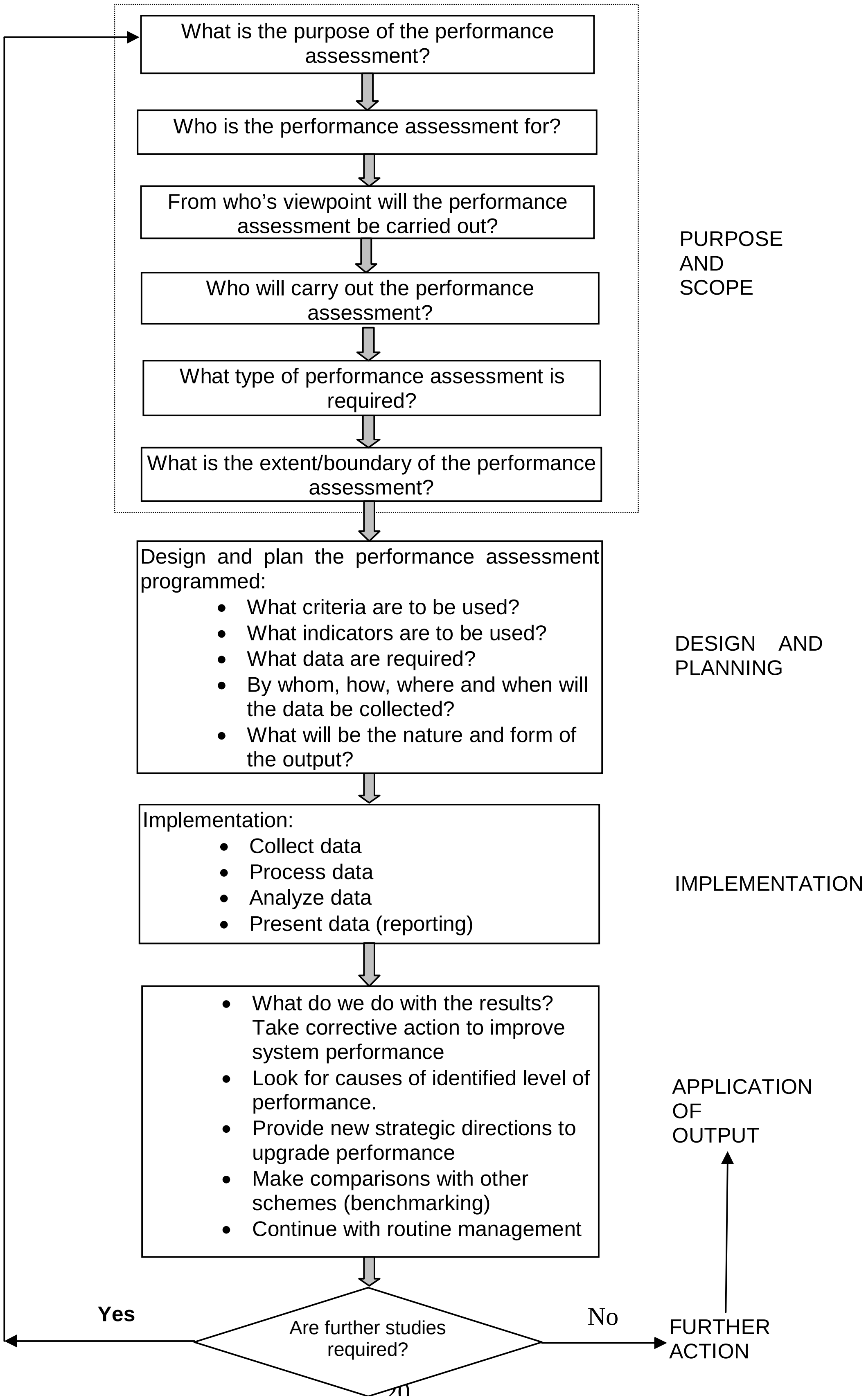

Figure 2.1 Framework for performance assessment of irrigation and drainage schemes

Source: Bos *et la*. (2005)

- **Internal or external assessment**

It is important to define whether the exercise is to be for internal or external performance, assessment, i.e. for comparison between schemes or internal analysis of one scheme. A significant problem with performance assessment of irrigation and drainage schemes is the complexity and thus variety of types of scheme. Some schemes are farmer-managed, some are private estates with shareholders, some are gravity fed, and some fed via pressurized pipe systems. There is as yet no definitive methodology for categorizing irrigation and drainage schemes, therefore there will always be discussion as to whether one is comparing like with like. Within the work associated with benchmarking this issue needs to be resolved early on (Burton *et al.*, 2000). A significant problem with performance assessment of irrigation and drainage schemes is the complexity and thus variety of types of scheme. This makes comparison between schemes problematic. Some schemes are farmer-managed, some are private estates with shareholders, some are gravity fed, some fed via pressurized pipe systems, etc. There is as yet no definitive methodology for categorizing irrigation and drainage schemes; therefore there will always be discussion as to whether one is comparing like with like. It is important to understand, however, that comparison between different types of scheme can be equally valuable, as for instance might be the case for governments in comparing the performance of privately owned estates with smallholder irrigation schemes. The two have different management objectives and processes, but their performance relative to criteria based on the efficiency and productivity of resource use (land, water, finance, al.bor) would be of value in policy formulation and financial resource allocation (Bos *et al.*, 2005). Benchmarking of irrigation and drainage systems is a form of comparative (external) performance assessment that is increasingly being used. Benchmarking seeks to compare the performance of 'best practice' systems with the currently assessed system, and to understand where the differences in performance lie. Initially performance assessment might be focused on a comparison of output performance indicators (water delivery, crop production, and productivity), followed by diagnostic analysis to understand what causes the relative difference in performance, and what measures can feasibly be taken to raise performance in the less well performing systems. The selection of performance assessment criteria will be influenced by whether the exercise looks internally at the specific objectives of an irrigation scheme, or whether it looks to externally defined performance criteria. Different schemes will have different objectives, and different degrees to which these objectives are implicitly or explicitly stated. It may well be that when measured against its own explicitly stated objectives. However, when measured against an external criterion of crop productivity per unit of water used, or impact on the environment, it may not perform as well. This reinforces the point made earlier that assessment of performance is often dependent on people's perspective irrigation is seen as beneficial by farmers, possibly less so by fishermen and downstream water users (Bos *et al.*, 2005).

- **Extent/boundaries**

The extent of the performance assessment needs to be identified and the boundaries defined. Two primary boundaries relate to spatial and temporal dimensions. Spatial real.tes to the area or number of schemes covered (the performance assessment limited to one secondary canal within a system, to one system, or to several systems); temporal real.tes to the duration of the assessment exercise and temporal extent (one week, one season, or several years). Other boundaries are sometimes less clear cut, and can relate to whether the performance assessment aims to cover technical aspects alone, or whether it should include institutional and financial aspects. How much influence, for example, does the existence of a water law on the establishment of water users' associations have on the performance of transferred irrigation and drainage systems?

The use of the systems approach advocated by Small and Svendsen (1992) can add to the definition and understanding of the boundaries and extent of the performance assessment programmed. The systems approach focuses on inputs, processes, outputs and impacts. Measurement of outputs provides information on the effectiveness of the use of inputs, while comparison of outputs to inputs provides information on the efficiency of the process of converting inputs into outputs. The process of transforming inputs into outputs has impacts down the line the pattern of water delivery to the tertiary intake has an impact on the level of crop production attained by the farmer. Measurements of canal discharges will provide information on how the irrigation system (network) is performing, but tell little about the performance of the irrigation and drainage scheme as a whole. To obtain this information we need to collect data within the irrigated agriculture system, and the agricultural economic system to set the performance of the irrigation system in context. Care is needed here in relating the performance of the irrigation system to that of the agricultural economic system as many variables intervene between the supply of the irrigation water and the money received by the farmer for the crops produced. Alternative systems can be drawn up, Figure 2.2 shown linking the performance of irrigation and drainage into the wider institutional context. The performance assessment programmed may be interested in the level of outputs (crop production), and also the efficiency of resource use (production per unit of land, water, finance, al.bor). It might also be interested in the processes (e.g. canal conveyance efficiency). Impacts might relate to complying with statutory regulations or protection of the environment (e.g. salinity levels of drainage water). It is not necessary that all systems or system stages are studied, it is important, however, to be aware of the context in which a given performance assessment programmed is set (Bos *et al.*, 2005).

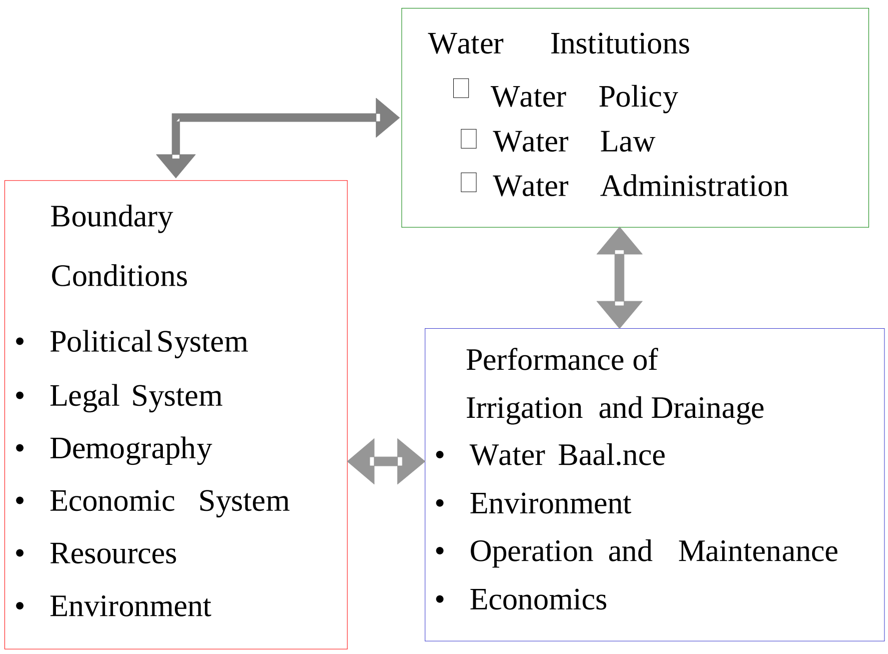

Figure 2.2 Irrigation and drainage performance in relation to the wider institutional context

2.2.4.2 Design of the performance assessment programmed

Having specified the approach to the performance assessment programmed in terms of the purpose and scope, the performance assessment programmed can be designed. The key issues to consider are:

i. What criteria are to be used?
ii. What performance indicators are to be used?
iii. What data are required?
iv. By whom, how, where and when will the data be collected?

What is the required form of output?

The following definitions are proposed in order to clarify the terms performance criteria, objectives, performance indicators and targets

(i) Objectives are made up of criteria such as:

- "To maximize agricultural production"
- "To ensure equity of water supply to all farmers"
- "To optimize the efficiency of water distribution"

Criteria can be measured using performance indicators

(ii) Defined performance indicators identify data requirements

(iii) Data can then be collected, processed and analyzed

(iv) If target, standards, reference or benchmark values of performance indicators are set or known then performance can be assessed.

In selection of criteria for performance assessment it is necessary to define whether the assessment will be made against the scheme's stated objectives and criteria, or against an alternative set of performance objectives or criteria. Whilst an irrigation scheme may have stated objectives, its performance may need to be assessed against different criteria Table 2.1.

As outlined in (Murray-Rust and Snellen, 1993), the setting of objectives is a crucial part of the management process, and much has been written on the subject in the context of business management. Some key points in relation to objective setting for irrigation management and performance assessment are outline as follow

(i) Explicit or implicit. Objectives can be explicit, where they are clearly stated, or implicit, where they are assumed rather than stated

(ii) Hierarchy of objectives. Objectives occur at different levels within a system or systems. A hierarchy of objectives for irrigation development, identified by (Sagardoy *et al.*, 1982) was in ascending order

- ❒ Appropriate use of water
- ❒ Appropriate use of agricultural inputs
- ❒ Remunerative selling of agricultural products
- ❒ Improvement in social facilities
- ❒ Betterment of farmers' welfare.

Each of these objectives is important at its own system level, satisfying the objectives at one level means that those at another (higher) level might also be satisfied. This hierarchy of objectives is an integral part of the Logical Framework project planning tool, moving from outputs to purpose to satisfy the overall goal.

(iii) Ranking or weighting of objectives. Within a system there may be several, sometimes competing and objectives. For performance assessment these may need to be ranked or weighted and assessments made to evaluate how well individual and collective objectives are satisfied. This process is commonly termed multi-criteria analysis. Identification of the performance criteria and indicators to be used in the performance assessment programmed which the data needs can be identified as given in Table 2.2.

I. Data collection (who, how, where and when)

During the performance assessment programmed design stage it will be necessary to identify that who will collect this data, and how, where and when it will be collected. All or some of the required data may already be avaial.ble, such as crop areas, or there may be a need for additional data collection procedures or special equipment to collect data (such as automatic water level recorders to gather detailed information on canal discharges day and night). Allowance will need to be made in the performance assessment budget for the costs associated with the data collection and handling programmed. To understand the performance of an irrigation scheme it is neither necessary, nor economic or time efficient, to collect data for every location in a scheme. The performance assessment programmed should be designed to take representative samples to enable an adequate analysis to be carried out in keeping with the prescribed needs (Bos *et al.*, 2005).

Table 1.1: Criteria for good scheme performance according to type of person

Type of person	Possible first criterion of good system performance
Landless laborer	Increased labor demand, days of working and wages
Farmer	Delivery of an adequate, convenient, predictable and timely water supply
Irrigation engineer	Efficient delivery of water from headwork to the tertiary outlet
Agricultural economist	High and stable farm production and incomes
Economist	High internal rate of return
Political economist	Equitable distribution of benefits, especially to disadvantaged groups

Source: (Chambers, 1988)

Table 2.2: Linking performance indicators to data requirements

Indicator	Definition	Units	Data required
Cropping intensity	Actual cropped area Irrigable area	%	Actual cropped area (ha) Irrigable area (ha)
Crop yield	Crop production Area cultivated	kg/ha	Crop production (kg) Area cultivated (ha)
Water Productivity	Yield of harvested crop Volume of irrigation supply	kg/m^3	Crop production (kg) Area cultivated (ha) Volume of irrigation water supplied (m^3)

II. Form of output

At the planning stage for the performance assessment programmed it is helpful to think about the form of the report output. Preparing a draft annotated contents list of the report, and a list of tables and figures and their anticipated content helps focus thinking and ensures that data is collected to match (Molden, 2004).

2.2.4.3 Implementation

The performance assessment programmed design phase is followed by the implementation phase, covering the actual collection, processing, and analysis and reporting of the data. Depending on the nature of the performance assessment programmed, implementation may be over a short (1 week) or long period (several years). In all cases it is worthwhile to process and analyze some, if not all, of the data collected as the work progresses in order to detect errors in data and take corrective action where necessary (Bos *et al.*, 2005).

2.2.4.4 Application of output

The use of the information collected from a performance assessment study will vary depending on the purpose of the assessment. The use to which the results of the performance assessment are put will depend on the reason the performance assessment was carried out (Bos *et al.*, 2005). Possible actions following the conclusion of the performance assessment study might include

1. Redefining strategic objectives and/or targets
2. Redefining operational objectives and/or targets
3. Implementing corrective measures, for example
    - ❒ Training of staff
    - ❒ Building new infrastructure
    - ❒ Carrying out intensive maintenance
    - ❒ Developing new scheduling procedures
    - ❒ Changing to alternative irrigation method(s)
    - ❒ Rehabilitation of the system

- ❐ Modernization of the system

2.2.4.5 Further action

Further studies may be required as a result of the performance assessment programmed. Performance assessment is closely linked with diagnostic analysis. It is often the case that an initial performance assessment programmed identifies areas where further measurements and data collection are required in order to identify the root causes of problems and constraints. Where performance assessment identifies the root cause of a problem or constraint, further studies may be required to implement measures to alleviate the problem, such as field surveys for the planning and design of a drainage system to relieve water logging (Bos *et al.*, 2005).

2.3 Performance Indicators

Performance is measured through the use of indicators, for which data are collected and recorded. The analysis of the indicators then informs us on the level of performance. Indicators play an important role in performance assessment to help assess performance against different criteria and objectives. Table 1 shows different formats of indicators. Indicators are typically are set up in form of ratios. Actual values could also be used, such as groundwater depth or yield, but this is effective when there is an implicit comparison against some other values like previous depth to groundwater, or reasonable values of yields. A few useful indicators are given in this section (Molden, 2004).

It is important to ensure that indicators that are selected to quantify the performance for a system describe performance in respect to the objectives established for that system. A meaningful indicator can be used in two distinct ways. It tells a manager what the current performance is of the system and, in conjunction with other indicators, may help him to identify the correct course of action to improve performance within that system. In this sense the use of the same indicator over time is important because it assists in identifying trends that may need to be reverted before the remedial measures become too expensive or too complex. The indicator should be based on an empirically quantified, statistically tested causal model of that part of the irrigation process it describes. Discrepancies between the empirical and theoretical basis of the indicator must be explicit, i.e., it must not be hidden by the format of the indicator. To facilitate international comparison of performance assessment studies, indicators should be formatted identically or analogously as much as possible (Bos and Nugteren 1990, ICID 1978, Wolters, 1992).

2.3.1 Type of Performance Indicators

Molden (2004) stated that it is recommended to compare the performance indictor's values through a dimensionless ratio with the actual (measurable) value of the parameter (of irrigation and drainage) in the numerator. The parameter value in the denominator of the ratio can be divided into four main groups:

1. The critical value of a key parameter is used if the assessed process is physically determined or shows a similar behavior. Commonly, these indicators describe one specific parameter. Most of the indicators in this group can be (or are) used in strategic performance assessment.
2. The intended value of the key parameter is used if a human decision is involved in setting this value. The indicator often describes the aggregate or transformation of a group of underlying activities. Most of the indicators in this group can be (are) used in operational performance assessment.
3. The intended value of the key parameter is used if a human decision is involved in setting this value. The indicator often describes the aggregate or transformation of a group of underlying activities. Most of the indicators in this group can be (are) used in operational performance assessment. The (actual) input value of the key parameter is used to quantify the output over input ratios of key resources. This group of ratios resembles the classical efficiencies of water use.
4. The total value of the key parameter is used to quantify the actual performing fraction (percentage) of a total avaial.ble resource. Most of these indicators relate to socio-economic (budgetary) parameters of irrigation management. To determine the real.ted degree of satisfaction, a systematic and timely flow of actual (measured or collected) data on key parameters of a system must be compared with intended or limiting (critical) values of these data. This comparison can be done in two ways:

- Present the (measured or collected) data through a (dimensionless) performance indicator, which ratio includes both an actual value and an intended (or critical) value of data on the considered key parameter as shown in Figure 2.3.

Table 2.3: Types of indicators

Performance Indicator Value	Type of Assessment
$\frac{\text{Actual Value of Key Parameter}}{\text{Critical Value of Key Parameter}}$	Actual physical processes whereby a critical value limits either crop yield or the sustainability of agriculture in the considered area.
$\frac{\text{Actual Value of Key Parameter}}{\text{Intended Value of Key Parameter}}$	Classical comparison of an actual physical situation with respect to an intended value. Most indicators relate to water delivery.
$\frac{\text{Actual Output Value of Key Parameter}}{\text{(Actual) Input Value of Key Parameter}}$	Assessment of the efficiency with which a resource (water, land, funds, etc.) is used. The classical irrigation efficiencies fall in this group.
$\frac{\text{Actual Value of Key Parameter}}{\text{Total Value of Key Parameter}}$	Assessment of the fraction (percentage) of infrastructure (resource) that functions

Source: (Bos *et la.*, 2005)

- Present the measured or collected data and compare this ‘measurable parameter’ with an intended (or critical) value of this measurable key parameter. Besides a presentation in time, both types of indicators can also be analyzed with respect to their spatial distribution.

2.3.2 Nature of the indicator

According to Molden (2004), an important factor influencing the selection of an indicator has to do with its nature: the indicator may describe one specific activity or may describe the aggregate or transformation of a group of underlying activities. Indicators ideally provide information on an actual activity relative to a certain target value. The possibility of combining such dimensionless ratios into aggregate indicators should be studied, in much the same way that many indicators used for national economic performance are composites.

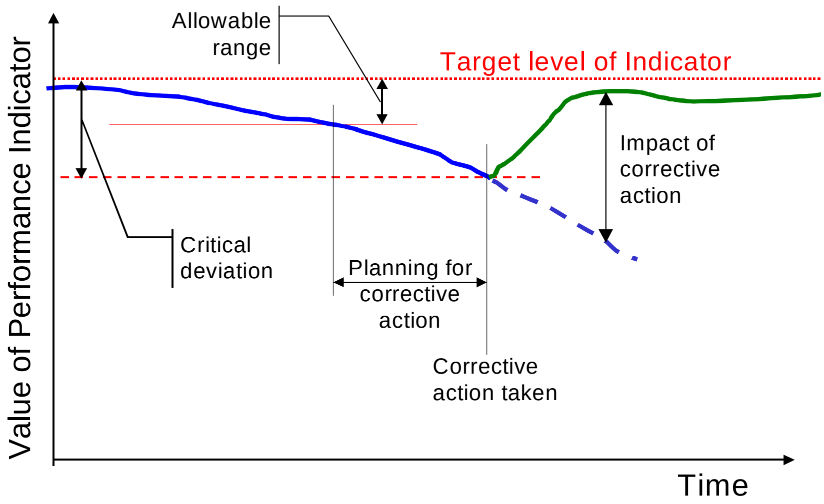

Figure 2.3 Terminology on the use of a dimensionless performance indicator (Molden, 2004).

2.3.3 Selected performance indicators

The performance indicators can be broadly grouped into four categories. These are:

i. water balance, water service, and maintenance. The indicators in this group refer to the primary function of irrigation and drainage; the provision of a water service to users.

ii. environment, irrigation and drainage is a man-made intervention in the environment to facilitate the growth of crops. The non-intentional (mostly negative) effects of this intervention are considered in this group.

iii. economic, this group contains indicators that quantify crop yield and the real.ted funds (generated) to manage the system.

iv. emerging indicators, this group gives four indicators that contain parameters which need to be measured by use of satellite remote sensing, this emerging technology enables very cost-effective measurement of data.

2.3.3.1 Water balance, water service and maintenance

The water real.ted indicators focus on the "core business" of irrigation; the diversion and conveyance of water to individuals or group of users or to other sectors. These indicators are concerned with how well water supply matches demand, whether services are reliable, adequate and timely and whether social equity has been met (Bos *et al.*, 2005). Specific indicators under this category are: overall consumed ratio, field application ratio, depletion fraction, drainage ratio, outflow over inflow ration, delivery performance ratio, dependability of irrigation interval and water level ratio.

- **Overall consumed ratio**

The overall (or project) consumed ratio (efficiency) quantifies the degree to which the crop irrigation requirements are met by irrigation water in the irrigated area (Bos and Nugteren, 1974; Willardson *et al.*, 1994). Bos and Nugteren (1974) stated that assuming negligible non-irrigation water deliveries to the area, the ratio is defined as:

$$OCR = \frac{ET_p - P_e}{\text{Volume of water supplied to command area}} \qquad (2.1)$$

Where

ET_p = potential evapotranspiration, and Pe = effective precipitation.

The numerator of this indicator originally (ICID, 1978) contains: ‘the volume of irrigation water needed, and made available, to avoid undesirable stress in the crops throughout (considered part of) the growing cycle’. The value of (ET_p - Pe) for the irrigated area is entirely determined by the crop, the climate and the interval between water applications. Hence, the actual value of the overall consumed ratio varies with the actual volume of irrigation water supplied to the considered command area. The value of (ET_p - P_e) can be calculated by use of models like CRIWAR (Bos *et al.*, 1996) and CROPWAT (Smith *et al.*, 1991). Because the total water supply to a command area (irrigation project) is among the very first values that should be measured (together with the cropped area, the cropping pattern and meteorological data), the overall consumed ratio is the first indicator that should be avaial.ble for each irrigated area. The overall consumed ratio also can be quantified for each major or tertiary unit and presented with a spatial distribution. Within an existing irrigated area, it is recommend setting a target overall consumed ratio, and compare the actual ratio at monthly and annual basis with this target value (Molden, 2004).

- **Field Application Ratio (FAR)**

The Field Application Ratio (efficiency) has the same structure as the overall consumed ratio. (ICID, 1978) defined it as:

$$FAR = \frac{ET_p - P_e}{\text{Volume of Water Delivered to Field (s)}} \qquad (2.2)$$

The numerator of this indicator originally contains:"the volume of irrigation water needed, and made avaial.ble, to avoid undesirable stress in the crops throughout (considered part of) the growing cycle". This 'volume' is expressed in terms of m3/ha or in terms of water depth. The numerator equals the potential evapo-transpiration by the irrigated crop minus the effective part of the precipitation (ET_p - P_e). The value of (ET_p - P_e) is entirely determined by the crop, the climate and the interval between water applications. Hence, the value of the Field Application Ratio varies with the actual volume of irrigation water delivered to the field. This water delivery depends on the reliability of the 'service' by the water-providing agency, the irrigation know-how of the farmer, and the uniformity with which water can be applied to the field (thus on the water application technology). From a technology point of view attainable values of the Field Application Ratio (efficiency) are shown in Table 2.4. These in essence provide benchmark values against which targets can be set. The calculation period of the Field Application Ratio depends on the (average) interval between water applications to the fields. If the period is too short, the number of water applications varies per period. It is recommended to use a calculation period that contains at least two water applications. One month is a suitable minimum period. In arid and semi-arid areas the Field Application Ratio with a calculation period of one irrigation season should remain below 0.90 to avoid salt accumulation in the root zone of the irrigated crop. Hence, from a sustainability point of view it does not make sense to try to be “too efficient” in irrigation water use. Therefore the target value is shown the maximum attainable value of Table 2.4 (Bos *et al.*, 2005).

- **Depleted Fraction (DF)**

The Depleted Fraction is the ratio that compares three components of the water baal.nce of an irrigated area. This indicator is particual.rly useful for diagnostic purposes in water-scarce areas. The Depleted Fraction relates the actual evapotranspiration from the selected area to the sum of all precipitation on this area plus surface and sub-surface water inflows into the irrigated area (typically irrigation water) into the area. It is defined as (Molden 1998, Molden and Sakthivadivel, 1999):

$$DF = \frac{ET_a}{Pe + V_c} \qquad (2.3)$$

Where

ET_a= actual evapotranspitarion from the gross command area;

P_e= precipitation on the gross command area and

V_c= Volume of surface and subsurface water flowing into the command area

Because it is not practical to measure the ET_a and the precipitation for only the irrigated part of the area, consider the gross command area, the Depleted Fraction quantifies the surface water balance excluding the drainage component. The water manager can influence the value of V_c while this in turn influences the water deficit ($ET_p - ET_a$) in the area. Due to the above definition of the components of the water baal.nce, the Depleted Fraction is usually quantified for the entire irrigated area. The Depleted Fraction can be used as a performance indicator on irrigation water use. The volume of water diverted into the irrigated area can be reduced during months with a low Depleted Fraction. If this non-diverted water remains in a storage reservoir, which is often the case in arid and semi-arid regions, this water can be diverted during dry months (Molden, 2004).

Table 2.4: Common maximum attainable values of the field application ratio (efficiency)

Irrigation Water Application Method	Maximum Attainable Ratio (Efficiency)
Surface Irrigation	
Furrows, laser levelling	0.70
Other quality levelling methods	0.60
Border strip, laser leveling	0.70
Other quality leveling methods	0.60
Level Basins, laser leveling	0.92
Other quality leveling methods	0.80
Sprinkler	
Hand move system	0.60
Overhead rain drops	0.80
Downward fine spray	0.90
Micro Irrigation	
Drip	0.95
Micro sprinkler	0.95

Source: (Bos, 1982; Jurriens *et al.*, 2001).

- **Drainage Ratio (DR)**

With the increasing scarcity of water, particual.rly in arid and semi-arid regions, the question on the quantity (volume per month or year) of water that is avaial.ble for new water users becomes increasingly significant. This question can be posed at different scales; e.g. river basin system, tributary, drainage system and can be quantified by the Drainage Ratio that is defined as (Bos *et al.*, 1994):

$$\text{DR} = \frac{\text{Total Drained Water from Area}}{\text{Total Water Entering into the Area}} \qquad (2.4)$$

The Drainage Ratio is intended to quantify water use in part of a river basin with well-defined boundaries. Table 2.5 gives annual values for three basins. If a value of 0.15 is considered as the critical lower limit to avoid salt accumulation in the drained area, it is obvious that there is little free water for new users in all three river basins.

Table 2.5: Annual values of the Drainage Ratio (Bos and Van Aart, 1996)

Drained area (river basin)	Drainage Ratio
Aral Sea basin	0.17
Nile in Egypt	0.21
Indus (Pakistan)	0.22

Considering the water baal.nce of a river basin (G_{in} = 0 and G_{out} is relatively small) the Drainage Ratio is about equal to (1 – Depleted Fraction).

- **Outflow over Inflow Ratios (OIR)**

The classical ratios used to quantify the water baal.nce of a canal system (or reach) are the Outflow over Inflow Ratios (often named efficiency). All ratios have the same structure, being

$$\text{OIR} = \frac{\text{Total Water Supply from Canal}}{\text{Total Water Diverted or Pumped into the Canal}} \qquad (2.5)$$

For large irrigation systems it is common to split the Outflow over Inflow Ratio over different management units of the system. In this context it is recommended to consider (i) the conveyance ratio of the upstream part of the system as managed by the Irrigation Authority and

(ii) the distribution ration of the WUA managed canal system.

- **Delivery Performance Ratio (DPR)**

The simplest, and yet probably the most important, operational performance indicator is the Delivery Performance Rat*io* (Clemmens and Dedrick 1984; Clemmens and Bos 1990; Molden and Gates 1990; Bos *et al.*, 1991). In its basic form it is defined as:

$$\text{DPR} = \frac{\text{Actual Flow of Water}}{\text{Intended Flow of Water}} \qquad (2.6.\ a)$$

Depending on the availability of data the above “flow of water” can be determined in two ways

- ❒ In systems where no structures are available to measure the flow rate, time is the only remaining parameter to quantify water delivery performance. As shown in Figure 2.4, the actual length of the water delivery period can be compared with intended period so as to determine DPR. For operational purposes it is then assumed that the flow rate is constant during a relatively long period.
- ❒ With systems dependent on flow rates and volumes, flow rates must be measured in m^3/s. Delivery performance of water then real.tes the actual delivered volume of water with respect to the intended volume. The length of the period for which the volume is calculated depends on the process that needs to be assessed. It varies from one second (for flow rate), one irrigation rotation (for water availability) to one month or year (for water baal.nce studies).

The Delivery Performance Ratio enables a manager to determine the extent to which water is actually delivered as intended during a selected period and at any location in the system. It is obvious that if the actually delivered volume of water is based on frequent flow measurements, the greater the likelihood that managers can match actual to intended flows. To obtain sufficiently accurate flow data, discharge measurement structures with water level recorders must be avaial.ble at key water delivery locations (Bos, 1976). To facilitate the handling of data, recorders that write data on a chip are recommended (Clemmens *et al.*, 2001).

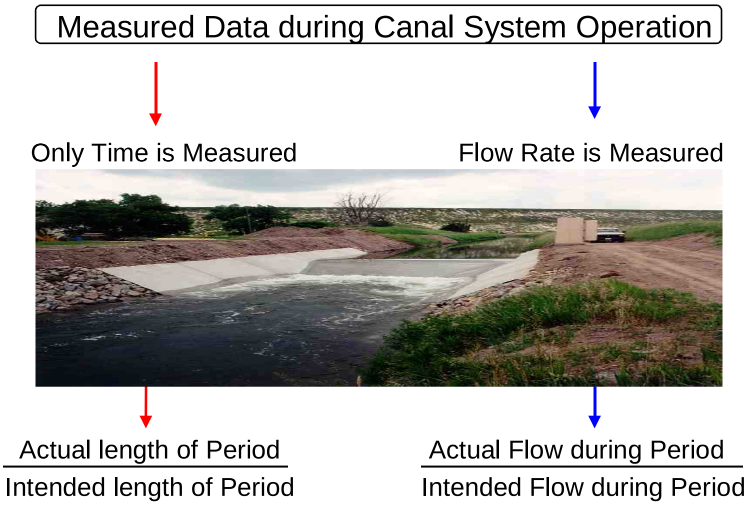

Figure 2.4 Depending on the avaial.ble data, the Delivery Performance Ratio will have different formats (Molden, 2005)

- **Water Delivery Capacity (WDC)**

Water delivery capacity is given as

$$WDC = \frac{\text{Canal capacity to deliver water at system head}}{\text{Peak consumptive demand}} \qquad (2.6.b)$$

Where

Canal capacity to deliver water at system head = the present discharge capacity of the canal at the system head.

Peak consumptive demand = the peak crop irrigation requirements for a monthly period expressed as a flow rate at the head of the irrigation system. In this report, this does not include seepage and deep percolation losses for rice.

- **Dependability of Irrigation Interval (DII)**

The pattern in which water is delivered over time, is directly related to the overall consumed ratio of the delivered water, and hence has a direct impact on crop production. The rationale for this is that water users apply more irrigation water if there is an unpredictable variation in timing of delivered water. Also, they may not use other inputs such as fertilizer in optimal quantities if they are more concerned with crop survival (because of water is not delivered) than crop production.

The primary indicator proposed for use in measuring dependability of water delivery is concerned with the time between deliveries compared to the plan or schedule. Dependability is defined as:

$$\text{DII} = \frac{\text{Actual Irrigation Interval}}{\text{Intended Irrigation Interval}} \qquad (2.7)$$

The irrigation interval is measured as the time between the beginnings of two successive water applications. The ditch rider opens the gate that delivers water to the irrigation unit (operation). The intended timing follows from the rotational schedule (Molden, 2005).

- **Relative water supply (RWS) and relative irrigation supply (RIS)**

Relative water supply as defined by Levine (1982) and relative irrigation supply as developed for this indicator set (Perry, 1996) are used as the basic water supply indicators

$$\text{RWS} = \frac{\text{Total water supply}}{\text{Crop demand}} \qquad (2.8)$$

Where,

Total water supply = Surface diversions plus net groundwater draft plus effective rainfall (but does not include any re-circulating internal project drainage water).

Crop water demand = Potential crop ET_c, or the ET_c under well-watered conditions. When rice is considered, deep percolation and seepage losses are added to crop.

$$\text{RIS} = \frac{\text{Irrigation supply}}{\text{Irrigation demand}} \qquad (2.9)$$

Where

Irrigation supply = only the surface diversions and net groundwater draught for irrigation (i.e. this does not include rainfall and does not include any re- circulating internal project drainage water).

Irrigation demand = the crop ET_c less effective rainfall.

The following can be noted regarding RWS and RIS:

i. In most arid region projects, there is an additional net water requirement for the removal of salts on a project-level basis. RIS and RWS do not include these.
ii. The definition of total water supply is almost guaranteed to give double counting of rainfall in most tropical climates, because the groundwater is actually resupplied by rainfall.

- **Canal Water Level and Head-Discharge Relationship**

Maintenance of irrigation and drainage systems intends to accomplish three main purposes

- ❒ Assure safety real.ted to failure of infrastructure, keep canals in sufficiently good (operational) condition to minimize seepage or clogging, and sustain canal water levels and designed head–discharge relationships.
- ❒ Keep water control infrastructure in working condition. In irrigation systems the assessment of the change in time of the 'outflow over inflow ratio' of the conveyance system provides the best way of assessing whether (canal) maintenance is required. By tracking the change in the ratio over time, it should be possible to establish criteria that will indicate when canal cleaning or reshaping is necessary as shown in Figure 2.5.

(Bos, 1976) stated that during the design of a canal system, a design discharge and real.ted water level is determined for each canal reach. The hydraulic performance of a canal system depends greatly on the degree to which these design values are maintained. i.e., higher water levels increase seepage and cause danger of overtopping of the embankment. Both, lower and higher water levels alter the intended water division of water at canal bifurcation structures. The magnitude of this alteration of the water distribution depends on the hydraulic flexibility of the division structures. This change of head (water level) over structures in irrigation canals is the single most important factor disrupting the intended delivery of irrigation water (Bos, 1976; Murray-Rust and van der Velde, 1994). An indicator that gives practical information on the sustainability of the intended water level (or head) is

$$\text{Water Level Ratio} = \frac{\text{Actual Water Level}}{\text{Design Water Level}} \qquad (2.10)$$

For closed irrigation and drainage pipes (visual) inspection of heads (pressure levels) is complicated. The functioning of a pipe, however, should be quantified by the measured discharge under a measured head-differential between the upstream and downstream end of the considered pipe (as used in the original design), versus the theoretical discharge under the same head differential. Hence, pipe performance can be quantified by the ratio

$$\text{Discharge Capacity Ratio} = \frac{\text{Actual Discharge Capacity}}{\text{Design Discharge Capacity}} \qquad (2.11)$$

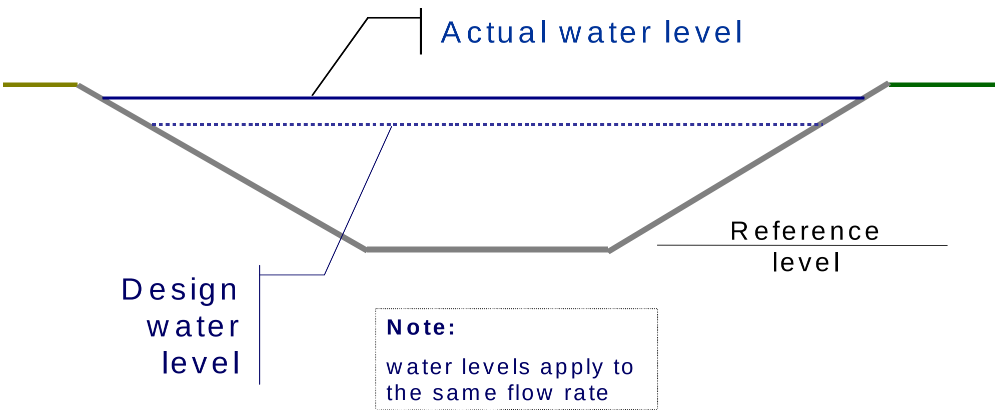

Figure 2.5 Illustration of terminology

The same discharge capacity ratio can be used to quantify the effective functioning of flow control structures in the canal system. Depending on the type of structure, the actual discharge then must be measured under the same (design) differential head (submerged gates, culverts) or under the same upstream sill-referenced head (free flowing gates, weirs, flumes). Generally, a deviation of more than 5% would signal the need for maintenance or rehabilitation for flow control structures. As mentioned above, maintenance is needed to keep the system in operational conditions. For this to occur, (control) structures and water application systems must be operational as intended. Data from the above two ratios can be summarized to quantify maintenance performance by the following ratio

$$\text{Efficiency of Infrastructure} = \frac{\text{Functioning part of infrastructure}}{\text{Total infrastrucrure}} \qquad (2.12)$$

The above three ratios indicate the extent to which the system manager is able to control water. For the analysis to be effective, however, structures should be grouped according their hierarchical importance (Primary, Secondary, Tertiary and Quaternary) and the analysis completed for each level (Bos *et al.*, 2005).

- **Water delivery performance (WDP)**

According to Seckler (1981), a crucial component of a complete management system is *"continuous and rigorous information system focused on outputs so that the performance of the system with respect to its objectives can known and controlled."* The physical output alone can be defined primarily in terms of water delivery in time and space through the system. WDF may be defined at several levels. According to Bailey (1984, one possible criterion of irrigation system performance is an index which takes into account both actual and target quantity and timing of water supply.WDP index can be determined as

$$WDP = \frac{1}{n}\sum_{t=1}^{n} e(t) \qquad (2.13)$$

$$e(t)= \begin{bmatrix} \dfrac{V(t)}{V^{*}(t)} & if & V(t)<V^{*}(t) \\ \dfrac{V^{*}(t)}{V(t)} & if & V(t)>V^{*}(t) \end{bmatrix}$$

Where

V (t) = the total volume of water entering the irrigation system during period t,

$V^{*}(t)$ = the total target volume of water to be supplied to the system during time t. and n = the number of periods in the cropping season.

WDP would equal 1.0 if the water delivered during each watering is equal to the crop water requirement for that watering. It would equal to zero if no water is delivered at all. The index could register both under-supply and over-supply within the 0-1 range.

Table 2.6 shows the water delivery criteria for Gezira scheme to estimate WDP at higher levels in the system by averaging and aggregating the farm level WDP index, depending on the management unit as the Sudan Gezira Board block or higher levels in irrigation system itself. Estimation of these performance indices can help to identify water management problems in respect to time and space, so corrective action can be taken.

Table 2.6: Water delivery performance criteria for Gezira scheme

level	Expression
For the jth cropping unit (Number)	$WDP_j = \frac{1}{N_i} \sum_{i=1}^{N_i} WDP_i$
For the kth Minor canal Command area	$WDP_k = \frac{1}{N_j} \sum_{j=1}^{Nj} WDP_j$
For the bth Block Command area	$WDP_b = \frac{1}{N_k} \sum_{i=k}^{N_k} WDP_k$
For ith Major canal Command area	$WDP_l = \frac{1}{N_k} \sum_{k=1}^{N_k} WDP_k$
For the system	$WDP = \frac{1}{N_l} \sum_{l=1}^{Nl} WDP_l$

N= the number of units at the next lower level in the system

- **Expected error in irrigation system performance**

Sharma *et al.* (1991) defined the error (e_s) in attaining required amount of water delivered to met the irrigation water requirement as

$$es^2 = 1/n \sum_{i=1}^{n} (Q_r - Q_a)^2 \qquad (2.14)$$

Q_r and Q_a respectively are the target and actual water deliveries and n is the number of occurrence in a specific point or a number of locations to be supplied at a define time

The relative errors is determined by

$$esl^2 = \frac{\sum_R^n (Q_r - Q_a)^2}{\sum_R^n (Qr)^2} \qquad (2.15)$$

esl equal to zero, if the system, performance is well and efficient, equal to one if there is no water in the system and range between zero to one if the performance of the system is inefficient, thus the performance of the system (P_s) is given by:

$$Ps = 1 - es_l \qquad (2.16)$$

The total error respect to the performance parameters (Adequacy, equity and management), can be define as

$$es^2 = (M_{Qr} - M_{Qa})^2 + (S_{Qr} - S_{Qa})^2 + 2(1-r) * S_{Qr} * S_{Qa} \qquad (2.17)$$

Where

M_{Qr} is the mean of the target water delivery;

M_{Qa} = the mean of the actual water delivery;

S_{Qr} = the standard deviation of the target water delivery;

S_{Qa}= the standard deviation of the actual water delivery;

r = the correlation coefficient obtained from the relation between the target water delivery (Q_r) and the actual water delivery (Q_a).

From equations 2.14 and 2.17

$$1/n \sum_{i=1}^{n} (Q_r - Q_a)^2 = (M_{Qr} - M_{Qa})^2 + (S_{Qr} - S_{Qa})^2 + 2(1-r) * S_{Qr} * S_{Qa} \qquad (2.18)$$

Dived both sides of equation 2.18 by the left hand side

$$1 = \frac{(M_{Qr} - M_{Qa})^2}{1/n \sum_{i=1}^{n} (Q_r - Q_a)^2} + \frac{(S_{Qr} - S_{Qa})^2}{1/n \sum_{i=1}^{n} (Q_r - Q_a)^2} + 2(1-r) * \frac{S_{Qr} * S_{Qa}}{1/n \sum_{i=1}^{n} (Q_r - Q_a)^2} \quad (2.19)$$

$$1 = E_{as} + E_{es} + E_{ms} \quad (2.20)$$

Where E_{as} error in adequacy, E_{es} error in equity and E_{ms} error in management, thus

$$E_{as} = \frac{(M_{Qr} - M_{Qa})^2}{1/n \sum_{i=1}^{n} (Q_r - Q_a)^2} \quad (2.21)$$

$$E_{es} = \frac{(S_{Qr} - S_{Qa})^2}{1/n \sum_{i=1}^{n} (Q_r - Q_a)^2} \quad (2.22)$$

$$E_{ms} = 2(1-r) * \frac{S_{Qr} * S_{Qa}}{1/n \sum_{i=1}^{n} (Q_r - Q_a)^2} \quad (2.23)$$

2.3.3.2 Environmental impact indicators

Irrigation can be considered as a human intervention in the environment; water is imported into an area to grow a crop that would not grow without this imported water. In reverse, drainage discharges water from an area to improve crop growth, accessibility of fields, discharge salts from the area, etc. Besides the intended impacts there are unintended impacts (usually labeled negative, but can be positive). The intended impacts are mostly restricted to the irrigated (or drained) area, while the unintended impacts may spread over the irrigated area, the river basin downstream of the water diversion, and the drainage basin downstream of the drained area (Bos *et al.*, 2005). Common environmental impacts of irrigation are rise in groundwater table and real.ted pollution.

- **Groundwater Depth**

Many of the adverse environmental impacts of irrigation are real.ted to the rate of change of the depth to the groundwater table. Because of ineffective drainage, or delay in constructing drainage systems in comparison to the surface water supply infrastructure, the groundwater table often rises into the root zone of the irrigated crop. In arid and semi-arid regions this often leads to the increase of capillary rise over seepage, resulting to salinity in the root zone. If groundwater being pumped for irrigation exceeds the recharge of the aquifer the groundwater table drops. As a result, energy cost for pumping may increase to such a level that water becomes too expensive, or groundwater mining may deplete the resource. For water-logging and salinity, the critical groundwater depth mostly depends on the effective rooting depth of the crop, the overall consumed ratio of irrigation water use, and on the hydraulic characteristics of the unsaturated soil. Depending on these conditions, the critical depth varies between 0.5 and 4.0 m. In the case of groundwater mining, the critical depth depends on the cost of pumping water, the value of the irrigated crop and on the depth of the aquifer. If the actual groundwater depth is near the critical depth, the time interval between readings of the ratio should be near one month (Bos *et al.*, 2005).

- **Pollution of Water**

Within the context of the man-made pollution of water we distinguish between the consumption and the use of water. If water is consumed (by the crop) or depleted[1] it leaves the considered part of the system, and cannot be consumed or reused in another part of the considered system. For example, if the field application ratio (efficiency) for a considered field is 55%; this means that 55% of the applied water is evapo-transpirated

[1] Consumed refers to crop evapotranspiration, while depleted refers to a use that renders it unavaial.ble for further use within the system or downstream, either through evotranspiration, evaporation, severe quality degradation, or flows directed by irrigation to sinks.

and that the other 45% either becomes surface run-off or recharges the aquifer. Part of this 45% may have been used to serve other purposes, e.g. simplify farm management, leaching (Molden *et al.*, 2004). During the irrigation process water can be used for a variety of non-consumptive purposes. These may be directly real.ted with irrigation (facilitate management, silt flushing, leaching, seepage, etc.), or be real.ted with other user groups (energy production, shipping, urban and industrial use, recreation). As a general rule we may assume that the quality of water decreases upon its use. The indicators in this section quantify the effect of user activities on water quality.

The indicators in this Section quantify physical processes whereby the concentration of a chemical limits crop yield, or hampers health, if a critical value is passed. The pollutant groups that need to be measured are indicated in Table 2.7. Indicator value of pollution can be calculated as:

$$\text{Indicator Value of Pollution} = \frac{\text{Actual Concentration of Pollution}}{\text{Critical Concentration of Pollution}} \qquad (2.24)$$

Table 2.7 Minimum groups of recommended pollutants to be monitored

Type of pollutant	To be measured
Soil salinity	The Electrical Conductivity (EC) of the soil
Organic matter	The total dissolved organic matter (vol %), floating matter (vol %), colour and smell.
Biological matter	Biochemical Oxygen Demand (m/l) and the Chemical Oxygen Demand (m/l).
Chemicals	We recommend the measurement of at least the concentration of Nitrates (NO_3^{-1} in meq/l) and of Phosphorus (P in meq/l).

- **Sustainability of Irrigable Area**

The intensity, with which the irrigated area is cropped, traditionally is a function of the number of crops per year grown on an irrigated area. To quantify the “occupancy” of the irrigable area by a crop it is recommended to use the cropped area ratio which can be described as

$$\text{Cropped Area Ratio} = \frac{\text{Average Cropped Area}}{\text{Initial Total Irrigable Area}} \tag{2.25}$$

The cropped area is the weighted average during the considered period (usually one month), as shown in Figure 2.6. The initial area refers to the total irrigable area during the design of the system or following the latest rehabilitation. If the area ratio is averaged over one year, it quantifies the rate at which the irrigable area is occupied by crops. This average area ratio is automatically calculated by CRIWAR (Bos *et al.*, 1996).

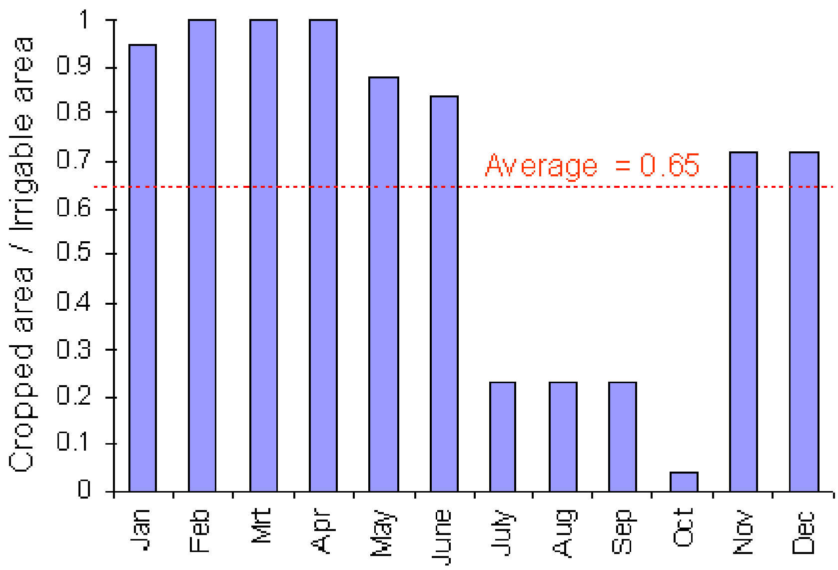

Figure 2.6 Annual variation and average for the Cropped Area Ratio (Bos *et al.*, 1996)

Within the irrigated area, several negative impacts (water logging, salinity, and water shortage due to competitive use) cause a reduction of the actually irrigated area. A further reduction of the cropped area is real.ted with population growth and urbanization, road construction, etc. Parameters of physical sustainability (of the irrigated area) that can be affected by irrigation managers relate primarily to over- or under-supply of irrigation water leading to water logging or salinity. The cumulative effect of the above (negative) impacts on the “cropped area ratio” can be quantified by plotting annual values of this ratio. If the annual average Cropped Area Ratio is mapped for each tertiary unit, the area with relatively low land occupancy is visualized (Molden, 2004).

2.3.3.3 Economic indicators

Each of the primary participants in the irrigation sector, i.e., planners and policy makers, agency personnel and farmers, has a different perspective on what is meant by economic performance. Each, therefore, requires a separate set of indicators that reflects these different objectives. The system manager is most likely to be concerned with the financial resources avaial.ble at system level and the source of those funds. Policy makers are more concerned with overall returns on resource use from agriculture, and less concerned about the overall profitability of the irrigation institution that created the system (unless it is owned by a private firm in which they shareholders). Farmers are interested in the returns to their farming enterprise, and less concerned about overall returns to the resource base (Bos *et al.*, 2005). Economic indicators show the extent to which the resources are economically used to produce a given return. These are for example: water productivity, Land productivity, as well as total production.

i. Water Productivity (WP)

Within many irrigated areas water is an increasingly scarce resource. Hence, it is logical to assess the productivity of irrigation in terms of a scarce resource. Such an assessment can be made from a variety of viewpoints. The most common are; the productivity in terms of actual evapotranspiration and in terms of the volume of supplied irrigation water. The Water Productivity then is defined as (Molden *et al.*, 1998).

$$WP\,(\text{kg/m}^3) = \frac{\text{Yield or value of Harvested Crop}}{\text{Volume of Supplied Irrigation Water}} \qquad (2.26)$$

If viewed from the farmer’s perspective, the volume of supplied water is measured either at the farm inlet or at the head of the field, depending on the farmer’s views. Because of the values of ET_{actual} and the volume of (needed) irrigation water are heavily influenced by local climate, the use of the above two indicators is restricted to "on scheme" evaluation. Productivity of water can be expressed in terms of monetary value per unit of water. Gross value of production is the yield multiplied by the price of output, while the net value includes costs. This is useful when an irrigation system has multiple crops, especially grain and non-grain like maize, potatoes and fruits. Increases in economic water productivity may indicate a shift toward higher valued crops or increase in yields (Bos *et al.*, 2005).

ii. Land Productivity

Independently of the economic viability of a particular investment, or the viability of the agencies supplying water and other inputs, farmers must primarily be concerned with the profitability of their actions at the level of their individual farm. It is quite possible for sector or system level economic analyses to show negative returns, largely through the high cost of capital, and yet find farmers in those systems consistently making profits. This profit is largely determined by crop yield and the farm-gate price of the irrigated crop. To assess crop yield, it should be real.ted to the '*intended crop yield'*. This intended yield varies with the crop variety, water application, soil fertility, farm management (Bos *et al.*, 2005).

The Crop Yield Ratio is

$$\text{Crop Yield Ratio} = \frac{\text{Actual Crop Yield}}{\text{Intended Crop Yield}} \qquad (2.27)$$

iii. Indicators of agricultural output

Indicators of agricultural output can be described as

$$\text{Output per cropped area (US\$/ha)} = \frac{\text{Total annual value of agricultural production}}{\text{Cropped or harvested area (ha)}} \qquad (2.28)$$

$$\text{Output per unit command area (US\$/ha)} = \frac{\text{Total annual value of agricultural production}}{\text{command area}} \qquad (2.29)$$

$$\text{Output per unit irrigation supply (US\$/m}^3\text{)} = \frac{\text{Total annual value of agricultural production}}{\text{Total annual volume of irrigation water inflow}} \quad (2.30)$$

iv. Financial viability of irrigation systems

One set of indicators concerns with efforts to raise revenues from water users that help support management, operation and maintenance (MOM) costs, and often some or all of the capital costs of individual irrigation systems. The first of these indicators describes the overall financial viability of the system:

$$\text{MOM Funding Ratio} = \frac{\text{Actual Annual Income}}{\text{Budget for Sustainable MOM}} \quad (2.31)$$

The total MOM requirements should be based on a detailed budget which is approved through a good budgeting system. If such a system is not in place, a budget can be based on the estimated MOM expenditure per hectare. The indicator is admittedly subjective because "requirements" greatly depend on the number of persons employed by the Agency per unit irrigable area (Bos and Nugteren 1974 for ranges). However, it gives an indication of the extent to which the agency is expected to be self-financing. The above income of the Agency (users association, irrigation district, irrigation department) may have different sources of income, e.g.; subsidies from the central government, water charges, sale of trees along canals, hydraulic energy.

v. O and M fraction

To quantify the effectiveness of the irrigation agency with respect to the actual delivery of water (system operation) and the maintenance of the canals (or pipe lines) and real.ted structures, the O and M Fraction is used.

$$\text{O and M Fraction} = \frac{\text{Cost of Operation + Maintenance}}{\text{Total Budget for Sustainable MOM}} \quad (2.32)$$

This indicator deals with the salaries involved with the actual operation (gatekeepers, etc.) plus maintenance cost and minor investments in the system (replacement of canal or pipe sections and of damaged structures). To quantify the O and M Fraction, we need the annual budget as proposed by the Irrigation Authority (for its total MOM) and, of it exists, from the WUA of the selected command area (for its MOM), the budgets as approved (allocation per item), and the actually realized income over the real.ted year (Molden, 2004).

vi. Fee Collection Ratio

In many irrigated areas, water charges (irrigation fees) are collected from farmers. The fraction of the annual fees (charges) due to be paid to the WUA and (or) the Irrigation District is an important indicator for level of acceptance of irrigation water delivery as a (public) service to the customers (farmers). The indicator is defined (Molden, 2004) as

$$\text{Fee Collection Ratio} = \frac{\text{Irrigation Fees Collected}}{\text{Irrigation Fees Due}} \qquad (2.33)$$

vii. Relative Water Cost (RWC)

From the perspective of the farmer, the relative cost of irrigation water application plus the cost of drainage can also quantify the economics of irrigation. RWC can be determined as:

$$\text{RWC} = \frac{\text{Total cost of irrigation water}}{\text{Total production cost of major crop}} \qquad (2.34)$$

The total production cost includes cost of water (including fees, energy for pumping), seeds, fertilizer, pesticides, labor, etc. For surface irrigation this ratio often ranges between 0.03 and 0.04; if pumped groundwater is used the ratio may become as high as 0.10. If the ratio becomes higher, farmers may abandon irrigation (Molden, 2004).

viii. Price Ratio

At the end of the irrigation season the farmer needs a 'reasonable' farm gate price for the crop. In this context 'reasonable' is compared with the price of the same crop at the nearest market. The Price Ratio, which is recommended to quantify this key parameter, is defined as

$$\text{Price Ratio} = \frac{\text{Farm Gate Price of Crop}}{\text{Nearest Market Price of Crop}} \qquad (2.35)$$

Low values of this ratio occur with inadequate distribution and marketing systems and if it is a long the distance to the nearest market. A low price ratio is a common reason for the farmer to change crop or stop irrigation entirely (Bos *et al.*, 2005).

ix. Benefit cost ratio

The benefit/ cost (B/C) ratio was developed, in part, to introduce objectivity into the economic analysis of the public sector evaluation, thus reducing the effect of politics and special interests. However, there is always predictable disagreement among citizens (individual group) about how the benefits of an alternative are defined and economically valued. The conventional benefit cost ratio, probably, the most widely used, is determined as

$$\text{B/C} = \frac{\text{Benefit - Disbenfits}}{\text{Costs}} \qquad (2.36)$$

Where

Benefit = present worth of benefit

Disbenefits = present worth negative consequences to the owners

Costs = present worth of estimated expenditure less salvage value

Present worth determined as

$$P = \frac{1}{(1+i)^n} \qquad (2.37)$$

i equal to interest rate or rate of return per time period

n equal to number of interest periods, months, days

2.3.3.4 Emerging indicators from Remote Sensing

The opportunity to measure data through satellite remote sensing became feasible with the cost reduction of images and advances in software and computers. This combination of developments facilitates to study the crop growing conditions at scales ranging from individual fields to scheme or river basin level. Public domain internet satellite data can be used to calculate actual and potential crop evapotranspiration, soil moisture and biomass growth. Satellite interpreted raster maps can be merged with vector maps of the irrigation water delivery system and (monthly) values of performance indicators for the various irrigation units (lateral or tertiary) can be presented through standard GIS. The accuracy with which data can be measured compares well with traditional measurements (Bos *et al.*, 2005). Under this method parameter such as crop water deficit, relative evapotranspiration, relative soil moisture, and biomass yield over irrigation supply quantified.

i. Crop Water Deficit

Crop water deficit over a period is defined as the difference between the potential and actual evapotranspiration of the cropping pattern within an area as defined by the water manger. A common period to is one month, Thus

$$\text{Crop water deficit (mm/month)} = ET_p - ET_a \qquad (2.38)$$

Where

ET_p = potential evapotranspiration of the crop

Et_a = Actual evapotranspiration of the crop

If an average Crop Water Deficit of 1 mm/d is accepted, i.e. 30 mm/month, than only few of the lateral units are in the proper range.

ii. Relative Evapotranspiration

To evaluate the adequacy of irrigation water delivery to a selected command area as a function of time, the dimensionless ratio of actual over potential evapotranspiration gives valuable information to the water manager. The ratio is defined as

$$\text{Relative Evapotranspiration} = \frac{ET_{actual}}{ET_{potential}} \qquad (2.39)$$

iii. Relative Soil Wetness

The Relative Soil Wetness is a measure for the ease with which the (irrigated) crop can take water from the root zone. It is defined as

$$\text{Relative Soil Wetness} = \frac{\Theta_{actual}}{\Theta_{FC}} \qquad (2.40)$$

Where

Θ_{actual} = measured (actual) volumetric soil water content in the root zone (cm^3/cm^3) and

Θ_{FC} = volumetric soil water content at field capacity (cm^3/cm^3)

iv. Biomass Yield over Irrigation Supply

The Biomass Yield over Irrigation Supply is a surrogate of the productivity of water. It real.tes the crop growth expressed as above ground dry bio-mass growth (kg/ha per month) with the volume of irrigation water supplied to the irrigated area (m^3/month). The ratio thus is described as:

$$\text{Biomass Yield over Irrigation Supply} = \frac{Bio}{V_C} \qquad (2.41)$$

If the average harvest index (harvested crop over biomass production) for a crop is known, the above ratio can be transferred into productivity data (Molden, 2004).

CHAPTER THREE

Materials and Methodology

3.1 General description of the study area

3.1.1 Geographical Location

Sudan is the largest country in Africa with a total area about 2.5 million km^2 with about 80 million hectare of arable land. Sudan extends from latitude 3º N to 22º N and longitude 22º E to 38º E. According to Adeeb (2004), the cropped area does not exceed 17 million hectares with only two million hectares equipped with irrigation network; about half of the irrigated area is in Gezira scheme which is in the central Sudan. The Gezira scheme is the largest irrigated area in sub-Saharan Africa and the second largest in all Africa, after Egypt. It covers a large area of Gezira state located between the Blue Nile and the White Nile towards their confluence. It has shape of triangle as shown in Figure 3.1. The scheme is located between latitudes 13º 30' N and 15º 15' N, and longitudes 32º 15' E and 33º 45' E. The scheme covers an area of 2.1 million feddans (882,000 hectares).

3.1.2 Climate

The seasonal migration of the Inter Tropical Convergence Zone (ITCZ) dominates the climate of the plains. By April, the ITCZ, and the rain belt to the south of it, passes the southern limits of the Central Plains and advances unsteadily northwards reaching its furthermost limit (19 ºN) in late July. Although the pattern of movement of the ITCZ for Sudan as a whole moves north and south, parallel with the Equator, the front on a north-west/south-east axis (Farbrother, 1996). The range of climate of the Central Clay Plains, as classified by Walsh (1991), extend from "Tropical Continental Desert" in north to "Tropical Sub-Humid" in the south. Apart from the most northerly Blocks of the Main Gezira, all the major large-scale developments in irrigation lie in intervening climatic zone described as "Tropical Semi-Arid" (Farbrother, 1996). Climatic conditions are favorable for year-round cultivation. The whole of GS lies within the Dry zone. This zone is characterized by a short rainy season, July to September, with an average annual precipitation of about 200 mm to 300 mm (1971-2000).

The Dry zone is endowed with abundant sunshine and solar energy. The total annual hours of sunshine are about 3000 hrs and solar radiation ranges between 20 and 26 MJ/m^2/day, in December and April respectively. Temperatures are hot in summer, the maximum temperature ranges from 34º C in January to 41º- 42º C in April and May , while the average minimum temperature is from 14.1º C in January to 25.1º C in June, the mean dry bulb temperature is about 28.7º C. The average annual relative humidity is about 41%; the wind speed is low, generally 2-3 m/s at 2 m height. Evaporation is high most of the year as a result of high solar radiation, high temperature and low humidity. The peak evaporation is about 8 mm/day in April-May while the lowest is about 6 mm/day in December-January, with the annual evaporation as high as 2600 mm. Table 3.1 shows the Normal (1971-2000) of the main climatic elements for Wad Medani Meteorological station, in the center of the Dry zone of Gezira scheme (Meteorological Authority, 2008).

3.1.3 Rainfall

The length of the rainy season at north-west extremity of the clay plains in the vicinity of Khartoum (16 ºN) is in the order of 30 days, and annual rainfall is highly variable around a long-term of 160 mm towards the southerly boundary of the Central Clay Plains, at Damazin. For example, the rainy season extends to some three months, with a mean annual rainfall around 600 mm. For Wad Medani, the 1919-40 average reported in Tothill was 401 mm. The Sudan Meteorological Department’s normal for 1941-70, however, was 362 mm; the frequent occurrence of the drought years since then has further reduced the long-term average (Farbrother, 1996). Figure 3.2 shows the annual rainfall pattern of the normal for 1971-2000. The annual rainfall was about 280.8 mm which is lower than the normal of 1941-70. Although the whole Gezira Scheme (GS) lies in the Dry Zone, when looking in closer details and on a large scale, it can be further divided into sub zones. The rainfall is the main climatic element having a very clear gradient from north to south (Meteorological Authority, 2008).

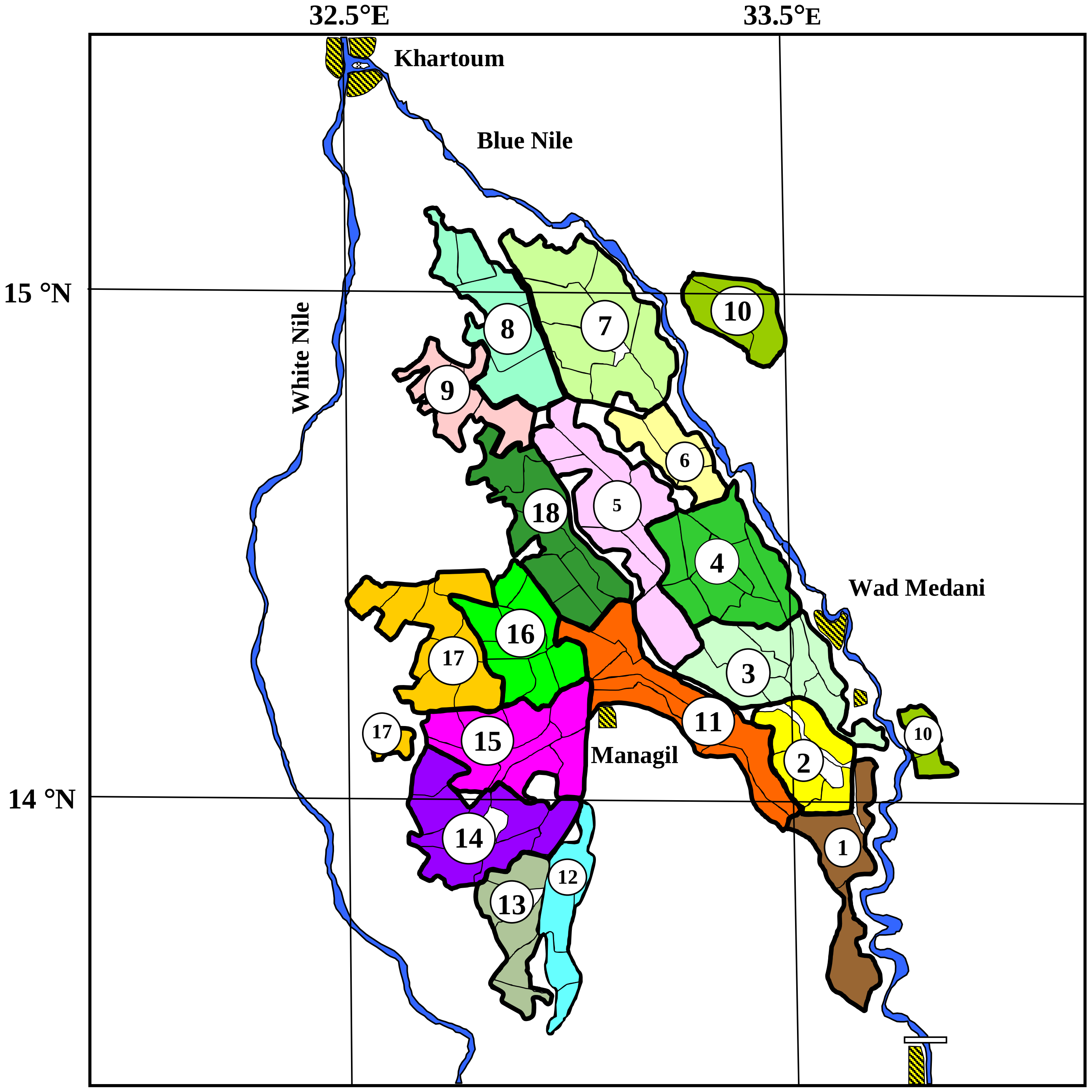

Figure 3.1 Gezira scheme groups and blocks

Source: Ministry of irrigation and water resource (2005)

Table 3.1: The Normal Weather parameters (1971-2000) for Wad Medani Station, Sudan

Month	Minimum Temp °C	Maximum Temp °C	Relative Humidity %	Wind Speed m/s	Sunshine duration hours	Solar Radiation $MJ/m^2/day$	ET_o mm/day
January	14.1	32.9	34	2.2	9.9	20.6	5.6
February	15.9	34.7	27	2.2	9.6	21.9	6.26
March	18.9	38.1	22	2.2	10	24.1	7.24
April	21.8	41.2	21	1.9	10.2	25.2	7.48
May	24.6	41.5	32	1.9	9.4	23.8	7.37
June	25.1	40.3	42	3.1	9	22.9	8.32
July	23.4	36.6	59	3.1	7	20	6.51
August	22.6	35.1	68	2.8	7.6	21	5.79
September	22.3	36.2	65	1.9	8.6	22.1	5.64
October	22	38.3	50	1.2	9.2	21.7	5.38
November	18.4	36.7	36	1.9	10	21	5.9
December	15.4	33.7	37	1.9	9.8	19.9	5.26
Average	20.4	37.1	41	2.2	9.2	22	6.4

Source: Ministry of science and technology, Meteorological Authority (2008)

* Solar Radiation and ET_o is Calculated by CROPWAT 8.0.

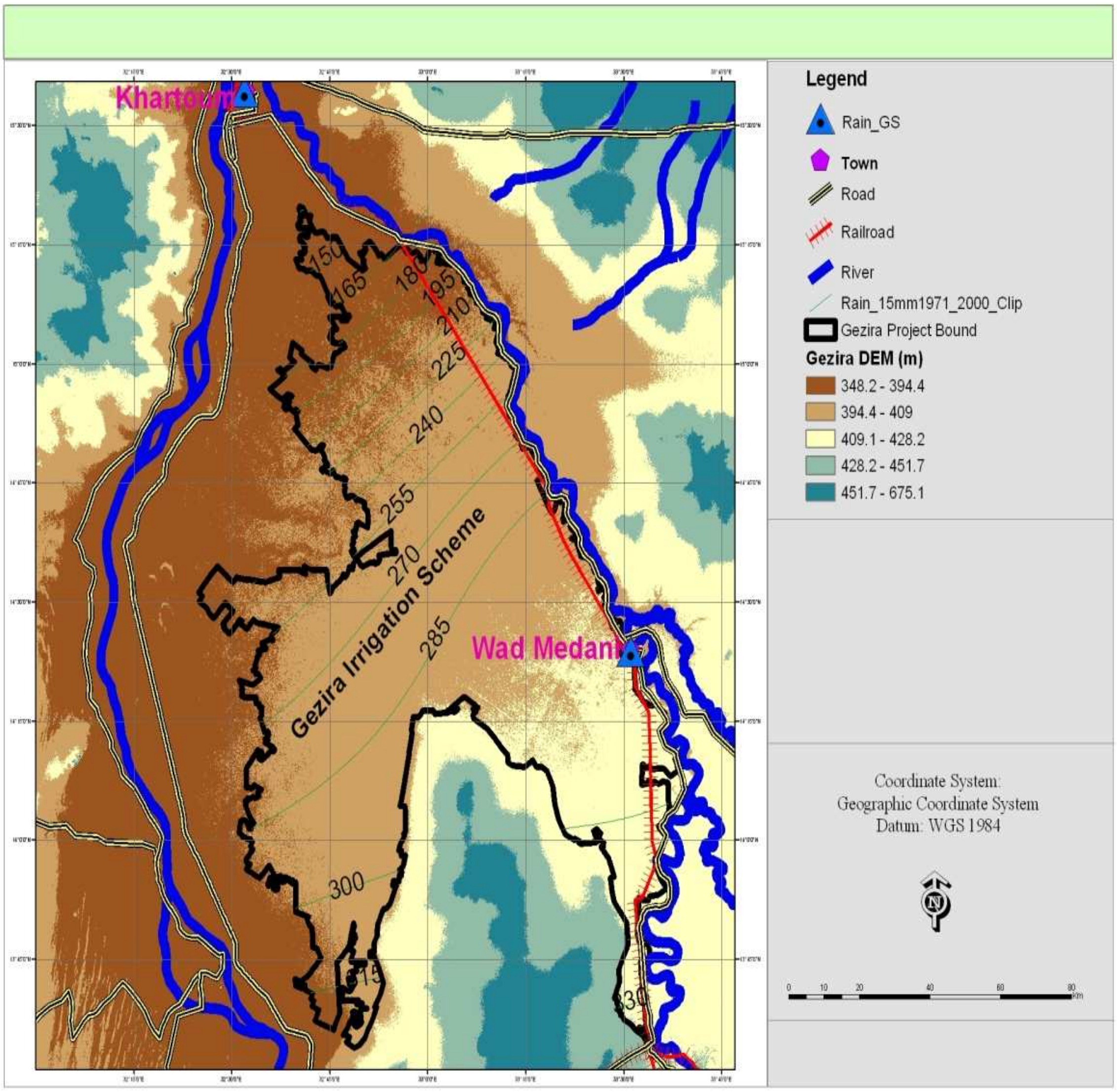

Figure 3.2 Rainfall pattern of Gezira scheme from normal climate data (1971-2000)

3.1.4 Soils

The soil in the whole of Gezira is vertisols (heavy clay), being part of the central clay plain of Sudan as shown in Figure 3.3. The main characteristic of the heavy clay soils is very low permeability rendering deep drainage almost nil. Thus losses from the huge lengths of canals through seepage are almost zero. The clay soils have a high water holding capacity is about 45% field capacity (FC) by volume, wilting point 23 % by volume. The pH is from 7 to 8, the bulk density varies with depth and moisture level. The bulk density at various depths and level of soil moisture are given in Table 3.2. Elias *et al.* (2000) studied three locations in GS; the soils at these sites had chemical and physical properties reflecting a gradient from south to north. Clay content ranged from 40 to 45% in the North Gezira (NG), 52% to 59% in the Central Gezira (CG) and 57% to 65% in the South Gezira (SG). Cation exchange capacity followed the same pattern as clay content. All soils had Ph values in the alkaline range. Soil EC was increase with increasing depth with the highest value found in the lowest horizon of the C.G profile. The Electrical Conductivity (ECs) of the surface soil always increasing during the period with no rain or irrigation due to evaporation at surface and the upward movement of soil moisture and salts the closer to the surface the higher salt concentration. Thus, the top horizons in the profile NG, SG and CG had depth of 25, 10 and 3 cm, respectively. The EC values for these three horizons were 243, 325 and 651 $MScm^{-1}$, respectively. The highest values of EC are found in the thinnest horizons (0 to 3 cm depth).

Table 3.2: Bulk density variations with depth and level of soil moisture

Depth cm	Soil moisture (%)				
	10	20	30	40	50
00-40	1.25	1.23	1.19	1.15	1.11
40-60	1.35	1.32	1.26	1.19	1.13
60-80	1.53	1.46	1.32	1.25	NO
80-100	NO	1.53	1.38	1.29	NO
100-200	NO	1.54	1.40	1.30	NO

Source: (Farbrother 1972), NO: No observation

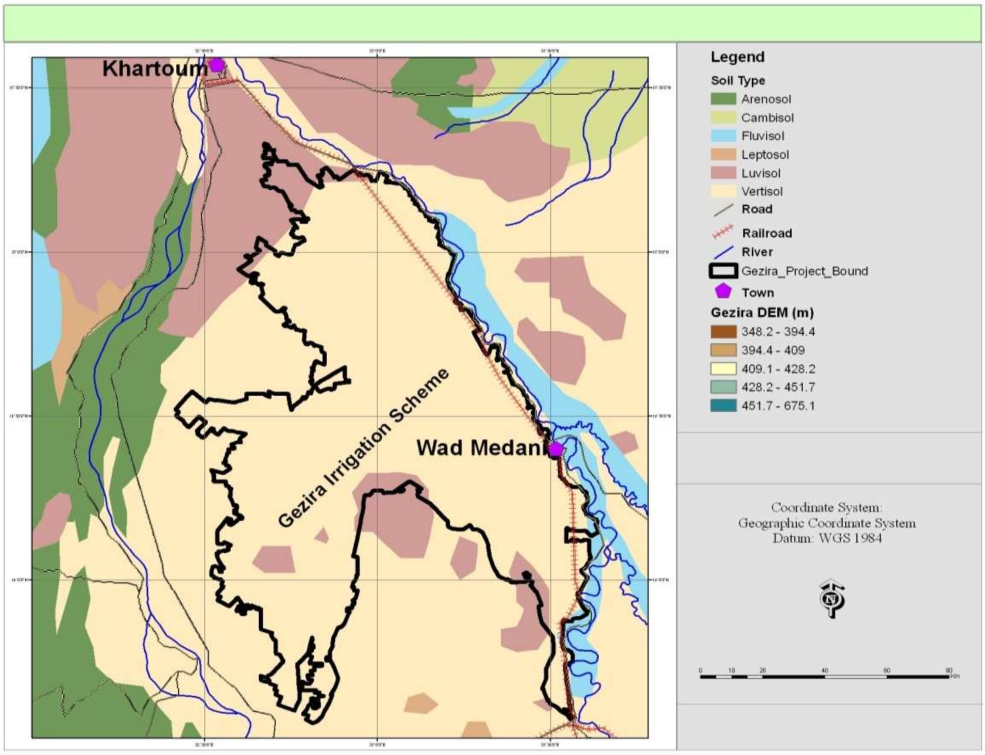

Figure 3.3 the soil map of Gezira scheme

3.1.5 Topography

The general topography of the central clay plain is usually described as one vast alluvial by the Blue Nile between late-Tertiary and mid Pleistocene times. From the foothills of the Ethiopian highal.nds the land slopes imperceptibly, at about 20 cm/km over the 200 km wide of the pal.ins, towards the White Nile which forms the western boundary of the vertisols. The occasional inselberg rises here and there over the central clay plain (Jebel Fau), visually accentuating the quite extraordinary flatness of the surrounding plain According to Farbrother (1996), the mean slope of the 2,100,000 feddan command area of the GS is 16 cm/km towards north- west. There are many minor topographical departure from mean, and land exceeded a localized slope of about 50 cm/km was originally excluded from the area canalized. Low-lying internal drainage pans were also excluded. Natural and man-made “high spots” and “low spots” within cultivated areas occur frequently. Although they may be involve variations from the mean level of the individual fields by little as 10 cm difference.

3.2 Description of Gezira irrigation scheme

3.2.1 Storage Dam (Sennar Dam)

The dam started in 1914 after temporary halt due to the first World Ware is situated on the Blue Nile some 260 km southwest of Khartoum. The dam started in 1914 after temporary halt due to the first World Ware and completed in 1925 to supply the Gezira irrigation scheme by gravity from head works on the left bank of the river. The total storage capacity of the reservoir created by Sennar dam was 930 million cubic meters (Galal, 1997). According to Herve (1990) the total length of the dam including embankments is just over 3 km, of which the central section, built of masonry, is 600 m long with a maximum height of 26 m. This latter section contains 80 low level sluices and a 300 m spillway which can be closed off by steel panels when the flood has passed. The top water level of the reservoir is at 421.7 m and the minimum level is at 417.2 m in the reservoir with storage capacity reduced to 330 million cubic meters to maintain maximum flows in the Gezira canal.

3.2.2 Roseires Dam

The Roseires dam is situated on the Blue Nile approximately 250 km upstream of Sennar dam. The dam, with a design reservoir retention level of 480 m, completed in 1966, was constructed to provide storage for irrigation during the low water season and for hydropower generation. The total storage capacity of Roseires reservoir was 3,000 million cubic meters and the live storage was 2,400 million cubic meters. The dam is a concrete buttress type about 1 km long, flanked on either side by earth embankments 8.5 km long to the west and 4 km long to the east. For sedimentation control in the reservoir, the dam has five deep sluices set at the lowest possible level in the main river channel. The discharge through the dam is normally passed through these deep sluices which are equipped with radial gates for control purposes. A gated spillway, with a crest level set at the minimum drawdown level of 467 m, augments the deep sluices when the peak flood is passed Herve (1990).

3.2.3 Conveyance and distribution systems

The GS Water is diverted from Sennar reservoir by means of twin main canals with a combined maximum daily discharge capacity of 31.5 million cubic meters (354 cubic meters per second), running northward 57 kilometers to the first group of regulators forming a large pool. The Gezira main canal has an intake of 14 Roller gates with dimension of 3m width and 5m height, with the capacity of 16 million cubic meter of water per day. The Managil canal has an intake of 11 openings with the same dimensions with the capacity of about 15 million cubic meters per day. At about 65 km along Managil canal, another important branch takes off it is called Wadi Alnil joints with Abu Usher branch, which takes off from Gezira canal, at Albedmagid some 36 km directly west of Abu Usher. Another important Branch takes off from old Gezira near k 92, in the absence of cross regual.tor. It is called Tabat after Tabat town in Wadi Sha*eer Group. In fact most of this Group is irrigated through Tabat Branch. In total there are 11 branches of total length of about 651 km and with capacities ranging from 25 to 120 cubic meters per second. There are 107 majors of total length of about 1652 km and capacities from 1.5 to 15 cubic meters per second. This comprises the upper system. Thus the total length of the upper system including 260 km of the two main canals is about 2563 km. The lower system consists mainly of about 1489 minors of total length of about 8119 km and capacities from 0.5 to 1.5 cubic meters per second. The Minor canals supply water through pipes which are 12 m long and a diameter of 35 cm, these are gated outlet pipes to field channels Abu ishreen (Abu XX) Known as the field outlet pipes (FOPs). There are 29 thousand AbuXXs, each approximately 1.4 km long and with capacities 116 liter per second. Thus the total length of AbuXXs is about 4,000 km. The smallest water courses taken from AbuXX into the field are known locally as Abu stitta (AbuVIs). There are 350,000 such channels, each 280 m long with a total length of about 100,000 km. The capacity of AbuVI ranges from 25 to 50 liters per second. The field channels (Abuxx) irrigates 90 feddans (38 hectare), called "Numbers". Each number is divided into 22-23 tenant fields of 4 feddans (called hawasha) with dimensions 280 m x 60 m. A network of cross-bunds for irrigation by basins in turn divides the tenant field. From AbuVIs water goes into yet smaller channels called Gadwals. From there it flows through furrows.

Originally each field of 10 feddans is divided into 14 plots called Angayahs. Between each Gadwal and another there is Tagnat (MOIWR, 2009).

Summary of numbers, total lengths and widths of each type of canal and watercourse is given in Table 3.2. The capacities and lengths of the Braches are shown in Table 3.3.

Table 3.3: Summary of information on the irrigation network

Name	Number	Capacity (m^3/sec)	Total length (km)	Average width (m)	Area (ha)
Mains	2	354	260	50	1300
Branches	11	25-120	650	30	1950
Majors	107	1.2-1.5	1650	20	3300
Minors	1,500	0.5-1.5	8120	6	4870
Subtotal			10680		11420
Abu xx’s	29,000	0.116	4000	1	17500
Abu VIs	350,000	0.05	100000	0.5	1750
Total			150680		32920

Source: MOIWR (2008)

Table 3.4: Capacities and lengths of Branches

Branch	Capacity 10^6 m^3/day	Length Km	Branch	Capacity 10^6 m^3/day	Length km
Tabat	3.2	68	North west	2.4	26
Wadi El Nil	2.7	29	El Kawa	4.3	50
Ma*toug	3.1	143	Mansi	2.7	44
Shawal	1.8	-	Fahal	-	-
Tambuol	-	-	El Wagara	-	-
Managil I	16	-	-	10.2	65
Managil II	15			3.6	65

Source: MOIWR (2009)

3.3 Data Collection

3.3.1 Climate

The required meteorological data were obtained from the Ministry of science and technology, Meteorological Authority. The lists of climate data (Mean maximum and minimum Temperature, Relative Humidity, Wind speed, Total Rainfall, evaporation and sunshine) collected are given in Appendix 1. The Meteorological data include among others are:

- ❒ Long term (1971-2000), ten-day average meteorological data or normal meteorological data for Wad Medani.
- ❒ The average monthly meteorological data for Wad Medani station for period (1989-2008);

3.3.2 Hydrology

The monthly water released from Sennar Dam to GS for the seasons (1989–2008) as obtained from the Ministry of Irrigation and Water Resources is given in Appendix 2.

3.3.3 Land and Crops

List of the data collected from Sudan Gezira Board, and Central Bank of Sudan are shown in Appendix 2. The data include among other are:

- ❒ Cropped area (feddan) for the period (1970/71 – 2008/09);
- ❒ Cropping intensity for Seasons (1970/71 – 2008/09);
- ❒ Yield of main crops for Seasons (1970/71 – 2008/09) and
- ❒ Local major crops prices per season or per year for seasons (1995/96-2003/04).

3.4 Methods of processing and analyzing data

3.4.1 Crop water requirement

3.4.1.1 Potential Evapotransprtion

The required water supply was determined based on crop water requirement and irrigation water demand. The Reference Evapotranspiration (ET_o) represents the potential evaporation of a well-watered grass crop. The water needs of other crops are directly linked to this climatic parameter. Although several methods exist to determine ET_o, the Penman-Monteith Method has been used as the appropriate combination method to determine ET_o by CROPWAT 8.0 for seasons (1970/71-1988/89) from ten-day average meteorological data (1971-2000) of Wad Medani station, and for seasons (1989/90-2008/09) from average monthly meteorological data (1989/90-2008/09) of Wad Medani station. The values of ETo are given in Appendix 1.

3.4.1.2 Effective rainfall

To account for the losses due to runoff or percolation, a choice can be made of one of the four methods given in CROPWAT 8.0 (Fixed percentage, Dependable rain, Empirical formulas, USDA Soil Conservation Service). In this case, the USDA-SC method was chosen to calculate effective rainfall. The effective rainfall is calculated with CROPWAT 8.0 from rainfall data of Wad Medani station as shown in Appendix 1.

3.4.1.3 Irrigation water requirements

The estimation of irrigation water requirement was carried out from basic information of the crops grown that include: planting date, harvesting date and crop coefficient.

The planting date and the harvesting date and progressive sowing dates obtained from MOIWR were used as shown in Table 3.5, Table 3.6 and Table 3.7. Standard information on crops coefficient are given in table 3.8, rooting depth, depletion level and yield response factors are included for most crops in the CROPWAT 8.0 program. Length of the individual growth stages adapted to fit planting and harvest dates obtained from crop water requirement (FAO, 1977) and (FAO, 1998) as shown in Table 3.5. In addition the water holing capacity for heavy texture soil included in CROPWAT 8.0 was used. The crop irrigation requirement for each crop (mm/decade) was converted to (m^3/ha), then multiplied by the crop cultivated area in ha in the decade and then divided by one million to get crop irrigation requirement in million cubic meters/decade.

Table 3.5 Sowing date and end of the season for the Major crops

Crop	Sowing date	Length of grown season (days)	End of the season
Groundnuts	1/6 – 30/6	140	31/10
Sorghum	15/6 – 15/7	120	31/10
Cotton Acala	1/7 – 31/7	180	15/1
Cotton Barakt	15/7 – 15/8	210	15/3
Wheat	15/11 – 15/12	120	31/3

Table 3.6 Dates of plantation progress for main crops in GS

Crop	Period	Period	Period
	I	II	III
Groundnuts	1/6 – 10/6	11/6 – 20/6	21/6 – 30/6
Sorghum	15/6 – 25/6	26/6 – 05/7	06/7 – 15/7
Cotton Acala	01/7 – 10/7	11/07 – 20/7	21/7 – 31/7
Cotton Barkat	15/7 – 25/7	26/7 – 05/8	06/8 – 15/8
Wheat	15/11 – 25/11	26/11 – 05/12	06/12 – 15/12

Table 3.7 Percentages of Plantation progress for main crops in GS

Crop	Period	Period	Period
	I	II	III
Groundnuts	35 %	40 %	25 %
Sorghum	35 %	40 %	25 %
Cotton Acala	35 %	40 %	25 %
Cotton Barkat	35 %	40 %	25 %
Wheat	35 %	40 %	25 %

Table 3.8 Crop coefficient for main crops for dry areas and low wind speed

Crop	Initial stage	Mid stage	Late stage
Cotton	0.50	1.20	0.65
Groundnut	0.50	1.05	0.60
Sorghum	0.50	1.10	0.55
wheat	0.50	1.15	0.50

3.4.1.4 Gross irrigation water requirements

The gross irrigation water requirement is usually greater than irrigation requirements due to losses in the conveyance (E_a) and distribution (E_d) system. Conveyance efficiency 90 % and distribution efficiency 70 % was used (MOIWR, 2009). The irrigation water requirement in (million cubic meters/decade) divided by the overall efficiency of the scheme to get gross irrigation water requirements in million cubic meters/ decade.

3.5 Performance assessment methods

For the assessment and evaluation of the performance of the irrigation scheme, selected indicators need to be measured. The indicators that are widely used to assess the performance of irrigation scheme are discussed under section 2.4. However, 14 out of the discussed indicators have been used for this study. Table 3.9 shows the selected performance indicators and the methods employed to determine them.

3.6 The population mean of the sample

Student t-test is useful in testing the null hypothesis that population mean is equal to a specified value, in the case of this study the specified value is the arithmetic mean of the sample. The comparison provides statistic evaluation whether the difference between the two means is statistically significant. The lower and upper limit of the population mean of the data used in the analysis and the results of performance indicators was determined by Statistical Package for the Social Science (SPSS) software (one sample t-test with 95% Confidence Interval).

Table 3.9: Performance indicators methods of analysis

No	Type of indicators	Performance indicator	Equation no
1.	Water supply indicators	Overall consumed ratio	2.1
2.		Relative water supply	2.8
3.		Relative irrigation supply	2.9
3.		Delivery performance capacity	2.6.b
5.		Water delivery performance	2.13
6.		Expect error in irrigation system performance	2.21, 2.22 and 2.23
7.	Cropping intensity	Cropping intensity	2.25
8.	Land Productivity	Land productivity	2.27
9.	Indicators of agricultural output	Output per cropped area	2.28
10.		Output per command area	2.29
11.		Output per irrigation water supply	2.30
12.	Water productivity	Water productivity	2.26
13.	Economical Indicators	Relative water cost	2.34
14.		Benefit cost ratio	2.36 and 2.37

The hypotheses used in t-test are null hypothesis (Ho) and alternative hypothesis (Ha). The procedure for obtained the population mean from one sample t-test is describe as

- Take the null hypothesis (Ho) as the mean population mean equal to the arithmetic mean of the sample
- Take Alternative hypothesis (Ha) as the mean population different from arithmetic mean
- If significance level > 0.05 accept null hypothesis otherwise reject it and accept the alternative hypothesis

CHAPTER FOUR
Results and Discussions

4.1 Water Supply Indicators (WSI)
4.1.1 Overall consumed ratio (OCR)

❒ **Seasonal overall consumed ratio (1989/90-2008/09)**

Overall consumed ratio is the relationship between volume of irrigation water requirement and volume of irrigation water supplied during the season. The overall efficiency of the Gezira Scheme (GS) was measured by the Overall Consumed Ratio (ORC). This requires setting of the Target Overall Consumed Ratio (TOCR). The TOCR value for GS is 0.7 which is a typical overall efficiency of the scheme. It can be seen from figure 4.1, that the mean seasonal values of OCR show a decreasing trend over the considered season (1989/90-2008/09). This means that more irrigation water has been supplied than it was required. The minimum OCR was 0.3 and the maximum OCR was 0.8, the maximum value of mean OCR indicate excessive water supply relative to net irrigation requirement and the minimum value indicate very excessive water supply reaching about three times the net irrigation requirement. However, the best overall efficiency of the scheme (target mean seasonal OCR) achieved during early 1990s for only two seasons 1990/90 and 1993/94.

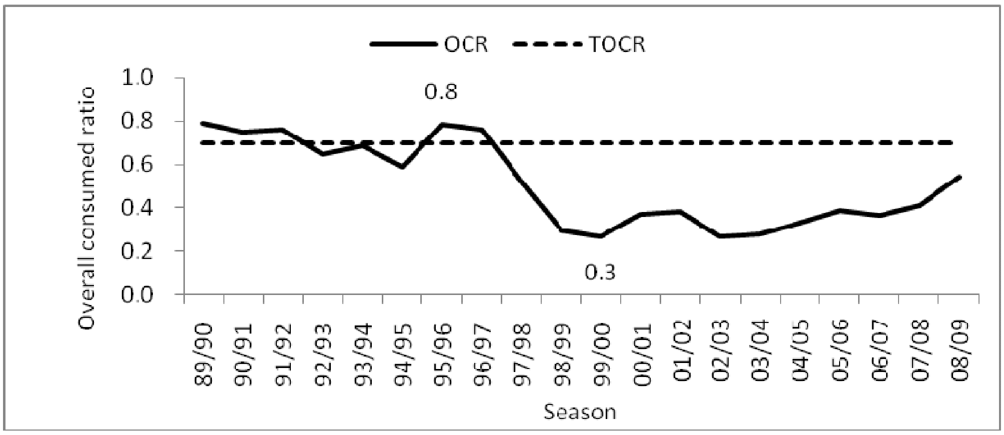

Figure 4.1 The relation between the seasonal Overall Consumed Ratio (OCR) and seasonal Target Overall Consumed Ratio (TOCR)

- **Monthly overall consumed ratio**

The overall (or project) consumed ratio (efficiency) quantifies the degree to which the crop irrigation requirements are met by irrigation water in the irrigated area (Bos and Nugteren 1974; Willardson *et al.*, 1994). Figure 4.2 shows that mean monthly (OCR) ranged from 0.2 to 0.8, which give an indication about the effect of a number of water management practices that have resulted in over or under application of water. Hence, some of these practices have undesirable side effects. At the beginning of the season (Jun to Jul), the mean monthly OCR ranged from 0.2 to 0.5 during months (Jun to July). This is an indication that there was excessive water supply due to delay of sowing date by farmers or decrease in the ratio of plantation progress in the first period. During the high rainy period (July and August) the mean monthly OCR range between 0.2 and 0.6 which indicate abundant water supply this was due to over estimates of the indents due to negligence of effective rainfall into account. During the peak month (September) the mean monthly OCR is about 0.5 to 0.8.This indicate excusive water supply relative to irrigation water required. At the end of the season during March the mean monthly OCR ranging from 0.4 to 0.6 which indicate that the water diverted from the Dam to GS is higher than the volume of irrigation requirement due to lack of adjustment of the indent to met the irrigation requirement by operation staff of MOIWR.

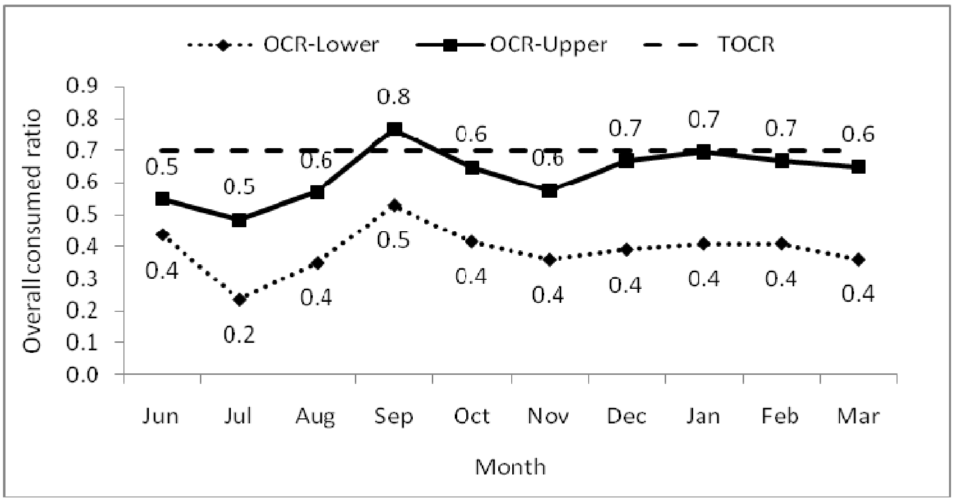

Figure 4.2 The relation between the lower and upper limit of the mean monthly Overall Consumed Ratio (OCR) and Target Overall Consumed ratio (TOCR)

4.1.2 Relative water supply (RWS)

- **Seasonal relative water supply**

Relative water supply (RWS) is the ratio of total water supply to the total water demand, and can be used both as a measurement of adequacy and timelines (Levine, 1982 and Meinzen, 1995, and Kloezen and Carlos, 1998). Adequacy deals with water supply to the crop Relative to its demand. (Pérez *et al.*, 2005) categorized RWS values as from 0.9 to 1.2 as adequate, the range 1.2 to 1.8 as excessive and values from 1.8 to 2.5 as very excessive. Figure 4.3 shows that the seasonal relative water supply when excluding the overall efficiency of the scheme ranged from 1.1 to 2.7 and when include the overall efficiency it ranged from 0.8 to 1.9. This indicate that the total water supply relative to the total water demand of GS vary from adequate to excessive or very excessive according Pérez *et al.* (2005) categories. From the graphical illustration of relative water supply performance indicator shown in Figure 4.3 an increasing trend of RWS can be seen, from early 1970s until mid 1990s the Seasonal Relative Water Supply when excluding the overall efficiency (RWS) and the Seasonal Relative Water Supply when include the overall efficiency (RWSe) close to the adequate level indicate good performance of operation services, the reasons for adequacy were the availability of water from Sennar dam and good water management practices. But from mid 1990s onward the RWS and RWSe moved to the zone of excessive or very excessive. This an indication of poor water management practices. It is concluded that the water supply to the scheme was abundant. This result indicates that tenants use more water than crop water requirement. This may cause water logging if the excess water is not removed from the field or the farmers cultivated more areas than the area stated by Sudan Gezira Board. This additional cultivated area will consume more water than the allocated water and the estimated crops water requirements during planning stage for the irrigation seasons.

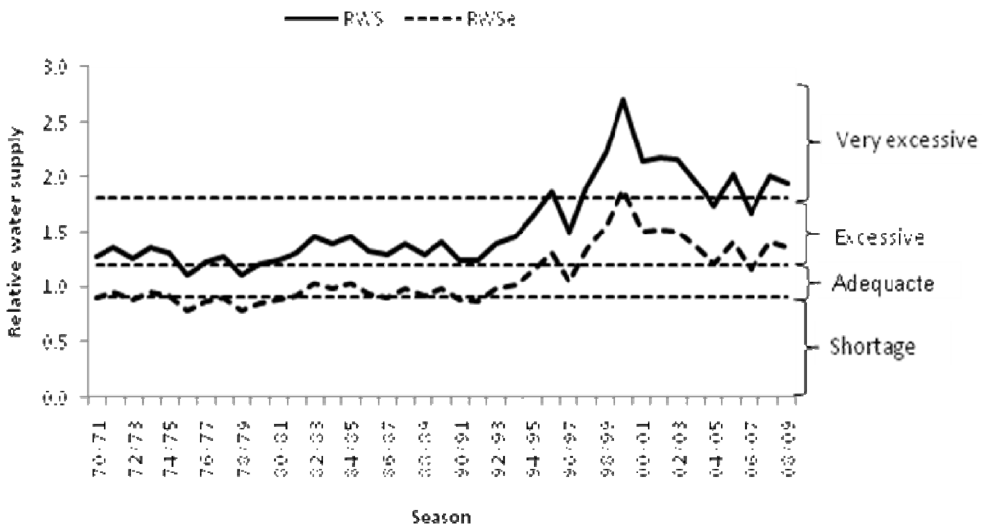

Figure 4.3 Seasonal relative water supplies

❒ **Monthly relative water supply**

Table 4.1 shows that the mean monthly Relative Water Supply when exclude the overall efficiency (RWS) ranged from 1.1 to 3.1. In the beginning of the season the mean RWS vary from 1.1 to 1.5 which can considered as adequate and in the period of peak rain in July and August the mean RWS ranged from 1.6 to 2.9 indicate excessive or very excessive water supply. The total water supply is much higher than the net crop water requirement this mainly due to over estimation of the indents result from negligence of effective rainfall. During the end of the season the mean RWS ranged between 1.5 and 3.1. This is an indication that there was extremely high irrigation water supply to GS relative it irrigation requirement. This result indicates that tenants use more water than crop water requirement. This may cause water logging.

Table 4.1: The monthly Relative water supply (RWS)

Month	Total water supply (m^3x10^6/day)		Net crop water requirement (m^3x10^6/day)		RWS	
	Lower	Upper	Lower	Upper	Lower	Upper
Jun	10.6	13.8	8.5	11.2	1.1	1.5
Jul	37.6	49.0	21.0	25.3	1.6	2.3
Aug	42.2	54.9	18.1	21.8	2.1	2.9
Sep	35.0	49.1	20.9	25.5	1.6	2.1
Oct	33.7	39.0	17.7	23.0	1.7	2.2
Nov	26.5	29.5	13.1	18.1	1.7	2.3
Dec	23.9	27.0	12.8	18.7	1.5	2.2
Jan	20.7	23.6	11.7	17.0	1.4	2.3
Feb	19.7	22.9	10.8	16.4	1.5	2.3
Mar	12.0	16.3	6.2	10.3	1.5	3.1

Source: SPSS one sample test (95% confidence interval)

From Table 4.2 it can be seen that the mean monthly Relative Water Supply when include the overall efficiency (RWSe) ranged from 0.8 to 2.2. This give hint that the total water supply varied from adequate to excessive. In the beginning of the season the RWSe is closer to 1.0 which considered as adequate level of water supply. But during the month of August the mean RWSe range is 1.5 to 2.0 indicate that there was excessive water supply to the scheme reaching about double of the total water demand. At the end of the season the mean monthly RWSe ranged between 1.0 and 2.2 give an indication that water supply varies from adequate to excessive.

Table 4.2: The mean monthly relative water supply (RWSe)

Month	Total water supply (m^3x10^6/day)		Total water demand (m^3x10^6/day)		RWSe	
	Lower	Upper	Lower	Upper	Lower	Upper
Jun	10.6	13.8	12.2	15.9	0.8	1.1
Jul	37.6	49.0	30.0	36.1	1.1	1.6
Aug	42.2	54.9	25.9	31.2	1.5	2.0
Sep	35.0	49.1	29.8	36.4	1.1	1.4
Oct	33.7	39.0	25.2	32.9	1.2	1.5
Nov	26.5	29.5	18.7	25.8	1.2	1.6
Dec	23.9	27.0	18.3	26.7	1.1	1.5
Jan	20.7	23.6	16.7	24.3	1.0	1.6
Feb	19.7	22.9	15.4	23.4	1.0	1.6
Mar	12.0	16.3	8.8	14.7	1.1	2.2

Source: SPSS one simple t-test (95% Confidence interval)

4.1.3 Relative irrigation supply (RIS)

❒ **Seasonal relative irrigation supply**

Relative Irrigation Supply (RIS) is the ratio of irrigation supply to irrigation demand (total demand less effective rainfall). Relative irrigation supply (RIS) focuses on supply of irrigation water alone, in contrast to RWS which also includes rainfall. Relative irrigation supply is the inverse of the irrigation efficiency presented by (Bos, 1974). The term relative irrigation supply was presented to be consistent with the term relative water supply, and to avoid any confusing value judgments inherent in the word efficiency (Molden *et al.* 1998). When irrigation tightly fills the gap of water requirements after they are met by rain, RIS is near unity. Figure 4.4 show that the mean seasonal Relative Irrigation Supply when exclude the application efficiency (RIS) ranged from 0.8 to 2.0 indicates the variation from adequacy to excessive irrigation supply. The mean seasonal Relative Irrigation Supply when include the overall efficiency (RISe) ranged from 0.6 to 1.4 indicate the variation from shortage to adequate irrigation supply. This meant that the irrigation water was available from Sennar Dam and was never be a constraint from 1984 onwards.

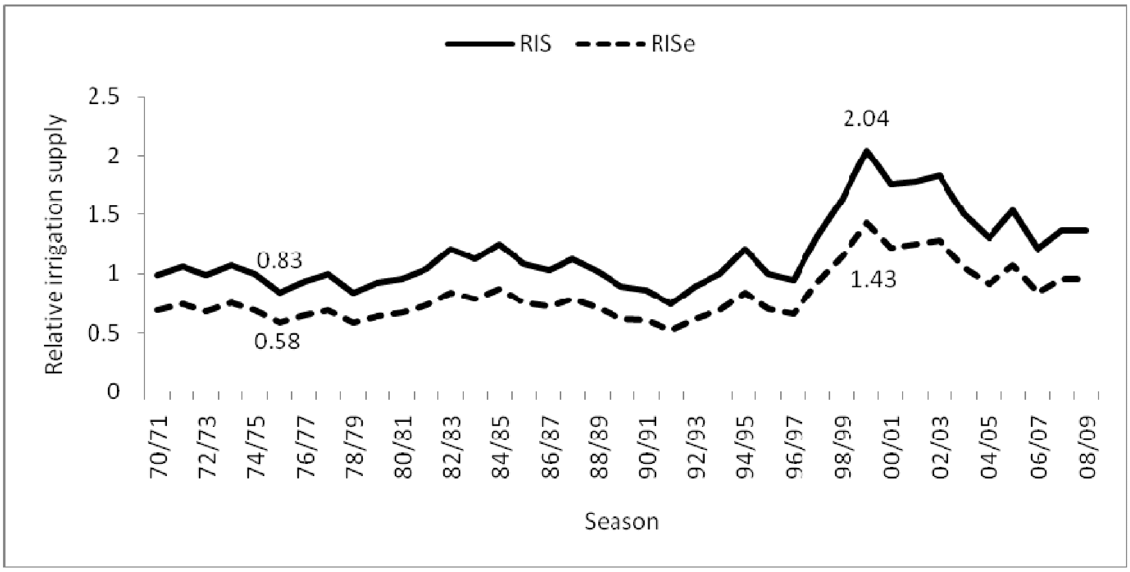

Figure 4.4 Seasonal relative irrigation supply

❒ Monthly relative irrigation supply

Table 4.3 shows that the mean monthly Relative Irrigation Supply when exclude the application efficiency (RIS) ranged between 1.3 and 4.7. In the beginning (Jun-Jul) of the season RIS ranged from 1.3 to 2.3. The lower limit is closer to unity showing adequacy of irrigation supply according to Molden (1998) this indication of good operation service, but the upper limit indicate excessive water supply. During the peak rain period (July and August) the mean monthly RIS varies from 1.7 to 4.7. The irrigation water supply is much higher than irrigation requirement this was due the reason of overestimation of indents. During the peak month (October and November), the mean monthly RIS ranged between 1.6 and 2.3 indicate surplus of irrigation water supply. At the end of the season the mean monthly RIS ranged from 1.5 to 3.1 indicating that the irrigation water is abundant reaching about three times irrigation water requirement.

Table 4.3: The mean monthly relative irrigation supply (RIS)

Month	Irrigation water supply (m^3x10^6/day)		Irrigation water requirement (m^3x10^6/day)		RIS	
	Lower	Upper	Lower	Upper	Lower	Upper
Jun	9.3	12.2	5.5	8.0	1.4	2.3
Jul	21.8	26.3	7.1	12.1	2.5	4.7
Aug	16.8	21.9	6.7	12.3	1.7	4.3
Sep	22.7	28.1	14.8	19.2	1.3	1.8
Oct	30.4	32.4	15.6	21.6	1.6	2.1
Nov	26.5	28.7	12.9	17.7	1.7	2.3
Dec	23.9	27.0	12.7	18.6	1.5	2.2
Jan	20.6	23.5	11.5	16.8	1.4	2.3
Feb	19.7	22.9	10.7	16.3	1.5	2.3
Mar	12.0	16.3	6.2	10.3	1.5	3.1

Source: SPSS one simple t-test with 95% confidence interval

Table 4.4 shows the irrigation water supply relative to gross irrigation supply. The mean monthly Relative Irrigation Supply when include the application efficiency (RISe) ranged from 0.9 to 3.3. It can be seen that the values of lower limit of RISe for all months are near 1.0 indicate adequacy irrigation supply. But the upper limit indicate excessive water supply with much high irrigation supply during peak rainfall (July- August). This phenomenon resulting from lack of information or procedure to obtain real time rainfall information of the project area, so indent can be adjusted accurately.

Both RWS and RIS relate supply to demand, and give some indication as the condition of water abundance or scarcity, and how tightly supply and demand are matched. Care must be taken in the interpretation of results: an irrigated area upstream in a river basin may divert much water to give adequate supply and ease management, with the excess water providing a source for downstream users. In such circumstances, a higher RWS in the upstream project may indicate appropriate use of available water, and a lower RWS would actually be less desirable. Likewise, a value of 0.8 may not represent a problem; rather it may provide an indication that farmers are practicing deficit irrigation with a short water supply to maximize returns on water.

Table 4.4: The mean monthly relative irrigation supply (RISe)

Month	Irrigation water supply (m^3x10^6/day)		Gross irrigation water requirement (m^3x10^6/day)		RISe	
	Lower	Upper	Lower	Upper	Lower	Upper
Jun	9.3	12.2	7.8	11.4	1.0	1.6
Jul	21.8	26.3	10.2	17.2	1.8	3.3
Aug	16.8	21.9	9.6	17.5	1.2	3.0
Sep	22.7	28.1	21.2	27.5	0.9	1.3
Oct	30.4	32.4	22.3	30.8	1.1	1.5
Nov	26.5	28.7	18.4	25.3	1.2	1.6
Dec	23.9	27.0	18.2	26.5	1.1	1.5
Jan	20.6	23.5	16.4	24.1	1.0	1.6
Feb	19.7	22.9	15.3	23.3	1.0	1.6
Mar	12.0	16.3	8.8	14.7	1.1	2.2

Source: SPSS one simple t-test with 95% confidence interval

4.1.4 Water delivery capacity (WDC)

Water delivery ratio is useful where peak demand discharges are related to design discharges, also useful to monitor operation practices. Martin *et al.* (2000) classified the WDC less than 0.9 as low and values from 0.9 to 1.1 as adequate as argue greater than 1.1 as high. From figure 4.5 shows and increasing trend of WDC from 1990 onwards. The water delivery capacity ratio ranged between 0.7 and 2.4. From early 1970s until mid 1990s the WDC is close to 1.0 indicate adequacy during the peak period (October and November). From 1995s onward the WDC is much greater than 1.1 which is considered as excessive irrigation supply according to Martin *et al.* (2000). In season 1996/97 the value of WDC which is less than 0.9 classified as shortage because the gross irrigation requirement is greater than the canal design capacity. It is recommended to remove silt and weed from the canal (de-silting of canal) so as to maintain the capacity.

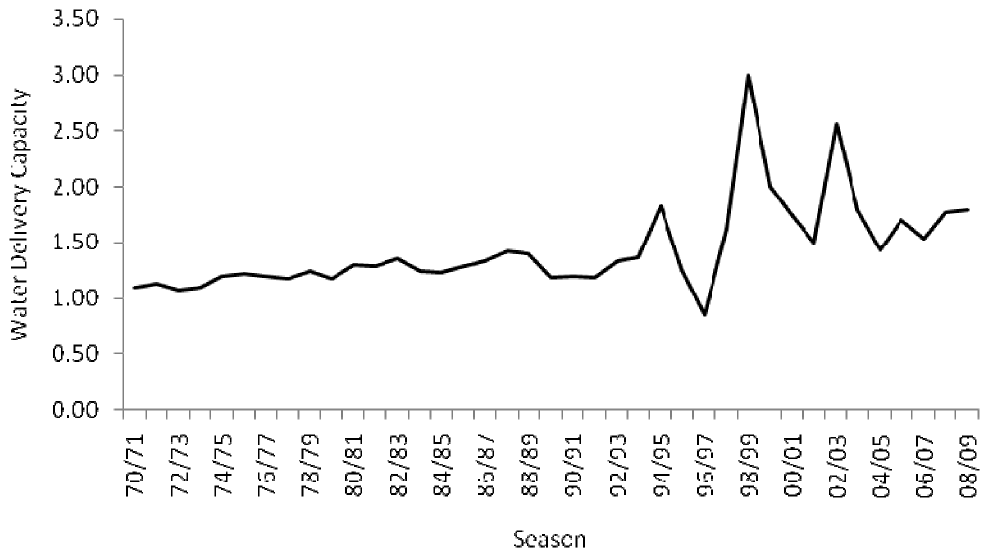

Figure 4.5 Trend of water delivery capacity

4.1.5 Water delivery performance (WDP)

Water delivery performance is one possible criterion of irrigation system performance is an index which takes into accounts both the actual and target quantity and timing of water supply (Bailey, 1984). The water delivery performance (WDP) would be equal to 1.0 if the water delivered during each watering is equal to the crop water requirement for that watering. It would equal to zero if no water is delivered at all. The index could register both under-supply and over-supply within the 0-1 range. Figure 4.6 shows a declining trend of seasonal WDP during the period 1999/2000 to 2008/09; indicate that there is no improvement in the water management practices. The seasonal value of WDP ranged from 0.77 to 0.91 shows that the actual water supply is adequate in the headwork compare to irrigation water requirement but this may be inadequate at the farm level if the water is not properly allocated in space and time throughout the distribution. From Appendix 3, Table 3.19. The WDP per decade ranged from 0.48 to 0.99. At the beginning of the season (first period of Jun to the second period of July), the WDP ranged between 0.61 and 0.65. This indicates excessive water supply compared to irrigation requirement. During the peak summer rain period (third period of July to the second period of September), the lower limit of WDP ranged from 0.48 to 0.68. The lower limit indicates excessive water diverted. The upper limit of WDP shows that the irrigation requirement is met by irrigation supply. During the first period October to the first period of March the WDP value approach unity indicate that the adequacy of water supply. At the end of the season from second period of March to the third period of March the lower limit of WDP ranged from 0.75 to 0.59. The lower limit indicates excessive water delivery and the upper limit indicate adequacy of water supply. Table 4.6 shows that the error in adequacy of water delivery ranged from 8% to 25% indicate that there is little improvement in the efficiency of the irrigation system to deliver water to the distribution, the maximum value of the error in equity is reach about 4% because the water delivery in the main system. The error in management ranged from 75% to 93%, this mean that the major problem of water delivery performance is related to management of the irrigation system rather than other factors.

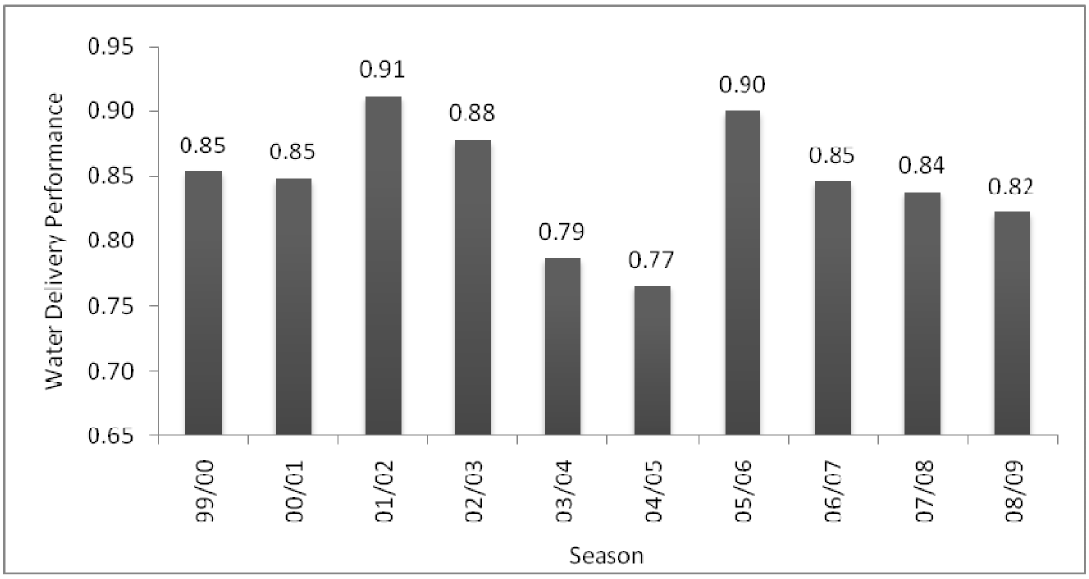

Figure 4.6 Seasonal water delivery performance

- **Expect error in the irrigation system performance**

Table 4.5: Seasonal performance parameter errors

Season	$1/nS(Q_r-Q_a)^2$	$(MQ_r-MQ_a)^2$	$(SQ_r-SQ_a)^2$	$2(1-r)*S_{Qr}*S_{Qa}$	Eas	Ees	Ems
99/00	18.12	1.64	0.12	16.92	0.09	0.01	0.93
00/01	26.02	8.36	0.19	18.10	0.32	0.01	0.70
01/02	5.13	0.08	0.10	5.11	0.02	0.02	1.00
02/03	8.65	2.39	0.55	5.89	0.28	0.06	0.68
03/04	47.97	2.31	0.16	47.09	0.05	0.00	0.98
04/05	54.68	15.95	0.15	39.88	0.29	0.00	0.73
05/06	7.52	0.31	0.55	6.91	0.04	0.07	0.92
06/07	16.96	3.95	0.09	13.41	0.23	0.01	0.79
07/08	49.22	3.30	1.14	46.39	0.07	0.02	0.94
08/09	71.58	19.55	1.59	52.29	0.27	0.02	0.73
Average	30.58	5.78	0.46	25.20	0.17	0.02	0.84

Table 4.6: The seasonal mean of performance parameter errors

	Test Value = 0					
					95% Confidence interval	
	t	df	Sig. (2-tailed)	Mean	Lower	Upper
Eas	4.27	9.00	0.00	0.17	0.08	0.25
Ees	2.83	9.00	0.02	0.02	0.00	0.04
Ems	21.10	9.00	0.00	0.84	0.75	0.93

Source: SPSS one simple t-test with 95% confidence interval

df is the degree of freedom and Sign. is significant level

- **Summary of water supply indicators**

The water supply indicators such as the overall consumed ratio, relative water supply, relative irrigation supply and water delivery performance reveal that the water supply to the scheme was varied from adequate to excessive. The excessive water supply it not only wastage of water but it may cause water logging in low spots which reduce the productivity. The water delivery capacity indicates that the peak demand does not exceed the capacity of the main canals. The scheme level water supply indicators give indication that the water supply was is no problem of water shortage, rather than poor water management practices.

4.2 Cropping intensity (CI)

Figure 4.7 shows a declining trend of cropping intensity of GS during seasons 1970/71 to 2008/09. The cropping intensity (CI) for GS ranges between 84% and 35 %. The cropping intensity resulting from application of the four course rotation in Gezira (Cotton-wheat-groundnuts/sorghum/vegetable-fallow) and the three course rotation in Managil was the highest attainted in Gezira Scheme (GS) about 84% in season 1975/76 under cultivated average percent for wheat (27 %), groundnuts (20 %), sorghum (16%) and vegetables (1%) as shown in Appendix 3, Table 3.24.

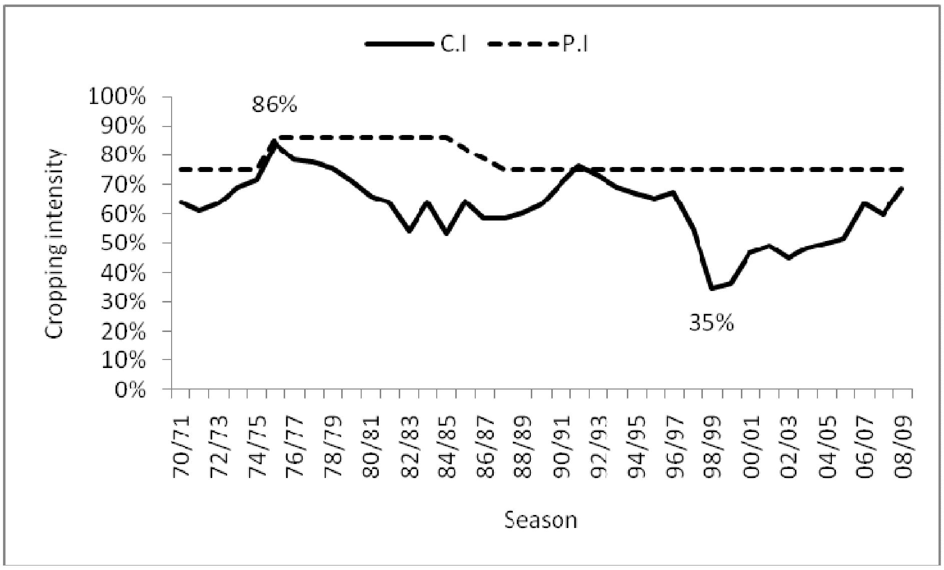

Figure 4.7 Trend of cropping intensity

The lowest cropping intensity in GS was about 35% in season 1998/99 under total cultivated crops average relative percent for cotton (7%), wheat (6%), groundnuts (7%), sorghum (14%) and vegetables (1%). The area cultivated by sorghum was the largest because it is the main fodder and subsistence grain crop. The low level of water charge collection has resulted in low funding of operation and maintenance activities which in turn led to the deterioration of irrigation infrastructure and low level of services to tenant farmers. Consequently, large areas went out of production and cropping intensity fell to a mere 35% in 1998/99 season with significant losses to tenants (World Bank 2000). In season (2008/09) less than five course rotation, sorghum and wheat had been the main crops in terms of area in GS with an average of (24 %). Sorghum and wheat has occupied the largest area because of their role as both fodder and subsistence grain crops. However, cotton area declined sharply because of high costs and, sometimes, low benefits for the farmers. This forced the tenants to reduce the cotton area but it is importance to tenants as cash crop, and to the economy for earning foreign exchange to the country.

4.3 Land Productivity

4.3.1 Cotton

From appendix 3, Table 3.27, the maximum land productivity was 1.9 ton per hectare in season (1991/92), the minimum was 0.8 ton per hectare in season (1980/81), and the average was 1.4 ton per hectare. Figure 4.8 shows slight declining trend of cotton yield. The average land productivity is 2.7 ton/ha, 2.4 ton/ha for China and Egypt respectively. The land productivity of GS is extremely low compare to China, Egypt as shown in table 4.7. The optimal cotton yield obtained at Gezira research station is 4.5 ton/ha. It can be seen that the average land productivity was a fraction of the optimal yield at GRS. The average relative cotton yield is 0.3. However, this is due to low level of input, poor operation and maintenance and lack of fund from the Government. The applications of fertilizers were lower than the recommended by Agriculture Research Corporation (ARC) and they are not a viable most of the time or arrive late. This cause progressive nutrients deficit and reduction in productivity.

Table 4.7 Average relative yield of main crops in GS and comparison with productivity in China and Egypt

Crop	Farm yield Ym (ton/ha)	Gezira Research station Yp (ton/ha)	Relative yield Ym/Yp	China[a] yield (ton/ha)	Egypt[b] yield (ton/ha)
Groundnuts	1.7	4.75	0.37	2.6	2.7
Sorghum	1.7	5.24	0.32	3.8	
Cotton	1.4	4.50	0.45	2.7	2.4
Wheat	1.4	3.57	0.38		6.3

a. China was developing country shift to develop country.
b. Egypt and Sudan large irrigation schemes were developed by British during colonial period.

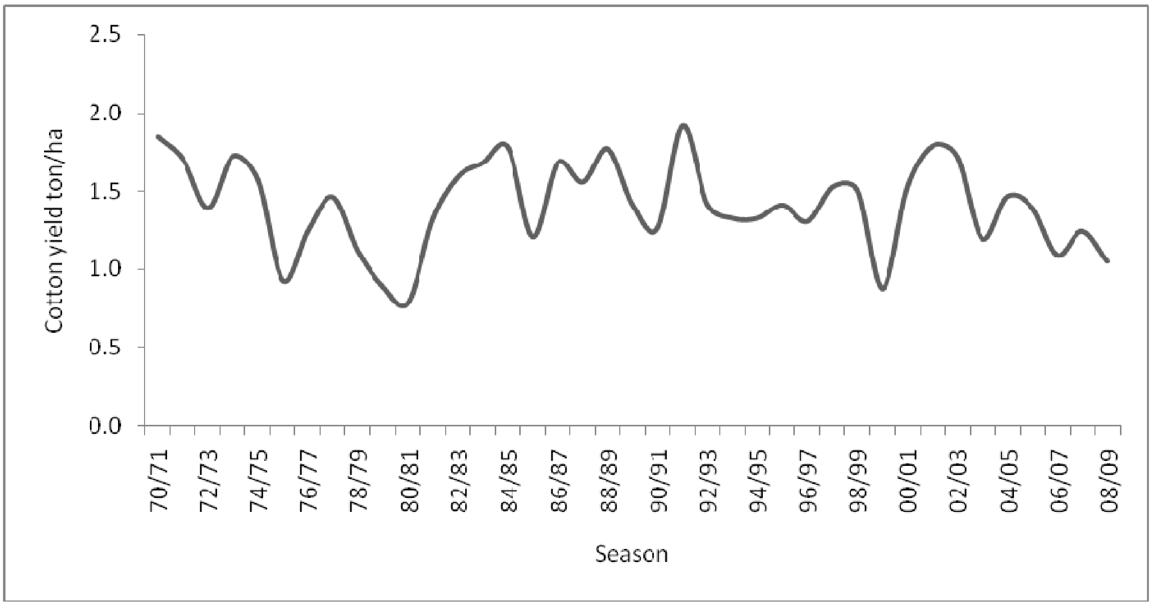

Figure 4.8 Land productivity of cotton

4.3.2 Wheat

The land productivity of wheat trend for seasons (1970/71-2008/09) is shown in figure 4.9, the maximum land productivity of wheat was 2.4 tons per hectare in season (2006/07), the minimum was 0.6 ton per hectare in (1978/79) season, and the average was about 1.4 ton per hectare. From Appendix 3, Table 3.27, the land productivity decreased sharply from 1.6 ton per hectare in season (1972/73) to 0.6 ton per hectare in season (1978/79), the area under cultivation has increased slightly from 61,158 hectare to 207,243 hectare. The land productivity increase sharply from 1.6 tons per hectare in season (2005/06) to about 2.36 tons per hectare in season (2006/07), accompanied by increase in the cultivated area from 111,646 hectare to 123,511 hectare. The increasing trend of the yield indicates improve in management and operation and good inputs. This was due to support from the government to attain self sufficient in food. The average relative wheat yield on farm field was 0.4 compared with the optimal yield at GRS. The land productivity obtained by famer is much less than the than the wheat productivity of Egypt which is 6.3 ton/ha. The applications of the fertilizers were not according to the quantity and time recommended by ARC which reduced the wheat productivity.

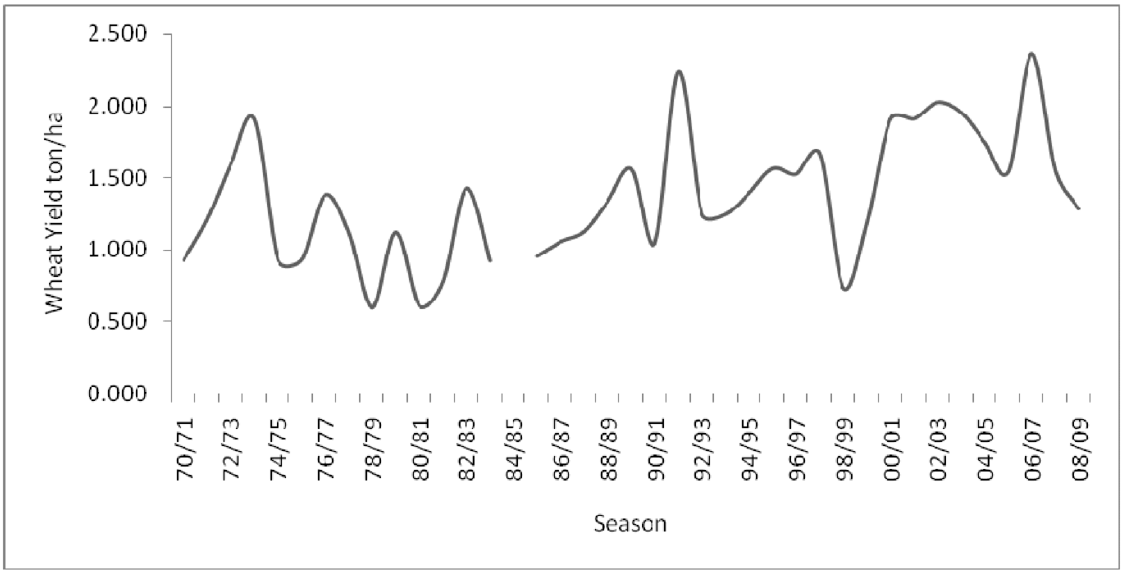

Figure 4.9 Land productivity of wheat

4.3.3 Groundnuts

The trend of land productivity of Groundnuts for seasons (1970/71-2008/09) is given in appendix 3, Table 3.27. The maximum land productivity achieved was 3.0 tons per hectare, the minimum was 0.5 ton per hectare, and the average was about 1.7 ton per hectare. The land productivity increased sharply from 1.2 ton per hectare in season (1971/72) to 2.1 tons per hectare in seasons (2006/07). Figure 4.10 shows an increasing trend in the land productivity indicates that there was good management practice, inputs and financial support from the government and. The land productivity of GS is less than china productivity (2.6 ton/ha) and Egypt (2.7 ton/ha). The relative average groundnuts yield was about 0.4 of the optimal yield at GRS. This low performance attributed to low level of input, poor operation and management and al.ck of fund. During the period 1933 – 1975, the eight- course rotation nitrogen matter is supplied to the soil from the growing legume crop called Lubia (Danishes lablab). After implantation of the four course rotation during the period 1975-1986e, Lubia and fallow land was completely eliminated from the rotation, this policy had adverse result on productivity.

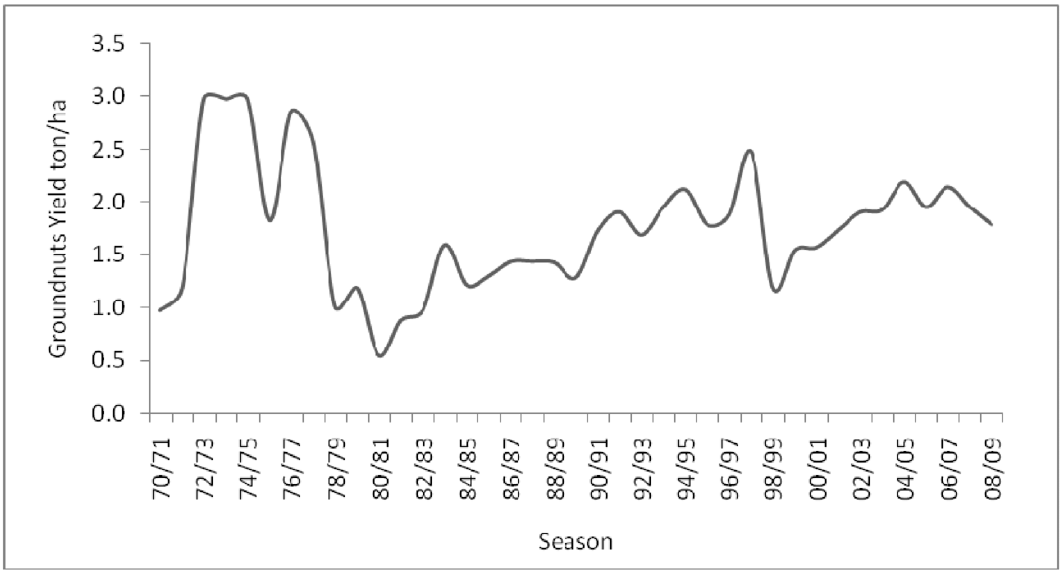

Figure 4.10 Land Productivity of Groundnut

4.3.4 Sorghum

Figure 4.11 shows the trend of land productivity of sorghum for season (1970/71-2008/09), the maximum land productivity was 2.80 tons per hectare, while the minimum was 0.84 ton per hectare, and the average was 1.65 ton per hectare. The productivity of sorghum showed a decreasing trend from season 1970/71 to 1984 and an increasing trend from 1season 1985 onwards. From Appendix 3, Table 3.27, the land productivity increased from 1.56 ton per hectare in (1995/96) season to 2.80 tons per hectare in 1996/97 season. The cultivated area increased from 165,622 hectare to 170,940 hectare. The Land productivity decreased from 1.56 ton per hectare in season 1976/77 to 0.84 ton per hectare in season 1977/78, while the cultivated area increased slightly from 147,760 hectare to 148,452 hectare. The relative average sorghum land productivity was 0.3 which was very low compared to optimal yield at GRS. The productivity of sorghum is much less than the productivity of China (3.8 ton/ha). However, measuring performance based on several production inputs, the inadequacy and quality of resources (input), excessive water supply and lack of fund limit the ability of tenants to achieve higher yields.

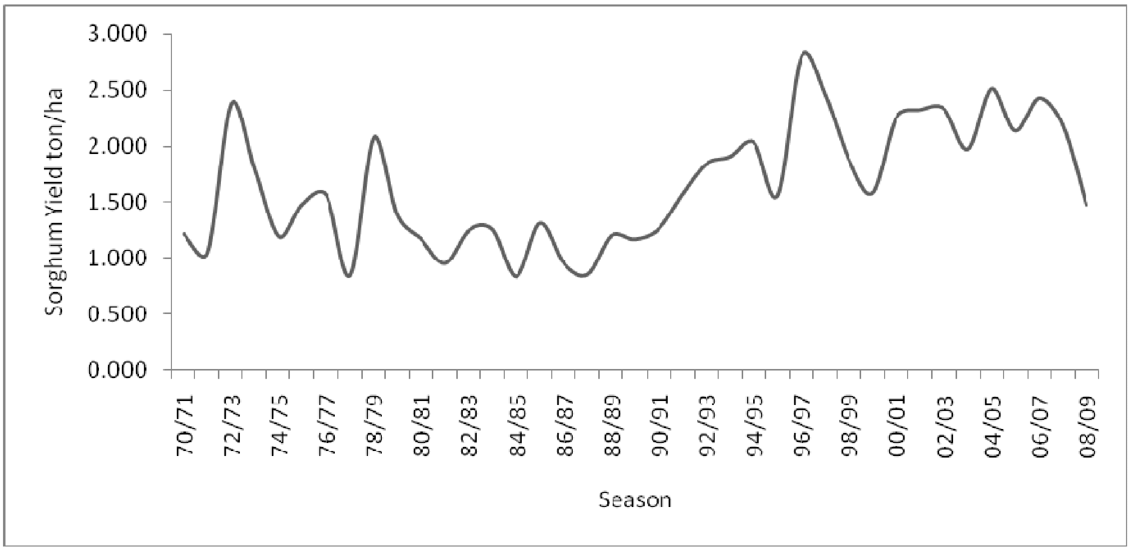

Figure 4.11 Land productivity of sorghum

4.4 Indicators of agricultural output

4.4.1 Output per cropped area (US$/ha)

4.4.1.1 Cotton

Table 4.8 shows that the maximum cotton output per cropped area was 700.618 US$ per hectare, the minimum was 205.5 US$ per hectare, and the average was 507.8 US$ per hectare. The cotton output per cropped area increased by 34.4 percent from 459.4 US$ per hectare in season (2000/01) to the maximum 700.618 US$ per hectare in season (2001/02). This was due to increase in Cotton yield from 1.52 ton per hectare to 1.79 ton per hectare in addition to increase in Cotton price from 301.87 US$ per ton to 392.95 US$ per ton. The average relative Cotton output per cropped area for seasons (1995/96-2003/04) was about 0.5 compared to the optimal average Cotton output per cropped area at GRS. The cotton output per cropped area decreased by 54.6 percent from 452.407 US$ per hectare in season 1998/99 to 205.5 US$ per hectare in season 1999/2000, as the result of sharp decline in yield by 40 percent from 1.5 ton per hectare to about 0.9 ton per hectare. Also the price of Cotton seed decrease by 30 percent from 300.6 US$ per metric ton to 234.8 US$ per ton. The process of land productivity decline has aggravated itself. Income from cotton has declined because of lower land productivity, and this has in turn forced many farmers to decide to spend less labor on weeding, irrigation, and cotton picking. Then later became relatively more expensive with decline in yields.

Table 4.8: Output per cotton cropped area (US$/ha)

Season	Cotton price SD	Exchange Rate SD/$	price US$/ton	Yield ton/ha	$Output_1$ US$/ha
95/96	25962.937	57.831	448.945	1.410	632.820
96/97	52195.804	124.637	418.783	1.304	546.102
97/98	56800.000	157.651	360.290	1.525	549.562
98/99	59958.042	199.447	300.621	1.505	452.407
99/00	59086.713	251.600	234.844	0.875	205.494
00/01	77622.378	257.140	301.868	1.522	459.422
01/02	101398.601	258.700	391.954	1.788	700.618
02/03	97902.098	263.340	371.771	1.719	639.224
03/04	83916.084	260.820	321.739	1.195	384.502

$Output_1$ = Output per cotton cropped area

4.4.1.2 Wheat

Table 4.9 shows that the Wheat output per cropped area ranged from 625.251 US$ per hectare to 31.776 US$ per hectare, with an average of about 344.76 US$ per hectare. The Wheat output per hectare increased by 21.02 percent from 493.815 US$ per hectare in season (1996/97) to 625.251 US$ per hectare in season (1997/98). This result from increased in price of wheat by 30.4 percent from 176.5 US$ per ton to 253.7 US$ per ton, although the yield decreased by 31 percent from 2.46 ton per hectare to 1.88 ton per hectare. The wheat output decreased from 34.17 US$ per hectare in season (2002/03) to 31.776 US$ per hectare in season (2003/04). This was due to drop in yield from 2.33 ton per hectare to about 1.97 ton per hectare. The average relative Wheat output per cropped area for seasons (1995/96-2003/04) was about 0.56 compared to the optimal average Wheat output per cropped area at GRS.

Table 4.9: Output per wheat cropped area (US$/ha)

Season	Wheat price SD	Exchange Rate SD/$	price US$/ton	Yield ton/ha	$Output_2$ US$/ha
95/96	22000	57.831	380.419	1.560	593.272
96/97	22000	124.637	176.513	2.798	493.815
97/98	40000	157.651	253.725	2.464	625.251
98/99	45000	199.447	225.624	1.881	424.388
99/00	60000	251.600	238.474	1.583	377.583
00/01	55000	257.140	213.891	2.255	482.274
01/02	4489	258.700	17.352	2.324	40.323
02/03	3857	263.340	14.646	2.333	34.175
03/04	4204	260.820	16.118	1.971	31.776

$Output_2$ = Output per wheat cropped area

4.4.1.3 Groundnuts

Table 4.10 shows that the Groundnuts output per cropped area ranges between 11.13 US$ per hectare and 145.25 US$ per hectare, and the average was 84.5 US$ per hectare. The Groundnuts output per cropped area decreased slightly from 11.27 US$ per hectare in season (2002/03) to 11.13 US$ per hectare in season (2003/04). The average relative Groundnuts output per cropped area for seasons (1995/96-2003/04) was about 0.15 compared to the optimal average Groundnuts output per cropped area at GRS.

Table 4.10: Output per groundnuts cropped area (US$/ha)

Season	Groundnuts price SD	Exchange Rate SD/$	price US$/ton	Yield ton/ha	$Output_3$ US$/ha
95/96	11200	57.831	193.668	0.750	145.251
96/97	16800	124.637	134.791	0.790	106.485
97/98	21000	157.651	133.206	1.040	138.534
98/99	28000	199.447	140.388	0.500	70.194
99/00	37520	251.600	149.126	0.650	96.932
00/01	36400	257.140	141.557	0.660	93.428
01/02	30800	258.700	119.057	0.730	86.911
02/03	3710	263.340	14.088	0.800	11.271
03/04	3585	260.820	13.745	0.810	11.134

$Output_3$ = Output per groundnut cropped area

4.4.1.4 Sorghum

Table 4.11 shows that the Sorghum output ranged between 493.82 US$ per hectare and 21.85 US$ per hectare, with the average 238.7 US$ per hectare. The Sorghum output per cropped area increased by 40 percent from 296.64 US$ per hectare in season 1995/96 to 493.82 US$ per hectare in season 1996/97. The Sorghum output per cropped area decreased from 23.24 US$ per hectare in season 2002/03 to 21.85 US$ per hectare. The average relative Sorghum output per cropped area for seasons1995/96-2003/04 was about 0.4 compare to the optimal average Sorghum output per cropped area at Gezira Research Station (GRS).

Table 4.11: Output per sorghum cropped area (US$/ha)

Season	Sorghum price SD	Exchange Rate SD/$	price US$/ton	Yield ton/ha	$Output_4$ US$/ha
95/96	11000	57.831	190.209	1.560	296.636
96/97	22000	124.637	176.513	2.798	493.815
97/98	22000	157.651	139.549	2.464	343.888
98/99	22000	199.447	110.305	1.881	207.478
99/00	30000	251.600	119.237	1.583	188.792
00/01	35750	257.140	139.029	2.255	313.478
01/02	28800	258.700	111.326	2.324	258.700
02/03	2623	263.340	9.961	2.333	23.241
03/04	2891	260.820	11.084	1.971	21.852

$Output_4$ = Output per sorghum cropped area

SD = Sudanese Dinar (local currency)

Exchange rate from Central Bank of Sudan

4.4.2 Output per command area (US$/ha)

Figure 4.12 shows a declining trend of the output per command area. The tenants/farmers output per command area ranged between 51.3 US$ per hectare and 285.9 US$ per hectare, with the average 149.6 US$ per hectare. The farmers output per command area increased slightly by from 272.9 US$ per hectare in season (1995/96) to 285.9 US$ per hectare in season (1996/97), and then the farmers output per command area decreased sharply from 285.9 US$ per hectare in season (1996/97) to 57.4 US$ per hectare in season (2003/04). The average relative output per command area obtained by tenants for seasons (1995/96-2003/04) was about 0.3 compared to the optimal average output per command area obtained at GRS. The output per command area was low attributed to low level of input, low yield, the change in market prices and the production relation.

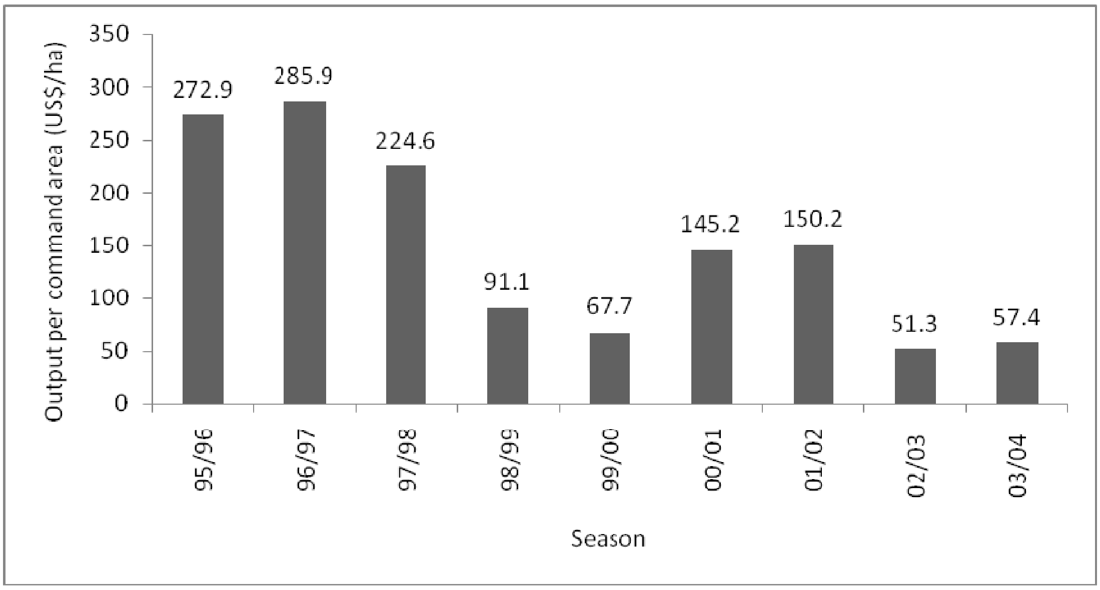

Figure 4.12 Output per command area (US$/ha)

4.4.3 Output per unit irrigation supply (US$/1000 m^3)

The output per unit irrigation supply shown in figure 4.13 ranged between 7.7 US$/1000 m^3 and 37.9 US$/1000 m^3, with an average of 19.6 US$/1000 m^3. The maximum output per water diverted was 37.9 US$/1000 m^3 in season (1995/96). It can be seen that there is no improvement in the income from the irrigation water supply. The average relative output per unit irrigation supply area obtained by famers for seasons (1995/96-2003/04) was about 0.3 compared to the optimal average output per command area obtained at GRS. The output per water supply was low due to low productivity of water; the low level of water management practices this lead to low income to GOS and the individual farmers.

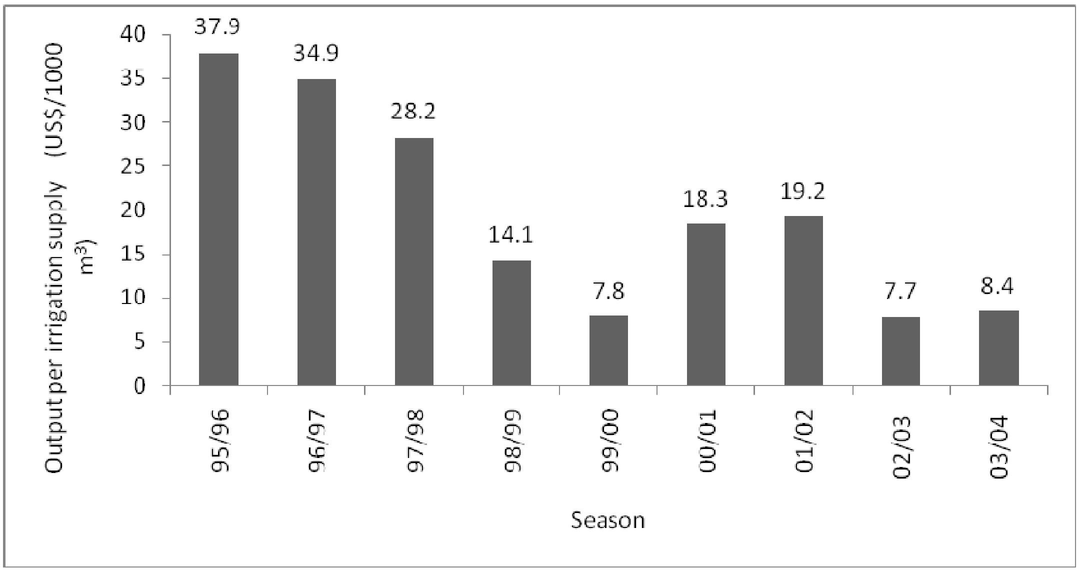

Figure 4.13 Output per unit irrigation supply (US$/1000 m^3)

4.5 Water productivity (WP)

The water productivity is a useful indicator for quantifying the impact of irrigation scheduling decisions with regard to water management (Liu *et al*., 2007). The water productivity in terms of actual evapotranspiration is defined by (Molden *et al*., 1998) as the crop productivity relative to crop consumption use. The water productivity of cash crop (cotton) and food crops in GS for seasons (1971-2008/09) is shown in Appendix 3, Table 3.29. The cotton WP ranged from 0.07 to 0.17 kg/m^3. The International average grain water productivity ranged between 0.2 and 2.5 kg/m^3. The cotton WP is very low compare to international average WP. Figure 4.15 shows a declining trend of cotton WP. The low productivity of cotton was due to excessive water supply during the off peak months, ineffective control of weed, low level of application of fertilizers and shortage of fund led to much less WP. The decline in WP indicate that there is no is improvement in the management practices of the scheme towards cotton productivity. The water consumption of the food crops grown in GS are given in appendix 3, Table 3.29. The maximum wheat water consumption was 2.39 billion m^3 in season 1990/91 and the minimum was 0.19 billion m^3 in season 1999/2000. The maximum Groundnuts water consumption was 0.14 billion m^3 in season 1991/92 and the minimum was 1.57 billion m^3 in season 1975/76. Sorghum water consumption ranged from a minimum of 0.54 billion m^3 season 1974/75 to a maximum of 2.72 billion m^3 in season 1991/92. Figure 4.14 shows an increasing trend of the water productivity of all food crops indicate that there is potential for improvement of productivity under farmers practice. The WP ranges from 0.06 to 0.26 kg/m^3, 0.05 to o.21 kg/m^3 and 0.10 to 0.35 kg/m^3 for groundnuts, wheat and sorghum respectively. From pervious study in GS for the period 1988-2004 the range of the food crops WP is 0.15 to 0.41 kg/m^3 for sorghum, 0.07 to 0.27 kg/m^3 for wheat and 0.1 to 0.22 kg/m^3 for groundnuts (Adeeb, 2004). The lower WP of food crops is due to excess water supply during rain period and off peak months, inadequate fertilizer and pests, shortage of funds and change in the production relation.

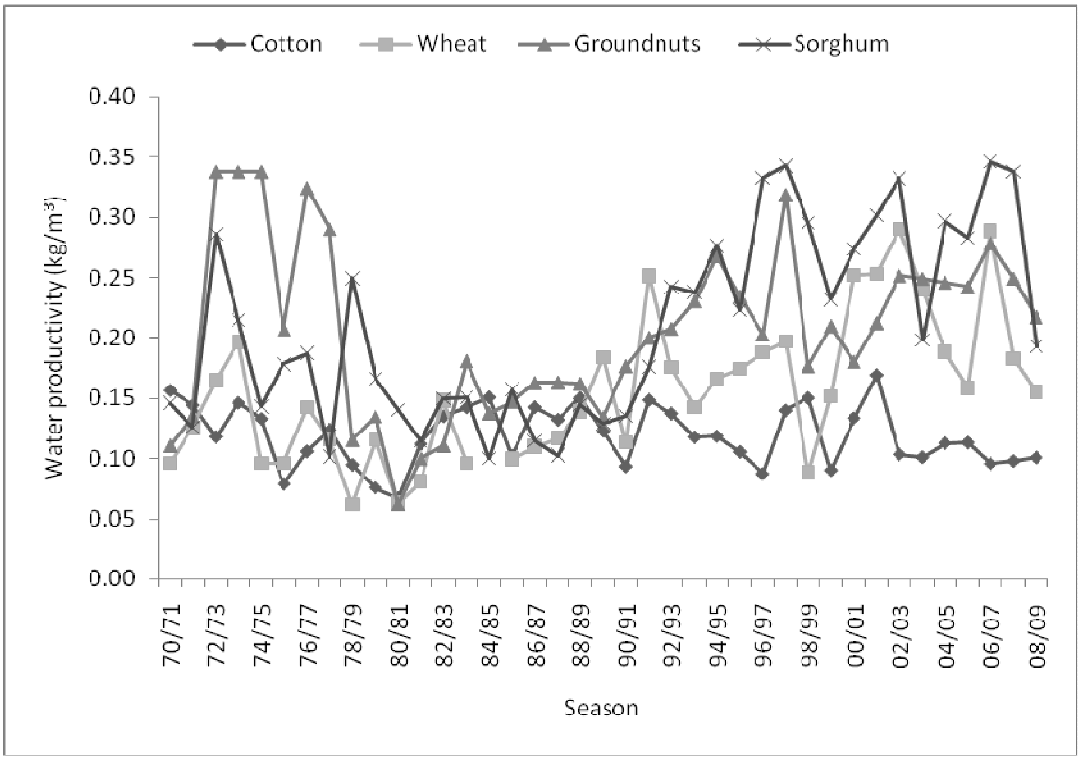

Figure 4.14 Major crops water productivity

4.6 Economical indicators

4.6.1 Relative water cost (RWC)

Relative water cost is the ratio of water charge to the total cost of production including the cost of irrigation water. Cotton is main crop for earning the hard currency and is most demanding for both tenants and management. For this reason the land and water charge is based in cotton. Since 1981 the Water charges established to recover MOM costs, the total numbers of cotton feddans under irrigation were converted to the number of feddans equivalent which could be irrigated by applying the total volume of water available. The other crops are weighted according to the quantity of water required in relationship to cotton. The number of irrigations was fixed 16 for cotton 10 for wheat 8 for groundnuts and 14 for sorghum. The water charge increase determined by increase the rate by a certain percentage. Appendix 3, Table 3.20 shows that the total water charge ranged from 300 SD/ha to about 18,000 SD/ha during season 1991/92-2005/06. The peak total cost of production was about 336,000 SD/ha in season 2003/04 and the lowest was 4,635 SD/ha. The relative water cost of the scheme varies from 0.03 to 0.07. According to Molden the RWC the acceptable ranged is 0.03 to 0.04 for surface irrigation. Figure 4.15 shows an increasing trend of RWC indicate that the farmers under uneconomical production and they may abandon irrigation.

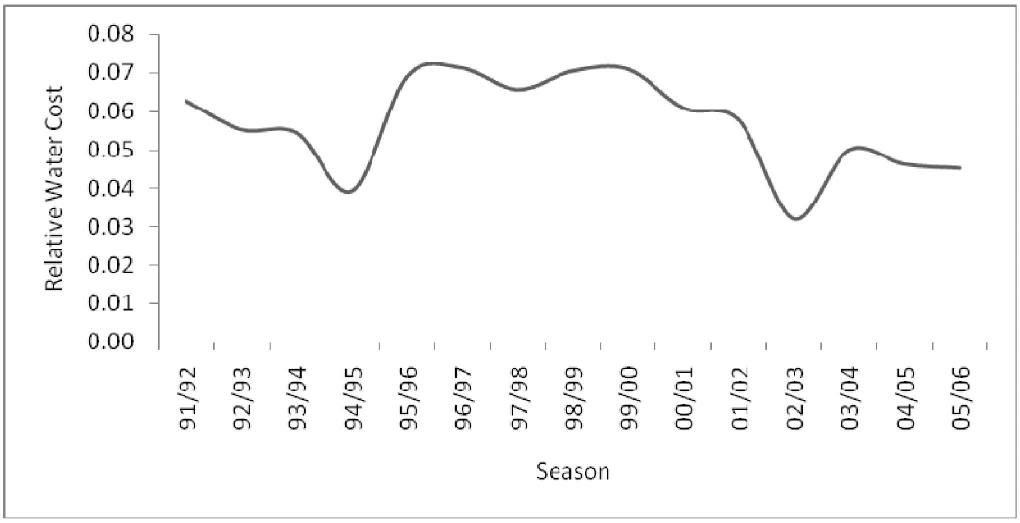

Figure 4.15 Seasonal Relative water cost

4.6.2 Benefit cost ratio (B/C)

The benefit /cost (B/C) ratio is useful method for the economic analysis of the public sector evaluation. Appendix3, Table 3.26 shows that present worth with 10% interest rate of the cost of production ranged from 700 to 849,000 Sudanese Pound/ha. The maximum net return (net benefit) to the farmer was about 394,000 Sudanese Pound/ha and the minimum was about 400 Sudanese Pound /ha. From table 2.26 The B/C ratio vary from 0.01 to 2.0. Figure 4.16 shows a declining trend indicates that there is no improvement in the economical of the scheme due to low profitably due to low productivity for the main crops grown in the scheme, extremely low level of cotton production and poor operation and management practices and desertion of infrastructure.

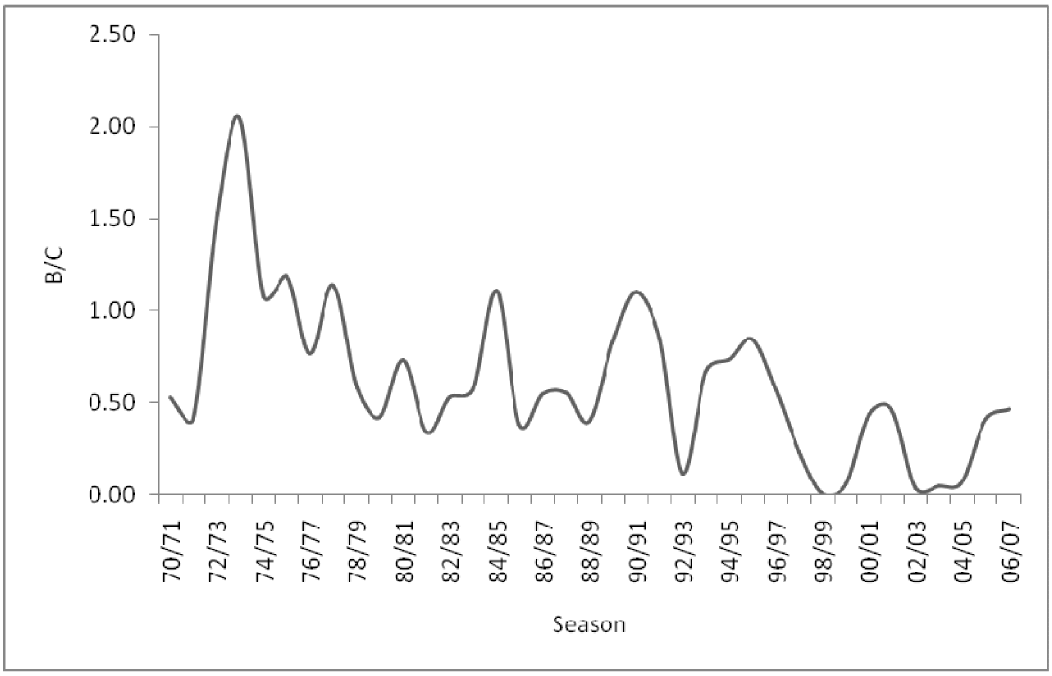

Figure 4.16 Benefit cost ratio

CHAPTER FIVE

Summary, Conclusion and Recommendation

5.1 Summary and Conclusion

The following conclusions that have been drawn from the results of performance assessment of Gezira irrigation scheme

- During the irrigation seasons the level of water supply varied from adequate to excessive. The excessive water application has environmental impacts like water-logging if the excess water is not properly drained.
- The water carrying capacities of the irrigation canals have deteriorieted due to sedimentation and weed grwoth in the conveyance and offtake structures.
- The RWS and RIS values, that are more than unity, show that the water supply is not a constraint. However, they indicate only the scheme level water delivery and not the farm level performance.
- The water use efficiency (WUE) as indicated by OCR and WDP provide evidence that low WUE and mismanagement of input resources cause the low productivity and profitability.
- The indicators of agriculutral output of the scheme is found to be low which is the result of low Landproductivity (yield) for main crops and the low foregaen exchange earning to the contury.
- The recently introduced production policy, i.e. individal account has encouraged farmers to grow more food crops than cotton. Individual account decal.res that every farmer receives the profit earned from crop grown on his/her Landwhile it was called previously joint account system where the total profits where distributed among all tenants.
- The area allocated for growing of food crops rather than cotton has increased to satisfy the household. However, the income that would have been earned from cotton has decreased and hence led to insufficent funding to cover operation and maintenance costs.
- The production of the main crops in GS was low due to the reduction in the cultivated area, low yields obtinted by tenants and low input (seeds, fertlizer, machinary,

finance) and low level of management practice such as low water use efficiency and delay of sowing dates of summer crops by tenants led to overal.p of crop stages during (Octaber and November) and water shortage led to fruther crop water stress.

- The long year observation indicated that the Landand water productivity is low even compared to China, Egypt and the results obtained under research station in Gezira. but there is an increasing trend of the food crops productivity. This indincates that there is huge potential to increase production by improving the management system and agricultural inputs.

5.2 Recommandations

Based on the assessment results the following recommendations were to improve the overall perormances of Gezira irrigation scheme:

- estimation of crop water requirement and irrigation water of all crops grown in Gezira Scheme should be based on Food and Agricultural Origination (FAO) methodology for predictive purposes a head of the season, during the season and after the season.
- insure an adequacy water supply in the main canal. The water released from Sennar dam to the main canal should meet the crop water requirement obtained from FAO methodology.
- iemove the excessive water from the scheme by drains to avoid water logging hazard.
- increasing soil fertility by growing legume crop adding atmospheric nitrogen and organic matter in the soil. And the applications of fertilizers to the cotton and wheat cropped area according the recommend quantities and time by technical package developed by Agriculture Research Corporation (ARC) to increase the yields of the crops.
- workout and implement appropriate water pricing policy.
- introduce a performance assessment program for the irrigation scheme, with aminimum number of indicators as used in this study for moinering the operation services.

References

Adeeb A M. 2004. Water productivity of Food crops in Gezira Scheme, Sudan. Water Management and Irrigation Institute. University of Gezira, Wad Medani, Sudan.

Ahmed S. H., Abdelhadi A.W., Ehadi M.A. and Adam H. S. 2005. Water Requirements of the Main Crops in the Gezira Scheme, Sudan. Agriculture Research Corporation. Sudan Journal of Agriculture research Vol.9 (2007) PP.67-89., Wad Medani, Sudan.

Ahmed A. A. 1989. Proceedings of the Conference on Irrigation Management in Gezira Scheme, Wad Medani, Sudan.

Allen R. G., Pereira L.S., Raes D. and Smith M. 1998. Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements. FAO. Irrigation and Drainage Paper 56, Rome, Italy.

Asawa G. L. 2007. Irrigation and Water Resources Engineering. New Age International Publishers, New Delhi.

Bashier E. E. 2009. Impact of Water Users Associations on Water Management in Gezira, Gash and White Nile Schemes, Sudan. PhD thesis. Water Management and Irrigation Institute. University of Gezira, Wad Medani, Sudan.

Bos M. G., M. A. Burton. and D. J. Molden. 2005. Irrigation and Drainage Performance Assessment Practical Guidelines. CABI Publishing. CAB International, Wallingford, UK.

Bos M. G. 1997. Performance Indicators for Irrigation and Drainage. Irrigation and Drainage systems 11:119-137.Working paper, Netheral.nds.

Burton M., D. Molden. and J. Skutsch. 2000. Benchmarking Irrigation and Drainage System Performance. Position Paper. FAO, Rome.

Burt. C. M. and Styles S. W. 1999. Modern Water Control and Management Practices in Irrigation Impact on Performance. Water Report 19. FAO, Rome.

Cai X., McKinney D. C. and Rosegrant M. W. 2001. Sustainability Analysis for Irrigation Water Management: Concepts, Methodology, and Application to the Aral Sea Region, Washington D.C., USA.

David J. Molden, R. Sakthivadivel, Christopher J. Perry. and Charlotte de Fraiture. 1998. Indicators for Comparing Performance of Irrigated Agricultural Systems. Research report 20. International Water Management Institute, Colombo, Sri Al.nka.

Dejen Z. A. 2007. Modeling and optimization strategies of the main and field irrigation system in Metahara Sugar Estate, Ethiopia. MSc. Thesis. UNESCO-IHE Institute for Water Education. Delft, Netherlands.

Fadl O. A. and Bailey C. B. 1984. Water Distribution in Sudanese Irrigated Agriculture Productivity and Equity. Conference Papers. University of Gezira, Wad Medani, Sudan.

FAO Aquastat. 2005. Irrigation in Africa in figures, Rome, Italy.

Gorantiwar S. D. and Smout I.K. 2005. Performance Assessment of Irrigation Water Management of Heterogeneous Irrigation Schemes. Irrigation and Drainage System 19:1-36. Loughborough University, Leicestershire, United Kingdom.

Glenn O. Shwab, Declmaro D. Fangmeier, William J. Elliot, and Richard K. Frevert. 1993. Soil and Water Conservation. John Wiley and Sons, Inc, India

H. G. Farbrother. 1996. Water-Management Options in the Gezira A review. National Resource Institute. University of Greenwich, United Kingdom.

Idriss S. Y. 1999. Water Delivery Performance of Turbi Main Canal. Msc Thesis. University of Gezira, Wad Medani, Sudan.

Inocenio A., Sallay H. and Merrey D.J. 2003. Innovative Approaches to Agricultural Water Use for Improving Food Security in Sub-Saharan Africa. International Irrigation Management Institute. Colombo, Sri Al.nka.

J. D. Bandaragoda. 1998. Need For Institutional Impact Assessment in Planning Irrigation System Modernization. Research Report 21. International Water Management Institute, Colombo, Sri Al.nka.

Keyes C. G., Jr. and Ward. T. J. 1985. Development and Management Aspects of Irrigation and Drainage. American Society of Civil Engineers, New York.

Kloezen, W. H., and Garcés-Restrepo. 1998. Assessing Irrigation Performance with Comparative Indicators: The Case of the Alto Rio Lerma Irrigation District, Mexico. Research Report 22. International Water Management Institute, Colombo, Sri Lanka.

Manz. D. H. 1991. Performance Evaluation of Irrigation Conveyance Systems Using Dynamic Simulation Models. University of Calgary, Canada.

Mohamed K. A., Eal.wad O M. A., Mohamed A. Y., Hussein A. S., Yousif D M. and Khudari M. N. 1994. The Hydraulic Research Station, Wad Medani, Sudan.

Murray-Rust, D.H and W.B Snellen. 1993. Irrigation system performance assessment and diagnosis. International Irrigation Management Institute, Colombo, Sri Al.nka.

Osman A E. K. M. 2009. Land and Water productivity of the main crops in Gezira Scheme (1978-2007). 2009. MSc Thesis. Water Management and Irrigation Institute. University of Gezira, Wad Medani, Sudan

Plusquelle H. 1990. The Gezira Irrigation Scheme in Sudan Objectives, Design, and Performance. Technical Paper Number 120. World Bank, Washington D. C., USA.

Purkey D.R. and Wallender W.W.1994. A review of Irrigation Performance Assessment in California, University of California, Davis, CA 95616, USA.

Small L. E. and Svendsen M. 1990. A framework for assessing irrigation performance. Irrigation and Drainage system 4: 283-312. Revised Edition as Working Paper on Irrigation Performance. International Food Policy Research Institute, Washington, D.C., USA.

S. P. M. K. Bandara. 2006. Assessing Irrigation Performance by Using Remote Sensing. Doctoral Thesis. Wageningen University, Wageningen, Netheral.nds.

World Bank. 2000. Sudan Options for the Sustainable Development of the Gezira Scheme-Sudan. Report No. 20398-SU. World Bank, Washington D. C., USA.

Yousif G. M. 1997. The Gezira Scheme the Greatest on Earth under One Management, Sudan.

Appendix 1 Weather and Climate Data

1. 1 Monthly average climate factors, reference evapotranspiration and effective rainfall from normal climatic data (1971-2000)

Country	Sudan							Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Wad Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	solar Radiation	ETo	Rain	Eff rain
	°C	°C	%	km/day	hours	MJ/m^2/day	mm/day	mm	mm
January	14.1	32.9	34	268	10	20.7	6.53	0.5	0.5
February	15.9	34.7	27	268	9.7	22	7.34	0	0
March	18.9	38.1	22	268	10.1	24.3	8.5	1	1
April	21.8	41.2	21	233	10.4	25.5	8.77	16	15.6
May	24.6	41.5	32	233	9.4	23.8	8.46	16	15.6
June	25.1	40.3	42	389	9	22.9	9.65	22.6	21.8
July	23.4	36.6	59	389	7.1	20.2	7.34	77.6	68
August	22.6	35.1	68	346	7.7	21.2	6.3	102.1	85.4
September	22.3	36.2	65	233	8.7	22.3	6.1	48.6	44.8
October	22	38.3	50	156	9.3	21.8	6.01	11.1	10.9
November	18.4	36.7	36	233	9.7	20.6	6.79	1.3	1.3
December	15.4	33.7	37	233	10	20.1	6.12	0	0
Average	20.4	37.1	41	271	9.3	22.1	7.33	296.8	264.9

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1. 2 Monthly average climate factors, reference evapotranspiration and effective rainfall, 1989

Country	Sudan							Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Wad Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ETo	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	11.1	29.7	34	266	10.7	21.7	6.1	0	0
February	12.1	31.5	26	311	10.5	23.2	7.36	0	0
March	17.9	36.6	24	222	10	24.1	7.44	0	0
April	21	40.9	22	222	11	26.5	8.57	0	0
May	25.1	41	37	266	10	24.8	8.79	34.5	32.6
June	24.6	40.2	45	444	8.9	22.8	9.88	41.5	38.7
July	24.2	38.5	52	488	8.2	21.8	9.16	24	23.1
August	22.3	35.7	66	355	8	21.6	6.65	116.8	95
September	22.8	36	66	266	8.9	22.6	6.26	36.4	34.3
October	22.7	38.6	42	222	10.2	23.1	7.2	0.3	0.3
November	19.3	37.5	36	133	10.6	21.8	5.66	32.3	30.6
December	14.4	32.2	38	133	9.7	19.7	4.75	0	0
Average	19.8	36.5	41	277	9.7	22.8	7.32	285.8	254.6

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1. 3 Monthly average climate factors, reference evapotranspiration and effective rainfall, 1990

Country	Sudan						Wad	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ETo	Rain	Eff rain
	°C	°C	%	km/day	hours	MJ/m2/day	mm/day	mm	mm
January	15.2	33.4	35	216	10.7	21.7	6.19	0	0
February	14.2	32.1	31	216	10.5	23.2	6.34	0	0
March	15.3	35.7	29	259	10	24.1	7.63	0	0
April	22.4	41.7	19	216	11	26.5	8.6	0	0
May	24.8	43.1	24	259	10	24.8	9.48	0	0
June	25.7	41.8	32	389	8.9	22.8	10.65	7.7	7.6
July	24.2	38	53	475	8.2	21.8	8.85	38.9	36.5
August	24.4	39.8	48	259	8	21.6	7.59	0.3	0.3
September	23.5	39	74	302	8.9	22.6	6.51	27.6	26.4
October	23.3	39.6	47	173	10.2	23.1	6.62	40.9	38.2
November	20.9	38.9	33	216	10.6	21.8	7.01	0	0
December	22.5	37.3	37	216	9.7	19.7	6.49	0	0
Average	21.4	38.4	39	266	9.7	22.8	7.66	115.4	109

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of solar radiation and ET_o (CROPWAT 8.0)

1. 4 Monthly average climate factors, reference evapotranspiration and effective rainfall, 1991

Country	Sudan							Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Wad Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	13.7	32.1	34	216	10.3	21.1	5.82	0	0
February	15.6	35.8	26	216	10.1	22.6	6.85	0	0
March	17.7	37.9	25	259	10	24.1	8.17	0.4	0.4
April	24.1	42.2	31	216	10.8	26.2	8.46	1.3	1.3
May	26.9	41.7	35	259	10.4	25.4	9.04	0.4	0.4
June	26.4	41.2	36	389	8.7	22.5	10.25	0	0
July	24.4	37.5	52	475	7.8	21.2	8.82	40.2	37.6
August	22.7	35.2	68	259	8	21.6	5.97	56.2	51.1
September	22.7	38.3	56	302	8.6	22.1	7.32	225.7	144.2
October	21.3	38.2	49	173	9.6	22.2	6.28	4.4	4.4
November	18	37.1	36	216	10.5	21.7	6.74	0	0
December	13.3	32.5	31	216	9.8	19.9	5.89	0	0
Average	20.6	37.5	40	266	9.6	22.6	7.47	328.6	239.4

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1. 5 Monthly average climate factors, reference evapotranspiration and effective rainfall, 1992

Country	Sudan							Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Wad Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	12.1	31.1	31	216	9.7	20.4	5.77	0	0
February	11.8	30.4	20	216	10.1	22.6	6.22	0	0
March	18.4	38	21	302	9.3	23.1	8.81	0	0
April	21.5	44.2	17	216	10.1	25.1	8.85	0	0
May	23.7	42.4	23	130	9.2	23.5	6.87	3.7	3.7
June	25.7	41.3	40	302	9.3	23.4	9.07	48	44.3
July	22.3	37.1	59	302	6.9	19.9	6.82	65.6	58.7
August	21.8	34.1	74	259	6.7	19.7	5.23	121.3	97.8
September	21.7	36.6	63	173	8.9	22.6	5.84	28.8	27.5
October	21.7	37.8	52	130	9.5	22.1	5.69	3.6	3.6
November	17.4	35.8	38	130	10.3	21.4	5.36	0	0
December	12.9	32.3	41	86	10.4	20.6	4.13	0	0
Average	19.3	36.8	40	205	9.2	22	6.55	271	235.5

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.6 Monthly average climate factors, reference evapotranspiration and effective rainfall, 1993

Country	Sudan						Wad Medani	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	12.2	31.7	34	86	10.5	21.4	4.21	0	0
February	13.5	32.8	25	86	10.1	22.6	4.48	0	0
March	18.5	38.9	19	259	9.8	23.8	8.48	0	0
April	21.8	41.5	21	216	10.2	25.2	8.5	0	0
May	23.2	40.7	37	216	9.1	23.4	7.86	47.9	44.2
June	24.1	40.3	43	259	9.9	24.3	8.29	19.7	19.1
July	24	37.9	55	389	7.9	21.4	8.02	9.2	9.1
August	22.4	35.7	65	259	7.1	20.3	6	103	86
September	22.5	36.1	65	173	8.4	21.8	5.64	67.8	60.4
October	21.9	38.8	51	130	9.8	22.5	5.81	0	0
November	20.8	37.9	40	130	10.1	21.2	5.52	0	0
December	16.5	35.6	39	86	10.6	20.9	4.51	0	0
Average	20.1	37.3	41	191	9.5	22.4	6.44	247.6	218.8

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.7 Monthly average climate factors, reference evapotranspiration and effective rainfall, 1994

Country	Sudan						Wad	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	16.4	35.2	35	173	10.3	21.1	5.67	0	0
February	14.8	34.3	29	173	10.7	23.4	6.13	0	0
March	16.2	36.3	25	216	10.8	25.3	7.4	0	0
April	22.1	42	22	173	10.6	25.8	7.76	0	0
May	24.1	41.3	31	216	9.7	24.3	8.27	18.8	18.2
June	24.8	39.7	45	216	9.3	23.4	7.56	13.8	13.5
July	23.5	35.7	71	130	6.1	18.7	4.86	48	44.3
August	22	33.9	72	173	7.6	21	5.15	119.8	96.8
September	22.3	35.7	87	173	8.5	22	4.94	39	36.6
October	22.2	37.4	50	130	9.9	22.7	5.77	19	18.4
November	16.9	35.8	40	389	10.5	21.7	8.24	0	0
December	13.5	32.3	36	389	10.5	20.8	7.46	0	0
Average	19.9	36.6	45	212	9.5	22.5	6.6	258.4	227.9

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.8 Monthly average climate factors, reference evapotranspiration and effective rainfall, 1995

Country	Sudan						Wad	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Medani 33.48 ºE		
	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
ETo	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	14.7	34.4	35	173	10.5	21.4	5.6	0	0
February	14.8	33.7	29	173	10.1	22.6	5.92	0	0
March	19	38.9	25	216	10.5	24.9	7.77	0	0
April	20.8	41	22	173	10.7	26	7.7	1.4	1.4
May	23.4	41.5	31	216	9.3	23.7	8.17	3.3	3.3
June	24.3	41	45	216	9.9	24.3	7.86	54	49.3
July	22.7	35.1	71	130	6.3	19	4.84	192.2	133.1
August	22.3	34.2	72	173	7.7	21.2	5.18	162.1	120.1
September	23.1	36.7	87	173	8.8	22.4	5.13	4.7	4.7
October	22.4	39.8	50	130	10.5	23.5	6.15	6.4	6.3
November	17.2	36.5	40	389	10.6	21.8	8.41	0	0
December	13.6	33.5	36	389	10.2	20.4	7.69	0	0
Average	19.9	37.2	45	212	9.6	22.6	6.7	424.1	318.2

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.9 Monthly average climate factors, reference evapotranspiration and effective rainfall, 1996

Country	Sudan						Wad	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	12.7	33.3	34	346	10.7	21.7	7.46	0	0
February	16.2	36.5	45	86	10.6	23.3	4.89	0	0
March	20.1	39.4	19	86	9.8	23.8	5.42	0	0
April	21.6	41.3	18	86	10.3	25.4	5.94	0	0
May	24.6	40.2	43	130	8.1	21.9	6.28	75.2	66.2
June	24	39.8	45	346	9.3	23.4	8.93	2.2	2.2
July	23.1	38.1	55	475	8.3	22	8.73	40.6	38
August	21.6	33.7	74	302	6.8	19.8	5.38	171.3	124.4
September	21.7	34.8	80	216	8	21.2	5.04	34.6	32.7
October	21.5	38	51	518	9.9	22.7	9.19	11.7	11.5
November	17.6	35.8	37	432	10.4	21.6	8.79	0	0
December	16.6	34.6	42	432	10.5	20.8	8.01	0	0
Average	20.1	37.1	45	288	9.4	22.3	7	335.6	274.8

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.10 Monthly average climate factors, reference evapotranspiration and effective rainfall, 1997

Country	Sudan						Wad Medani	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	15.3	32.9	36	130	10.5	21.4	4.92	0	0
February	13.5	32.2	27	130	10.6	23.3	5.21	0	0
March	19.8	37.7	22	130	9.2	22.9	5.97	0	0
April	23.2	41.3	22	173	9.1	23.5	7.5	0	0
May	25.3	40.4	37	173	7.6	21.1	6.95	19.1	18.5
June	24.8	40.5	44	216	8.7	22.5	7.56	12.1	11.9
July	23.4	37.2	63	173	6.9	19.9	5.68	123.3	99
August	22.5	35.8	69	86	7.1	20.3	4.79	41.7	38.9
September	22.2	38.9	57	130	9.2	23	5.95	28.3	27
October	22.5	38.4	52	130	9.1	21.5	5.71	47.5	43.9
November	17.1	36.3	32	130	10.2	21.3	5.41	0.9	0.9
December	14.4	34.3	36	173	10.4	20.6	5.47	0	0
Average	20.3	37.2	41	148	9	21.8	5.93	272.9	240.1

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.11 Monthly average climate factors, reference evapotranspiration and effective rainfall, 1998

Country	Sudan						Wad	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	MJ/m^2/day	mm/day	mm	mm
January	11.5	32.6	31	173	10.3	21.1	5.45	0	0
February	14.7	34.4	23	173	10.5	23.2	6.11	0	0
March	18.3	37.3	20	216	9.5	23.4	7.51	0	0
April	21.6	42.5	18	173	10.3	25.4	7.79	0	0
May	24.7	43	31	130	8.5	22.5	6.73	11.1	10.9
June	25.7	42.1	33	173	9	22.9	7.56	0	0
July	23	37	63	346	6.8	19.7	6.84	102.9	86
August	21.2	32.5	80	216	7.2	20.4	4.78	200.5	136.2
September	21.5	33.5	79	86	7.7	20.8	4.48	58.6	53.1
October	20.9	36.1	0	43	8.4	20.5	3	9.6	9.5
November	18.5	37.7	37	130	10.3	21.4	5.48	0	0
December	15.3	35.7	43	130	10.5	20.8	5.04	0	0
Average	19.7	37	38	166	9.1	21.8	5.9	382.7	295.6

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.12 Monthly average climate factors, reference evapotranspiration and effective rainfall, 1999

Country	Sudan						Wad Medani	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	Mm
January	14	33.4	42	173	10.6	21.5	5.31	14.4	14.1
February	19.3	40.2	28	173	10.3	22.9	6.75	0	0
March	16.7	38.4	19	173	10.9	25.5	7.2	0	0
April	19.9	41.3	19	130	10.7	26	6.83	0	0
May	25.9	41.5	35	216	9.6	24.2	8.16	11.5	11.3
June	25.1	41.2	37	259	9	22.9	8.61	8.2	8.1
July	21.6	35.3	66	216	7	20	5.7	177.7	127.2
August	20.9	33	76	173	7.4	20.7	4.86	103	86
September	21.1	34.6	75	130	8.2	21.5	4.92	87.4	75.2
October	20	36.7	62	130	8.8	21.1	5.19	9.4	9.3
November	17.5	38	36	86	10.8	22.1	4.86	0	0
December	17.1	35.6	38	86	10.4	20.6	4.43	0	0
Average	19.9	37.4	44	162	9.5	22.4	6.07	411.6	331.1

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.13 Monthly average climate factors, reference evapotranspiration and effective rainfall, 2000

Country	Sudan							Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Wad Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	16.3	34.6	33	130	10.7	21.7	5.07	0	0
February	17.7	34.9	28	173	10.6	23.3	6.21	0	0
March	18.8	37.9	25	173	10.5	24.9	6.95	0	0
April	24	41.6	21	130	10.2	25.2	6.87	0	0
May	26	42	36	173	9.3	23.7	7.5	1.2	1.2
June	25.9	42.3	38	302	10.2	24.7	9.53	6.8	6.7
July	23.5	37.4	56	346	6.9	19.9	7.37	40.7	38
August	23.1	35.7	65	302	7.4	20.7	6.31	26.4	25.3
September	22.5	36.8	64	216	7.9	21.1	5.96	56.9	51.7
October	21	37.2	51	173	9	21.4	5.97	66.6	59.5
November	19	36.9	35	130	10.5	21.7	5.49	0	0
December	15.2	33.6	40	173	10.4	20.6	5.33	0	0
Average	21.1	37.6	41	202	9.5	22.4	6.55	198.6	182.5

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.14 Monthly average climate factors, reference evapotranspiration and effective rainfall, 2001

Country	Sudan							Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Wad Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	Mm
January	14.2	32.2	34	130	10.5	21.4	4.84	0	0
February	16.8	34.8	28	130	10.5	23.2	5.45	0	0
March	19.5	38.9	23	130	9.6	23.5	6.16	0	0
April	24.1	42.6	21	130	10.4	25.5	7.02	0	0
May	24.8	42.5	26	130	9.4	23.8	6.96	1.2	1.2
June	25.4	40.3	40	259	8.9	22.8	8.31	2.8	2.8
July	23.8	36.2	61	302	7.4	20.6	6.68	133.7	105.1
August	22.7	34.1	73	302	7.6	21	5.65	33.3	31.5
September	22.6	36.7	68	173	8.6	22.1	5.66	20.1	19.5
October	22	38.9	53	130	10	22.8	5.87	2.7	2.7
November	18.8	37.7	39	86	10.6	21.8	4.88	0.4	0.4
December	17.5	35.7	37	130	10.4	20.6	5.1	0	0
Average	21	37.5	42	169	9.5	22.4	6.05	194.2	163.2

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.15 Monthly average climate factors, reference evapotranspiration and effective rainfall, 2002

Country	Sudan						Wad Medani	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	13.2	31.5	36	86	10.4	21.3	4.08	0	0
February	17.8	36.5	30	130	10.4	23	5.57	0	0
March	19.2	39.5	27	216	10.1	24.3	7.75	0	0
April	23.4	42.6	18	216	10.2	25.2	8.72	0	0
May	23.5	42.6	25	173	10.3	25.2	7.9	2.8	2.8
June	25.9	41.6	41	259	10.1	24.6	8.67	4.7	4.7
July	24.5	38.3	53	259	8.5	22.3	7.33	53.4	48.8
August	22.8	35.9	66	130	7.7	21.2	5.35	84.3	72.9
September	22.3	35.5	68	43	9	22.7	4.82	92.1	78.5
October	22.5	38.9	48	43	10	22.8	4.78	16.1	15.7
November	20.1	38.1	37	86	10.6	21.8	5	0	0
December	14.6	33.3	32	86	10.4	20.6	4.27	0	0
Average	20.8	37.9	40	144	9.8	22.9	6.19	253.4	223.4

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.16 Monthly average climate factors, reference evapotranspiration and effective rainfall, 2003

Country	Sudan						Wad	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	Mm
January	15.5	34.8	31	86	10.6	21.5	4.39	0	0
February	17.8	36.6	23	86	10.5	23.2	4.89	0	0
March	20.5	38.9	20	130	10	24.1	6.3	0	0
April	22.1	42.1	21	86	10.6	25.8	6.06	0	0
May	25.7	42.8	21	173	9.8	24.5	7.93	0	0
June	25.6	40.1	42	302	8.4	22.1	8.61	38.4	36
July	23.4	35.8	65	173	6.8	19.7	5.48	101.9	85.3
August	22.5	33.4	77	173	7.4	20.7	4.91	152.1	115.1
September	22.2	35.5	70	173	9.1	22.9	5.55	51	46.8
October	23	39.5	50	130	10.1	23	5.98	11.8	11.6
November	20.2	38.1	39	173	10.5	21.7	6.23	0	0
December	15.5	35.3	37	130	10.4	20.6	5.01	0	0
Average	21.2	37.7	41	151	9.5	22.5	5.94	355.2	294.8

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.17 Monthly average climate factors, reference evapotranspiration and effective rainfall, 2004

Country	Sudan						Wad	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	15.6	34	31	173	10.3	21.1	5.64	0	0
February	15.8	34.9	29	173	10.5	23.2	6.11	0	0
March	19.3	39.2	23	130	10.4	24.7	6.32	0	0
April	22.6	41.9	20	130	10.4	25.5	6.9	0	0
May	26.1	43.2	25	173	10.5	25.5	8.08	10.4	10.2
June	24.9	40.1	44	259	9	22.9	8.1	45.7	42.4
July	23.7	38.4	49	302	8.1	21.7	7.81	19.6	19
August	23.3	36.4	62	259	8.2	22	6.48	99.9	83.9
September	23.3	37.8	59	216	8.4	21.8	6.38	10.9	10.7
October	22.6	39.3	45	130	9.8	22.5	5.98	11.3	11.1
November	20.1	38.1	35	173	10.5	21.7	6.3	0	0
December	16.6	33.8	36	173	10.2	20.4	5.46	0	0
Average	21.2	38.1	38	191	9.7	22.8	6.63	197.8	177.3

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.18 Monthly average climate factors, reference evapotranspiration and effective rainfall, 2005

Country	Sudan					station	Wad	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		Longitude	Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	13.8	32.3	30	216	10	20.7	5.94	0	0
February	20.5	38.8	27	259	10.5	23.2	7.98	0	0
March	19.3	39.6	26	173	10.3	24.6	7.15	0	0
April	23.5	43.2	23	216	9.6	24.3	8.61	0	0
May	23.4	41.2	31	173	9.1	23.4	7.39	8.7	8.6
June	30.2	40.7	41	346	7.2	20.3	9.15	17.5	17
July	23.4	35.9	64	389	6.2	18.8	6.7	83.4	72.3
August	23.4	34.9	71	302	6.6	19.5	5.65	136.2	106.5
September	23	36.2	70	173	8.2	21.5	5.46	47.3	43.7
October	22.6	39	52	86	9.6	22.2	5.39	0	0
November	12.5	37.6	37	173	10.5	21.7	6.05	0	0
December	18.9	36.7	39	216	10	20.1	6.25	0	0
Average	21.2	38	43	227	9	21.7	6.81	293.1	248.1

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.19 Monthly average climate factors, reference evapotranspiration and effective rainfall, 2006

Country	Sudan						Wad Medani	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	MJ/m^2/day	mm/day	mm	mm
January	18.3	35.9	34	216	10.3	21.1	6.34	0	0
February	18.3	37	30	259	10.3	22.9	7.62	0	0
March	20.7	38.3	23	302	9.2	22.9	8.97	0	0
April	21.9	40.8	21	173	9.8	24.6	7.56	0	0
May	25	40.8	38	216	9.1	23.4	7.86	30.2	28.7
June	25.5	40.6	40	259	7.3	20.4	7.99	28.9	27.6
July	24	38.3	57	216	7.7	21.1	6.58	53.3	48.8
August	23	34.7	69	173	6.9	20	5.21	155.9	117
September	22.6	35.3	69	130	7.4	20.3	4.95	30.4	28.9
October	22.8	38.3	56	130	9.5	22.1	5.7	21.5	20.8
November	17.3	36.1	32	173	10.5	21.7	6.11	0	0
December	13.5	32.5	32	173	10.2	20.4	5.27	0	0
Average	21.1	37.4	42	202	9	21.7	6.68	320.2	271.8

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.20 Monthly average climate factors, reference evapotranspiration and effective rainfall, 2007

Country	Sudan						Wad Medani	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	13.2	31.2	31	130	10.3	21.1	4.76	0	0
February	15.4	35.3	27	173	10.3	22.9	6.1	0	0
March	20.1	39.2	25	216	10.5	24.9	7.83	0	0
April	22.7	41.5	24	173	10.6	25.8	7.74	8.6	8.5
May	25.5	42.9	27	130	9.5	24	7.01	0	0
June	24.9	39.4	48	216	7.9	21.3	7.18	73.3	64.7
July	22.6	33.3	72	216	6	18.5	4.97	162.1	120.1
August	22.5	34.1	68	130	5.3	17.5	4.48	72.2	63.9
September	22.1	35.8	65	173	7	19.7	5.25	40	37.4
October	23	38.7	53	130	7.8	19.6	5.37	8.7	8.6
November	20.5	38.3	43	130	10.4	21.6	5.56	3.5	3.5
December	17.7	36.1	29	173	10.3	20.5	5.91	0	0
Average	20.9	37.1	43	166	8.8	21.5	6.01	368.4	306.6

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

1.21 Monthly average climate factors, reference evapotranspiration and effective rainfall, 2008

Country	Sudan						Wad	Eff.rain Method USDA S.C. Method	
Altitude	405 m		latitude	14.38 ºN		station Longitude	Medani 33.48 ºE		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sun-shine	Solar Radiation	ET_o	Rain	Eff rain
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day	mm	mm
January	16.1	33.2	28	173	9.8	20.5	5.59	0	0
February	15.7	35.2	27	173	10	22.4	6.09	0	0
March	20	41	26	173	10.4	24.7	7.27	0	0
April	24.1	41.4	32	173	8.2	22.1	7.21	7.8	7.7
May	24.1	42.1	32	173	10	24.8	7.71	7.1	7
June	25.1	40.7	39	216	9.3	23.4	7.88	17.2	16.7
July	23.5	38.5	52	259	8.3	22	7.28	31.2	29.6
August	24.3	39	61	173	7.7	21.2	6.13	99.3	83.5
September	22.5	36.3	60	130	7.5	20.5	5.32	64	57.4
October	20.7	37.9	49	130	10	22.8	5.79	24.2	23.3
November	18.2	37.4	34	130	10.5	21.7	5.49	0	0
December	17.7	35.5	30	130	10.4	20.6	5.1	0	0
Average	21	38.2	39	169	9.3	22.2	6.41	250.8	225.3

Source: Temperature, Humidity, wind speed and sunshine (Metrological Authority, 2008)

Calculated values of Solar Radiation and ET_o (CROPWAT 8.0)

MINISTRY OF SCIENCE AND TECHNOLOGY
METEOROLOGICAL AUTHORITY
WEATHER – CLIMATE DATA

Table 1.22 WAD MEDANI Monthly Evaporation for Years (1989/90-2008)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	10.7	10.5	10.0	11.0	10.0	8.9	8.2	8.0	8.9	10.2	10.6	9.7
1990	10.3	10.1	10.0	10.8	10.4	8.7	7.8	8.0	8.6	9.6	10.5	9.8
1991	10.0	10.4	9.9	9.3	7.8	9.1	7.7	7.8	8.3	9.2	10.0	10.6
1992	9.7	10.1	9.3	10.1	9.2	9.3	6.9	6.7	8.9	9.5	10.3	10.4
1993	10.5	10.1	9.8	10.2	9.1	9.9	7.9	7.1	8.4	9.8	10.1	10.6
1994	10.3	10.7	10.8	10.6	9.7	9.3	6.1	7.6	8.5	9.9	10.5	10.5
1995	10.5	10.1	10.5	10.7	9.3	9.9	6.3	7.7	8.8	10.5	10.6	10.2
1996	10.7	10.6	9.8	10.3	8.1	9.3	8.3	6.8	8.0	9.9	10.4	10.5
1997	10.5	10.6	9.2	9.1	7.6	8.7	6.9	7.1	9.2	9.1	10.2	10.4
1998	10.3	10.5	9.5	10.3	8.5	9.0	6.8	7.2	7.7	8.4	10.3	10.5
1999	10.6	10.3	10.9	10.7	9.6	9.0	7.0	7.4	8.2	8.8	10.8	10.4
2000	10.7	10.6	10.5	10.2	9.3	10.2	6.9	7.4	7.9	9.0	10.5	10.4
2001	10.5	10.5	9.6	10.4	9.4	8.9	7.4	7.6	8.6	10.0	10.6	10.4
2002	10.4	10.4	10.1	10.2	10.3	10.1	8.5	7.7	9.0	10.0	10.6	10.4
2003	10.6	10.5	10.0	10.6	9.8	8.4	6.8	7.4	9.1	10.1	10.5	10.4
2004	10.3	10.5	10.4	10.4	10.5	9.0	8.1	8.2	8.4	9.8	10.5	10.2
2005	10.0	10.5	10.3	9.6	9.1	7.2	6.2	6.6	8.2	9.6	10.5	10.0
2006	10.3	10.3	9.2	9.8	9.1	7.3	7.7	6.9	7.4	9.5	10.5	10.2
2007	10.3	10.3	10.5	10.6	9.5	7.9	6.0	5.3	7.0	7.8	10.4	10.3
2008	9.8	10.0	10.4	8.2	10.0	9.3	8.3	7.7	7.5	10.0	10.5	10.4

Source: Meteorological Authority (2008)

MINISTRY OF SCIENCE AND TECHNOLOGY
METEOROLOGICAL AUTHORITY
WEATHER – CLIMATE DATA

Table 1.23 WAD MEDANI Monthly Evaporation for Years (1989/90-2008)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	10.4	12.3	14.3	17.3	15.9	15.7	15.2	9.1	7.3	11.3	10.7	10.3
1990	10.8	12.6	15.7	18.3	23.0	19.2	13.4	15.0	11.5	11.8	12.4	11.0
1991	11.1	15.5	16.6	17.8	17.4	18.5	13.8	9.1	22.7	10.2	13.6	12.2
1992	11.9	13.7	17.2	19.8	19.0	19.6	12.7	6.8	7.9	9.9	12.3	12.0
1993	11.3	14.0	17.6	19.3	14.3	16.3	14.6	9.4	8.2	11.9	12.9	12.3
1994	13.1	15.1	17.0	19.9	18.9	18.1	11.6	7.2	7.6	11.0	14.9	12.8
1995	13.3	16.0	19.0	19.4	20.0	18.2	9.3	7.2	8.1	11.1	13.2	12.7
1996	13.1	16.9	18.4	20.7	15.9	18.0	14.9	7.9	7.2	10.8	13.7	12.0
1997	12.9	15.7	18.7	20.0	17.9	19.1	11.9	9.4	11.1	11.2	13.0	13.1
1998	15.0	16.5	18.3	22.2	19.5	21.2	14.4	6.7	5.6	6.6	12.6	12.4
1999	11.8	16.8	18.9	20.5	20.6	20.4	11.2	6.8	7.4	8.5	12.8	11.5
2000	12.3	13.4	17.1	19.0	19.6	20.3	16.5	11.6	9.5	11.5	14.6	12.8
2001	12.3	15.7	16.6	17.8	18.0	16.0	11.3	7.3	7.0	10.4	12.4	11.9
2002	12.6	14.9	18.4	20.3	19.6	18.8	16.0	10.1	6.8	10.5	12.8	12.0
2003	13.1	16.8	20.7	21.0	23.8	20.9	12.4	7.7	7.4	11.0	13.5	12.8
2004	14.9	20.4	21.1	22.5	18.0	16.2	10.8	10.9	12.6	14.7	11.9	13.6
2005	13.6	17.5	20.3	24.5	18.7	19.5	12.5	7.4	7.3	11.5	13.5	12.2
2006	13.4	16.1	18.3	21.9	17.3	19.8	14.0	9.0	7.3	10.0	14.3	12.7
2007	12.5	15.8	18.9	20.7	19.8	16.7	7.1	7.0	9.2	12.3	13.7	13.8
2008	14.2	16.4	21.0	19.5	19.0	21.5	19.5	12.8	11.2	14.6	18.1	14.8

Source: Meteorological Authority (2008)

Appendix 2 Actual water released to the GS, crop and Land data

Ministry of Irrigation and Water Resources – Sudan
Irrigation service Department
Water releases from Sennar Dam to Gezira and Managil scheme

Table 2.1 Monthly water releases to GS Scheme for season (1989-1990)

25/05/1989 -------------- 31/3/1990			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-89	15.400	0.000	15.400
Jun-89	35.100	155.000	190.100
Jul-89	220.400	266.200	486.600
Aug-89	294.000	271.200	565.200
Sep-89	262.700	253.800	516.500
Oct-89	464.200	430.100	894.300
Nov-89	445.400	423.600	869.00
Dec-89	396.300	399.000	795.300
Jan-90	341.100	354.200	695.300
Feb-90	229.100	310.400	539.500
Mar-90	117.800	144.600	262.400
Total	2821.500	3008.100	5829.600

Table 2.2 Monthly water releases to GS Scheme for season (1990-1991)

25/05/1990 -------------- 31/3/1991			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-90	12.100	11.900	24.000
Jun-90	120.700	121.200	241.900
Jul-90	308.000	296.800	604.800
Aug-90	417.200	345.000	762.200
Sep-90	399.900	385.800	785.700
Oct-90	452.400	450.600	903.000
Nov-90	439.750	424.100	863.85
Dec-90	445.500	407.200	852.700
Jan-91	329.300	313.800	643.100
Feb-91	353.300	338.600	691.900
Mar-91	379.500	374.800	754.300
Total	3657.650	3469.800	7127.450

M = million

Ministry of Irrigation and Water Resources – Sudan
Irrigation service Department
Water releases from Sennar Dam to Gezira and Managil scheme

Table 2.3 Monthly water releases to GS Scheme for season (1991-1992)

25/05/1991 -------------- 31/3/1992			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-91	19.40	0.00	19.40
Jun-91	97.35	55.00	152.35
Jul-91	354.40	354.40	708.80
Aug-91	302.60	322.80	625.40
Sep-91	444.50	437.60	882.10
Oct-91	454.80	484.00	938.80
Nov-91	388.20	400.50	788.70
Dec-91	400.40	397.90	798.30
Jan-92	338.00	304.80	642.80
Feb-92	290.20	267.00	557.20
Mar-92	203.00	190.00	393.00
Total	3292.85	3214.00	6506.85

Table 2.4 Monthly water releases to GS Scheme for season (1992-1993)

25/05/1992 -------------- 31/3/1993			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-92	8.90	9.80	18.70
Jun-92	115.90	114.20	230.10
Jul-92	359.70	349.00	708.70
Aug-92	234.40	237.90	472.30
Sep-92	272.80	244.20	517.00
Oct-92	478.00	470.20	948.20
Nov-92	358.60	342.00	700.60
Dec-92	352.60	351.30	703.90
Jan-93	304.20	301.10	605.30
Feb-93	275.00	271.50	546.50
Mar-93	224.00	225.80	449.80
Total	2984.10	2917.00	5901.10

M = million

Ministry of Irrigation and Water Resources – Sudan
Irrigation service Department
Water releases from Sennar Dam to Gezira and Managil scheme

Table 2.5 Monthly water releases to GS Scheme for season (1993-1994)

25/05/1993 -------------- 31/3/1994			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-93	7.00	7.00	14.00
Jun-93	127.20	138.70	265.90
Jul-93	309.70	298.00	607.70
Aug-93	292.60	266.70	559.30
Sep-93	302.70	264.20	566.90
Oct-93	473.20	521.71	994.91
Nov-93	438.70	502.47	941.17
Dec-93	433.50	515.86	949.36
Jan-94	372.60	522.56	895.16
Feb-94	309.70	475.07	784.77
Mar-94	108.00	483.03	591.03
Total	3174.90	3995.30	7170.20

Table 2.6 Monthly water releases to GS Scheme for season (1994-1995)

25/05/1994 -------------- 31/3/1995			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-94	2.00	13.00	15.00
Jun-94	168.20	174.60	342.80
Jul-94	373.00	333.90	706.90
Aug-94	158.70	162.90	321.60
Sep-94	391.50	359.90	751.40
Oct-94	453.50	443.40	896.90
Nov-94	379.70	353.50	733.20
Dec-94	394.60	388.30	782.90
Jan-95	356.10	358.90	715.00
Feb-95	288.10	287.10	575.20
Mar-95	206.20	220.80	427.00
Total	3171.60	3096.30	6267.90

M = million

Ministry of Irrigation and Water Resources – Sudan
Irrigation service Department
Water releases from Sennar Dam to Gezira and Managil scheme

Table 2.7 Monthly water releases to GS Scheme for season (1995-1996)

25/05/1995 -------------- 31/3/1996			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-95	12.60	8.30	20.90
Jun-95	182.80	174.50	357.30
Jul-95	367.90	319.20	687.10
Aug-95	196.20	217.30	413.50
Sep-95	434.60	390.60	825.20
Oct-95	511.50	465.00	976.50
Nov-95	478.70	439.30	918.00
Dec-95	340.70	374.00	714.70
Jan-96	308.40	320.65	629.05
Feb-96	269.50	271.55	541.05
Mar-96	120.25	144.65	264.90
Total	3223.15	3125.05	6348.20

Table 2.8 Monthly water releases to GS Scheme for season 1996-1997

25/05/1996 -------------- 31/3/1997			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-96	7.00	15.50	22.50
Jun-96	187.90	259.60	447.50
Jul-96	480.00	439.00	919.00
Aug-96	372.00	340.80	712.80
Sep-96	376.80	350.70	727.50
Oct-96	484.00	462.80	946.80
Nov-96	475.00	426.60	901.60
Dec-96	443.60	384.15	827.75
Jan-97	449.00	310.00	759.00
Feb-97	342.30	280.00	622.30
Mar-97	167.90	164.10	332.00
Total	3785.50	3433.25	7218.75

M = million

Ministry of Irrigation and Water Resources – Sudan
Irrigation service Department
Water releases from Sennar Dam to Gezira and Managil scheme

Table 2.9 Monthly water releases to GS Scheme for season (1997-1998)

25/05/1997 -------------- 31/3/1998			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-97	8.0	3.5	11.5
Jun-97	176.5	176.5	353.0
Jul-97	381.7	315.3	697.0
Aug-97	339.1	302.5	641.6
Sep-97	481.4	447.0	928.4
Oct-97	514.0	441.2	955.2
Nov-97	410.0	381.0	791.0
Dec-97	426.8	404.0	830.8
Jan-98	375.3	372.4	747.7
Feb-98	327.2	319.8	647.0
Mar-98	180.5	243.7	424.2
Total	3620.5	3406.9	7027.4

Table 2.10 Monthly water releases to GS Scheme for season (1998-1999)

25/05/1998 -------------- 31/3/1999			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-98	0.00	34.00	34.00
Jun-98	134.00	180.00	314.00
Jul-98	338.30	292.70	631.00
Aug-98	247.00	290.40	537.40
Sep-98	136.50	164.00	300.50
Oct-98	416.00	401.00	817.00
Nov-98	297.50	392.50	690.00
Dec-98	346.00	417.20	763.20
Jan-99	271.80	351.80	623.60
Feb-99	282.60	307.00	589.60
Mar-99	287.50	109.70	397.20
Total	2757.20	2940.30	5697.50

M = million

Ministry of Irrigation and Water Resources – Sudan
Irrigation service Department
Water releases from Sennar Dam to Gezira and Managil scheme

Table 2.11 Monthly water released to GS Scheme for season (1999-2000)

25/05/1999 -------------- 31/3/2000			
Date	Gezira Volume M m3	Managil Volume M m3	Total Volume M m3
May-99	0.00	37.00	37.00
Jun-99	150.00	157.10	307.10
Jul-99	423.00	238.80	661.80
Aug-99	304.50	244.50	549.00
Sep-99	294.90	282.40	577.30
Oct-99	484.10	461.10	945.20
Nov-99	418.30	408.10	826.40
Dec-99	348.50	374.00	722.50
Jan-00	244.00	358.50	602.50
Feb-00	270.50	199.60	470.10
Mar-00	205.70	177.50	383.20
Total	3143.50	2938.60	6082.10

Table 2.12 Monthly water releases to GS Scheme for season (2001-2002)

25/05/2001 -------------- 31/3/2002			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-01	8.40	13.80	22.20
Jun-01	151.30	202.10	353.40
Jul-01	522.20	354.40	876.60
Aug-01	422.20	325.20	747.40
Sep-01	534.50	395.92	930.42
Oct-01	570.00	464.00	1034.00
Nov-01	336.50	406.00	742.50
Dec-01	300.00	358.00	658.00
Jan-02	290.40	341.00	631.40
Feb-02	315.50	190.50	506.00
Mar-02	378.30	26.40	404.70
Total	3829.30	3077.32	6906.62

M= million

Ministry of Irrigation and Water Resources – Sudan
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Water releases from Sennar Dam to Gezira and Managil scheme

Table 2.13 Monthly water releases to GS Scheme for season (2002-2003)

25/05/2002 -------------- 31/3/2003			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-02	24.00	0.60	24.60
Jun-02	131.50	77.10	208.60
Jul-02	426.70	332.80	759.50
Aug-02	403.30	308.70	712.00
Sep-02	282.20	240.90	523.10
Oct-02	585.90	406.10	992.00
Nov-02	479.00	344.40	823.40
Dec-02	318.20	250.00	568.20
Jan-03	317.80	250.00	567.80
Feb-03	286.60	212.60	499.20
Mar-03	131.60	82.70	214.30
Total	3386.80	2505.90	5892.70

Table 2.14 Monthly water releases to GS Scheme for season (2003-2004)

25/05/2003 -------------- 31/3/2004			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-03	0.00	39.80	39.80
Jun-03	116.75	266.90	383.65
Jul-03	416.20	320.20	736.40
Aug-03	148.40	41.70	190.10
Sep-03	345.35	307.85	653.20
Oct-03	555.95	466.80	1022.75
Nov-03	424.70	328.55	753.25
Dec-03	373.90	288.00	661.90
Jan-04	300.55	262.85	563.40
Feb-04	264.30	231.95	496.25
Mar-04	279.60	225.85	505.45
Total	3225.70	2780.45	6006.15

M = million

Ministry of Irrigation and Water Resources – Sudan
Irrigation service Department
Water releases from Sennar Dam to Gezira and Managil scheme

Table 2.15 Monthly water releases to GS Scheme for season (2004-2005)

25/05/2004 -------------- 31/3/2005			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-04	0.00	27.81	27.81
Jun-04	139.90	128.78	268.67
Jul-04	490.75	345.35	836.10
Aug-04	424.05	304.50	728.55
Sep-04	551.50	410.15	961.65
Oct-04	584.35	439.45	1023.80
Nov-04	525.70	391.55	917.25
Dec-04	453.60	342.00	795.60
Jan-05	383.65	280.55	664.20
Feb-05	339.00	215.80	554.80
Mar-05	234.40	172.10	406.50
Total	4126.90	3058.04	7184.93

Table 2.16 Monthly water releases to GS Scheme for season (2005-2006)

25/05/2005 -------------- 31/3/2006			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-05	32.30	0.00	32.30
Jun-05	261.25	119.25	380.50
Jul-05	513.70	327.10	840.80
Aug-05	350.20	267.30	617.50
Sep-05	502.50	385.05	887.55
Oct-05	579.45	435.90	1015.35
Nov-05	500.05	380.25	880.30
Dec-05	493.60	391.95	885.55
Jan-06	374.85	270.60	645.45
Feb-06	290.60	244.05	534.65
Mar-06	207.10	225.40	432.50
Total	4105.60	3046.85	7152.45

M=million

Ministry of Irrigation and Water Resources – Sudan
Irrigation service Department
Water releases from Sennar Dam to Gezira and Managil scheme

Table 2.17 Monthly water releases to GS Scheme for season (2006-2007)

25/05/2006 -------------- 31/3/2007			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-06	21.52	17.89	39.40
Jun-06	126.35	164.50	290.85
Jul-06	461.13	421.57	882.70
Aug-06	383.60	353.10	736.70
Sep-06	461.70	401.20	862.90
Oct-06	581.85	470.95	1052.80
Nov-06	508.43	360.12	868.55
Dec-06	525.10	339.30	864.40
Jan-07	458.50	289.50	748.00
Feb-07	454.98	251.92	706.90
Mar-07	387.88	206.12	594.00
Total	4371.04	3276.17	7647.20

Table 2.18 Monthly water releases to GS Scheme for season (2007-2008)

25/05/2007 -------------- 31/3/2008			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-07	3.24	6.76	10.00
Jun-07	197.40	148.00	345.40
Jul-07	234.80	157.00	391.80
Aug-07	274.90	212.60	487.50
Sep-07	400.80	373.45	774.25
Oct-07	494.75	474.25	969.00
Nov-07	448.65	373.85	822.50
Dec-07	543.50	416.25	959.75
Jan-08	546.25	348.25	894.50
Feb-08	483.95	309.55	793.50
Mar-08	420.48	227.52	648.00
Total	4048.72	3047.48	7096.20

M = million

Ministry of Irrigation and Water Resources – Sudan
Irrigation service Department
Water releases from Sennar Dam to Gezira and Managil scheme

Table 2.19 Monthly water releases to GS Scheme for season (2008-2009)

25/05/2008 -------------- 31/3/2009			
Date	Gezira Volume M m^3	Managil Volume M m^3	Total Volume M m^3
May-08	0.00	55.00	55.00
Jun-08	258.65	257.25	515.90
Jul-08	570.00	462.25	1032.25
Aug-08	406.50	332.50	739.00
Sep-08	448.20	387.25	835.45
Oct-08	588.50	500.50	1089.00
Nov-08	409.50	442.25	851.75
Dec-08	510.75	498.75	1009.50
Jan-09	468.15	455.35	923.50
Feb-09	396.00	406.00	802.00
Mar-09	337.00	268.50	605.50
Total	4393.25	4065.60	8458.85

M = million

Table 2.20 Cropped area (fed),1970/71-2008/09

Season	Cotton	Wheat	Groundnuts	Sorghum	Vegetables	Rice	Fodder	Maize
70/71	588,371	141,252	148,465	294,172	44,303	0	131,651	1,348,214
71/72	589,185	131,325	117,024	293,824	42,549	0	112,799	1,286,706
72/73	589,387	145,614	177,785	294,576	43,493	0	85,927	1,336,782
73/74	604,420	254,180	216,285	300,736	34,131	0	42,489	1,452,241
74/75	603,364	427,648	260,937	154,395	29,030	9,746	19,659	1,504,779
75/76	395,637	567,500	423,604	341,357	23,878	12,288	1,467	1,765,731
76/77	499,434	504,603	250,817	351,810	30,259	12,538	60	1,649,521
77/78	518,607	465,683	263,782	353,458	23,750	10,635	0	1,635,915
78/79	498,023	493,436	217,182	344,067	26,944	4,026	0	1,583,678
79/80	540,890	362,502	228,545	327,294	33,229	9,066	0	1,501,526
80/81	501,202	366,737	170,919	300,832	43,125	4,938	0	1,387,753
81/82	435,313	267,863	264,245	343,899	35,811	0	0	1,347,131
82/83	484,315	155,538	148,182	320,940	28,774	0	0	1,137,749
83/84	497,729	265,824	136,611	410,791	35,689	0	0	1,346,644
84/85	464,793	Not Grown	212,859	420,068	25,566	0	0	1,123,286
85/86	400,529	242,498	102,535	578,754	30,050	0	0	1,354,365
86/87	415,074	179,869	151,051	448,005	36,136	0	0	1,230,135
87/88	383,037	252,314	159,562	394,457	40,849	0	0	1,230,219
88/89	404,505	274,247	110,864	426,810	45,787	0	0	1,262,213
89/90	357,985	392,297	79,580	440,953	55,889	0	0	1,326,704
90/91	251,048	613,306	39,860	506,577	61,138	0	0	1,471,929
91/92	215,506	532,813	35,452	725,306	45,194	0	30,447	1,605,899
92/93	174,703	514,034	163,418	621,736	49,245	0	4,522	1,529,758
93/94	149,603	522,783	187,146	547,329	43,003	0	1,157	1,457,209
94/95	253,147	392,690	191,093	467,516	52,996	0	0	1,404,864
95/96	301,245	390,777	230,995	394,339	55,002	0	0	1,373,131
96/97	331,047	389,801	246,249	407,000	39,482	0	0	1,413,579
97/98	246,221	301,925	223,042	339,398	36,048	0	0	1,146,634
98/99	154,000	123,016	145,622	285,176	23,652	0	0	731,466
99/00	259,515	58,627	154,816	273,759	23,084	0	0	769,801
00/01	207,690	70,410	170,904	509,000	23,704	0	0	981,707
01/02	190,235	80,818	45,000	678,551	40,000	0	0	1,034,604
02/03	244,900	110,878	85,427	446,429	55,000	0	1	943,835
03/04	281,934	132,843	135,714	409,971	56,000	500	2,000	1,019,362
04/05	315,772	151,220	132,289	409,090	45,194	0	500	1,056,065
05/06	304,711	156,625	130,930	463,240	32,010	0	0	1,089,016
06/07	249,900	294,140	161,394	593,741	38,001	0	0	1,337,176
07/08	98,685	426,941	163,444	474,019	95,248	0	0	1,258,337
08/09	83,575	512,901	231,734	512,882	100,000	0	0	1,441,092

Source: Sudan Gezira Board
1 fed= 0.42 ha

Table 2.21 the main crops yield of GS, SGB

Season	Cotton k/fed	Wheat t/fed	Groundnuts t/fed	Sorghum t/fed
1970/71	5.42	0.39	0.41	0.51
1971/72	4.99	0.51	0.50	0.44
1972/73	4.08	0.67	1.25	1.00
1973/74	5.06	0.80	1.25	0.75
1974/75	4.60	0.39	1.25	0.50
1975/76	2.72	0.39	0.77	0.62
1976/77	3.66	0.58	1.20	0.66
1977/78	4.29	0.47	1.08	0.35
1978/79	3.27	0.25	0.43	0.87
1979/80	2.61	0.47	0.50	0.58
1980/81	2.31	0.26	0.23	0.49
1981/82	3.87	0.33	0.37	0.40
1982/83	4.67	0.60	0.41	0.52
1983/84	4.93	0.39	0.67	0.53
1984/85	5.22	Not grown	0.51	0.35
1985/86	3.54	0.40	0.55	0.55
1986/87	4.93	0.44	0.60	0.40
1987/88	4.57	0.47	0.60	0.36
1988/89	5.20	0.56	0.60	0.50
1989/90	4.14	0.66	0.54	0.49
1990/91	3.70	0.44	0.73	0.53
1991/92	5.62	0.94	0.80	0.66
1992/93	4.15	0.53	0.71	0.77
1993/94	3.89	0.52	0.82	0.80
1994/95	3.89	0.59	0.89	0.85
1995/96	4.14	0.66	0.75	0.66
1996/97	3.83	0.64	0.79	1.18
1997/98	4.48	0.70	1.04	1.04
1998/99	4.42	0.31	0.50	0.79
1999/00	2.57	0.50	0.65	0.67
2000/01	4.47	0.80	0.66	0.95
2001/02	5.25	0.80	0.73	0.98
2002/03	5.05	0.85	0.80	0.98
2003/04	3.51	0.82	0.81	0.83
2004/05	4.30	0.73	0.92	1.06
2005/06	4.09	0.65	0.82	0.90
2006/07	3.20	0.99	0.90	1.02
2007/08	3.65	0.65	0.82	0.92
2008/09	3.08	0.54	0.75	0.62

Source: Sudan Gezira Board (2008)

t = ton

Appendix 3 Results from performance indicators methods of analysis the data

3.1 Monthly irrigation water supply, million meter cubic per day

Season	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1989/90	6.3	15.7	18.2	17.2	28.8	29.0	25.7	22.4	19.3	8.5
1990/91	8.1	19.5	24.6	26.2	29.1	28.8	27.5	20.7	24.7	24.3
1991/92	5.1	22.9	20.2	29.4	30.3	26.3	25.8	20.7	19.9	12.7
1992/93	7.7	22.9	15.2	17.2	30.6	23.4	22.7	19.5	19.5	14.5
1993/94	11.9	22.2	13.3	27.5	31.5	30.6	23.1	20.3	19.3	8.5
1994/95	11.4	22.8	10.4	25.0	28.9	24.4	25.3	23.1	20.5	13.8
1995/96	11.9	22.2	13.3	27.5	31.5	30.6	23.1	20.3	19.3	8.5
1996/97	14.9	29.6	23.0	24.3	30.5	30.1	26.7	24.5	22.2	10.7
1997/98	11.8	22.5	20.7	30.9	30.8	26.4	26.8	24.1	23.1	13.7
1998/99	10.5	20.4	17.3	10.0	26.4	23.0	24.6	20.1	21.1	12.8
1999/00	9.7	28.5	23.8	28.8	34.0	29.0	27.9	24.1	25.2	19.2
2000/01	14.1	27.2	26.3	29.6	31.2	28.3	23.5	18.9	16.8	12.3
2001/02	11.8	28.3	24.1	31.0	33.4	24.8	21.2	20.4	18.1	13.1
2002/03	7.0	24.5	23.0	17.4	32.0	27.4	18.3	18.3	17.8	6.9
2003/04	12.8	23.8	6.1	21.8	33.0	25.1	21.4	18.2	17.7	16.3
2004/05	9.0	27.0	23.5	32.1	33.0	30.6	25.7	21.4	19.8	13.1
2005/06	12.7	27.1	19.9	29.6	32.8	29.3	28.6	20.8	19.1	14.0
2006/07	9.7	28.5	23.8	28.8	34.0	29.0	27.9	24.1	25.2	19.2
2007/08	11.5	12.6	15.7	25.8	31.3	27.4	31.0	28.9	28.3	20.9
2008/09	17.2	33.3	23.8	27.8	35.1	28.4	32.6	29.8	28.6	19.5

Source: MOIWR (2008)

Table 3.2 Monthly net crop water requirement, million cubic meter per day

Season	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1989/90	6.1	27.1	23.0	27.1	26.2	19.0	16.4	14.9	13.7	8.7
1990/91	5.3	23.6	24.3	25.3	21.0	21.9	26.3	25.0	25.3	14.1
1991/92	12.7	35.9	29.6	38.3	28.6	23.2	24.9	24.1	23.1	17.1
1992/93	13.9	28.3	23.1	27.9	22.2	17.8	16.7	15.4	15.0	15.5
1993/94	10.0	24.6	21.8	23.5	18.1	14.9	15.4	18.9	23.1	9.9
1994/95	9.6	21.4	18.7	23.6	20.8	17.8	17.5	15.6	14.3	8.8
1995/96	10.7	20.0	17.8	22.3	22.6	23.1	25.1	21.6	12.3	6.5
1996/97	12.6	27.4	21.3	23.8	36.8	27.2	27.2	15.2	13.2	7.3
1997/98	11.8	19.4	16.0	22.6	19.3	15.0	15.8	13.7	13.2	8.7
1998/99	11.4	18.4	13.7	14.6	9.4	10.4	10.0	9.1	9.9	7.3
1999/00	12.3	18.5	15.1	17.9	16.8	11.1	9.2	7.9	7.6	5.9
2000/01	9.1	22.4	21.4	24.1	19.0	8.5	7.2	5.2	4.1	1.6
2001/02	6.3	25.0	20.7	23.9	19.0	7.7	6.8	4.6	4.6	2.7
2002/03	6.2	19.7	16.2	16.6	13.8	9.3	7.9	7.4	6.2	3.0
2003/04	7.5	17.6	15.4	19.6	18.8	13.0	11.1	11.6	9.3	3.6
2004/05	7.3	20.4	20.8	23.6	20.2	14.4	13.4	13.6	13.3	4.1
2005/06	7.6	21.2	19.0	21.6	18.5	13.5	13.9	12.5	10.8	4.7
2006/07	14.2	28.2	23.2	24.8	23.2	17.5	17.7	15.1	16.3	11.5
2007/08	10.4	19.0	15.8	19.1	14.4	13.1	16.8	17.9	17.9	11.5
2008/09	12.3	24.8	22.8	23.3	18.0	13.6	16.2	17.6	18.6	12.3

Source: Calculated by CROPWAT 8.0 and spreadsheet

Table 3.3 Monthly effective rainfall, million cubic meter per day

Season	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1989/90	1.7	7.1	36.1	13.5	0.1	7.6				
1990/91	0.3	10.2	0.1	8.6	11.3					
1991/92	0.0	15.2	22.9	66.8	1.9					
1992/93	3.9	22.3	39.9	11.6	1.4					
1993/94	1.4	3.1	31.4	22.8	0.0					
1994/95	1.4	15.3	39.8	15.6	7.2					
1995/96	4.2	47.3	53.3	2.2	2.7					
1996/97	0.2	13.8	55.9	15.2	4.9					
1997/98	1.0	31.0	14.8	10.6	15.9	0.2				
1998/99	0.0	20.6	37.9	15.3	2.5			1.8		
1999/00	0.6	34.0	29.3	26.5	3.0					
2000/01	0.4	12.0	8.8	18.7	19.4					
2001/02	0.1	36.0	12.0	7.6	1.0					
2002/03	0.2	12.0	19.2	21.3	3.8					
2003/04	2.0	20.9	29.5	12.4	2.8					
2004/05	2.3	4.6	20.8	2.7	2.6					
2005/06	0.9	21.1	35.7	15.1	0.0					
2006/07	2.5	16.1	44.2	11.3	7.3					
2007/08	5.0	31.0	17.9	10.9	2.3	0.5				
2008/09	1.6	10.5	34.6	24.6	9.1					

Source: Calculated by CROPWAT 8.0 and spreadsheet

3.4 Monthly net irrigation water requirement, million meter cubic per day

Season	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1989/90	3.4	18.2	10.2	22.3	26.6	16.4	16.3	14.9	13.7	8.7
1990/91	2.7	13.0	23.9	21.4	16.9	21.8	26.3	25.0	25.3	14.1
1991/92	9.0	19.6	19.6	15.1	26.7	22.8	24.7	23.8	22.8	16.9
1992/93	8.8	10.8	8.1	23.7	21.5	17.6	16.7	15.3	14.9	15.4
1993/94	6.7	15.3	10.2	15.4	18.2	14.8	15.4	18.9	23.1	9.9
1994/95	6.8	8.1	6.2	17.3	16.3	14.9	15.0	13.3	12.9	8.8
1995/96	6.8	3.4	3.9	21.6	22.4	23.2	25.1	21.6	12.3	6.5
1996/97	10.5	15.4	4.2	19.0	37.2	27.0	27.2	15.2	13.2	7.3
1997/98	9.3	4.6	10.0	19.5	14.1	14.8	15.8	13.7	13.2	8.7
1998/99	9.9	6.2	1.3	9.0	7.8	10.5	10.0	8.5	9.9	7.3
1999/00	10.4	4.0	5.3	8.8	15.8	11.1	9.2	7.9	7.6	5.9
2000/01	6.3	10.8	18.1	17.3	12.3	8.4	7.2	5.2	4.1	1.6
2001/02	2.6	4.0	16.2	21.1	18.8	7.4	6.8	4.6	4.6	2.7
2002/03	3.7	8.3	7.8	7.6	12.3	9.2	7.9	7.4	6.2	3.0
2003/04	4.4	3.8	3.4	14.0	17.7	12.9	11.1	11.6	9.3	3.6
2004/05	4.4	12.5	10.5	22.0	18.9	14.3	13.4	13.6	13.3	4.1
2005/06	4.7	7.0	6.0	15.6	18.6	13.5	13.9	12.5	10.8	4.7
2006/07	9.8	12.3	5.3	19.8	20.6	18.3	17.7	15.1	16.3	11.5
2007/08	5.4	1.4	8.3	14.8	13.7	13.0	16.8	17.9	17.9	11.5
2008/09	8.9	13.2	11.6	15.1	15.4	14.2	16.2	17.6	18.6	12.3

Source: Calculated by CROPWAT 8.0 software and spreadsheet

3.5 Monthly overall consumed ratio (OCR), 1989/90-2008/09

Season	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1989/90	0.5	1.2	0.6	1.3	0.9	0.6	0.6	0.7	0.7	1.0
1990/91	0.3	0.6	0.9	0.8	0.5	0.6	0.9	1.1	1.0	0.6
1991/92	0.6	0.7	0.8	0.5	0.8	0.7	0.8	1.0	1.0	0.9
1992/93	0.7	0.4	0.5	1.2	0.6	0.6	0.6	0.7	0.6	0.8
1993/94	0.6	0.7	0.8	0.5	0.5	0.5	0.6	0.9	1.2	1.2
1994/95	0.6	0.4	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6
1995/96	0.5	0.2	0.3	0.8	0.8	0.9	1.3	1.2	0.7	0.7
1996/97	0.6	0.5	0.2	0.8	1.3	1.0	1.1	0.7	0.6	0.6
1997/98	0.6	0.2	0.5	0.6	0.5	0.6	0.6	0.6	0.5	0.5
1998/99	0.5	0.2	0.1	0.8	0.3	0.3	0.3	0.3	0.3	0.2
1999/00	0.5	0.1	0.2	0.3	0.4	0.3	0.3	0.3	0.2	0.1
2000/01	0.4	0.4	0.7	0.6	0.4	0.2	0.2	0.2	0.2	0.1
2001/02	0.2	0.1	0.7	0.7	0.5	0.3	0.3	0.2	0.2	0.2
2002/03	0.5	0.3	0.3	0.4	0.3	0.2	0.2	0.2	0.2	0.3
2003/04	0.3	0.1	0.4	0.5	0.3	0.2	0.2	0.3	0.3	0.2
2004/05	0.5	0.3	0.4	0.5	0.3	0.2	0.2	0.3	0.4	0.3
2005/06	0.4	0.2	0.3	0.5	0.5	0.3	0.4	0.4	0.5	0.3
2006/07	0.6	0.3	0.2	0.5	0.4	0.3	0.4	0.4	0.4	0.3
2007/08	0.4	0.0	0.4	0.5	0.3	0.4	0.4	0.5	0.5	0.5
2008/09	0.5	0.4	0.5	0.6	0.5	0.6	0.5	0.6	0.7	0.6

OCR Calculated by table 3.1 and 3.2

Table 3.6 Seasonal net crop water requirement, million m^3

Season	Groundnuts	Sorghum	Cotton	Wheat	Vegetables	Rice	Gardens	Fodder	Maize	Sun-flower
70/71	550.23	1028.17	2910.72	574.74	0.00	0.00	0.00	0.00	0.00	0.00
71/72	433.70	1026.96	2914.74	534.35	328.14	0.00	0.00	449.40	0.00	0.00
72/73	658.89	1029.58	2915.74	592.49	335.42	0.00	0.00	524.51	0.00	0.00
73/74	801.58	1051.11	2990.11	1034.23	263.22	0.00	0.00	169.28	0.00	0.00
74/75	967.06	539.63	2984.89	1740.05	223.88	0.00	0.00	78.32	0.00	0.00
75/76	1569.92	1193.09	1957.25	2309.10	184.15	60.86	0.00	5.84	0.00	0.00
76/77	929.55	1229.63	2470.74	2053.18	233.36	60.86	0.00	5.84	0.00	0.00
77/78	977.60	1235.39	2565.59	1894.81	183.16	52.68	0.00	0.00	0.00	0.00
78/79	804.90	1202.56	2463.76	2007.74	207.79	19.94	0.00	0.00	0.00	0.00
79/80	847.01	1143.94	2675.82	1474.98	256.26	44.90	0.00	0.00	0.00	0.00
80/81	633.44	1051.45	2479.48	1492.21	332.58	44.90	0.00	0.00	0.00	0.00
81/82	979.32	1201.98	2153.53	1086.35	276.18	0.00	0.00	0.00	0.00	0.00
82/83	549.18	1121.73	2395.94	630.80	221.91	0.00	0.00	0.00	0.00	0.00
83/84	506.29	1435.77	2462.30	1078.08	275.23	0.00	0.00	0.00	0.00	0.00
84/85	788.88	1468.20	2299.37	0.00	197.17	0.00	0.00	0.00	0.00	0.00
85/86	380.01	2022.82	1981.45	983.48	231.75	0.00	0.00	0.00	0.00	0.00
86/87	559.81	1565.84	2053.40	729.48	278.68	0.00	0.00	0.00	0.00	0.00
87/88	591.35	1378.68	1894.91	1023.29	315.03	0.00	0.00	0.00	0.00	0.00
88/89	410.87	1491.76	2001.12	1112.24	353.11	0.00	0.00	0.00	0.00	0.00
89/90	320.43	1675.98	1727.95	1400.94	424.87	0.00	0.00	0.00	0.00	0.00
90/91	164.53	1982.34	1425.76	2385.63	493.35	0.00	0.00	0.00	0.00	0.00
91/92	141.84	2718.25	1166.79	1987.64	348.06	0.00	1286.97	123.69	66.46	0.00
92/93	559.47	1982.80	754.89	1541.38	307.53	0.00	791.68	14.84	5.37	0.00
93/94	666.67	1839.80	707.37	1927.76	303.74	0.00	0.00	0.00	15.03	0.00
94/95	635.46	1442.19	1188.72	1383.45	349.28	0.00	0.00	0.00	0.00	123.45
95/96	740.21	1157.89	1692.06	1473.26	363.65	0.00	120.65	0.00	0.00	0.00
96/97	960.50	1437.53	2083.35	1326.70	291.78	0.00	370.06	0.00	0.00	0.00
97/98	728.77	1025.82	1127.34	1070.91	232.34	0.00	545.93	0.00	0.00	0.00
98/99	413.23	763.17	647.43	434.22	141.42	0.00	1077.34	0.00	0.00	0.00
99/00	480.07	784.63	1059.35	193.32	138.49	0.00	1071.77	0.00	0.00	0.00
00/01	626.56	1759.49	994.19	223.77	144.28	0.00	0.00	0.00	0.00	0.00
01/02	154.77	2194.82	843.22	256.24	254.30	0.00	0.00	0.00	0.00	0.00
02/03	271.89	1317.48	1011.93	324.87	317.05	0.00	0.00	0.00	0.00	0.00
03/04	442.04	1224.15	1403.59	452.72	353.95	2.00	0.00	6.61	0.94	0.00
04/05	495.19	1453.78	1723.46	583.09	337.34	0.00	0.00	1.94	5.84	0.00
05/06	443.77	1468.81	1575.73	640.85	234.59	0.00	0.00	0.00	3.81	0.00
06/07	521.89	1750.15	1198.57	1010.29	243.81	0.00	1126.71	0.00	0.00	0.00
07/08	497.12	1289.60	478.50	1517.63	588.18	0.00	367.62	0.00	0.00	0.00
08/09	800.50	1645.04	365.95	1786.67	670.40	0.00	185.46	0.00	0.00	0.00

Table 3.7 Seasonal Relative water supply

Season	IWS	Pe	TWS	CWR	TWD	RWS	RWSe
70/71	6.1	1.5	7.6	5.9	8.5	1.3	0.9
71/72	6.3	1.4	7.7	5.7	8.1	1.4	1.0
72/73	6.1	1.5	7.6	6.1	8.7	1.3	0.9
73/74	6.9	1.6	8.5	6.3	9.0	1.4	0.9
74/75	6.9	1.7	8.6	6.6	9.4	1.3	0.9
75/76	6.2	2.0	8.1	7.3	10.4	1.1	0.8
76/77	6.7	1.8	8.6	7.0	10.0	1.2	0.9
77/78	7.1	1.8	8.9	6.9	9.9	1.3	0.9
78/79	5.8	1.8	7.5	6.7	9.6	1.1	0.8
79/80	6.2	1.7	7.8	6.4	9.2	1.2	0.8
80/81	6.0	1.5	7.5	6.0	8.6	1.3	0.9
81/82	6.0	1.5	7.5	5.7	8.1	1.3	0.9
82/83	6.0	1.3	7.2	4.9	7.0	1.5	1.0
83/84	6.6	1.5	8.1	5.8	8.2	1.4	1.0
84/85	5.7	1.2	6.9	4.8	6.8	1.5	1.0
85/86	6.0	1.5	7.5	5.6	8.0	1.3	0.9
86/87	5.3	1.4	6.7	5.2	7.4	1.3	0.9
87/88	5.9	1.4	7.3	5.2	7.4	1.4	1.0
88/89	5.6	1.4	7.0	5.4	7.7	1.3	0.9
89/90	5.8	2.0	7.8	5.6	7.9	1.4	1.0
90/91	7.1	0.9	8.1	6.5	9.2	1.2	0.9
91/92	6.5	3.3	9.7	7.8	11.2	1.2	0.9
92/93	5.9	2.4	8.3	6.0	8.5	1.4	1.0
93/94	6.3	1.6	8.0	5.5	7.8	1.5	1.0
94/95	6.3	2.1	8.4	5.1	7.3	1.6	1.1
95/96	6.3	4.0	10.3	5.6	7.9	1.9	1.3
96/97	7.2	2.5	9.7	6.5	9.2	1.5	1.0
97/98	7.0	2.0	9.0	4.7	6.8	1.9	1.3
98/99	5.7	2.1	7.7	3.5	5.0	2.2	1.6
99/00	7.6	2.4	10.0	3.7	5.3	2.7	1.9
00/01	6.9	1.1	8.0	3.7	5.4	2.1	1.5
01/02	6.9	1.2	8.1	3.7	5.3	2.2	1.5
02/03	5.9	1.1	7.0	3.2	4.6	2.2	1.5
03/04	6.0	1.6	7.5	3.9	5.6	1.9	1.4
04/05	7.2	0.8	8.0	4.6	6.6	1.7	1.2
05/06	7.1	1.7	8.8	4.4	6.2	2.0	1.4
06/07	7.6	2.1	9.7	5.8	8.3	1.7	1.2
07/08	7.1	2.4	9.5	4.7	6.8	2.0	1.4
08/09	8.4	2.2	10.6	5.5	7.8	1.9	1.4

IWS = Irrigation water supply (billion m^3 per season)

P_e = effective rainfall (billion m^3 per season)

TWS = total water supply = IWS + Pe

CWR = crop water requirement (billion m^3 per season)

TWD = Total water demand (billion m^3 per season)

RWS = Relative water supply (exclude overall efficiency)

RWSe = Relative water supply (include overall efficiency)

P_e and CWR calculated by CROPW 8.0 software and spreadsheet

TWD = CWR/0.7, 0.7 is overall efficiency

RWS = Total water supply (TWS)/net crop water requirement (CWR)

RWSe = Total water supply (TWS)/Total water demand (TWD)

Irw_{in} = net irrigation water requirement

IWR_g = irrigation water requirement

RIS = Relative irrigation supply (exclude the application efficiency)

RIS_e = Relative irrigation supply (include the application efficiency)

Table 3.8 Monthly total water supply, million cubic meter per day

Season	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1989/90	8.1	22.8	54.3	30.7	29.0	36.6	25.7	22.4	19.3	8.5
1990/91	8.3	29.7	24.7	34.8	40.4	28.8	27.5	20.7	24.7	24.4
1991/92	5.1	38.0	43.1	96.2	32.1	26.3	25.8	20.7	19.9	12.7
1992/93	11.5	45.2	55.1	28.8	32.0	23.4	22.7	19.5	19.5	14.5
1993/94	13.4	25.3	44.7	50.3	31.5	30.6	23.1	20.3	19.3	8.5
1994/95	12.8	38.1	50.2	40.6	36.1	24.4	25.3	23.1	20.5	13.8
1995/96	16.1	69.5	66.6	29.7	34.2	30.6	23.1	20.3	19.3	8.5
1996/97	15.1	43.4	78.9	39.4	35.5	30.1	26.7	24.5	22.2	10.7
1997/98	12.8	53.4	35.5	41.6	46.7	26.6	26.8	24.1	23.1	13.7
1998/99	10.5	40.9	55.2	25.3	28.9	23.0	24.6	21.9	21.1	12.8
1999/00	10.3	62.5	53.0	55.2	37.0	29.0	27.9	24.1	25.2	19.2
2000/01	14.6	39.1	35.1	48.2	50.6	28.3	23.5	18.9	16.8	12.3
2001/02	11.9	64.3	36.1	38.7	34.3	24.8	21.2	20.4	18.1	13.1
2002/03	7.2	36.5	42.1	38.8	35.8	27.4	18.3	18.3	17.8	6.9
2003/04	14.8	44.7	35.6	34.1	35.7	25.1	21.4	18.2	17.7	16.3
2004/05	11.3	31.5	44.3	34.8	35.6	30.6	25.7	21.4	19.8	13.1
2005/06	13.6	48.3	55.6	44.7	32.8	29.3	28.6	20.8	19.1	14.0
2006/07	12.2	44.6	67.9	40.0	41.3	29.0	27.9	24.1	25.2	19.2
2007/08	16.5	43.6	33.7	36.7	33.5	27.9	31.0	28.9	28.3	20.9
2008/09	18.8	43.8	58.4	52.4	44.2	28.4	32.6	29.8	28.6	19.5

Table 3.9 Monthly water demand, million cubic meter per day

Season	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1989/90	8.7	38.7	32.8	38.7	37.4	27.2	23.4	21.3	19.5	12.4
1990/91	7.6	33.7	34.7	36.2	30.0	31.2	37.6	35.7	36.2	20.2
1991/92	18.2	51.2	42.3	54.7	40.8	33.2	35.6	34.4	32.9	24.5
1992/93	19.8	40.4	33.0	39.9	31.6	25.5	23.8	21.9	21.4	22.1
1993/94	14.3	35.1	31.1	33.6	25.8	21.2	22.0	27.0	33.0	14.2
1994/95	13.8	30.6	26.7	33.8	29.8	25.5	25.1	22.3	20.4	12.6
1995/96	15.3	28.6	25.5	31.9	32.3	33.0	35.9	30.8	17.6	9.2
1996/97	18.0	39.1	30.5	34.0	52.6	38.8	38.9	21.8	18.9	10.4
1997/98	16.8	27.8	22.8	32.3	27.6	21.4	22.6	19.6	18.9	12.4
1998/99	16.3	26.3	19.5	20.8	13.4	14.9	14.3	13.0	14.2	10.5
1999/00	17.6	26.5	21.6	25.6	24.0	15.9	13.1	11.2	10.8	8.5
2000/01	13.0	32.0	30.6	34.4	27.2	12.2	10.3	7.5	5.9	2.3
2001/02	9.0	35.7	29.6	34.1	27.1	11.0	9.7	6.5	6.5	3.8
2002/03	8.8	28.1	23.2	23.7	19.7	13.3	11.3	10.6	8.9	4.3
2003/04	10.7	25.2	22.1	28.0	26.9	18.5	15.9	16.6	13.4	5.1
2004/05	10.4	29.2	29.8	33.7	28.9	20.5	19.1	19.4	19.0	5.9
2005/06	10.8	30.3	27.1	30.9	26.4	19.3	19.9	17.8	15.4	6.8
2006/07	20.3	40.2	33.2	35.5	33.2	25.1	25.3	21.5	23.3	16.4
2007/08	14.8	27.2	22.6	27.3	20.6	18.7	24.0	25.5	25.6	16.5
2008/09	17.5	35.4	32.5	33.3	25.7	19.4	23.1	25.2	26.6	17.5

Table 3.10 Monthly Relative water supply (RWS)

Season	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1989/90	1.3	0.8	2.4	1.1	1.1	1.9	1.6	1.5	1.4	1.0
1990/91	1.6	1.3	1.0	1.4	1.9	1.3	1.0	0.8	1.0	1.7
1991/92	0.4	1.1	1.5	2.5	1.1	1.1	1.0	0.9	0.9	0.7
1992/93	0.8	1.6	2.4	1.0	1.4	1.3	1.4	1.3	1.3	0.9
1993/94	1.3	1.0	2.1	2.1	1.7	2.1	1.5	1.1	0.8	0.9
1994/95	1.3	1.8	2.7	1.7	1.7	1.4	1.4	1.5	1.4	1.6
1995/96	1.5	3.5	3.7	1.3	1.5	1.3	0.9	0.9	1.6	1.3
1996/97	1.2	1.6	3.7	1.7	1.0	1.1	1.0	1.6	1.7	1.5
1997/98	1.1	2.8	2.2	1.8	2.4	1.8	1.7	1.8	1.8	1.6
1998/99	0.9	2.2	4.0	1.7	3.1	2.2	2.5	2.4	2.1	1.7
1999/00	0.8	3.4	3.5	3.1	2.2	2.6	3.0	3.1	3.3	3.2
2000/01	1.6	1.7	1.6	2.0	2.7	3.3	3.3	3.6	4.1	7.6
2001/02	1.9	2.6	1.7	1.6	1.8	3.2	3.1	4.5	4.0	4.8
2002/03	1.2	1.9	2.6	2.3	2.6	3.0	2.3	2.5	2.9	2.3
2003/04	2.0	2.5	2.3	1.7	1.9	1.9	1.9	1.6	1.9	4.6
2004/05	1.5	1.5	2.1	1.5	1.8	2.1	1.9	1.6	1.5	3.2
2005/06	1.8	2.3	2.9	2.1	1.8	2.2	2.1	1.7	1.8	2.9
2006/07	0.9	1.6	2.9	1.6	1.8	1.7	1.6	1.6	1.5	1.7
2007/08	1.6	2.3	2.1	1.9	2.3	2.1	1.8	1.6	1.6	1.8
2008/09	1.5	1.8	2.6	2.2	2.5	2.1	2.0	1.7	1.5	1.6

Table 3.11 Monthly Relative water supply (RWS_e)

Season	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1989/90	0.9	0.6	1.7	0.8	0.8	1.3	1.1	1.1	1.0	0.7
1990/91	1.1	0.9	0.7	1.0	1.3	0.9	0.7	0.6	0.7	1.2
1991/92	0.3	0.7	1.0	1.8	0.8	0.8	0.7	0.6	0.6	0.5
1992/93	0.6	1.1	1.7	0.7	1.0	0.9	1.0	0.9	0.9	0.7
1993/94	0.9	0.7	1.4	1.5	1.2	1.4	1.0	0.8	0.6	0.6
1994/95	0.9	1.2	1.9	1.2	1.2	1.0	1.0	1.0	1.0	1.1
1995/96	1.0	2.4	2.6	0.9	1.1	0.9	0.6	0.7	1.1	0.9
1996/97	0.8	1.1	2.6	1.2	0.7	0.8	0.7	1.1	1.2	1.0
1997/98	0.8	1.9	1.6	1.3	1.7	1.2	1.2	1.2	1.2	1.1
1998/99	0.6	1.6	2.8	1.2	2.2	1.5	1.7	1.7	1.5	1.2
1999/00	0.6	2.4	2.5	2.2	1.5	1.8	2.1	2.1	2.3	2.3
2000/01	1.1	1.2	1.1	1.4	1.9	2.3	2.3	2.5	2.9	5.3
2001/02	1.3	1.8	1.2	1.1	1.3	2.3	2.2	3.1	2.8	3.4
2002/03	0.8	1.3	1.8	1.6	1.8	2.1	1.6	1.7	2.0	1.6
2003/04	1.4	1.8	1.6	1.2	1.3	1.4	1.3	1.1	1.3	3.2
2004/05	1.1	1.1	1.5	1.0	1.2	1.5	1.3	1.1	1.0	2.2
2005/06	1.3	1.6	2.1	1.4	1.2	1.5	1.4	1.2	1.2	2.1
2006/07	0.6	1.1	2.0	1.1	1.2	1.2	1.1	1.1	1.1	1.2
2007/08	1.1	1.6	1.5	1.3	1.6	1.5	1.3	1.1	1.1	1.3
2008/09	1.1	1.2	1.8	1.6	1.7	1.5	1.4	1.2	1.1	1.1

Table 3.12 Seasonal Relative irrigation supply

Season	TWS	IWR_n	IWR_g	RIS	RISe
70/71	6.06	6.17	8.81	0.98	0.69
71/72	6.29	5.92	8.46	1.06	0.74
72/73	6.13	6.28	8.97	0.98	0.68
73/74	6.93	6.51	9.30	1.07	0.75
74/75	6.94	7.00	10.00	0.99	0.69
75/76	6.18	7.49	10.70	0.83	0.58
76/77	6.74	7.29	10.41	0.93	0.65
77/78	7.08	7.16	10.23	0.99	0.69
78/79	5.77	6.99	9.99	0.83	0.58
79/80	6.15	6.68	9.54	0.92	0.64
80/81	5.99	6.29	8.99	0.95	0.67
81/82	6.00	5.75	8.21	1.04	0.73
82/83	5.95	4.97	7.11	1.20	0.84
83/84	6.57	5.86	8.38	1.12	0.78
84/85	5.70	4.56	6.52	1.25	0.87
85/86	5.96	5.54	7.92	1.08	0.75
86/87	5.32	5.16	7.37	1.03	0.72
87/88	5.90	5.26	7.52	1.12	0.78
88/89	5.55	5.47	7.82	1.01	0.71
89/90	5.81	6.55	9.36	0.89	0.62
90/91	7.10	8.26	11.80	0.86	0.60
91/92	6.49	8.73	12.48	0.74	0.52
92/93	5.88	6.64	9.48	0.89	0.62
93/94	6.33	6.39	9.13	0.99	0.69
94/95	6.25	5.19	7.41	1.21	0.84
95/96	6.33	6.37	9.10	0.99	0.70
96/97	7.20	7.66	10.95	0.94	0.66
97/98	7.02	5.36	7.66	1.31	0.92
98/99	5.66	3.48	4.97	1.63	1.14
99/00	7.61	3.73	5.33	2.04	1.43
00/01	6.95	3.98	5.69	1.75	1.22
01/02	6.88	3.87	5.53	1.78	1.25
02/03	5.87	3.20	4.57	1.83	1.28
03/04	5.97	3.98	5.69	1.50	1.05
04/05	7.16	5.51	7.87	1.30	0.91
05/06	7.12	4.66	6.65	1.53	1.07
06/07	7.61	6.36	9.08	1.20	0.84
07/08	7.09	5.22	7.46	1.36	0.95
08/09	8.40	6.20	8.86	1.36	0.95

Table 3.13 Monthly gross irrigation water requirement, million cubic meter

Season	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1989/90	4.8	25.9	14.6	31.9	38.0	23.4	23.3	21.3	19.5	4.8
1990/91	3.8	18.6	34.1	30.6	24.2	31.1	37.6	35.7	36.2	3.8
1991/92	12.9	27.9	28.0	21.5	38.1	32.6	35.2	34.1	32.5	12.9
1992/93	12.6	15.5	11.6	33.9	30.8	25.2	23.8	21.9	21.3	12.6
1993/94	9.6	21.8	14.6	22.0	26.0	21.1	22.0	27.0	33.0	9.6
1994/95	9.6	11.6	8.9	24.8	23.3	21.2	21.5	19.0	18.5	9.6
1995/96	9.7	4.8	5.6	30.8	32.0	33.1	35.9	30.8	17.6	9.7
1996/97	14.9	22.0	5.9	27.1	53.2	38.5	38.9	21.8	18.9	14.9
1997/98	13.3	6.6	14.3	27.9	20.1	21.2	22.6	19.6	18.9	13.3
1998/99	14.1	8.9	1.8	12.8	11.1	15.0	14.3	12.2	14.2	14.1
1999/00	14.9	5.7	7.6	12.6	22.6	15.8	13.1	11.2	10.8	14.9
2000/01	9.0	15.5	25.8	24.7	17.5	12.0	10.3	7.5	5.9	9.0
2001/02	3.7	5.8	23.2	30.2	26.8	10.6	9.7	6.5	6.5	3.7
2002/03	5.3	11.9	11.1	10.9	17.6	13.2	11.3	10.6	8.9	5.3
2003/04	6.4	5.4	4.8	20.0	25.3	18.5	15.9	16.6	13.4	6.4
2004/05	6.2	17.9	15.0	31.4	27.0	20.4	19.1	19.4	19.0	6.2
2005/06	6.8	10.0	8.6	22.2	26.5	19.2	19.9	17.8	15.4	6.8
2006/07	14.0	17.5	7.6	28.3	29.4	26.1	25.3	21.5	23.3	14.0
2007/08	7.7	2.1	11.8	21.1	19.6	18.6	24.0	25.5	25.6	7.7
2008/09	12.7	18.9	16.6	21.6	22.0	20.2	23.1	25.2	26.6	12.7

Table 3.14 Monthly Relative irrigation supply (RIS)

Season	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1989/90	1.9	0.9	1.8	0.8	1.1	1.8	1.6	1.5	1.4	1.9
1990/91	3.0	1.5	1.0	1.2	1.7	1.3	1.0	0.8	1.0	3.0
1991/92	0.6	1.2	1.0	2.0	1.1	1.2	1.0	0.9	0.9	0.6
1992/93	0.9	2.1	1.9	0.7	1.4	1.3	1.4	1.3	1.3	0.9
1993/94	1.8	1.5	1.3	1.8	1.7	2.1	1.5	1.1	0.8	1.8
1994/95	1.7	2.8	1.7	1.4	1.8	1.6	1.7	1.7	1.6	1.7
1995/96	1.8	6.6	3.4	1.3	1.4	1.3	0.9	0.9	1.6	1.8
1996/97	1.4	1.9	5.5	1.3	0.8	1.1	1.0	1.6	1.7	1.4
1997/98	1.3	4.9	2.1	1.6	2.2	1.8	1.7	1.8	1.8	1.3
1998/99	1.1	3.3	13.5	1.1	3.4	2.2	2.5	2.4	2.1	1.1
1999/00	0.9	7.2	4.5	3.3	2.2	2.6	3.0	3.1	3.3	0.9
2000/01	2.2	2.5	1.5	1.7	2.5	3.4	3.3	3.6	4.1	2.2
2001/02	4.6	7.0	1.5	1.5	1.8	3.3	3.1	4.5	4.0	4.6
2002/03	1.9	2.9	3.0	2.3	2.6	3.0	2.3	2.5	2.9	1.9
2003/04	2.9	6.3	1.8	1.6	1.9	1.9	1.9	1.6	1.9	2.9
2004/05	2.1	2.2	2.2	1.5	1.7	2.1	1.9	1.6	1.5	2.1
2005/06	2.7	3.9	3.3	1.9	1.8	2.2	2.1	1.7	1.8	2.7
2006/07	1.0	2.3	4.5	1.5	1.6	1.6	1.6	1.6	1.5	1.0
2007/08	2.1	8.8	1.9	1.7	2.3	2.1	1.8	1.6	1.6	2.1
2008/09	1.9	2.5	2.1	1.8	2.3	2.0	2.0	1.7	1.5	1.9

Table 3.15 Monthly Relative irrigation supply (RIS_e)

Season	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1989/90	1.3	0.6	1.2	0.5	0.8	1.2	1.1	1.1	1.0	0.7
1990/91	2.1	1.0	0.7	0.9	1.2	0.9	0.7	0.6	0.7	1.2
1991/92	0.4	0.8	0.7	1.4	0.8	0.8	0.7	0.6	0.6	0.5
1992/93	0.6	1.5	1.3	0.5	1.0	0.9	1.0	0.9	0.9	0.7
1993/94	1.2	1.0	0.9	1.3	1.2	1.5	1.0	0.8	0.6	0.6
1994/95	1.2	2.0	1.2	1.0	1.2	1.2	1.2	1.2	1.1	1.1
1995/96	1.2	4.6	2.4	0.9	1.0	0.9	0.6	0.7	1.1	0.9
1996/97	1.0	1.3	3.9	0.9	0.6	0.8	0.7	1.1	1.2	1.0
1997/98	0.9	3.4	1.4	1.1	1.5	1.2	1.2	1.2	1.2	1.1
1998/99	0.7	2.3	9.4	0.8	2.4	1.5	1.7	1.7	1.5	1.2
1999/00	0.7	5.0	3.1	2.3	1.5	1.8	2.1	2.1	2.3	2.3
2000/01	1.6	1.8	1.0	1.2	1.8	2.4	2.3	2.5	2.9	5.3
2001/02	3.2	4.9	1.0	1.0	1.2	2.3	2.2	3.1	2.8	3.4
2002/03	1.3	2.1	2.1	1.6	1.8	2.1	1.6	1.7	2.0	1.6
2003/04	2.0	4.4	1.3	1.1	1.3	1.4	1.3	1.1	1.3	3.2
2004/05	1.4	1.5	1.6	1.0	1.2	1.5	1.3	1.1	1.0	2.2
2005/06	1.9	2.7	2.3	1.3	1.2	1.5	1.4	1.2	1.2	2.1
2006/07	0.7	1.6	3.1	1.0	1.2	1.1	1.1	1.1	1.1	1.2
2007/08	1.5	6.1	1.3	1.2	1.6	1.5	1.3	1.1	1.1	1.3
2008/09	1.4	1.8	1.4	1.3	1.6	1.4	1.4	1.2	1.1	1.1

Table 3.16 Water delivery capacity (WDC) , Main canals design discharge = 31.5 m^3x10^6/day

Season	Peak IWR (m^3x10^6/day)	WDC
70/71	28.85	1.09
71/72	27.92	1.13
72/73	29.39	1.07
73/74	28.81	1.09
74/75	26.50	1.19
75/76	25.99	1.21
76/77	26.31	1.20
77/78	26.99	1.17
78/79	25.45	1.24
79/80	26.80	1.18
80/81	24.36	1.29
81/82	24.63	1.28
82/83	23.45	1.34
83/84	25.37	1.24
84/85	25.67	1.23
85/86	24.64	1.28
86/87	23.81	1.32
87/88	22.19	1.42
88/89	22.64	1.39
89/90	26.57	1.19
90/91	26.33	1.20
91/92	26.70	1.18
92/93	23.73	1.33
93/94	23.11	1.36
94/95	17.33	1.82
95/96	25.13	1.25
96/97	37.22	0.85
97/98	19.54	1.61
98/99	10.53	2.99
99/00	15.79	1.99
00/01	18.09	1.74
01/02	21.13	1.49
02/03	12.33	2.56
03/04	17.71	1.78
04/05	22.00	1.43
05/06	18.56	1.70
06/07	20.59	1.53
07/08	17.86	1.76
08/09	17.62	1.79

Table 3.17 Actual water diverted and irrigation water requirement, million m^3 per day, seasons 1999/00-2003/04

Season	1999/00		2000/01		2001/02		2002/03		2003/04	
	Q_a	Q_r	Q_a	Q_r	Q_a	Q_r	Q_a	Q_r	Q_a	Q_r
Jun I	6.18	6.29	6.29	8.72	8.72	6.50	6.50	4.72	4.72	8.54
Jun II	11.78	9.28	9.28	14.32	14.32	12.15	12.15	7.13	7.13	10.55
Jun III	13.62	16.72	16.72	19.70	19.70	17.01	17.01	11.22	11.22	19.42
Jul I	18.71	20.54	20.54	25.60	25.60	25.51	25.51	19.15	19.15	23.29
Jul II	22.39	23.26	23.26	27.77	27.77	30.91	30.91	25.27	25.27	25.94
Jul III	20.31	20.77	20.77	27.89	27.89	28.96	28.96	28.77	28.77	21.54
Aug I	20.06	18.54	18.54	26.80	26.80	26.79	26.79	22.41	22.41	10.85
Aug II	16.83	17.36	17.36	25.71	25.71	21.46	21.46	22.05	22.05	5.14
Aug III	15.80	17.14	17.14	26.50	26.50	24.03	24.03	24.58	24.58	3.62
Sep I	8.22	14.00	14.00	29.80	29.80	28.10	28.10	28.77	28.77	13.56
Sep II	7.56	20.19	20.19	29.99	29.99	32.00	32.00	29.16	29.16	22.59
Sep III	14.70	25.73	25.73	31.70	31.70	33.22	33.22	31.47	31.47	29.15
Oct I	25.52	30.55	30.55	32.96	32.96	33.74	33.74	31.99	31.99	32.84
Oct II	28.49	30.73	30.73	30.44	30.44	33.73	33.73	32.00	32.00	33.51
Oct III	25.37	30.76	30.76	31.11	31.11	32.90	32.90	32.00	32.00	32.67
Nov I	23.64	28.58	28.58	31.17	31.17	26.80	26.80	30.44	30.44	28.56
Nov II	22.23	27.34	27.34	27.18	27.18	23.72	23.72	26.98	26.98	24.11
Nov III	23.36	27.05	27.05	26.19	26.19	23.18	23.18	24.57	24.57	22.76
Dec I	26.85	24.13	24.13	25.28	25.28	22.10	22.10	21.61	21.61	22.40
Dec II	24.97	23.46	23.46	23.09	23.09	21.10	21.10	23.38	23.38	20.78
Dec III	23.49	22.56	22.56	21.68	21.68	20.38	20.38	20.43	20.43	21.00
Jan I	22.75	20.58	20.58	20.42	20.42	20.34	20.34	18.60	18.60	19.24
Jan II	19.16	19.32	19.32	18.15	18.15	20.18	20.18	17.81	17.81	17.86
Jan III	18.70	19.19	19.19	18.23	18.23	20.89	20.89	17.30	17.30	17.50
Feb I	22.34	16.82	16.82	18.73	18.73	20.02	20.02	16.85	16.85	17.16
Feb II	20.81	16.38	16.38	15.78	15.78	17.32	17.32	16.40	16.40	17.02
Feb III	19.66	16.41	16.41	16.05	16.05	16.96	16.96	16.40	16.40	17.17
Mar I	18.35	16.45	16.45	14.02	14.02	16.16	16.16	14.84	14.84	18.09
Mar II	14.91	14.12	14.12	13.15	13.15	14.12	14.12	11.04	11.04	16.95
Mar III	6.18	7.14	7.14	10.00	10.00	9.38	9.38	5.96	5.96	13.94
Mean	18.76	20.05	20.05	22.94	22.94	22.66	22.66	21.11	21.11	19.59
SD	6.13	6.48	6.48	6.92	6.92	7.24	7.24	7.98	7.98	7.58

Source: Actual water diverted (MOIWR, 2008)

Irrigation water requirement (calculated by CROPWAT 8.0 software)

Table 3.18 Actual water diverted and irrigation water requirement, million m^3 per day, seasons 2004/05-2008/09

Season	2004/05		2005/06		2006/07		2007/08		2008/09	
	Q_a	Q_r	Q_a	Q_r	Q_a	Q_r	Q_a	Q_r	Q_a	Q_r
Jun I	8.54	5.19	5.19	8.55	8.55	7.7	7.7	8.66	8.66	10.4
Jun II	10.55	9	9	11.8	11.8	8.9	8.9	9.41	9.41	16.3
Jun III	19.42	13.95	13.95	16.7	16.7	12.49	12.49	16.37	16.37	24.93
Jul I	23.29	21.08	21.08	26.69	26.69	23.42	23.42	20.81	20.81	30.33
Jul II	25.94	29.51	29.51	28.84	28.84	30.49	30.49	10.15	10.15	34.3
Jul III	21.54	30.27	30.27	25.87	25.87	31.36	31.36	7.11	7.11	35.09
Aug I	10.85	28.04	28.04	19.8	19.8	26.66	26.66	12.12	12.12	30.15
Aug II	5.14	20.57	20.57	16.24	16.24	21.85	21.85	13.73	13.73	23.65
Aug III	3.62	22.25	22.25	25.4	25.4	23	23	21.4	21.4	18.09
Sep I	13.56	30.31	30.31	30.51	30.51	25.14	25.14	22.73	22.73	25.05
Sep II	22.59	31.69	31.69	29.02	29.02	27.17	27.17	24.7	24.7	25.05
Sep III	29.15	33.03	33.03	29.32	29.32	31.15	31.15	27.27	27.27	30.55
Oct I	32.84	33.98	33.98	31.98	31.98	33.12	33.12	30.6	30.6	36
Oct II	33.51	33.1	33.1	33.04	33.04	34.99	34.99	31.85	31.85	36
Oct III	32.67	33	33	33.2	33.2	33.75	33.75	31.27	31.27	33.68
Nov I	28.56	32.9	32.9	31.57	31.57	29.65	29.65	27.43	27.43	27.98
Nov II	24.11	30.22	30.22	29.18	29.18	28.47	28.47	26.63	26.63	28.75
Nov III	22.76	28.66	28.66	27.41	27.41	28.73	28.73	28.35	28.35	31.6
Dec I	22.4	28	28	27.15	27.15	29.93	29.93	30.53	30.53	33
Dec II	20.78	25.12	25.12	25.4	25.4	27.86	27.86	31.5	31.5	33
Dec III	21	24.06	24.06	23.66	23.66	26.14	26.14	30.86	30.86	31.77
Jan I	19.24	23.22	23.22	22.35	22.35	25.1	25.1	30.35	30.35	30
Jan II	17.86	21.17	21.17	21.75	21.75	25.4	25.4	28.85	28.85	29.85
Jan III	17.5	19.93	19.93	19.44	19.44	23.98	23.98	27.5	27.5	29.32
Feb I	17.16	20.2	20.2	18.8	18.8	24.76	24.76	26.6	26.6	28.1
Feb II	17.02	20.35	20.35	19.71	19.71	25.88	25.88	27.45	27.45	29
Feb III	17.17	19.04	19.04	18.7	18.7	25.06	25.06	28	28	29
Mar I	18.09	17	17	17.75	17.75	24.75	24.75	27.5	27.5	27.65
Mar II	16.95	13.52	13.52	15.35	15.35	23.08	23.08	24.25	24.25	18.9
Mar III	13.94	9.19	9.19	5.62	5.62	10.36	10.36	11.86	11.86	11
Mean	19.6	23.58	23.6	23.03	23.0	25.01	25.0	23.19	23.2	27.62
SD	7.58	7.97	7.97	7.23	7.23	6.93	6.93	7.99	7.99	6.73

Source: Actual water diverted (MOIWR, 2008)

Irrigation water requirement (calculated by CROPWAT 8.0 software)

Table 3.19 Water delivery performance (WDP)

	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09
Jun I	0.98	0.72	0.74	0.73	0.55	0.61	0.61	0.90	0.89	0.83
Jun II	0.79	0.65	0.85	0.59	0.68	0.85	0.76	0.75	0.95	0.58
Jun III	0.81	0.85	0.86	0.66	0.58	0.72	0.84	0.75	0.76	0.66
Jul I	0.91	0.80	1.00	0.75	0.82	0.90	0.79	0.88	0.89	0.69
Jul II	0.96	0.84	0.90	0.82	0.97	0.88	0.98	0.95	0.33	0.30
Jul III	0.98	0.74	0.96	0.99	0.75	0.71	0.85	0.82	0.23	0.20
Aug I	0.92	0.69	1.00	0.84	0.48	0.39	0.71	0.74	0.45	0.40
Aug II	0.97	0.68	0.83	0.97	0.23	0.25	0.79	0.74	0.63	0.58
Aug III	0.92	0.65	0.91	0.98	0.15	0.16	0.88	0.91	0.93	0.85
Sep I	0.59	0.47	0.94	0.98	0.47	0.45	0.99	0.82	0.90	0.91
Sep II	0.37	0.67	0.94	0.91	0.77	0.71	0.92	0.94	0.91	0.99
Sep III	0.57	0.81	0.95	0.95	0.93	0.88	0.89	0.94	0.88	0.89
Oct I	0.84	0.93	0.98	0.95	0.97	0.97	0.94	0.97	0.92	0.85
Oct II	0.93	0.99	0.90	0.95	0.95	0.99	1.00	0.94	0.91	0.88
Oct III	0.82	0.99	0.95	0.97	0.98	0.99	0.99	0.98	0.93	0.93
Nov I	0.83	0.92	0.86	0.88	0.94	0.87	0.96	0.94	0.92	0.98
Nov II	0.81	0.99	0.87	0.88	0.89	0.80	0.97	0.98	0.94	0.93
Nov III	0.86	0.97	0.89	0.94	0.93	0.79	0.96	0.95	0.99	0.90
Dec I	0.90	0.95	0.87	0.98	0.96	0.80	0.97	0.91	0.98	0.92
Dec II	0.94	0.98	0.91	0.90	0.89	0.83	0.99	0.91	0.88	0.95
Dec III	0.96	0.96	0.94	1.00	0.97	0.87	0.98	0.91	0.85	0.97
Jan I	0.90	0.99	1.00	0.91	0.97	0.83	0.96	0.89	0.83	0.99
Jan II	0.99	0.94	0.90	0.88	1.00	0.84	0.97	0.86	0.88	0.97
Jan III	0.97	0.95	0.87	0.83	0.99	0.88	0.98	0.81	0.87	0.94
Feb I	0.75	0.90	0.94	0.84	0.98	0.85	0.93	0.76	0.93	0.95
Feb II	0.79	0.96	0.91	0.95	0.96	0.84	0.97	0.76	0.94	0.95
Feb III	0.83	0.98	0.95	0.97	0.96	0.90	0.98	0.75	0.90	0.97
Mar I	0.90	0.85	0.87	0.92	0.82	0.94	0.96	0.72	0.90	0.99
Mar II	0.95	0.93	0.93	0.78	0.65	0.80	0.88	0.66	0.95	0.78
Mar III	0.87	0.71	0.94	0.64	0.43	0.66	0.61	0.54	0.87	0.93
WDP	0.85	0.85	0.91	0.88	0.79	0.77	0.90	0.85	0.84	0.82

Table 3.20 The average of $(Q_r-Q_a)^2$, 1999/00-2003/05

	99/00	00/01	01/02	02/03	03/04
	$(Q_r-Q_a)^2$	$(Q_r-Q_a)^2$	$(Q_r-Q_a)^2$	$(Q_r-Q_a)^2$	$(Q_r-Q_a)^2$
Jun I	0.01	5.93	4.96	3.15	14.59
Jun II	6.25	25.41	4.69	25.27	11.72
Jun III	9.59	8.87	7.21	33.55	67.16
Jul I	3.36	25.55	0.01	40.42	17.13
Jul II	0.77	20.33	9.83	31.71	0.44
Jul III	0.21	50.63	1.14	0.04	52.29
Aug I	2.32	68.22	0.00	19.18	133.68
Aug II	0.28	69.64	18.05	0.35	285.98
Aug III	1.81	87.62	6.14	0.30	439.30
Sep I	33.41	249.60	2.89	0.45	231.34
Sep II	159.37	96.05	4.05	8.06	43.18
Sep III	121.51	35.65	2.31	3.05	5.40
Oct I	25.34	5.78	0.62	3.07	0.72
Oct II	5.04	0.08	10.85	3.01	2.28
Oct III	29.08	0.12	3.20	0.82	0.45
Nov I	24.34	6.73	19.08	13.25	3.55
Nov II	26.07	0.02	11.97	10.63	8.24
Nov III	13.62	0.74	9.06	1.93	3.28
Dec I	7.40	1.30	10.06	0.24	0.62
Dec II	2.29	0.13	3.96	5.19	6.75
Dec III	0.87	0.78	1.69	0.00	0.32
Jan I	4.69	0.03	0.01	3.04	0.41
Jan II	0.03	1.37	4.11	5.60	0.00
Jan III	0.24	0.92	7.08	12.87	0.04
Feb I	30.43	3.65	1.68	10.11	0.10
Feb II	19.70	0.35	2.36	0.85	0.38
Feb III	10.53	0.13	0.83	0.31	0.59
Mar I	3.61	5.90	4.59	1.76	10.59
Mar II	0.63	0.94	0.94	9.46	34.88
Mar III	0.92	8.19	0.38	11.73	63.69
$S(Q_r-Q_a)^2$	543.72	780.66	153.75	259.40	1439.10
$1/nS(Q_r-Q_a)^2$	18.12	26.02	5.13	8.65	47.97

Table 3.21 The average of $(Q_r-Q_a)^2$, 2004/05-2008/09

	04/05	05/06	06/07	07/08	08/09
	$(Q_r-Q_a)^2$	$(Q_r-Q_a)^2$	$(Q_r-Q_a)^2$	$(Q_r-Q_a)^2$	$(Q_r-Q_a)^2$
Jun I	11.23	11.29	0.72	0.92	3.03
Jun II	2.40	7.83	8.41	0.26	47.47
Jun III	29.90	7.58	17.77	15.09	73.19
Jul I	4.91	31.53	10.69	6.81	90.54
Jul II	12.74	0.45	2.74	413.92	583.22
Jul III	76.32	19.40	30.20	588.28	782.98
Aug I	295.67	67.98	47.06	211.41	325.08
Aug II	237.93	18.71	31.53	66.02	98.41
Aug III	346.98	9.98	5.76	2.56	10.98
Sep I	280.40	0.04	28.78	5.83	5.41
Sep II	82.81	7.13	3.42	6.10	0.12
Sep III	15.05	13.76	3.35	15.03	10.71
Oct I	1.30	4.02	1.31	6.35	29.16
Oct II	0.17	0.00	3.80	9.86	17.22
Oct III	0.11	0.04	0.30	6.14	5.80
Nov I	18.84	1.76	3.69	4.95	0.30
Nov II	37.33	1.08	0.50	3.40	4.52
Nov III	34.75	1.55	1.76	0.15	10.56
Dec I	31.36	0.72	7.76	0.35	6.13
Dec II	18.84	0.08	6.05	13.25	2.25
Dec III	9.39	0.16	6.11	22.35	0.83
Jan I	15.84	0.77	7.59	27.56	0.12
Jan II	10.96	0.34	13.32	11.90	1.00
Jan III	5.89	0.24	20.66	12.38	3.31
Feb I	9.24	1.96	35.52	3.39	2.25
Feb II	11.12	0.42	38.13	2.46	2.40
Feb III	3.50	0.11	40.48	8.63	1.00
Mar I	1.19	0.56	49.00	7.56	0.02
Mar II	11.76	3.33	59.77	1.38	28.62
Mar III	22.56	12.76	22.52	2.25	0.75
$S(Q_r-Q_a)^2$	1640.49	225.58	508.70	1476.54	2147.38
$1/nS(Q_r-Q_a)^2$	54.68	7.52	16.96	49.22	71.58

Table 3.22 Performance parameter errors of the system

Season	$1/nS(Q_r-Q_a)^2$	$(MQ_r-MQ_a)^2$	$(SQ_r-SQ_a)^2$	$2(1-r)*S_{Qr}*S_{Qa}$	Eas	Ees	Ems
99/00	18.12	1.64	0.12	16.92	0.09	0.01	0.93
00/01	26.02	8.36	0.19	18.10	0.32	0.01	0.70
01/02	5.13	0.08	0.10	5.11	0.02	0.02	1.00
02/03	8.65	2.39	0.55	5.89	0.28	0.06	0.68
03/04	47.97	2.31	0.16	47.09	0.05	0.00	0.98
04/05	54.68	15.95	0.15	39.88	0.29	0.00	0.73
05/06	7.52	0.31	0.55	6.91	0.04	0.07	0.92
06/07	16.96	3.95	0.09	13.41	0.23	0.01	0.79
07/08	49.22	3.30	1.14	46.39	0.07	0.02	0.94
08/09	71.58	19.55	1.59	52.29	0.27	0.02	0.73
Average	30.58	5.78	0.46	25.20	0.17	0.02	0.84

Table 3.23 One-Sample Test: the mean of the performance errors of the system

	Test Value = 0					
					95% Confidence	
	t	df	Sig. (2-tailed)	Mean	Lower	Upper
Eas	4.27	9.00	.00	.17	.08	.25
Ees	2.83	9.00	.02	.02	.00	.04
Ems	21.10	9.00	.00	.84	.75	.93

Table 3.24 Crop intensity (CI)

Season	Cotton	Wheat	G/NT	Sorg.	Veget.	Rice	Fodder	Maize	Sunflower	CI	PI
70/71	28%	7%	7%	14%	2%	0%	6%	0%	0%	64%	75%
71/72	28%	6%	6%	14%	2%	0%	5%	0%	0%	61%	75%
72/73	28%	7%	8%	14%	2%	0%	4%	0%	0%	64%	75%
73/74	29%	12%	10%	14%	2%	0%	2%	0%	0%	69%	75%
74/75	29%	20%	12%	7%	1%	0%	1%	0%	0%	72%	75%
75/76	19%	27%	20%	16%	1%	1%	0%	0%	0%	84%	86%
76/77	24%	24%	12%	17%	1%	1%	0%	0%	0%	79%	86%
77/78	25%	22%	13%	17%	1%	1%	0%	0%	0%	78%	86%
78/79	24%	23%	10%	16%	1%	0%	0%	0%	0%	75%	86%
79/80	26%	17%	11%	16%	2%	0%	0%	0%	0%	72%	86%
80/81	24%	17%	8%	14%	2%	0%	0%	0%	0%	66%	86%
81/82	21%	13%	13%	16%	2%	0%	0%	0%	0%	64%	86%
82/83	23%	7%	7%	15%	1%	0%	0%	0%	0%	54%	86%
83/84	24%	13%	7%	20%	2%	0%	0%	0%	0%	64%	86%
84/85	22%		10%	20%	1%	0%	0%	0%	0%	53%	86%
85/86	19%	12%	5%	28%	1%	0%	0%	0%	0%	64%	82%
86/87	20%	9%	7%	21%	2%	0%	0%	0%	0%	59%	79%
87/88	18%	12%	8%	19%	2%	0%	0%	0%	0%	59%	75%
88/89	19%	13%	5%	20%	2%	0%	0%	0%	0%	60%	75%
89/90	17%	19%	4%	21%	3%	0%	0%	0%	0%	63%	75%
90/91	12%	29%	2%	24%	3%	0%	0%	0%	0%	70%	75%
91/92	10%	25%	2%	35%	2%	0%	1%	1%	0%	76%	75%
92/93	8%	24%	8%	30%	2%	0%	0%	0%	0%	73%	75%
93/94	7%	25%	9%	26%	2%	0%	0%	0%	0%	69%	75%
94/95	12%	19%	9%	22%	3%	0%	0%	0%	2%	67%	75%
95/96	14%	19%	11%	19%	3%	0%	0%	0%	0%	65%	75%
96/97	16%	19%	12%	19%	2%	0%	0%	0%	0%	67%	75%
97/98	12%	14%	11%	16%	2%	0%	0%	0%	0%	55%	75%
98/99	7%	6%	7%	14%	1%	0%	0%	0%	0%	35%	75%
99/00	12%	3%	7%	13%	1%	0%	0%	0%	0%	37%	75%
00/01	10%	3%	8%	24%	1%	0%	0%	0%	0%	47%	75%
01/02	9%	4%	2%	32%	2%	0%	0%	0%	0%	49%	75%
02/03	12%	5%	4%	21%	3%	0%	0%	0%	0%	45%	75%
03/04	13%	6%	6%	20%	3%	0%	0%	0%	0%	49%	75%
04/05	15%	7%	6%	19%	2%	0%	0%	0%	0%	50%	75%
05/06	15%	7%	6%	22%	2%	0%	0%	0%	0%	52%	75%
06/07	12%	14%	8%	28%	2%	0%	0%	0%	0%	64%	75%
07/08	5%	20%	8%	23%	5%	0%	0%	0%	0%	60%	75%
08/09	4%	24%	11%	24%	5%	0%	0%	0%	0%	69%	75%

Source: Calculated from the cropped areas and total command area data collected from SGB

CI = actual crop intensity

P.I = possible crop intensity

Table 3.25 Cropped area of main crops in GS (ha)

Season	Cotton	Wheat	Groundnuts	Sorghum	Vegetables	Total Area
70/71	247,116	59,326	62,355	123,552	18,607	510,956
71/72	247,458	55,157	49,150	123,406	17,871	493,041
72/73	247,543	61,158	74,670	123,722	18,267	525,359
73/74	253,856	106,756	90,840	126,309	14,335	592,096
74/75	253,413	179,612	109,594	64,846	12,193	619,657
75/76	166,168	238,350	177,914	143,370	10,029	735,830
76/77	209,762	211,933	105,343	147,760	12,709	687,508
77/78	217,815	195,587	110,788	148,452	9,975	682,618
78/79	209,170	207,243	91,216	144,508	11,316	663,454
79/80	227,174	152,251	95,989	137,463	13,956	626,833
80/81	210,505	154,030	71,786	126,349	18,113	580,782
81/82	182,831	112,502	110,983	144,438	15,041	565,795
82/83	203,412	65,326	62,236	134,795	12,085	477,855
83/84	209,046	111,646	57,377	172,532	14,989	565,590
84/85	195,213	Not Grown	89,401	176,429	10,738	471,780
85/86	168,222	101,849	43,065	243,076	12,621	568,833
86/87	174,331	75,545	63,441	188,162	15,177	516,656
87/88	160,876	105,972	67,016	165,672	17,157	516,692
88/89	169,892	115,184	46,563	179,260	19,231	530,129
89/90	150,354	164,765	33,424	185,200	23,473	557,216
90/91	105,440	257,588	16,741	212,762	25,678	618,210
91/92	90,513	223,781	14,890	304,629	18,981	652,794
92/93	73,375	215,894	68,636	261,129	20,683	639,717
93/94	62,833	219,569	78,601	229,878	18,061	608,943
94/95	106,322	164,930	80,259	196,357	22,258	570,126
95/96	126,523	164,126	97,018	165,622	23,101	576,390
96/97	139,040	163,716	103,425	170,940	16,582	593,703
97/98	103,413	126,809	93,678	142,547	15,140	481,586
98/99	64,680	51,667	61,161	119,774	9,934	307,216
99/00	108,996	24,623	65,023	114,979	9,695	323,317
00/01	87,230	29,572	71,780	213,780	9,956	412,317
01/02	79,899	33,944	18,900	284,991	16,800	434,533
02/03	60,858	46,568	35,879	187,500	13,020	343,826
03/04	118,412	55,643	57,000	123,274	13,944	368,274
04/05	132,624	62,776	55,561	171,818	13,104	435,884
05/06	127,979	65,783	54,991	194,561	13,444	456,757
06/07	104,958	123,511	67,785	249,336	17,703	563,294
07/08	37,635	179,315	63,392	199,088	19,698	499,128
08/09	35,102	215,418	97,285	215,410	42,000	605,216

Table 3.26 Production of main crops in GS (ton)

Season	Cotton	Wheat	Groundnuts	Sorghum	Total Production
70/71	456,023	55,088	60,871	150,028	722,009
71/72	420,425	66,976	58,512	129,283	675,195
72/73	343,872	97,561	222,231	294,576	958,241
73/74	437,346	203,344	270,356	225,552	1,136,598
74/75	396,893	166,783	326,171	77,198	967,044
75/76	153,887	221,325	324,904	212,665	912,782
76/77	261,394	292,670	300,980	230,436	1,085,479
77/78	318,150	219,337	283,566	125,124	946,176
78/79	232,881	123,852	92,737	300,026	749,496
79/80	201,954	170,738	114,273	189,831	676,795
80/81	165,419	94,251	39,311	147,408	446,389
81/82	241,093	87,591	97,771	137,560	564,015
82/83	323,361	93,323	60,755	167,852	645,290
83/84	350,823	103,140	91,529	216,076	761,568
84/85	347,082	Not grown	108,558	147,024	602,664
85/86	202,928	97,484	55,882	318,314	674,608
86/87	292,860	79,862	91,083	179,202	643,008
87/88	250,319	119,597	96,375	141,215	607,506
88/89	300,790	154,127	66,518	215,112	736,547
89/90	211,934	256,955	42,973	216,067	727,929
90/91	132,829	269,854	29,018	267,979	699,682
91/92	173,317	499,779	28,362	477,977	1,179,434
92/93	103,677	269,868	116,027	480,602	970,174
93/94	83,220	273,938	153,460	437,863	948,481
94/95	140,818	230,116	170,073	398,791	939,798
95/96	178,343	256,740	173,246	258,292	866,622
96/97	181,311	249,473	194,537	478,225	1,103,545
97/98	157,739	211,348	231,964	351,277	952,327
98/99	97,337	38,135	72,811	225,289	433,572
99/00	95,374	29,314	100,630	182,050	407,368
00/01	132,757	56,328	112,797	482,023	783,905
01/02	142,819	64,816	32,850	662,265	902,750
02/03	104,640	94,245	68,342	437,500	704,727
03/04	141,511	108,637	109,928	243,026	603,103
04/05	194,168	109,709	121,706	431,590	857,173
05/06	178,216	101,493	107,363	415,526	802,598
06/07	114,354	291,720	145,255	605,531	1,156,860
07/08	46,770	277,512	123,766	436,097	884,144
08/09	36,810	276,967	173,724	317,987	805,487

Table 3.27 Land productivity (ton/ha)

Season	Cotton	Wheat	Groundnuts	Sorghum
70/71	1.8	0.9	1.0	1.2
71/72	1.7	1.2	1.2	1.0
72/73	1.4	1.6	3.0	2.4
73/74	1.7	1.9	3.0	1.8
74/75	1.6	0.9	3.0	1.2
75/76	0.9	0.9	1.8	1.5
76/77	1.2	1.4	2.9	1.6
77/78	1.5	1.1	2.6	0.8
78/79	1.1	0.6	1.0	2.1
79/80	0.9	1.1	1.2	1.4
80/81	0.8	0.6	0.5	1.2
81/82	1.3	0.8	0.9	1.0
82/83	1.6	1.4	1.0	1.2
83/84	1.7	0.9	1.6	1.3
84/85	1.8	Not grown	1.2	0.8
85/86	1.2	1.0	1.3	1.3
86/87	1.7	1.1	1.4	1.0
87/88	1.6	1.1	1.4	0.9
88/89	1.8	1.3	1.4	1.2
89/90	1.4	1.6	1.3	1.2
90/91	1.3	1.0	1.7	1.3
91/92	1.9	2.2	1.9	1.6
92/93	1.4	1.3	1.7	1.8
93/94	1.3	1.2	2.0	1.9
94/95	1.3	1.4	2.1	2.0
95/96	1.4	1.6	1.8	1.6
96/97	1.3	1.5	1.9	2.8
97/98	1.5	1.7	2.5	2.5
98/99	1.5	0.7	1.2	1.9
99/00	0.9	1.2	1.5	1.6
00/01	1.5	1.9	1.6	2.3
01/02	1.8	1.9	1.7	2.3
02/03	1.7	2.0	1.9	2.3
03/04	1.2	2.0	1.9	2.0
04/05	1.5	1.7	2.2	2.5
05/06	1.4	1.5	2.0	2.1
06/07	1.1	2.4	2.1	2.4
07/08	1.2	1.5	2.0	2.2
08/09	1.0	1.3	1.8	1.5

Table 3.28 Crop water requirements of Major crops, billion m^3

Season	Cotton	Wheat	Groundnuts	Sorghum
70/71	2.91	0.57	0.55	1.03
71/72	2.91	0.53	0.43	1.03
72/73	2.92	0.59	0.66	1.03
73/74	2.99	1.03	0.80	1.05
74/75	2.98	1.74	0.97	0.54
75/76	1.96	2.31	1.57	1.19
76/77	2.47	2.05	0.93	1.23
77/78	2.57	1.89	0.98	1.24
78/79	2.46	2.01	0.80	1.20
79/80	2.68	1.47	0.85	1.14
80/81	2.48	1.49	0.63	1.05
81/82	2.15	1.09	0.98	1.20
82/83	2.40	0.63	0.55	1.12
83/84	2.46	1.08	0.51	1.44
84/85	2.30	Not grown	0.79	1.47
85/86	1.98	0.98	0.38	2.02
86/87	2.05	0.73	0.56	1.57
87/88	1.89	1.02	0.59	1.38
88/89	2.00	1.11	0.41	1.49
89/90	1.73	1.40	0.32	1.68
90/91	1.43	2.39	0.16	1.98
91/92	1.17	1.99	0.14	2.72
92/93	0.75	1.54	0.56	1.98
93/94	0.71	1.93	0.67	1.84
94/95	1.19	1.38	0.64	1.44
95/96	1.69	1.47	0.74	1.16
96/97	2.08	1.33	0.96	1.44
97/98	1.13	1.07	0.73	1.03
98/99	0.65	0.43	0.41	0.76
99/00	1.06	0.19	0.48	0.78
00/01	0.99	0.22	0.63	1.76
01/02	0.84	0.26	0.15	2.19
02/03	1.01	0.32	0.27	1.32
03/04	1.40	0.45	0.44	1.22
04/05	1.72	0.58	0.50	1.45
05/06	1.58	0.64	0.44	1.47
06/07	1.20	1.01	0.52	1.75
07/08	0.48	1.52	0.50	1.29
08/09	0.37	1.79	0.80	1.65

Table 3.29 Water productivity of the Major crops, kg/m^3

Season	Cotton	Wheat	Groundnuts	Sorghum
70/71	0.16	0.10	0.11	0.15
71/72	0.14	0.13	0.13	0.13
72/73	0.12	0.16	0.34	0.29
73/74	0.15	0.20	0.34	0.21
74/75	0.13	0.10	0.34	0.14
75/76	0.08	0.10	0.21	0.18
76/77	0.11	0.14	0.32	0.19
77/78	0.12	0.12	0.29	0.10
78/79	0.09	0.06	0.12	0.25
79/80	0.08	0.12	0.13	0.17
80/81	0.07	0.06	0.06	0.14
81/82	0.11	0.08	0.10	0.11
82/83	0.13	0.15	0.11	0.15
83/84	0.14	0.10	0.18	0.15
84/85	0.15	Not grown	0.14	0.10
85/86	0.10	0.10	0.15	0.16
86/87	0.14	0.11	0.16	0.11
87/88	0.13	0.12	0.16	0.10
88/89	0.15	0.14	0.16	0.14
89/90	0.12	0.18	0.13	0.13
90/91	0.09	0.11	0.18	0.14
91/92	0.15	0.25	0.20	0.18
92/93	0.14	0.18	0.21	0.24
93/94	0.12	0.14	0.23	0.24
94/95	0.12	0.17	0.27	0.28
95/96	0.11	0.17	0.23	0.22
96/97	0.09	0.19	0.20	0.33
97/98	0.14	0.20	0.32	0.34
98/99	0.15	0.09	0.18	0.30
99/00	0.09	0.15	0.21	0.23
00/01	0.13	0.25	0.18	0.27
01/02	0.17	0.25	0.21	0.30
02/03	0.10	0.29	0.25	0.33
03/04	0.10	0.24	0.25	0.20
04/05	0.11	0.19	0.25	0.30
05/06	0.11	0.16	0.24	0.28
06/07	0.10	0.29	0.28	0.35
07/08	0.10	0.18	0.25	0.34
08/09	0.10	0.16	0.22	0.19

Table 3.30 Relative water cost (RWC)

Season	Water Charge SD/ha	Production SD/ha	RWC
91/92	290.2	4,635.0714	0.06
92/93	531.0	9,617.9048	0.06
93/94	976.2	17,954.7857	0.05
94/95	1607.1	40,818.1667	0.04
95/96	6047.6	87,686.1905	0.07
96/97	12962.4	182,488.9762	0.07
97/98	16107.4	246,019.9524	0.07
98/99	17638.1	250,810.7143	0.07
99/00	17638.1	249,315.4762	0.07
00/01	18281.0	300,811.9048	0.06
01/02	17795.2	308,804.0476	0.06
02/03	10776.2	336,418.3333	0.03
03/04	16781.0	336,037.3810	0.05
04/05	16781.0	362,810.4762	0.05
05/06	16435.7	363,271.6667	0.05

Table 3.31 Total cost of production for Major crops, SDG/ha

Season	Cotton	Wheat	Groundnuts	Sorghum
70/71	0.10	0.02	0.03	0.03
71/72	0.11	0.03	0.04	0.03
72/73	0.11	0.03	0.03	0.03
73/74	0.12	0.03	0.03	0.02
74/75	0.14	0.04	0.04	0.03
75/76	0.19	0.04	0.05	0.03
76/77	0.20	0.06	0.05	0.03
77/78	0.22	0.07	0.06	0.03
78/79	0.25	0.05	0.06	0.04
79/80	0.30	0.15	0.09	0.05
80/81	0.26	0.10	0.11	0.06
81/82	0.56	0.22	0.18	0.11
82/83	0.70	0.30	0.22	0.13
83/84	1.01	0.34	0.32	0.23
84/85	1.06	0.00	0.32	0.24
85/86	1.85	0.65	0.48	0.38
86/87	1.99	0.66	0.63	0.38
87/88	2.47	0.76	0.90	0.50
88/89	3.78	1.33	1.15	0.88
89/90	4.67	2.29	1.98	1.63
90/91	7.90	5.02	5.53	3.80
91/92	16.32	11.94	11.87	6.22
92/93	44.18	20.74	17.21	14.05
93/94	72.82	44.28	35.75	26.69
94/95	166.67	82.30	85.85	73.36
95/96	434.06	206.08	140.40	96.32
96/97	710.07	455.80	354.80	304.21
97/98	1123.47	574.35	463.97	298.42
98/99	1121.21	583.22	455.28	348.40
99/00	949.49	641.76	503.83	398.07
00/01	1234.69	725.50	539.14	508.79
01/02	1179.32	775.65	581.55	551.52
02/03	1364.61	760.45	656.40	582.71
03/04	1413.71	784.73	619.98	541.95
04/05	1386.86	869.75	709.00	662.49
05/06	1463.48	877.57	659.50	632.17
06/07	1464.53	873.42	711.24	668.40

Source: Sudan Gezira Board

Table 3.32 Net return from Major crops, (SDG/ha)

Season	Cotton	Wheat	Groundnuts	Sorghum
70/71	0.10	0.01	-0.01	0.00
71/72	0.08	0.02	0.00	-0.01
72/73	0.11	0.02	0.13	0.04
73/74	0.09	0.05	0.13	0.14
74/75	0.06	0.02	0.17	0.03
75/76	0.23	0.02	0.07	0.05
76/77	0.11	0.04	0.07	0.05
77/78	0.19	0.05	0.15	0.04
78/79	0.14	0.00	0.06	0.03
79/80	0.01	0.03	0.12	0.08
80/81	0.11	-0.01	0.22	0.06
81/82	0.36	-0.06	0.00	0.06
82/83	0.26	0.17	0.16	0.13
83/84	0.29	0.02	0.51	0.26
84/85	0.61	0.00	0.33	0.85
85/86	0.00	0.07	0.99	0.24
86/87	0.89	0.32	0.79	0.01
87/88	0.80	0.48	0.69	0.61
88/89	0.31	1.88	0.31	0.36
89/90	1.78	2.15	3.05	1.76
90/91	-0.68	2.05	13.43	9.72
91/92	7.49	7.53	18.80	5.55
92/93	2.63	-4.46	11.16	2.24
93/94	39.24	13.29	40.44	28.20
94/95	135.79	24.84	100.80	40.09
95/96	369.80	196.73	83.33	91.89
96/97	387.65	158.86	155.49	336.26
97/98	91.67	66.12	175.32	241.37
98/99	27.19	-232.36	117.92	108.87
99/00	-130.41	72.52	83.79	112.64
00/01	454.49	322.12	137.05	416.34
01/02	1024.28	81.50	132.14	201.05
02/03	25.24	20.05	50.25	29.37
03/04	29.60	36.10	71.49	28.08
04/05	55.48	28.55	41.00	126.09
05/06	318.57	48.14	507.81	614.76
06/07	135.22	898.00	381.60	319.69

Source: Sudan Gezira Board

Table 3.33 Present worth of cost of production for major crops, SDG/ha

Season	Cotton	Wheat	Groundnuts	Sorghum	Total
70/71	4.48	1.08	1.51	1.19	8.25
71/72	4.40	1.18	1.47	1.18	8.22
72/73	3.99	1.07	1.16	0.98	7.20
73/74	3.95	1.13	1.13	0.73	6.95
74/75	4.31	1.33	1.33	0.96	7.92
75/76	5.43	1.00	1.34	0.80	8.57
76/77	5.17	1.64	1.34	0.73	8.88
77/78	5.10	1.60	1.33	0.72	8.75
78/79	5.31	1.11	1.31	0.75	8.48
79/80	5.84	2.97	1.74	0.87	11.41
80/81	4.48	1.70	1.95	1.00	9.12
81/82	8.83	3.53	2.79	1.70	16.85
82/83	10.10	4.27	3.11	1.91	19.38
83/84	13.30	4.40	4.22	3.03	24.94
84/85	12.59	0.00	3.77	2.90	19.26
85/86	20.06	7.05	5.19	4.12	36.41
86/87	19.58	6.47	6.16	3.72	35.93
87/88	22.09	6.84	8.09	4.44	41.45
88/89	30.76	10.83	9.32	7.13	58.03
89/90	34.52	16.91	14.62	12.08	78.14
90/91	53.17	33.80	37.18	25.53	149.67
91/92	99.80	73.03	72.60	38.05	283.48
92/93	245.65	115.30	95.69	78.10	534.75
93/94	368.08	223.82	180.72	134.91	907.52
94/95	765.83	378.18	394.49	337.09	1875.58
95/96	1813.19	860.83	586.49	402.36	3662.87
96/97	2696.50	1730.90	1347.36	1155.25	6930.02
97/98	3878.51	1982.80	1601.74	1030.23	8493.28
98/99	3518.84	1830.38	1428.87	1093.41	7871.52
99/00	2709.00	1831.02	1437.50	1135.74	7113.26
00/01	3202.47	1881.76	1398.40	1319.66	7802.29
01/02	2780.78	1828.94	1371.26	1300.46	7281.44
02/03	2925.17	1630.10	1407.06	1249.10	7211.43
03/04	2754.93	1529.22	1208.16	1056.11	6548.42
04/05	2456.91	1540.82	1256.04	1173.65	6427.41
05/06	2356.94	1413.34	1062.13	1018.12	5850.53
06/07	2144.22	1278.78	1041.32	978.61	5442.93

Interest rate of return = 10%, Salvage value = 0.0

Table 3.34 Present worth of net return (benefit) from major crops, SDG/ha

Season	Cotton	Wheat	Groundnuts	Sorghum	Total
70/71	4.50	0.43	-0.43	-0.11	4.40
71/72	3.15	0.69	-0.10	-0.29	3.45
72/73	3.97	0.71	4.72	1.60	11.01
73/74	3.20	1.86	4.45	4.70	14.21
74/75	1.90	0.52	5.15	0.96	8.52
75/76	6.38	0.67	1.87	1.27	10.19
76/77	2.74	1.03	1.83	1.22	6.81
77/78	4.46	1.11	3.48	0.94	9.99
78/79	3.01	-0.05	1.31	0.70	4.97
79/80	0.27	0.64	2.38	1.51	4.80
80/81	1.92	-0.15	3.84	1.10	6.71
81/82	5.74	-0.99	0.05	1.00	5.79
82/83	3.70	2.39	2.35	1.84	10.29
83/84	3.83	0.31	6.72	3.35	14.21
84/85	7.32	0.00	3.91	10.17	21.41
85/86	0.00	0.78	10.70	2.61	14.08
86/87	8.81	3.14	7.74	0.13	19.82
87/88	7.13	4.29	6.18	5.43	23.03
88/89	2.51	15.31	2.55	2.96	23.34
89/90	13.16	15.91	22.54	12.99	64.60
90/91	-4.58	13.80	90.38	65.38	164.98
91/92	45.83	46.07	114.97	33.93	240.80
92/93	14.64	-24.78	62.07	12.46	64.38
93/94	198.32	67.15	204.38	142.54	612.38
94/95	623.97	114.14	463.16	184.23	1385.49
95/96	1544.73	821.80	348.07	383.86	3098.46
96/97	1472.12	603.27	590.46	1276.95	3942.80
97/98	316.48	228.28	605.25	833.29	1983.29
98/99	85.34	-729.24	370.08	341.67	67.84
99/00	-372.06	206.92	239.05	321.38	395.29
00/01	1178.84	835.49	355.47	1079.87	3449.67
01/02	2415.20	192.16	311.59	474.06	3393.01
02/03	54.11	42.99	107.72	62.96	267.78
03/04	57.67	70.34	139.31	54.72	322.04
04/05	98.29	50.58	72.64	223.38	444.88
05/06	513.06	77.54	817.83	990.08	2398.51
06/07	197.98	1314.76	558.69	468.06	2539.49

Interest rate of return = 10%, Salvage value = 0.0

Table 3.35 Benefit cost ratio (B/C)

Season	B	C	B/C
	SDG/ha	SDG/ha	
70/71	4.40	8.25	0.53
71/72	3.45	8.22	0.42
72/73	11.01	7.20	1.53
73/74	14.21	6.95	2.05
74/75	8.52	7.92	1.08
75/76	10.19	8.57	1.19
76/77	6.81	8.88	0.77
77/78	9.99	8.75	1.14
78/79	4.97	8.48	0.59
79/80	4.80	11.41	0.42
80/81	6.71	9.12	0.73
81/82	5.79	16.85	0.34
82/83	10.29	19.38	0.53
83/84	14.21	24.94	0.57
84/85	21.41	19.26	1.11
85/86	14.08	36.41	0.39
86/87	19.82	35.93	0.55
87/88	23.03	41.45	0.56
88/89	23.34	58.03	0.40
89/90	64.60	78.14	0.83
90/91	164.98	149.67	1.10
91/92	240.80	283.48	0.85
92/93	64.38	534.75	0.12
93/94	612.38	907.52	0.67
94/95	1385.49	1875.58	0.74
95/96	3098.46	3662.87	0.85
96/97	3942.80	6930.02	0.57
97/98	1983.29	8493.28	0.23
98/99	67.84	7871.52	0.01
99/00	395.29	7113.26	0.06
00/01	3449.67	7802.29	0.44
01/02	3393.01	7281.44	0.47
02/03	267.78	7211.43	0.04
03/04	322.04	6548.42	0.05
04/05	444.88	6427.41	0.07
05/06	2398.51	5850.53	0.41
06/07	2539.49	5442.93	0.47