NATIONAL COUNCIL FOR RESEARCH

COUNCIL FOR SCIENTIFIC & TECHNOLOGICAL RESEARCH

WATER RESOURCES IN SUDAN

KHARTOUM 1982

1st. edition 1982

ERRATA

Several printing errors have been observed after the comp iling of this publication, many of them being mistakes in spelling, placing of the correct punctuation marks, words merging into the other without having the necessary spaces etc. In order to present the material in an intelligible manner without recourse to a detailed list of all the errors, it is proposed to set out below and clarify only those printing errors which are necessary for the correct understanding of the context. Those that do not directly effect the meaning and clarity have not been included in the list of errors given below.

Page	Line from the top of the page	Word or Statement to be corrected.	Correction
21	24	Fig. 2.2.1.1.6a	Fig. 2.2.1.1.5
46	2	sitting	Silting
46	2	Word "type" is missing	Hafirs of this "type" is.
47	11	ined	lined
51	7	geological	geological
51	11	dophysical	geophysical
103	16 (table 2.7)	10	10%
133	19 (table 3.3.1.1.)	60	1.0
159 &			
161 &			
163	--		Paragraphs on pages 161, & 163 should form a continuation of the contents on page 159.

ERRORS IN TABLES

Table 2.2.1.1.3 -------- page 20

Year 1912 - Figure 18.99 under lake Albert outflow to be inserted and the other figures to be shifted to the right.

Year 1948 - Lake Albert outflow should be 27.64 and not 27.46 :
Last column figure should be 14.93. Print not clear.

Table 2.2.1.1.5. ---------- page 25

Under (3) Minimum year (1913 - 1914)
Roseiris (B.N.) ..... second column should read 213 and **not** 312.

Table 2.2.1.1.6 -------Page 29

Torrents between lake Albert and Mongolla
Column 5 should read 6. It is printed as 0.

Table 2.2.1.3.1. ---------- page 37

Under 6. Arab-Khor Arab should be (Lat Long).

18 88 37 02
------------------ and not
18 21 36 16

20 El Dibakaya ... last coloum should be 16,507,118. It has been printed 69,507,118

Page 60 :

6. River Atbara basin .... 23.0 mm^3
Printed 3.o m.m

Table 2.4.4. page 93 :

Machar Marshes first coloum should be 4.0
Printed 14.0

Table 3.5.3. .... page 106 to 107 :

Printed twice - delete page 107

Table 3.2.1. ...... page 115 :
West Pakistan 1968 47.0-- 11.70. 249 -- shift line to the right.

Table 3.3.1.1. page 133 :
Milk powder 200 Union of South Africa 200 Barbarosa
Milk factory 1.0 Printed as 60.0

Table 3.3.1.2. .... page 134 :
Figure in second column against textiles is printed 11.345.6000y should read 11.365.600y

Paragraph 3.3.2.2. ..... cooling **water Evaluation printed on page 137 should be printed after contents on page 139.**

Table 3.3.3.6. .... page 159 :
Total under first column is printed 188
should be 118.
Fourth down the second column should be 500
The figure 500 should be shifted to the 2nd column from 3rd column.

Table 3.4.1. .... page 154 :
18. El Gharashi .... printed 816,00
correct ... 816,000

Table 3.5.3. .... page 169 :
Last line:
7.315 .... 7.808 .. 8.140 8.595 (correct)
7315 .... 7.313 7.808 8.140 (printed wrong)

Table 4.3.2. ...... page 195 :
Total alkalinity Ca Co 3....
5th Column figure of 110 should be 100

Ammonia
Correct : 0.4.. Nil..Nil .. Nil .. Nil .. Nil .. Nil .. Nil . 0.39 .05 Nil Nil 0.10
Printed as: 0.40 Nil Nil Nil Nil Nil Nil Nil. 0.39 0.5 Nil 0.10

Table 2.1 Appendix 2..... page 226:

Year total 1464 should be under rainfall column.
Printed under V. P. column
also year total 1368 should be under Penman evaporation column
Printed under Piche Evaporation column

Table 2.2 .... page 226 :

Year total printed wrong under column V.P Piche Evaporation
should be 368 under rainfall
and 2635 under Penman Evaporation

Table 2.6. .... page 228 :

M (March) third column printed 18 should be 81

Table 2.7. .... page 228 :

July .... seventh column-printed 3.6 should be 6.3

Table 2.8. .... page 228 :

J (jan) line to shifted

Table 2.10 :

Table Number should be 2.10 and not 10 as printed
August, and September not printed
A- 33.7 22.6 66 5 23.5 1 L0 6.3 182
S 36.3 23.0 80 4 21.6 51 7.6 191

Table 2.16. .... page 231 :

Line under N to be shifted to the right.

Table 2.17. .... page 231 :

Total under column 5 to be shifted to column 6 and total under 7 should be shifted to column 8.
Last column against F should be 197
Printed as 2197

FOREWORD

This study is a part of the main project "Survey of **Natural resources" under** execution by the National Council for Research . The Council for Scientific and Technological Research requested a team of scientists headed by Dr. Abdin M. A. Salih to prepare a study on the evaluation of the Sudan water resources.

The study has been successfully completed by the team and appraised by Sayed Sageron El Zein Chairman of Board of Directors. The Public Corporation for Irrigation Works and Earth Moving, and Sayed Yousif Suleiman, Director **General, Geological and Mineral Resources Dept.**

The National Council for Research is planning to present this study in a national seminar in the near future.

The National Council for Research would like to thank Sayed Sageron and Sayed Yousif Suleiman and the team for their genuine effort in this study.

DIRECTOR COUNCIL FOR

SCIENTIFIC & TECHNOLOGICAL

RESEARCH

preface

In March 1976 the Council for Scientific and Technological Research of the National Council for Research has invited a team of researchers to study the problem of sprinkler irrigation. In its first meeting the team has suggested that the problem should be widened to include, among other aspects, preliminary evaluation to the country's water resources. On its second meeting the team has requested Dr. Abdin M. A. Salih to lead another team to study the **above** mentioned problem.

On a letter to the Council, Dr. Abdin emphasized that such a study is of a complex nature and would basically require complete cooperation between governmental department, universities, research centres and private units inside and outside the country. Further, the study should also aim towards drawing a comprehensive national management plan for the counrty's water resources.

Hence the preliminary work presented in this Report is deliberately confined to being, in most of its sections, as problem identification study.

The team was originally suggested to be formed of the following researchers:

Dr. Abdin M. A. Salih	Team leader
Dr. El Tayeb M. Saeed	Member
Dr. Mohd. El Amin M. Nur	Member
Eng. Osman El Buluk	Member
Eng. Mohd. Hassan El Tayeb	Member
Eng. Abbass Hidayat Alla	Member
Dr. Hussein Suliman	Member
Mr. Ramsis P. Salama	Member

Unfortunately, Engineer Hidayat Alla and Mr. R. Salama were involved in other very important projects at the time when the team was conducting this work. However, they were kind enough to explain and cooperate whenever they were needed in all stages of this work. On a later stage of this study, contributers from outside the selected team were invited to prepare papers on aspects that are thought to be very important for the completion of this work (list of contributers). Sincere gratitude is owed to them.

The editors of this report would like to acknowledge the unfailing support of Sayed Wadei Habashi, Chairman of the National Council for Research, and Professor Ahmed A. Rahman El Agib, Chairman of the Council for Scientific and Technological Research. At all times during this work, the editors have received sympathetic encouragement from the director of the Council for Scientific and Technological Research, Eng. A. Rahman Ahmed El Agib, and his assistant Dr. Ibrahim Hassan. For without their encouragement and helpful cooperation this work would have never been finished in its planned schedule.

The editors are also indebted to the following authorities: the Ministry of Irrigation and H. E. P., Rural Water Corporation, Public Electricity and Water

Corporation, Geological and Mineral Resources Department, Ministry of Industry, River Transport Corperation, Ministry of Agriculture and Natural Resources, and the University of Khartoum. For without their cooperation in providing the data and the contributing personnel this work would not have come out.

The editors would like also to thank all those who helped in preparing the final drawings, and the different stages of typing and organizing the report. Special thanks are however due to Sayed A. Alla Hussein, Sayed Mirghani H. Arbab, Sayed Mohd. El Mubarak, Sayed E. M. El Sheikh and Sayed Mohd. Habashi.

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List of Plates (x)

(x) It must be noted that all these plates are included in a separate enclosure.

Contents

CHAPTER ONE

INTRODUCTION

Regionally and internationally water resources studies are receiving, at present, considerable attention through universities, research centres, various United Nations Organizations and Programmes (ie. F.A.O., UNESCO, WHO, WMO, IHP, IHD.....etc.), together with national and international conferences. Such studies are extremely important in arid regions, such as the Sudan, where water becomes a vital element for the existence of almost every human activity.

Historically and up to a very recent date the common belief in the Sudan was that the Nile is the basic supplier of its water resources while agriculture is its major consumer. That belief might have been justifiable at a time where the supplied water is much higher than the demand for it. At present, the vast expansion in the country's irrigated area, has unfortunately led to almost the total consumption of the country's share of the Nile water, the sole traditional source. Hence the Sudan has to look for water from other resources, and to optimize between, more expensive sources in order to go further with its proposed irrigation development plans. Such new sources may include conservation of water from swampy regions, development of ground water, improving various utilization efficiencies, controlling non-nilotic streams, recycling and desalination processes. Further-more due attention must be paid for the fastly growing claims of water for other important users such as hydro-power generation, industrial dvelopment, domestic, navigation, fisheries and recreation.

The planners for the Sudan water resources would hence be faced with many complicated options, on the sources of water and also on the purposes to which that sources can be utilized. These options are, however, made more complex by wide variation in the quality and quantity of water and its availability and scarcity in time and space. Such a complex situation can only be resolved through a new approach to the management of the country's water resources. This new approach must pay a considerable attention to the hydrological, ecological, economical and political effects. A complete analysis of such a management plan would be beyond the scope of this Report.

The aim of this report is thus confined to giving in a very broad way the first initial touches on the various parameters affecting the conservation of the water resources of this country. The different sources of water are presented in Chapter 2, while Chapter 3 includes the different uses to which that water can be put. Chapter 4 contains topics which are of great relevance to the management of the country's water supply, while Chapter 5 includes a brief summary and recommendations that are reached by the editors of this Report.

The editors admit beforehand that this work is by no means more than a preliminary broad study on a very complex and extremely variable topic as the conservation of water resources of an arid country as the Sudan. A wider project, with more facilities for detailed survey and analysis, ultimately aiming at improving knowledge of water resources and formulating plans well in advance so as to minimize costs of development and to avoid costly mistakes, is urgently needed.

CHAPTER TWO

SOURCES OF WATER

2.1. RAINFALL AND EVAPORATION

2.1.1. Rainfall

Rainfall is directly or indirectly the source of useful water. while evaporation is one of the main factors contributing to water losses. In arid areas evaporation is the major factor through which valuable water is lost.

(i) Measurement of rainfall

Rainfall is measured with an ordinary raingauge to give the total amount of rainfall that falls in 24 hours. The usual time of measurement is 0800 local time. The recording rainguage gives a continuous record of rain. This type of guage is more useful since it gives such valuable information as time of fall. the duration of the storm and the intensity of that storm. However. it is more expensive than the ordinary rainguage and requires well trained observers to run it.

(ii) The network

The density of the network is determined by the special variability of rainfall. The higher the special variability the higher density of network required. The special variability increases with a decrease in rainfall. Thus more rainguages are needed per unit area in low rainfall zones. The special variability is higher when one considers daily values than when monthly totals are considered. It decreases further when annual totals are used. and even further when an average of annual totals over a long period is used. The density of network required also depends on whether the date is used for planning or operational purposes. A good example of this is the Gezira Scheme. For planning purposes only three rainguages are used. One for Northern Gezira. another for central Gezira and a third for southern Gezira. But for operational purposes over 300 guages are needed.

The optimum density for each situation should be studied. The Sudan Meteorological Department has carried out such a study for Jebel Marra area. The formula used is:

$$n = \left(\frac{V_r}{V_R}\right)^2$$

where n is the number of guages needed to give a special variability V_R when the actual variability is V_r. Thus if the actual variability is 50 (percent) and the required variability is 10 (percent) then 25 guages are needed for that area. This type of study should be carried out for the different areas of the Sudan.

At present there are more than a 1000 ordinary rainguages in the Sudan. The distribution is usually governed by the availability of a Government body to look after the rainguage such as a school. a post office. a police station. etc. Thus one finds that the potential areas for development lack the valuable records of rainfall essential for the planning of their development. Recording rainguages are installed only at the first class meteorological stations because they need extra care for their operation. There are about 40 such guages in the Sudan. This number should be increased whenever possible.

(iii) Annual rainfall

The annual rainfall ranges from zero in the north of the country to more than 1500 mm in the extreme south west of the Sudan. Fig. 2.1.1. shows the distribution over the country. The isohytes are zonal (parallel to latitude) up to latitude 14° N. After that the pattern changes to give a low rainfall along the White Nile axis, a high rainfall close to the Ethiopian border and another high rainfall in the south west part of the country close to Zaire border.

(iv) The variability from year to year

The mean annual rainfall is not a reliable measure of the rainfall, unless accompanied by a measure of the variation of rainfall around that mean. The standard deviation is usually taken as a good indication of the variability. The Sudan Meteorological Department has carried out the calculation of the standard deviation for more than 30 stations. The standard deviation is found to increase with decreasing rainfall.

A better analysis of rainfall is to calculate the probability of having a certain amount of rainfall. Or the amount of rainfall expected with a certain probability at a given place. This last method is the one usually used. The rainfall expected 4 of five years (80 percent probability) is usually taken as suitable for planning purposes. Thus the rainfall expected with an 80 (percent) probability is calculated for 30 stations. This rainfall is found to correlate well with the mean rainfall. The following formula can be used to calculate the 80 (percent) probability rainfall from the mean rainfall.

$$80 \text{ (percent) rainfall} \approx 0.92 \times (\text{ mean rainfall }) - 53 \text{ mm.}$$

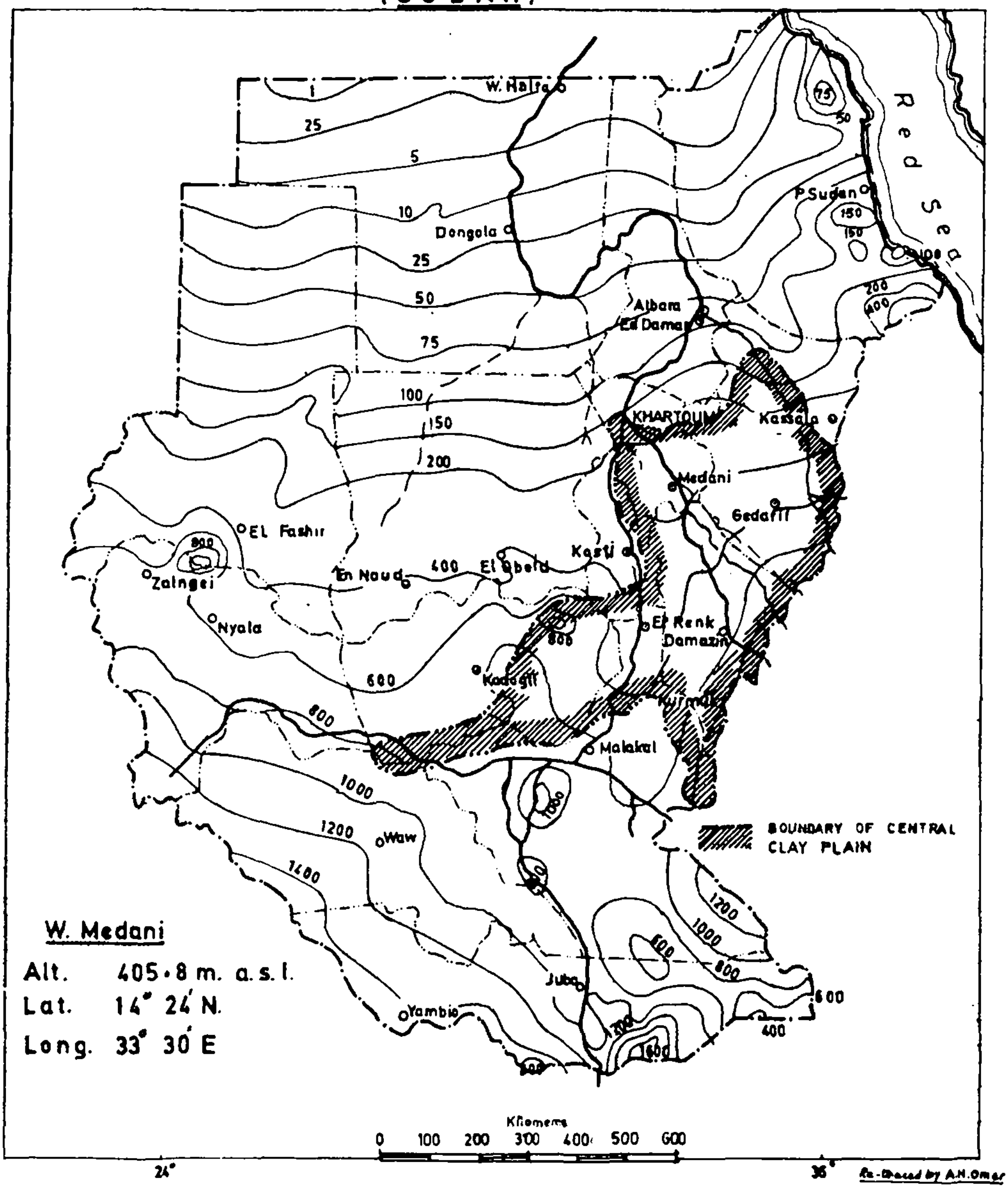
The following table shows the 80 (percent) rainfall corresponding to the given mean rainfall.

Mean rainfall	200	400	600	800	1000	1200	1400	1600
80 (percent) rainfall	130	315	500	680	870	1050	1235	1420

(v) Monthly rainfall

As mentioned above, the variability of monthly rainfall is higher than that of annual rainfall. Dr. Yassin Abdin has calculated the standard deviation for 30 stations for the months of June, July, August and September. Using these values the standard deviation is correlated with mean monthly values. The following formula is derived:

Fig. 2.1.1 AVERAGE ANNUAL RAINFAL—1931 – 1960 (M M)
(S U D A N)



Standard deviation ≈ 0.18 (mean rainfall) $+ 30$
for monthly rainfall $\geqslant 50$ mm.

The coefficient of variation, which is the ratio of the standard deviation to the mean rainfall, is very high. For mean monthly rainfall of 50 mm. the variation is 80 (percent), for a 100 mm. it is 48 (percent), for 200 mm. it is 40 (percent) and even for the months with mean rainfall of 300 mm. the variation is still high, 28 (percent).

So one can say that monthly rainfall is very variable.

(vi) Daily rainfall

The rainfall that falls in 24 hours is very valuable for run off calculations. The maximum rainfall ever recorded at a number of stations is given below. Most of the stations recorded their maximum in the range of 100 to 150 mm. The highest fall recorded within 24 hours in the Sudan is 193 mm at Kosti.

Station	Gedaref	Kadugli	Aroma	Malakal	Raja	El Fasher
Highest rainfull in 24 h.	126	97	118	176	160	128
	Wau	Nasir	Juba	Roseiris		
	119	150	116	116		

The highest rainfall in 24 hours is not a good indicator of the intensity of rainfall. The intensity of rainfall should be analysed statistically i. e. to determine the probability of having 200 mm. in one day, 100 mm in one day and so on. This needs a lot of time but it is very important and one hopes it is going to be done in the near future.

(vii) The rainy season

The beginning of the rainy season is of importance for many purposes. The rainy season begins early in the south of the Sudan and is delayed as one goes north. It is found that the beginning of the rainy season is well correlated with latitude. The following table shows the date of the beginning of the rainy season with latitude.

Latitude° N	2	4	6	8	10	12	14	16
Date:	1st March	20th March	10th April	30th April	18th May	7th June	27th June	15th July

The end of the rainy season is not so well correlated with latitude. The length of the rainy season increases as one goes south. It is only 60 days at Kosti, 100 days at Abu Naama, 130 days at Kadugli, 160 days at Malakal, 200 days at Juba and 275 days at Yambio.

2.1.2. Evaporation

(i) Measurement of evaporation

The Sudan Meteorological Department has got more than 70 stations where evaporation is measured with Piche tubes. Most of these stations have records of evaporation for more than 40 years. Class (A) pans are used only in the first class stations. The measurement of evaporation from class (A) pan is taken twice a day so that daytime and nighttime evaporation are taken separately. At the main observatory evaporation is measured from a large sunken pan.

Measurement from class (A) pans needs great care and should be handled by well trained observers. The Piche tube is much easier to use. However, the values found using both instruments do not represent evaporation from an extended water surface. These values have to be used with certain correction factor.

(ii) Estimation of evaporation

A lot of work has been done on the estimation of evaporation from meteorological parameters. Many empirical formulae have been tried. The Penman formula has proved to be the most suitable one. Thus Penman formula is used whenever the meteorological elements needed are available. These elements are available only at the first class stations. To go around this difficulty an attempt is made to make use of the more available Piche records by correlating Penman evaporation with Piche evaporation. The ratio of the two depends on the latitude and the month of the year and is by no means constant.

Thus the long practical method of multiplying the Piche evaporation by a constant of 0.5 for all months and for all places is no longer valid and should not be used. Table 2.1.1. shows the ratios that should be used for each month and for each latitude.

(iii) Distribution of evaporation in the Sudan

As shown in Fig. 2.1.2. The evaporation decreases from North to South. The pattern is similar to that of rainfall but the gradient is reversed. There is a marked ridge over the White Nile corresponding to the trough of rainfall over the same area. The maximum annual evaporation occurs in the Northern parts of the Sudan totalling to a grand sum of 2800 mm. decreasing to 2500 mm in the centre of the country and to a minimum of 1400 mm in the extreme south west of the Sudan. It is only in this part that the rainfall exceeds the evaporation. In the rest of the country there is a water deficit that increases as one goes North. reaching a maximum of 2800 mm.

The maximum daily evaporation in the south is about 6 mm during February - March. and the minimum is 4 mm during July - August. In the centre a maximum of 8 mm during April and two minima of 5 mm during August and December. In the North up to 9 mm can be evaporated during the day and a minimum of 4 mm in December.

The Red Sea area being different from the rest of the country. and having winter rainfall. has its maximum evaporation of 7.5 mm in July - August and its minimum of 4 mm in December - January. In Tables (2.1.2. - 2.1.23) annexed at the end of this Report (appendix 2.1.). the mean monthly values of temperature. sunshine. vapour pressure. wind speed. rainfall. Piche and Penman evaporation are given.

Fig. 2.1.2

ANNUAL EVAPORATION (mm)

(SUDAN)

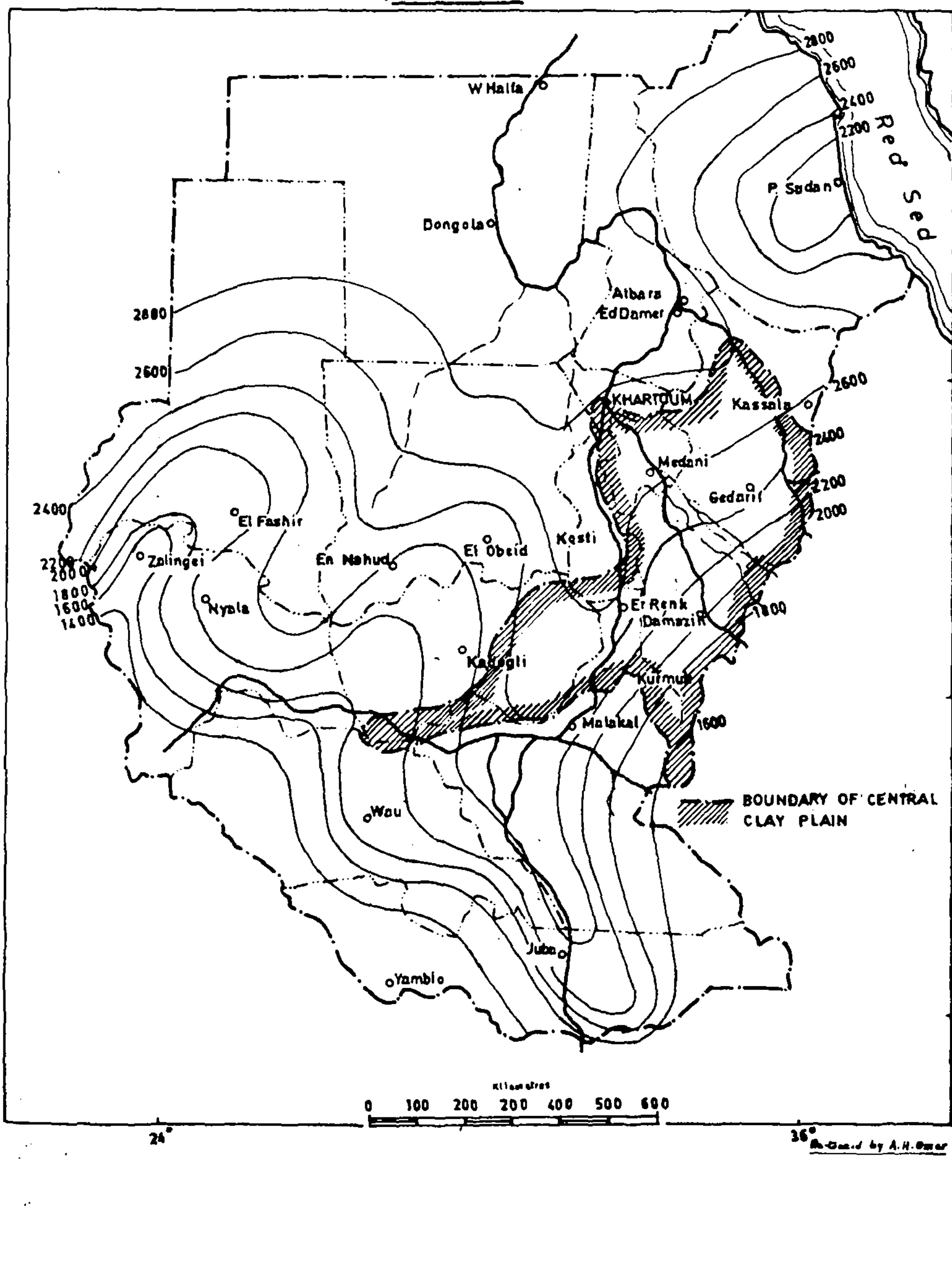


Table 2.1.1. Average ratios of Penman estimate (Eo) to Piche evaporation (Ei) for the different regions of the Sudan

Region	J	F	M	A	M	J	J	A	S	O	N	D
	Month											
Red Sea Are	0.5	0.6	0.7	0.7	0.6	0.5	0.5	0.5	0.6	0.7	0.6	0.5
Northern Sudan North of 17° N	← 0.3 →											
Central Sudan												
a. 14 - 17° N							0.5	0.6	0.9	0.7	0.5	
b. 12 - 14° N	← 0.4 →						0.6	0.8	1.2	1.1	0.7	0.4
c. 10 - 12° N							0.6	0.9	1.4	1.3	0.9	
Southern Sudan												
a. 8 - 10° N	← 0.4 →			0.5	0.6	0.9	1.2	1.5	1.5	1.1	0.6	0.4
b. 6 - 8° N	0.5	0.5	0.6	0.7	0.9	1.1	1.3	1.5	1.4	1.1	0.7	0.5
c. South of 6° N	0.6	0.6	0.7	0.8	1.2	1.3	1.4	1.5	1.4	1.2	1.2	0.7

Ec Penman estimate from an open water surface

E_i Measured evaporation from the Piche inside the screen at 100 cm.

2.2.1. RIVERS

2.2.1.1. RIVER NILE AND TRIBUTRIES

2.2.1.1.1. Geographical features of the Nile basin

1 - The Nile River is almost the longest river in the world. It has established a channel across the greatest deserts in the world; a channel assumed to be formed as a result of a great geological movement.

2 - Four relief regions are readily distinguished within the Nile basin (1, 2):

- i. The plateau and mountains of the Southern and South-eastern water sheds.
- ii. The clay plain of the Southern and Central Sudan.
- iii. The Desert plateau, extending from just north of Khartoum to the Mediteranean coast line.
- iv. The Nile valley.

3 - Four types of climates are also distinguished:

- i. The equatorial climate, prevails south of about latitude 5 degrees north. It is characterised by small temperature range and double rainfall maxima. The total rainfall varies with exposure. While in rain-shadow areas rainfall may be less than 750 mm, it rises to about 2000 mm on the mountains.

- ii. Tropical continental climate, prevails between latitude 5^{o} and 18^{o} north. South to north, drought in winter lengthens from two months to 12 months while the rainy season shortens from ten months to nil, and the annual rainfall decreases from about 1200 mm to nil.

- iii. The hot desert climate, extends from latitude 18^{o} N to latitute 30^{o} N. The heat is extreme in summer, the cool season is more marked as the latitute increases. Rainfall is negligible.

- iv. Mediteranean climate prevails north of latitute 30 N and along the Red Sea coast, though close to the arid margin of this type of climate.

4. Four vegetation zones corresponding with the four types of climates also exist:

- i. The equatorial zone, characterized by the tropical forests.
- ii. The tropical continental zone, characterized by the savanah. In the south of Sudan and the Ethiopian plateau, are tall grasses and semi - d ecidious broad - leaved trees. Further north in Sudan, mainly of the acacia genus. In the swamps of Bahr El Jebl dense papyrus and various other water plants prevail.

- iii. The Desert zones. is virtually without vegetation.

2.2.1.1.2. General hydrological feature of the Nile basin

1 - The Nile receives its waters from basins which can be categorized into three main groups:

i. The Equatorial lakes plateau which comprises some of the lands of Tanzania, Kenya, Uganda, Congo, Rwanda and Burundi (Fig. 2.2.1.1.1.).

ii. The Bahr El Ghazal basin in the South - west Sudan.

iii. The basins of rivers from the Ethiopian plateau - Sobat, Blue Nile and Atbara rivers (Fig. 2.2.1.1.2.).

2 - These basins differ considerably in their annual and seasonal contributions to the Nile flow. The Ethiopian Plateau contributes about 90 (percent) of the flood discharge of the Nile and only about 28 (percent) of the low period discharge. At the dry season, 72 (percent) of the discharge is supplied by the Equatorial Plateau.

3 - The Ethiopian Plateau supply 84 (percent) of the average annual flow of the river, and the Equatorial Plateau supplies the remaining 16 (percent).

4 - Bahr El Ghazal basin contributes virtually nothing to the Nile. All its waters are lost in the swamps region.

5 - About 50 (percent) of the Equatorial lakes plateau discharges are lost in Bahr El Jebel swamps.

6 - The Nile flow has a regular seasonal fluctuation. The lowest discharge in a year may drop to 25 m cubic m perday, and the maximum discharge may rise to 1250 mi. cu. m. per day. The six months of the low period bring only one fifth of the total annual flow and four fifth of the flow is brought during the six months of the flood period.

7 - The variation of the Nile flow from year to year is noticeable. It may rise to 150 milliards cubic meter in a wet year, and may drop to 40 milliards cubic meter in a dry year.[1]

8 - The average annual flow of the Nile is estimated to be about 84 milliards as at Aswan.

2.2.1.1.3. Basic features of the Equatorial lakes

1 - The table below summarizes the basic features of the Equatorial lakes:

Lake / basic features	Victoria	Kioga	George	Edward	Albert
Basin km^3	262000	75000	800	12000	17000
Surface area km^3	67000	6270	300	2200	5000
Average rainfall (m)	1.19	1.30	1.37	1.37	1.26
Average evaporation (m)	1.12	2.00	1.2	1.20	1.20
Average outflow (mm^3/yr)	20.4	19.0		2.30	22.7

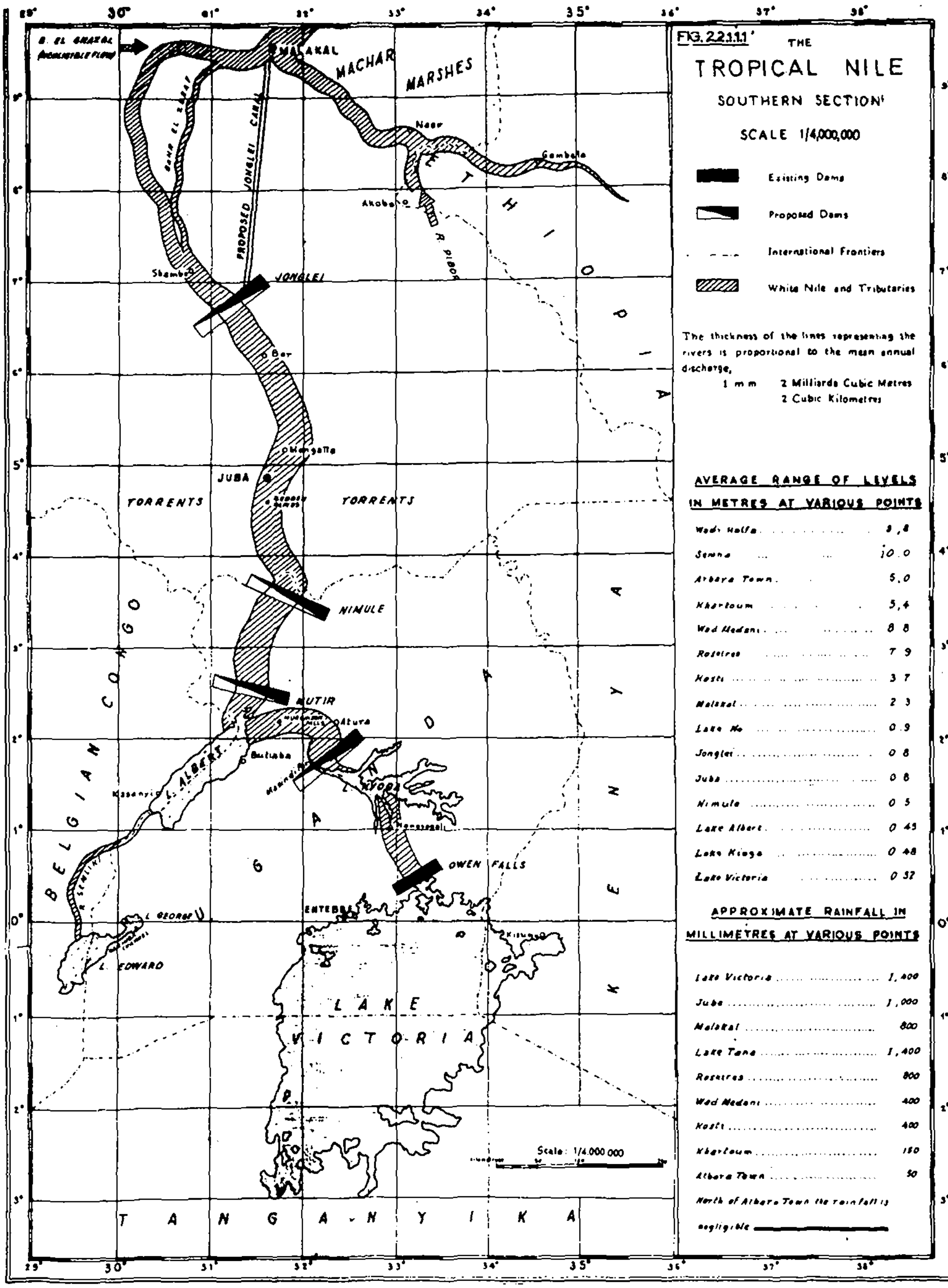
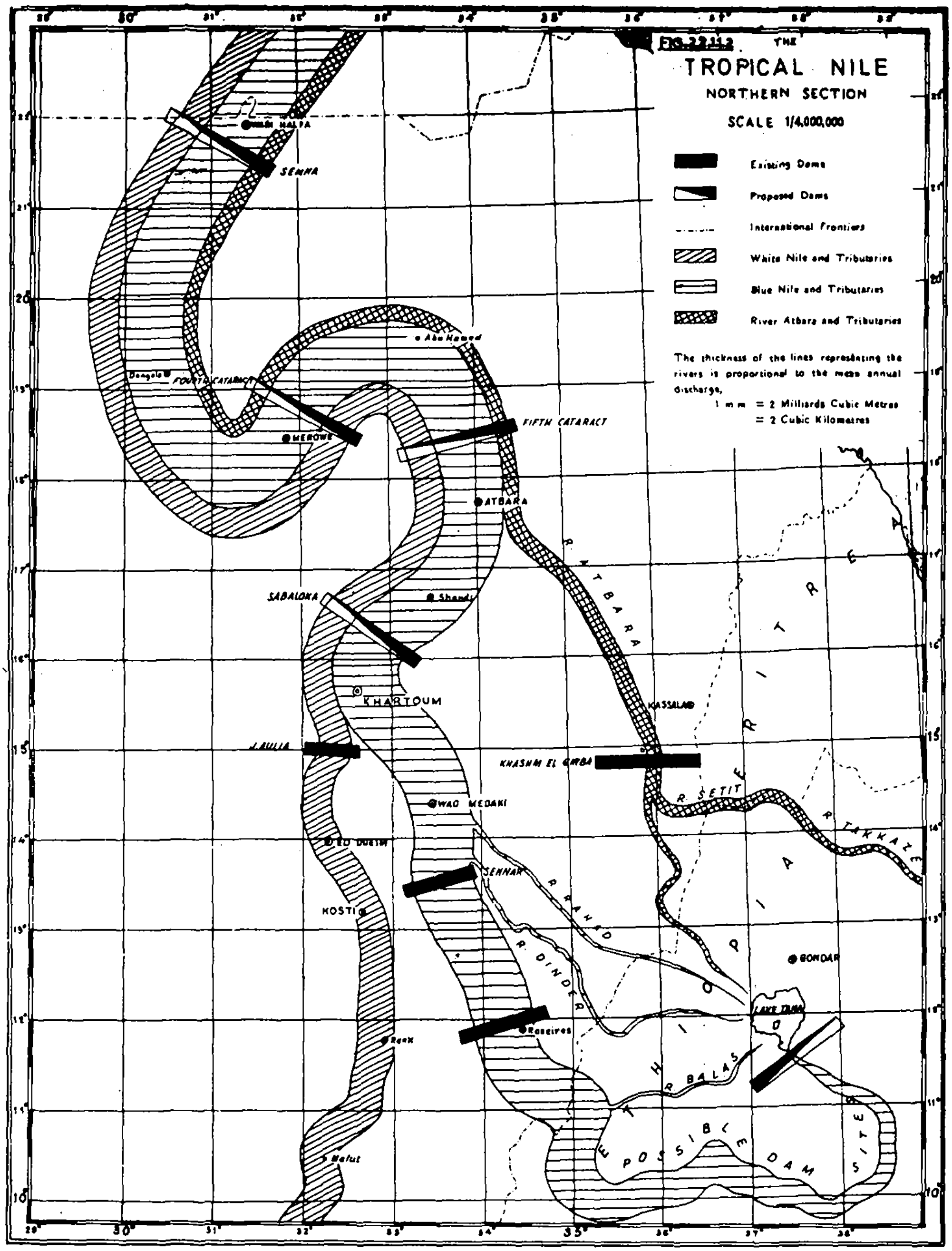


FIG. 2.2.1.1.
THE
TROPICAL NILE
SOUTHERN SECTION
SCALE 1/4,000,000
Existing Dams
Proposed Dams
International Frontiers
White Nile and Tributaries
The thickness of the lines representing the rivers is proportional to the mean annual discharge,
1 mm 2 Milliards Cubic Metres
2 Cubic Kilometres
AVERAGE RANGE OF LEVELS IN METRES AT VARIOUS POINTS
Wadi Halfa
Semna 10.0
Atbara Town 5.0
Khartoum 5.4
Wad Medani 8.8
Roseires 7.9
Kosti 3.7
Malakal 2.3
Lake No 0.9
Jonglei 0.8
Juba 0.8
Nimule 0.5
Lake Albert 0.45
Lake Kioga 0.48
Lake Victoria 0.37
APPROXIMATE RAINFALL IN MILLIMETRES AT VARIOUS POINTS
Lake Victoria 1,400
Juba 1,000
Malakal 800
Lake Tana 1,400
Roseires 800
Wad Medani 400
Kosti 400
Khartoum 150
Atbara Town 50
North of Atbara Town the rainfall is negligible
MALAKAL
MACHAR MARSHES
Nasir
Gambela
Akobo
R. PIBOR
PROPOSED JONGLEI CANAL
Shambe
JONGLEI
Bor
Mongalla
JUBA
TORRENTS
TORRENTS
NIMULE
NUTIR
Atura
Butiaba
L. ALBERT
Kasenyi
L. KYOGA
OWEN FALLS
ENTEBBE
Kisumu
L. GEORGE
L. EDWARD
R. SEMLIKI
LAKE VICTORIA
BELGIAN CONGO
UGANDA
KENYA
ETHIOPIA
TANGANYIKA
Scale: 1/4.000.000


THE
TROPICAL NILE
NORTHERN SECTION
SCALE 1/4,000,000
Existing Dams
Proposed Dams
International Frontiers
White Nile and Tributaries
Blue Nile and Tributaries
River Atbara and Tributaries
The thickness of the lines representing the rivers is proportional to the mean annual discharge,
1 mm = 2 Milliards Cubic Metres
= 2 Cubic Kilometres
SEMNA
Dongola
FOURTH CATARACT
MEROWE
Abu Hamed
FIFTH CATARACT
ATBARA
SABALOKA
Shendi
KHARTOUM
J. AULIA
KASSALA
KHASHM EL GIRBA
WAD MEDANI
ED DUEIM
SENNAR
KOSTI
R. RAHAD
R. DINDER
GONDAR
LAKE TANA
Roseires
Renk
R. BALAS
POSSIBLE DAM SITE
Malut
R. ATBARA
R. SETIT
R. TAKKAZE
ERITREA
ETHIOPIA

HYDROGRAPH OF MONTHLY MEAN GAUGES OF LAKE VICTORIA (ENTEBBE) LAKE KYOGA (MASINDI) AND LAKE ALBERT (BUTIABA)

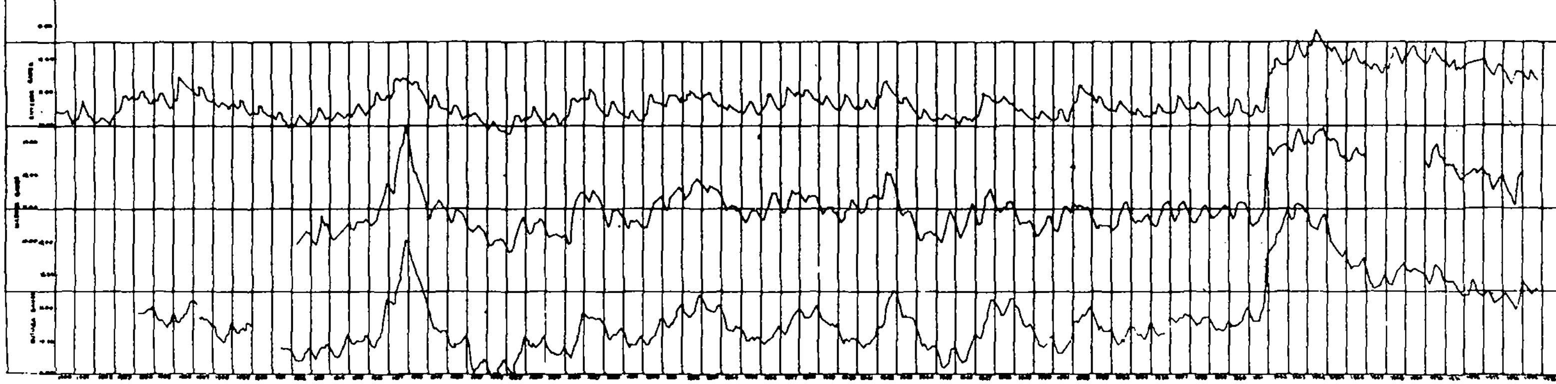
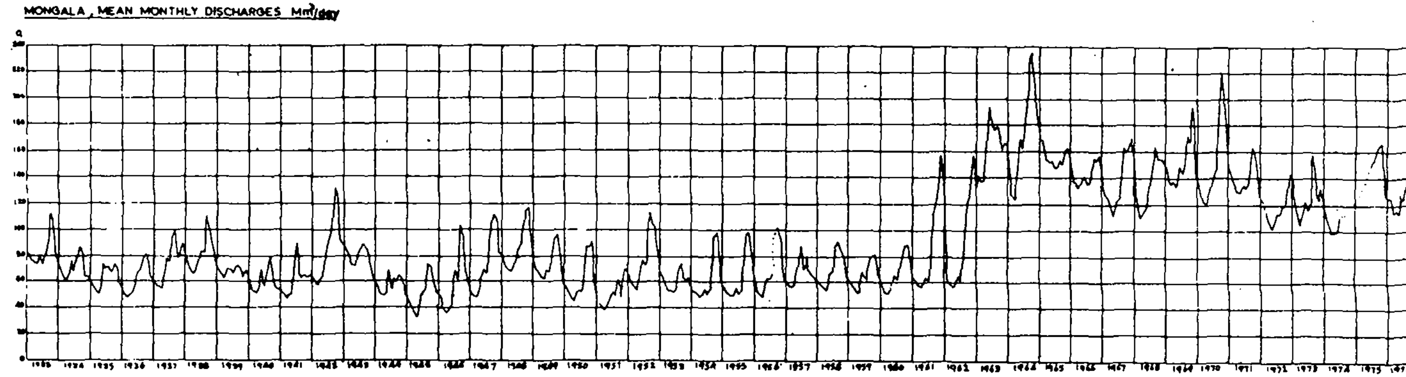


FIG 2.2.11.3

MONGALA, MEAN MONTHLY DISCHARGES Mm³/day

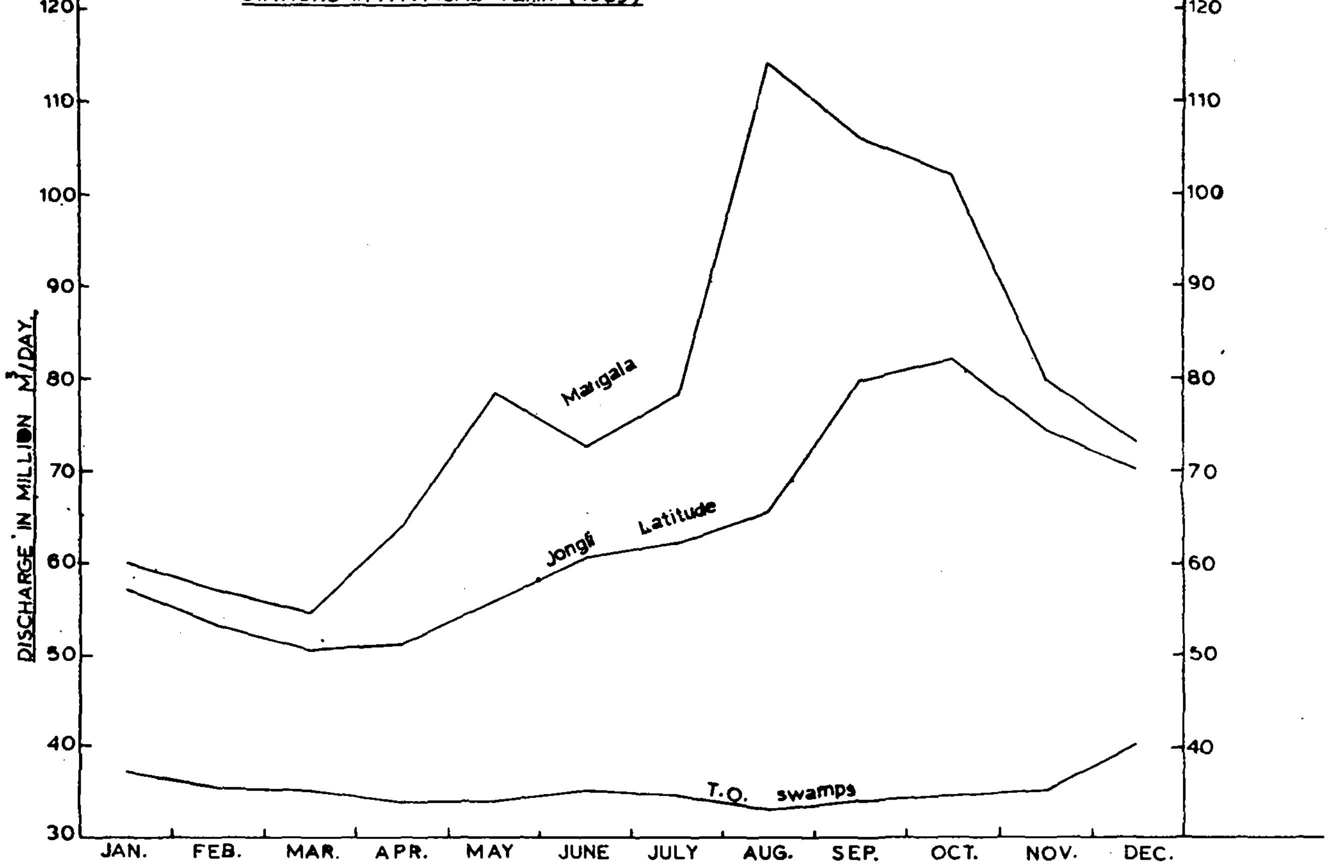


2 - Steady rises in levels and discharges have been registered for the Equatorial lakes since 1962. As demonstrated by the hydrographs a and b (Fig. 2.2.1.1.3.), these rises attained their peaks in May 1964. It has been shown also that in 1970 the levels and discharge of the Equatorial lakes were hardly any lower than in the first years after the rise peak.
3 - The consequencies of these changes on the Bahr El Jebel discharge are illustrated by the Mongalla hydrograph (hydrograph Fig. 2.2.1.1.4).
4 - In studying this phenomenon, an important question arises whether the lakes' levels and discharges, and consequently the Mongalla discharge will eventually return to their former values or not, and if so, how long this will take.

2.2.1.1.4. Hydrology of Bahr El Jebel system
1 - The main sources of Bahr El Jebel river are the equatorial lakes and the torrential rivers of the south-east Sudan plateau. The torrents superimpose short-period runoff peaks on the relatively constant outflow of Lake Albert.
2 - Between Nimule and Mongalla the river has relatively steep slope of about 100 cm per kilometer, and flows in one channel. North of Mongalla the river divides into several channels in a broad flood plain, the level of which is lower than the high water levels. Vast areas are inundated at high discharges forming the swamps of Bahr El Jebel.
3 - Nearly 50 (percent) of Bahr El Jebel discharge is lost in the swampy region by overspilling and evaporation. The major part of the losses takes place between Jonglei latitude and the tail of the swamps. As illustrated by tables 2.2.1.1.1. and 2.2.1.1.2. the losses increase steadily with the discharge.
4 - The peaks in Bahr El Jebel discharges fade out in the swampy region. The distinctive hydrological feature of the river at the tail of the swamps is the well distribution of its discharge throughout the year. This is demonstrated by Table 2.2.1.1.1. and Fig. 2.2.1.1.4. The maximum discharge is about 40 m cubic m per day in December and the minimum discharge is about 34 which occurs in April.
5 - Table 2.2.1.1.3. shows the annual discharges of the Upper Nile reaches to the tail of the swamps, for the period 1905 - 1965.
Below is the summary:

	Mean	Maximum	Minimum	
Lake Victoria outflow	22.5	51.4	12.7	(milliard cubic meter)
Lake Albert outflow	22.3	56.9	13.5	
Torrent discharges	4.8	9.8	1.8	
Mongalla	28.99	65.51	14.98	
Tail of the swamps	14.74	33.00	10.29	

FIG. 2.2.1.1.4 DISCHARGE HYDROGRAPH OF BEHRELJEBEL AT PRINCIPAL STATIONS IN A TYPICAL YEAR (1953)



2.2.1.1.5. Rivers of Bahr El Ghazal basin

1 - The basin comprises the catchments of about 20 tributaries which end in the Bahr El Ghazal swamps as shown. The area of the basin is about 526000 square km. The area of the swamps is about 40000 square km.

2 - The total normal discharges of these rivers is approximately 14.0 milliards cubic meter, out of which only about 0.2 milliards cubic meter reaches the White Nile. The rest is lost in the swamps of Bahr El Ghazal.

Table 2.2.1.1.1. Bahr El Jebel Discharge losses in the swampy region for average year (1952)

Month / Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average	Total for year (mm^3)
Mongalla discharge mm/day	60.3	56.7	54.3	63.8	77.6	72.6	78.1	114	106	102	80.0	72.7	78.1	28.600
Jonglei latitude discharge (mm/day)	57.0	52.6	50.3	51.2	56.0	60.4	61.9	65.9	79.5	81.9	73.9	64.7	57.0	20.800
Malakal (T. O. swamps (mm/day)	37.7	35.4	34.1	34.3	35.2	34.4	32.8	34.1	34.5	35.0	34.8	40.3	35.2	12.900

Table 2.2.1.2. Discharge losses relationship in Bahr El Jebel swamps

Site	**Discharge in millions of cubic m. per day**									
Mongalla	**120**	**110**	**100**	**90**	**80**	**70**	**60**	**50**	**40**	**30**
Jonglei latitude	**102.5**	**94.5**	**86.5**	**78.6**	**70.6**	**62.6**	**54.6**	**46.6**	**37.5**	**28.5**
% loss of Mongalla discharge	**14.6**	**14**	**13.5**	**12.7**	**11.8**	**10.6**	**9**	**6.8**	**6.3**	**5**
Peaks latitude	**51.9**	**50.6**	**49.6**	**48.5**	**46.7**	**44.2**	**41.6**	**39.0**	**34.0**	**27.0**
% loss of Mongalla discharge	**56.8**	**54.0**	**50.4**	**46.0**	**41.6**	**36.9**	**30.7**	**22.0**	**15**	**10**
T.O. swamps	**46.0**	**44.5**	**43.0**	**41.0**	**39.5**	**38.0**	**36.0**	**34.0**	**31.0**	**25.0**
% loss of Mongalla discharge	**61.7**	**59.5**	**57.0**	**54.0**	**50.6**	**45.7**	**40.0**	**32.0**	**22.5**	**17.0**

Table 2.2.1.1.3. Annual Discharge of the Upper Nile reaches in milliard cubic m. per year

year	lake Victoria outflow	Lake Albert outflow	Torrent discharges	Mongalla discharges	Discharges of Jebel and Zeraf as at Malakal
1905 / 06	25.06	31.38	4.69	26.09	12.72
6	29.14	35.19	4.66	39.32	13.73
7	24.24	29.15	4.25	32.52	13.50
8	22.02	26.69	5.29	30.37	14.82
9	19.85	28.30	4.78	31.14	16.36
10	18.17	24.87	5.45	28.79	14.40
11	15.31	19.69	4.74	23.61	12.89
12	15.98	6.49	24.28	13.60	
13	17.69	20.59	2.97	22.63	13.36
14	18.34	22.45	5.82	27.39	13.90
15	25.72	23.65	5.42	27.97	13.18
16	25.99	33.79	13.13	44.54	16.71
17	31.70	53.86	9.83	61.02	18.67
18	24.31	37.82	1.78	37.87	19.37
19	20.29	25.17	4.21	28.48	15.54
20	18.01	21.36	2.97	22.27	12.45
21	14.58	14.60	3.13	15.62	10.93
22	12.71	13.54	3.21	14.98	10.29
23	18.91	17.13	5.36	22.41	11.69
24	16.30	17.83	2.52	19.76	11.17
25	17.00	15.98	3.34	18.69	11.50
26	24.69	23.38	5.78	28.28	11.88
27	20.97	23.30	4.05	26.29	12.50
28	19.42	20.37	4.66	24.11	13.67
29	18.42	18.62	3.12	21.01	13.25
30	23.29	22.86	2.67	24.41	13.10
31	24.36	26.96	4.74	30.38	13.80
32	25.77	29.53	5.21	33.31	14.70
33	22.26	26.44	3.73	29.10	16.50
34	19.45	21.21	4.47	24.85	14.99
35	20.76	19.30	4.09	22.66	13.85
36	23.63	21.51	4.44	24.90	12.87
37	27.09	25.96	4.48	29.47	13.75
38	24.90	25.85	4.81	29.47	13.58
39	22.40	21.56	2.72	23.51	13.67
1940 / 41	22.54	18.37	3.39	21.58	14.27
41	24.32	21.29	4.21	24.78	14.31
1942 / 43	25.35	20.49	4.44	33.82	15.35
43	19.01	22.20	3.75	25.09	15.17
44	16.60	15.95	3.06	18.32	13.99
45	16.02	15.17	4.43	19.07	13.23
46	17.48	18.12	4.00	24.33	13.54
47	24.31	27.82	4.02	30.49	14.35
48	21.75	27.46	4.67	[illegible]	[illegible]
49	16.99	20.99	4.20	24.16	15.17
50	16.72	17.23	4.86	21.27	14.54
51	18.73	19.92	3.13	22.00	13.49
52	19.11	24.49	4.64	27.97	14.51
53	19.30	19.46	2.85	21.37	14.25
54	19.83	19.67	4.36	23.15	14.24
55	18.24	19.59	4.89	23.62	14.43
56	20.20	21.44	5.30	25.77	14.86
57	21.01	22.62	2.53	24.27	14.69
58	20.24	21.33	4.73	25.05	14.37
59	19.21	20.12	4.28	23.43	14.08
60	19.61	22.76	3.79	25.47	14.05
61	28.11	39.85	9.77	43.01	15.49
1962 / 63	41.44	53.32	6.43	54.51	1927
1963 / 64	47.75	56.92	8.38	65.51	22.90
64	51.36	47.70	12.23	59.59	33.00
65	43.00	40.18	5.79	42.46	23.80
M.D.	22.49	25.30	4.84	28.99	14.74
Max.D.	51.36	56.92	9.77	65.51	33.00
Min.D.	12.71	13.54	1.78	14.98	10.29

M.D. mean discharge
D. discharge

2.2.1.1.6. The Rivers of the Ethiopian Plateau

1 - The principal rivers of the Ethiopian Plateau are:

i. The Sobat River

ii. The Blue Nile

iii. Atbara River.

The sources of these rivers are mainly the rains falling on the western side of the Ethiopian Plateau. The occurrence of rainfall on the Ethiopian highlands has a well defined pattern, but the amount falling each year is varied erratically. The result is that the annual discharges of the rivers collecting the run - off of this area, including the Blue Nile vary over a wide range as also do the peak discharges during flood periods.

2 - The Sobat River :

The Sobat is the principal tributary of the White Nile and is responsible for the greater part of the fluctuations in level and discharges. It contributes about 13 milliards annually or just under half the total of White Nile discharge. The Sobat discharge varies from below 10 m cubic m per day in February and March to over 60 m cubic m per day during October.

The Sobat is formed by the junction of two streams, the Baro and the Pibor. The first rises and runs almost entirely in Ethiopia and the second runs in Sudan but gets most of its water also from Ethiopia.

All the streams forming the Sobat tend to overflow and form swamps on reaching the flat plain and loose part of their discharges by evaporation and overspilling.

Typical hydrographs for Sobat main tributaries are shown in Fig. 2.2.1.1.6 a a. principal stations. Table 2.2.1.1.4. is a summary of data showing the characteristic flow of the Sobat, Baro and Pibor.

3 - Machar Marches :

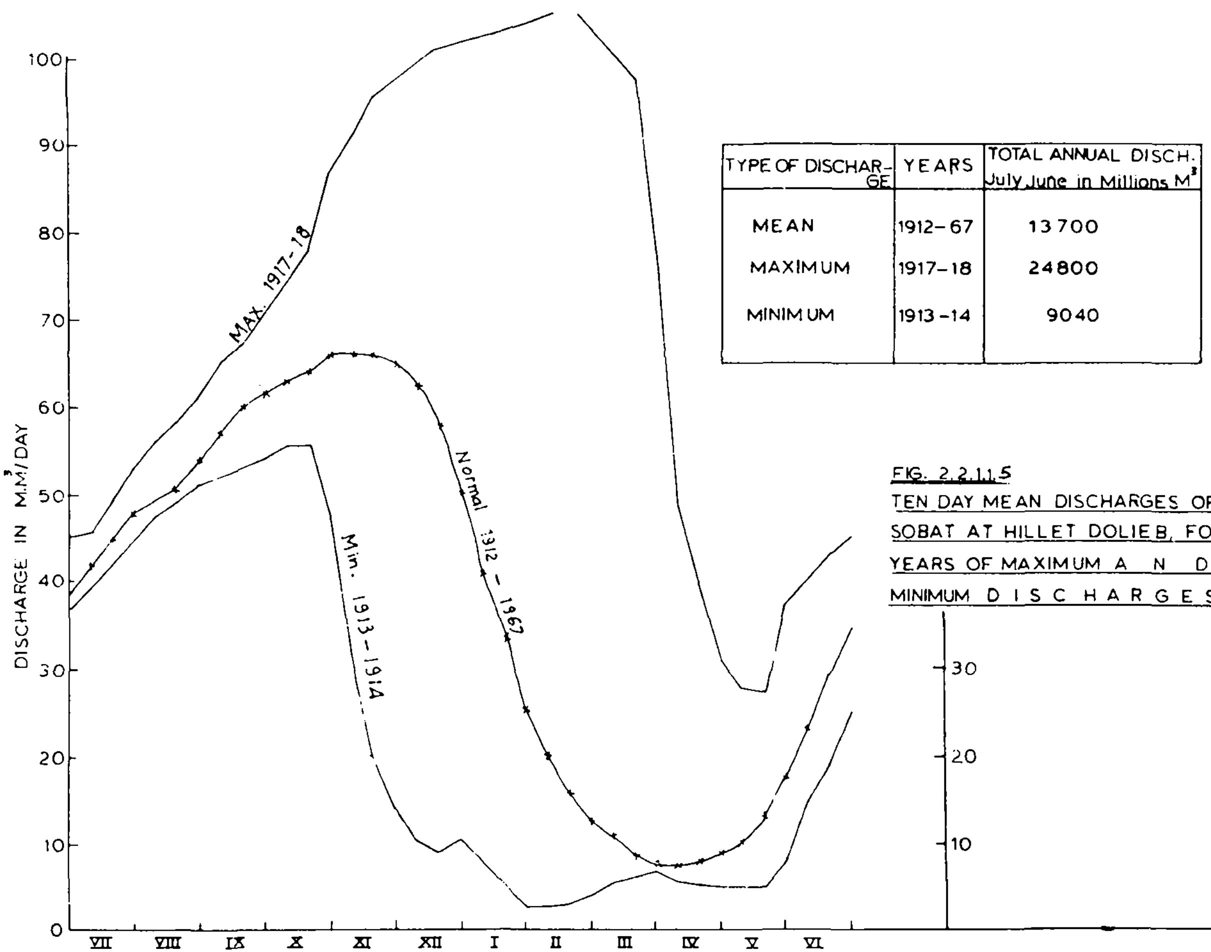
Machar Marches is fed by escapage from the Baro river and many small streams coming from the Abysinnian Plateau of which the principal ones are:

1 Khor Daga of estimated discharge	= 370 million cubic m.
2. Khor Yabus of estimated discharge	= 540 million cubic m.
3. Others of estimated discharge	= 1160 million cubic m.
Total	= 2070 million cubic in
Escapage from Baro (1929 - 1957)	= 4080 million cubic m.
Total escapage to the Machar swamps	= 6150 million cubic m.

Machar swamps is connected to the White Nile by Khor Adar. Khor Adar is a small stream joining the White Nile near Melut. The estimated discharge of Khor Adar is about 1900 cubic meter per year. Hence losses in the swamps of Machar is in the range of 4000 cubic meter.

Table 2.2.1.1.4. River Sobat characteristic flow at principal guaging stations
(in million m^3/day)

Site	Month: year type	Jan	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average	Total for year in mm^3
Baro Gambella	Mean 1928-1956	8.1	5.8	4.8	6.5	14.9	40.1	63.8	86.0	100.0	65.9	24.9	14.3	36.6	13.300
Baro mouth	Mean 1929-1957	8.3	5.5	4.1	5.9	13.8	30.8	43.2	47.7	47.6	45.6	36.0	18.4	25.2	9.220
Escapage to Machar swamps		0.2	0.3	0.7	0.6	1.1	9.3	20.6	38.3	52.4	20.3	11.1	04.1	11.4	4.080
Sobat Head Nasir	1929-1957	17.6	8.5	6.1	7.8	15.1	34.4	48.0	56.4	61.6	64.5	56.9	36.0	34.6	12.600
Mean River Pibor flow at junction with Baro (Nasir-Baro Mouth)		9.3	3.0	2.0	1.8	1.3	3.6	4.8	10.7	14.0	18.9	20.9	17.6	9.9	3.480
Sobat Mouth *Hellet Doleib*	1912-1957	*29.3*	*13.0*	*8.0*	*7.5*	*13.1*	*28.7*	*41.6*	*51.2*	*58.7*	*64.1*	*65.8*	*55.0*	*36.5*	*13.300*



TYPE OF DISCHARGE	YEARS	TOTAL ANNUAL DISCH. July June in Millions M³
MEAN	1912–67	13700
MAXIMUM	1917–18	24800
MINIMUM	1913–14	9040

FIG. 2.2.1.1.5
TEN DAY MEAN DISCHARGES OF SOBAT AT HILLET DOLIEB, FOR YEARS OF MAXIMUM AND MINIMUM DISCHARGES

4 - The Blue Nile

Apart from lake Tana, the overall effects of which is small, there are no natural balancing reservoirs on the Blue Nile to even out the river discharge. Unlike the Sobat and other White Nile tributaries, the Blue Nile has no swamps and hence no extraordinary losses.

Before the construction of Roseiris dam the upper most guaging stations were at Roseiris and Wad El Ais. At present El Deim guaging station in the Ethiopian frontier is the most upstream guaging station in the Sudan territory. Khartoum, being the point where the river joins with the White Nile, is the most downstream guaging station. Between Khartoum and Roseiris the Blue Nile is joined by two tributaries, the Dindir and the Rahad rivers.

Table 2.2.1.1.5 is a summary of a study on the 10-day mean data for the period 1912 - 1957. Typical hydrographs are shown in Fig. 2.2.1.1.6.

5 - Atbara River

The Atbara river and its major tributaries, Bahr El Salam, Setit and Atbara branch, are seasonal rivers. They have a torrential character of flow. Nearly more than 70 (percent) of their flow occur in the period of mid July to mid September. The Atbara river transports high quantities of sediment which reaches a maximum of 2500 ppm.

The discharge characteristic of the river at principal guaging stations are summarized below:

At km 3 from mouth:

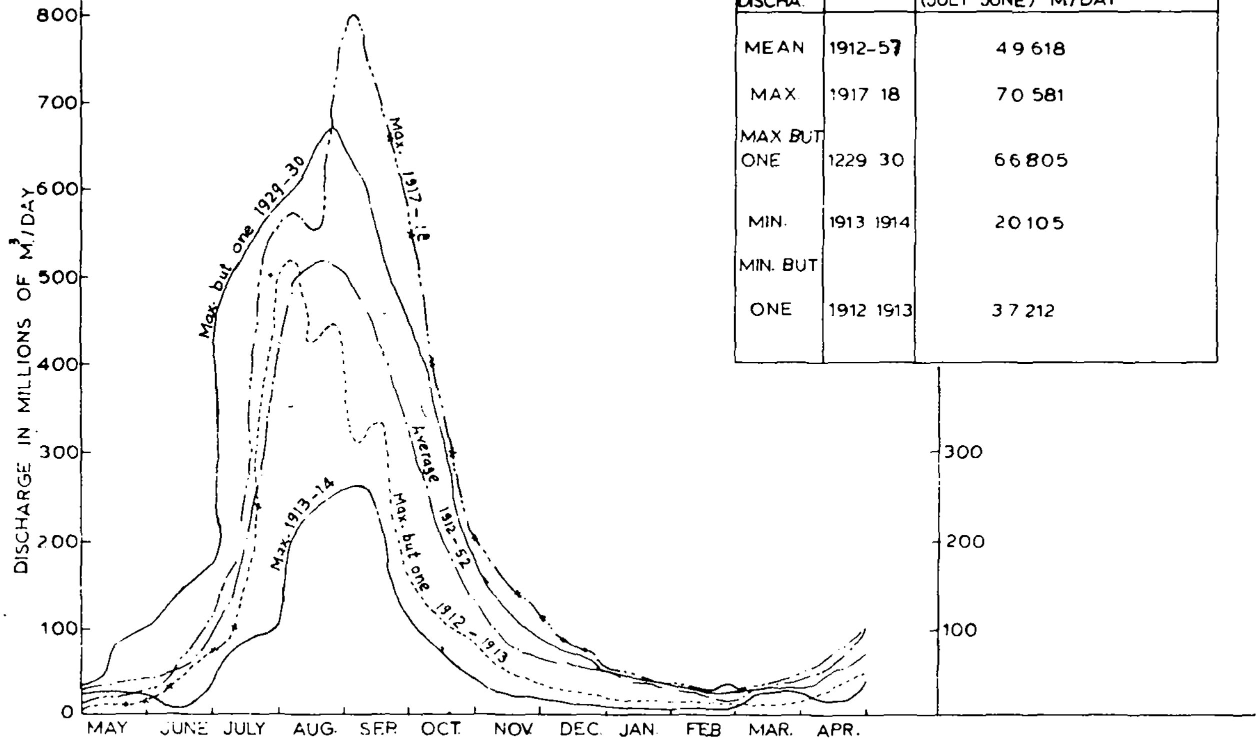
Normal total annual discharge (1912-1947)	11.8 mm^3
Highest total annual discharge 1916	24.3 "
Lowest total annual discharge 1941	6.5 "
Normal maximum ten-day mean	2.310 m^3 - sec.
Highest maximum ten-day mean (mid August, 1916)	5.000 m^3 - sec.
Lowest maximum ten-day mean 1941	1.250 m^3 - sec.

(All these data are from the Nile Basin, volume IV and supplements).

Table 2.2.1.1.5. Characteristic flow of the Blue Nile

Station	July mm³/day	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Total mm³
(1) Peak flood year (1946 - 1947) :													
Roseiris (B.N)	306	812	508	233	101	51	29	18	15	23	13	35	
Dindir (at mouth)	16	42	50	14	3	1	-	-	-	-	-	-	
Rahad (at mouth)	5	7	11	9	3	1	-	-	-	-	-	-	
Total	327	861	569	256	107	53	29	18	15	23	13	35	
(2) Maximum annual discharge year (1917 - 1918):													
Roseirs (B.N)	265	592	705	363	130	66	37	27	21	18	31	66	70,580
Dindir (at Mouth)	13	33	48	24	3	-	-	-	-	-	-	-	3,710
Rahad (at Mouth)	4	9	17	9	-	-	-	-	-	-	-	-	1,160
Total	282	634	770	396	133	66	37	27	21	18	31	66	75,450
(3) Minimum year (1913 - 1914) :													
Roseiris (B.N)	75	312	203	69	25	10	6	5	5	8	6	33	20,100
Dindir (at Mouth)	7	22	16	2	-	-	-	-	-	-	-	-	1,420
Rahad (at Mouth)	2	11	12	-	-	-	-	-	-	-	-	-	,776
Total	84	246	221	71	25	10	6	5	5	8	6	33	22,296
(4) Mean year (1912 - 1957):													
Roseiris (B.N)	214	504	428	219	88	44	25	16	12	11	20	55	50,100
Dindir (at Mouth)	11	34	37	13	2	-	-	-	-	-	-	-	1,060
Rahad (at Mouth)	3	11	13	8	1	-	-	-	-	-	-	-	2,960
Total	228	549	478	240	91	44	25	16	12	11	20	55	54,120

FIG. 2.2.1.1.6 CHARACTERISTIC FLOW OF THE BLUE NILE AT ROSEIRS



TYPE OF DISCHA.	YEARS	TOTAL ANNUAL DISCHARGE (JULY JUNE) M^3/DAY
MEAN	1912-57	49 618
MAX.	1917 18	70 581
MAX BUT ONE	1229 30	66 805
MIN.	1913 1914	20 105
MIN. BUT ONE	1912 1913	37 212

2.2.1.1.7. The average yield of the Nile system

1. It has been shown that the Nile receives its waters from three main basin systems. Below is the average contribution of each system:

(1) Bahr El Jebel and the Equatorial lakes basins:

Upper reaches	lower reaches	swamps losses
(Mongalla) Milliard m^3	(Tail of swamps) Milliard m^3	(milliard m^3)
28.99	14.75 (Malakal)	14.24

(2) Bahr El Ghazal Basin:

14.00 (upper reaches)	0.20 (mouth)	13.80

(3) The Ethiopian Plateau basins:

	Upper reaches	Lower reaches	swamps area
1. Blue Nile	54.12	54.12 (Roseiris+Dinder mouth+Rahad mouth)	
2. Atbara	11.80	11.80	
3. Sobat	17.38 (upper reaches)	13.30 (mouth)	4.08
Total	126.29	94.17	32.12

The potential total flow of the Nile is about 126.0 milliard cubic meter. The actual flow is about 94.0. About 32 milliards is lost annually in the swamps. Plans are under study to reclaim about 18 milliard cubic meter of the quantity lost in the swamps. Jonglei project is now umder construction and is planned to reclaim about 4.6 million cubic m in first phase to reach about 7.00 million cubic m annually in the final phase.

Table 2.2.1.1.6 and Fig. 2.2.1.1.7 show the monthly discharge of the Nile system at principal guaging stations in an average year (1953).

2.2.1.1.8. River Nile guaging in Sudan

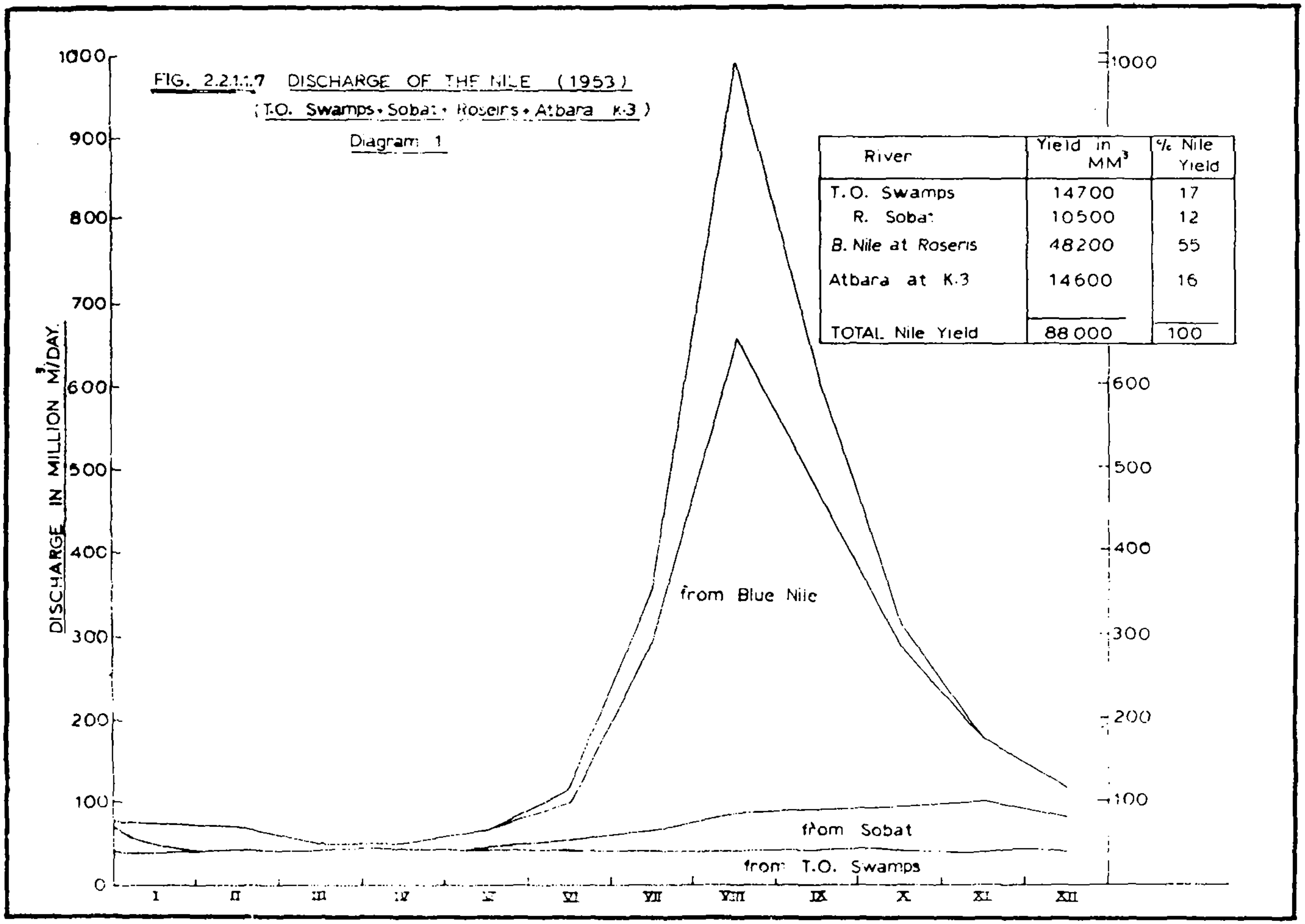
1 - Distribution of guaging stations and administratory agencies:

Distribution of the existing guaging stations on the Nile is shown on Plate 2.2.1.1.1. The systematic guaging of River Nile in the Sudan was started by the Egyptian Irrigation in 1903. There are now two agencies which are administrating the guaging of the Nile system in the Sudan. These are:

FIG. 2.2.1.1.7 DISCHARGE OF THE NILE (1953)

(T.O. Swamps + Sobat + Roseirs + Atbara K-3)

Diagram 1



River	Yield in MM³	% Nile Yield
T.O. Swamps	14700	17
R. Sobat	10500	12
B. Nile at Roseris	48200	55
Atbara at K-3	14600	16
TOTAL Nile Yield	88 000	100

Table 2.2.1.1.6. Monthly discharges of the Nile and its principal tributaries in a representative year (1951) in millions of cubic metres per day, showing the seasonal fluctuation of discharges

Site	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year mean	Year total
Main Nile at Aswan	90	67	70	80	52	49	125	208	292	449	211	132	228	83300
Main Nile at Kajnarty	80	65	75	81	49	58	168	743	679	411	181	117	226	82700
River Atbara at Mouth (k 3)	1	0	0	0	0	7	66	237	124	31	7	4	40	14600
Main Nile at Hassanab	79	74	91	77	56	80	203	535	478	322	159	115	190	69300
Main Nile at Tamaniat	73	71	91	72	56	80	227	574	462	284	143	107	188	68500
Blue Nile at Roseiris	20	12	9	8	18	30	221	570	375	188	78	42	132	48200
White Nile at Khartoum (Mogran)	58	65	78	61	41	50	35	25	53	74	78	73	57	20900
White Nile at Malakal	54	45	41	42	46	58	71	84	42	98	99	79	68	24700
River Sobat at Hilat Doleeb	11	4	2	4	10	22	35	47	53	57	59	38	29	10500
Tail of the swamps	42	40	39	40	39	38	39	41	42	43	42	41	40	14700
Bahr El Jebel at Mongalla	64	59	55	54	62	65	69	76	63	62	64	53	62	22600
Torrents between Lake Albert and Mongalla	0	0	0	0	0	10	15	21	8	8	9	0	7	2360
Lake Albert exit	67	62	57	56	59	57	57	57	57	57	58	56	54	19500
Victoria at Nile at Namasagal	50	51	54	57	49	51	54	50	54	50	45	43	41	18500

(a) The Ministry of Irrigation and H. E. P., and
(b) The General Inspectorate of the Egyptian Irrigation in the Sudan.

2 - The Ministry of Irrigation

The Ministry of Irrigation and H. E. P. administers the guaging stations along the Blue Nile and its tributaries, the guaging stations along the Atbara River and its tributaries and Bahr El Ghazal River and its tributaries. Table 2.2.1.1.7 shows the distribution of the River guaging stations administered by the Ministry of Irrigation and H. E. P.

Table 2.2.1.1.7. Ministry of Irrigation River guaging stations

River	W. level guaging	Discharge & W. level guaging	Discharge guaging	Disch. & W.L. sedi- mentguaging	Total
Blue Nile and tributaries	15	5	-	1	21
Atbara and tributaries	4	2	-	3	9
Bahr El Ghazal and tributaries	12	18	3	-	33
Total	31	25	3	4	63

3 - Egyptian Irrigation

The general inspectorate of the Egyptian Irrigation in the Sudan is entrusted for guaging the following parts of the River Nile system:

i Bahr El Jebel and tributaries.
ii Sobat and tributaries.
iii White Nile.
iv The main Nile.

Table 2.2.1.1.8. displays the distribution of the guaging stations entrusted to the Egyptian Irrigation.

Table 2.2.1.1.8. Egyptian Irrigation (River guaging stations) in the Sudan

River	W. level guaging	Discharge & W. Level guaging	Di sch a rge guaging	Discharge.W L. and sediment guaging	Total
Bhr El Ghazal system	7	26	5		38
Sobat system	8	13	3		24
White Nile	17	6	4		27
Main Nile	6	-	-	3	9
Total	38	45	12	3	98

The total guaging stations of the Nile system in the Sudan are 161 stations. About 60 (percent) of these stations are entrusted to the Egyptian Irrigation and 40 (percent) are admininstered by the Sudanese Ministry of Irrigation. Suspended sediment sampling stations are confined to the stations incorporated with the reservoirs and these are seven in number.

4 - Location of guaging stations

Generally speaking guaging stations have been established at the following places:

1. Near inflows of tributaries.
2. Near points where branches separate or join.
3. Near the inflows of rivers into lakes.
4. At upstream and downstream sides of dams.
5. For operational uses at points just out of the backwater effects of reservoirs.
6. At the national borders.
7. At main towns.
8. At easily accessible places between the above points if the river reach is very long.
9. At principal points of water abstractions and at sites of potential water resources development.

The network of the guaging stations seems to be adequate for the purpose of obtaining an insight into the hydrological situation as a whole and for the operation of the existing dams.

5 - Methods of guaging the water level of the Nile

Levels of the Nile are mainly measured by staff guages. The guage consists primarily of a scale, usually of marble, on which the level of the water is observed.

The standard type of the Nile guage consists of a series of steps to each of which a section of the scale is fixed. These steps are built into the river bank and the scale is protected by using walls to lessen the effect of the waves and so make it easier to observe. As a rule guages are read daily.

The levels of most of the guages have been determined by means of lines of level carried along the Nile and its tributaries. These lines of levels are based on an assumed value of 360.00 m for the level of the zero of Khartoum guage. This datum is known as the Irrigation Datum. The true level of the zero of Khartoum guage is 363.083 m. and is known as the survey datum.

The existence of two datums for the guages somtimes leads to confusion and error. Recently the tendency is to work on the survey datum only, but much effort is needed to comit all the existing guages.

6 - Methods of measuring the Nile discharges

Nearly all the discharges of the Nile and its tributaries are measured by current meters. Types of current meters commonly used are:

(1) Qurley current meters, bucket wheel rotor, American make.

(2) Ott current meters, propeller rotor, British make.

(3) Neyrpic current meters, propeller rotor, French make.

7 - Several means are used for measuring the discharge depending on the condition of the measuring site:

(a) By means of boat equipped with crane to suspend the current meter. The boat moves across the river by a cable way stretched across the river. This method is usually used in the White Nile and tributaries where the river is moderate in size and the current is slow.

(b) By means of guaging cableways where the current meter is moved along the cable by means of pulleys and winch on bank. This method is used in the torrential tributaries of River Atbara where the river section is moderate.

(c) By means of cableway with self propolling carrier. The carrier moves across the river on the cable way and measurements are taken from the carrier by the river technician. This is especially suitable for torrential rivers with wide section, and is used on the Blue Nile at El Diem guaging station.

(d) By means of a motor boat, the boat moves across the river and its position at the measuring points relative to fixed point on the bank is determined by a box section. This method is used in the main Nile and the lower reaches of the Blue Nile and River Atbara. It is suitable for very big rivers.

8 - The accuracy of the discharge measurements

With such a large number of discharges measured by means of different methods and many different observers under a wide range of conditions it is certain that there are large differences in the accuracy of observations.

Discharge taken under very close supervision and with well kept insturments, the probable error is less than 2 (percent). The error may rise to 10 (percent) for careless observations. The probable error adopted for discharges measured by current meters is 5 (percent).

9 - Data compilation

Ten-day mean discharge of the Nile and its tributaries at various sites have been computed in various ways.

The most general way is to plot a guage-discharge curve for the year, distinguishing rising and falling stages. From the curve the discharges corresponding to 5-day mean guages are read off and the 10-day means, monthly means and monthly totals computed from these. This method is adopted when a considerable number of discharges have been observed at a site during the year.

In cases the discharges are observed almost daily, the missed discharges are interpolated between the observed discharge and the straight foreward mean of the 10 - day discharges computed.

In cases no discharges were observed during the year at a site but the guages were read regularly, a general gauge - discharge curve is constructed from all discharges measured in other years at the site and the discharges corresponding to the 10-day mean guages read off this curve.

Data are compiled by the Nile control Department of the Egyptian Ministry of Irrigation in Cairo. Ten - day and monthly mean guages and discharges are published in a series of books, given the title, (The Nile Basin):

Nile Basin, volume (II) and supplements are for the measured discharges.

Nile Basin volume (III) and supplements are for the ten - day and monthly mean guages.

Nile Basin volume (V) and supplements are for the ten - day and monthly discharges.

Each supplement contains the data for five years.

All data up to 1967 are published.

It is always recommended that a data compilation centre for the Nile data should be established in Khartoum.

Compilation of data is done manually using out-of-date calculating machines. The time has come to introduce the electronic computor facilities.

The published data is exactly 10 years lagging behind. Facilities should be introduced to close the time lag between the observed data and the published data.

2.2.1.2. Gash and Baraka Rivers

2.2.1.2.1. Gash River

Gash river is a seasonal stream that collects its water from its catchment within the Eritrean highlands. From the point it enters the Sudan up to the proximity of Kassala town, the river consists of a wide sandy bed often more than a kilometre in width. From this point up to its delta the meandering course of the river had led to many branching, rebranching and silting - up of some of these branches.

Stream guaging had started in this river since 1907 and the following values could be representative discharges, at Kassala, for the period 1907 - 1964:

(a) average annual flow equals 0.56 billion cubic meter.
(b) minimum annual flow 0.14 billion cubic meter (1963)
(c) maximum annual flow 1.26 billion cubic meter (1929).

The above figures shows the high variation in annual flow quantities. Similar variation in discharge amounts were noticed during the flow season (July - October) itself.

There are at present 12 stream guaging stations distributed along the river course. In most of these stations, discharges are measured by the float method. Cross sections at guaging stations are surveyed before and after the flood period. In this season (1976-77) through the Dutch aid, automatic recording and current meter measurement were introduced at Kassala station.

The meandering course of the river together with the recently high spates of flood has constituted a continuous danger to the inhabitants of Kassala town. Training of the river course at that location is receiving, at present, a considerable attention.

2.2.1.2.2. Baraka River

Two main branches, Barka and Anseba, originate from the Eritrean highlands south of Kerin. Khor Langeb, a further feeder of the river, has its catchment within the hilly regions north of Gash Delta (inside Sudan). Baraka river is thus a torrential stream with large variations in its annual and seasonal flows.

The total catchment area of Baraka and its tributaries is estimated as about 45000 kilometre square. The unified river after Langeb junction has a wide sandy channel with a bed slope of about half meter per km. At about 33 km south of Tokar, the river is constricted into a narrow gorge at Shidden rock. Downstream of that gorge the river bed slope averages to about a meter per km. Six kilometres later on its journey the river reaches the coastal plains where it divides up into the delta and spreads in minor distributaries to the surface of the irrigated land.

The delta lies about 90 km south of Suakin city and forms roughly an equilateral triangle of 70 km sides (i.e. 386000 feddan in area). The delta, is however, very much affected by the action of silt and wind.

River Baraka is unfortunately unguaged, nevertheless, the quantity of annual flood was estimated by many authorities by using the flooded area. A reasonably accepted annual average value is estimated as about 0.45 billion cubic meter.

Another feature of the river is the heavy amount of silt carried by its flood water. That amount of silt is estimated as about 10.6 (percent) (by weight) of its flowing water.

The high silt content, together with the great variation in flow have led among other factors to the present difficulties in controlling the river.

2.2.1.3. Other Streams and Khors

2.2.1.3.1. Introduction :

There are quite a number of ephimeral streams with high potentialites all over the country. The need to evaluate such resources is vital and the practice of guaging some of these streams started early. Many of the surface water points on such streams are based on these records or on an estimate for the unguaged ones. Discharge and stage data are truely hydrological in nature and they are basic to the solution of most hydrological design and operation problems. Similarly lake or reservoir stage is used to derive changes in storage which is a basic factor in the water budget of a basin. The need for guaging (and since river flow is a natural phenomenon which never repeats) is to use some statistical approaches to the actual records so that some events of specific return period can be predicted for design purposes. Such events are quite important for the decision of the reservoir capacities and flood control, i.e. by proper design of spillways etc. The risk is minimised in such predictions as the records continue for longer periods.

2.2.1.3.2. History of hydrometric guaging stations

Gauging ephimeral (seasonal) streams is one of the main activities in the R.W. Corporation. This started in 1956 when it was Land Use and Rural Water Department, by constructing Arbaat guaging station in Khor Arbaat in the Red Sea province. Before the year 1966 when the Rural Water and Development Corporation was established there were only 11 guaging stations all over the country. Now there are 46 of them, and they will go up to 72 by the end of this season (June 1977) while the number will total 132 in the coming six years plan (1977 - 1983).

Table 2.2.1.3.1. and Plate 2.2.1.3.1. show the stations and locations and methods of guaging. The gauged streams are quite few and the period of gauging is still too short to give reliable and representative data. Three methods of gauging are used in this field.

2.2.1.3.3. Float method

About 40 of these stations are operated either by normal staff gauge or more than one together with a water level recorder or by a direct measurement of the depths using an observation well connected to the stream. The velocity is measured by a float thrown along a 100 m stretch and the average velocity is taken as 0.7 of the surface velocity. This factor is not the same for different streams, so some experiments are to be carried out using current meter or any other method in order ro revise it. The velocity and the stages are usually taken every 15 minutes during the flood on the streams with small catchments and great slopes. Other intervals are used in some other places (i. e. 1 hr., 2 hrs. and 6 hrs.). The cross section is taken twice before the wet season and after it and the average is used to allow for the erosion and deposition during the floods. No sediment transport measurement is taken .

Table 2.2.1.3.1. Hydrometric stations operated by rural water corporation

Serial No	Name of station	Stream	Coordinate Lat.	Long.	Province	Year of start	Method of gauging	Average annual discharge in cubic m.
1	Arbaat	Khor Arbaat	19 48	37 03	Red Sea	1956 up to date	Record-depth reading	17,810,000
2	Salloum	Khor Salloum	19 23	37 08	Red Sea	1958 - 1968	Staff reading-float	4,880,796
3	Adrous	Khor Adrous	19 06	36 32	Red Sea	1960 up to date	Staff reading-float	2,866,276
4	Gowb (A)	Khor Gowb	18 58	37 17	Red Sea	1957 up to date	Float-staff reading	6,495,920
5	Gowb (B)	Khor Gowb	18 57	37 16	Red Sea	1975 up to date	Float-auto-recorder	16,437,452
6	Arab	Khor Arab	18 21	36 16	Red Sea	1960 up to date	Staff reading float	16,309,894
7	Enha	Khor Arab	18 21	36 16	Rea Sea	1974 up to date	Auto-recorder-staff re-adingfloat	11,901,323
8	Tahamyam	Khor Arab	18 20	36 32	Red Sea	1974 up to date	Auto-recorder staff reading	4,577,258
9	Abu Fargha	Khor Abu Fargha	14 03	36 22	Kassala	1960 up to date	Auto-recorder-staff re-adingfloat	4,772,573
10	Azazat el Fil	Khor Azazat el Fil	13 19	25 18	Kassala	1966 up to date	Recorder-staff reading float	21,258,430
11	El Sagia	Khor El Sagia	12 30	35 10	Kassala	1967 - 1974	Float-depth reading	1,415,693
12	Abu ghamida	Khor Abu Ghamida	13 32	35 22	Kassala	1965 - 1973	Float-depth reading	1,070,843
13	Turdat Abu Zabad	Abu Zabad	12 21	29 15	S. Kordof.	1973 up to date	depth reading	---
14	El Sunt	Wadi El Galla	12 10	29 53	S. Kordof.	1965 up to date	Recorder-staff reading float	17,901,119
15	El Negaat	Wadi El Galla	11 43	28 39	S. Kordof.	1972 up to date	Recorder-staff float	44,270,741
16	El Daba El Tawila	Wadi El Galla	11 35	28 19	S. Kordof.	1973 up to date	Depth-reading-float	10,077,718
17	El Senata El Zarga	Wadi El Galla	11 06	28 01	S. Kordof.	1973 up to date	Depth-reading-float	6,504,534
18	El Far	Wadi Shalango	11 36	28 58	S. Kordof.	1968 up to date	Recorder-depth reading float	24,825,059
19	Shalango El Nabg	Wadi Shalango	11 28	28 56	S. Kordof.	1972 up to date	Recorder-depth reading float	69,962,119
20	El Dibakaya	Wadi Shalango	11 13	28 50	S. Kordof.	1973 - 1975	Recorder-depth reading float	69,507,118
21	Abu El Likry	Wadi Shalango	10 59	28 49	S. Kordof.	1973 up to date	Recorder-depth reading float	103,395,106
22	El Bardab	Khor El Berdab	11 12	29 40	S. Kordof.	1972 up to date	Recorder-depth reading float	50,097,002
23	El Kadi	Khor El Berdab	11 14	29 33	S. Kordof.	1973 up to date	Depth reading-float	4,042,112
24	El Kofa	Khor El Berdab	10 59	29 29	S, Kordof.	1972 up to date	Recorder-depth reading float	12,329,842
25	Meri Barr	Khor El Berdab	11 53	29 35	S. Kordof.	1970 up to date	Depth reading	
26	Umm Adara	Khor El Batha	11 10	29 21	S. Kordof.	1972 up to date	Recorder-depth reading-float	9,961,528
27	El Abbasiya	Khor El Abbasiya	12 10	31 19	S. Kordof.	1968 up to date	Recorder-depth reading-float	1,105,885
28	Abu Gubeiha	Khor Galli Batha	11 28	31 14	S. Kordof.	1973 - 1975	Staff reading-float	16,129,735
29	Rashad	Khor Rashad	11 01	31 04	S. Kordof.	1974 - 1976	Staff reading-float	8,519,638
30	Umm Berembita	Khor UmmBerembita	11 01	30 41	S. Kordof.	1974 up to date	Recorder-depth reading float	89,619,020
31	El Dilling	Khor Abu Habil	12 02	29 39	S. Kordof.	1974 up to date	Recorder-depth reading float	22,256,070
32	Abu Habil	Khor Abu Habil	12 39	30 42	S. Kordof.	1969 up to date	Recorder-depth float	100,000,000
33	Turdat El Rahad (Feeder canal)	Khor Abu Habil	12 32	30 24	S. kordof.	1969 up to date	Depth reading float	29,178,612
34	El Rahad Turda	El Rahad Turda	12 12	30 18	S. Kordof.	1969 up to date	Staff reading	---
35	El Ban Gadeid	Wadi El Ban Gadeid	13 04	30 14	S. Kordof.	1967 up to date	Reading depth of wells	---
36	Khor Bagara	Khor Bagara	13 02	30 22	S. Kordof.	1972 up to date	Staff reading	4,448,840
37	Abu gidad	Wadi Abu Sunt	14 07	23 14	N. Darfur	1964 - 1974	Recorder-depth reading	3,919,590
38	Tilfou	Wadi Abu Sunt	14 24	23 32	N. Darfur	1965 - 1974	Recorder-depth reading	2,707,991
39	Erigi	Wadi Abu Sunt	14 00	24 15	N. Darfur	1965 up to date	Recorder-depth reading	8,208,441
40	Afando	Wadi Kalkandi	11 53	25 10	S. Darfur	1972 up to date	Staff reading-float	20,949,666
41	Higeirat	Bahr El Arab	10 18	25 05	S. Darfur	1972 up to date	Recorder-depth reading float	607,222,187
42	Abu Likeilik	Wadi Abu Likeilik	10 44	23 41	S. Darfur	1973 up to date	Recorder-depth reading float	97,652,519
43	Idd El Ghanam	Wadi Kaya	13 43	25 31	S, Darfur	1973 up to date	Depth reading-float	45,182,982
44	Nashala	Wadi Ebra	10 59	20 32	S. Darfur	1973 up to date	Recorder-depth reading float	298,460,086
45	Timbusko	Wadi Bulbul	11 47	24 35	S. Darfur	1972 up to date	Recorder-depth reading float	55;844,862
46	El Hamra	Wadi El Hamra	12 54	25 03	S. Darfur	1973 up to date	Staff reading-float	261,843,993

This is recommended to start very soon and at least 15 (percent) of the existing stations should be equiped with sediment samplers. Previous flowscan be used to produce a sediment discharge curve. The base flow is ignoredin all streams which dry up completely after each flood and all the runoff isconsidered as the response of the storm causing the flood. In some stationslike Arbaat the base flow and levels are measured all through the year.

2 - Stations with current meter calibration i.e. Arbaat

The site is located in a gorge bounded by the two rock formation and it could be considered as a well defined and stable cross section. The calibration was done by a current meter suspended from a permanent cable way and correlation of stage flow is now used for analysis. The calibration was not covering extreme flows so an extrapolation was used for such high flows. A new current meter measurement is to be taken as a recheck for the previous calibration

3 - Rectangular gates in Khor Abu Habil was constructed since 1969 to control and distribute the water to Elsemeih canal, El Rahad Turda and the down stream of Abu Habil. Three rectangular gates are present of three meter width each, the water stages is taken from a staff gauge fixed at the gates and a water level recorder is installed downstream.

2.2.1.3.4. Comments

As the need for these hydrological data for both the planner and the designer is vital some new techniques are to be introduced to cope with the high demand for such data. To find a natural suitable site is quite difficult so some modification of these courses are to be started and new techniques such as V - shape, rectangular weirs and partial flumes are to be used. These might look more expensive but it proved to be more economical in the long run. Current meter measurements chemical injection methods are to start in some of these stations. The operation of these stations now started to be undertaken by qualified staff who know how important the accurate and reliable data is. A well defined future plan is to be studied so that this net work can be close to the international standards (1000 - 2500 square km of catchment). Some representative areas are to be selected (i.e. sandy, clay bed materials, etc.) so that new actual coefficients can be revised as runoff coefficients, roughness factors, anticident water index, etc.

The purpose of these studies was only total flows of the stream for construction of hafirs and small dams but other parameters are to be accounted for as run off coefficients, base flow, design floods (frequency magnitudes and duration), dry years and minimum flows. Very few studies tried some approaches to evaluate the runoff coefficients of some small catchments. The limitations for these studies were the lack of existing rainfall records within the catchments,other data like evapotranspiration, infiltration rates and correct effective catchment areas.

2.2.1.3.5. Runoff coefficients

Some trials were made to evaluate such factors which are governed by type of catchment soils, slope, soil cover, size of catchment, rainfall pattern etc. This is quite important to design hafirs and dams according to the catchment yield. A study is made for Elfar stream in Kordofan, a main tributary of Shallengo (Savannah project Phase I, 1973) and the average runoff was 2 - 3 (percent) with the extremes of 1 (percent) and 11 (percent). For this computation rainfall from Lagawa and Dilling were used and both were outside the catchment. This figure was confirmed later as 2.0 - 3.1 (percent) in the (Savannah project Phase II, 1976).

Another analysis of Wadi Kaya in Southern Darfur where they used the U.S.S.C.S. curves and they came out with a figure for local runoff ranging between 1.6 and 6.14 i.e. an average of 2.98 per cent which is quite close to Kordofan estimate. For Wadi Bulbul the coefficient was higher using the same method (HTS 1974).

In the Savannah project Phase II, March 1976 analysis for runoff were computed from rainfall and flow records for the main streams in Kordofan i.e. Wadi Elgalla, Shellengo, Elfar, Elberdab, and Elbatha., Table 2.2.1.3.2. shows different streams which were studied including Abu Fargha water shed studied by a technical committee in 1973 and by M.T. El Hag (M.Sc.in 1974). The data used were flow measurements for 13 years and the corresponding precipitations. From the table it is evident that three main catchments yields are present. Wadi Elgalla, Elbatha, Wadi Kia and Wadi Ibra represent streams in sandy planes with

Table 2.2.1.3.2.Runoff coefficents for different streams

No.	Stream	Catchment area in sq. km.	Average annual rainfall mm.	Average total flow cubic m.	Average annual runoff coef-fici-ent %
1	Abu Fargha	110	575	4,772,258	7.5
2	Wadi El galla	2300	470	17,901,119	1.7
3	El far	1000	649	24,825,059	3.8
4	Shellengo	2500	649	69,962,119	4.3
5	El berdab	980	620	50,097,002	8.2
6	El batha	865	635	9,961,528	1.8
7	Wadi Kia	3329	595	43,100,000	2.2
8	WaDI Ibra	1506	525	29,700,000	3.7
9	Arbaat	4000	46,5	17,810,000	9.6
10	Goub	296	184	6,495,920	11.9

"catchment gauged catchment only".

low runoff ranging from 1.7 - 3.7 (percent). Abu Fargha represents heavy clay soils with steep slopes 7.5 (percent), together with Elfar, Shellengo and Berdab of clay and loam with coefficient ranging from 3.8 - 8.2 (percent). A representative of Jebel catchment, Goup and Arbaat with sub surface flow under the sandy bed ranging from 9.6 - 11.9 (percent). These values can be used to estimate the annual yields expected from different catchments. For design of spillways the extreme flows runoff should be used. (The Technical Committee for Abu Fargha gave a figure of 46 (percent) during the catastrophic flood in September 1973).

2.2.1.3.6. Roughness factor

This factor can be revised using stream records (levels and discharges), which could be used to estimate missing floods and flows in ungauged streams when maximum levels and durations are known (from water marks and local people). The figures used in estimating flows are taken from the empirical formula suggested by Ven Te Chow for different conditions in different streams. In the study of Khor Abu Fargha actual roughness factors are evaluated ranging from 0.0300 to 0.0378 with an average value of 0.0325. By Ven Te Chow method the factor is overestimated (0.04). and thus the expected flow is less than the actual as the flow is in inverse proportion to the roughness. Other computations for representative streams are to be carried out.

2.2.1.3.7. Assessment of ephemiral streams water resources

Out of 46 gauging stations 42 of them are measuring direct flows (others measuring water levels in lakes and Turdas). The annual average flows are of the order of 2.15 billion cubic meters. If we exclude those contributing directly to the Nile tributaries 1.4 billion is lost either by evaporation or infiltration. The gauged streams are about 20 (percent) of the total ephemeral streams in Sudan (ephemiral streams are expected to yield about 7 billion cubic meters). Some main streams are not gauged like Yobous in Blue Nile and Azom in Darfur. An estimated annual yield of 350 million cubic meters is expected from Khor Azom and a similar from Yabous.These represent the largest streams which do not flow to the Nile tributaries.

2.2.1.3.8. Recommendations

For a country like Sudan with vast areas depending entirely on water resources and land use, more attention should be given to the field of hydrology with both funds and better organizations. For improvement of work and more benefits from the hydrological studies the following points worth mentioning.

1 - For more efficient work only one body is to be responsible for water resources all over the country.

2 - Due to the direct inter-relation between surface and ground water (hydrologic cycle) both studies should go together.

3 - A joint effort is needed to collect and sort out the previous reports and data scattered in different places and put them together and at hand for use.

4 - A plan is to be considered and since Sudan is very wide with limited finance the best is to make studies on some representative areas. Regarding stream gauging priorities are to be given to those with high potentialities and promising future development.

5 - The existing rain gauge network should be intensified and more recording gauges are needed for hydrological studies.

6 - More attention is to be given to other hydrological elements (evaporation, evapotranspiration, soil moisture, ground water levels, etc.).

7 - Exchange of information and experience with other countries of similar climatic conditions and with international institutes for water resources.

8 - Training of staff on modern techniques for hydrological data collection.

9 - Introduction of standard computer programmes to be used in analysis of hydrological data.

10- Use can be made of the air photographs and the newly introduced remote sensing programmes to renew the obsolete quarter million scale topographical maps.

11 - Special attention is to be given to river training.

12 - Specialists are asked to lead a nation-wide campaign and explain the importance of water resources for a country like Sudan.

2. 2. 2. HAFAIRS AND DAMS

2. 2. 2. 1. Introduction

The practice of hafirs (an open excavated reservoir 2-8 meters deep with capacity up to 500,000 cubic meters started very early when people used to dug small ponds in the natural depressions to reserve water for the dry period. this practice was developed later and machinery was introduced for excavation. The responsibility of developing rural areas in Sudanis undertaken mainly by the R. W. Corporation through its surface and ground water administrations. 809 hafirs with total capacity of 18 million cubic meters were excaVATED BY THE END OF SEASON 1975-76 TOGERHER WITH 32 EARTH AND MASONRY DAMS OF CAPACITY 24.5 MILLION CUBIC METERS (SEE Table 2.2.2.1.1 and plate 2.2.2.1.1) and small check dams as water spreading schemes for cultivation with a total watered area of 4,000 feddans. It is planned to construct 200 hafirs and dams in the coming six years. It is very difficult to evaluate these hafirs and dams since the number of people using the hafir is not fixed (specially in nomadic areas) and some of them serve all through the dry periods. others get dry in the first 2-3 months. pattern of construction is given in Figs 2.2.2.1.1. and 2.2.2.1.2.

2.2.2.2. Conventional hafirs

These hafirs are usually sited in places where both the soil and hydrology are favourable. It is of rectangular plan with a shape of an inverted frustrum of a pyramid having slopes of 1:2 or 1:1.5 along the longsides with 1:3 or 1:4 on the end rams to allow machines to work. There are two types of hafirs with respect to feeding.

iOn stream hafirs: these are usually on small stream and the hafirs is sited across the course. Spillway is needed to safeguard the hafirs in case of extreme flows. Designs of such hafirs need a good hydrological data about the stream and its annual expected flow. The advantage of such hafirs is that they take all flows from the stream.

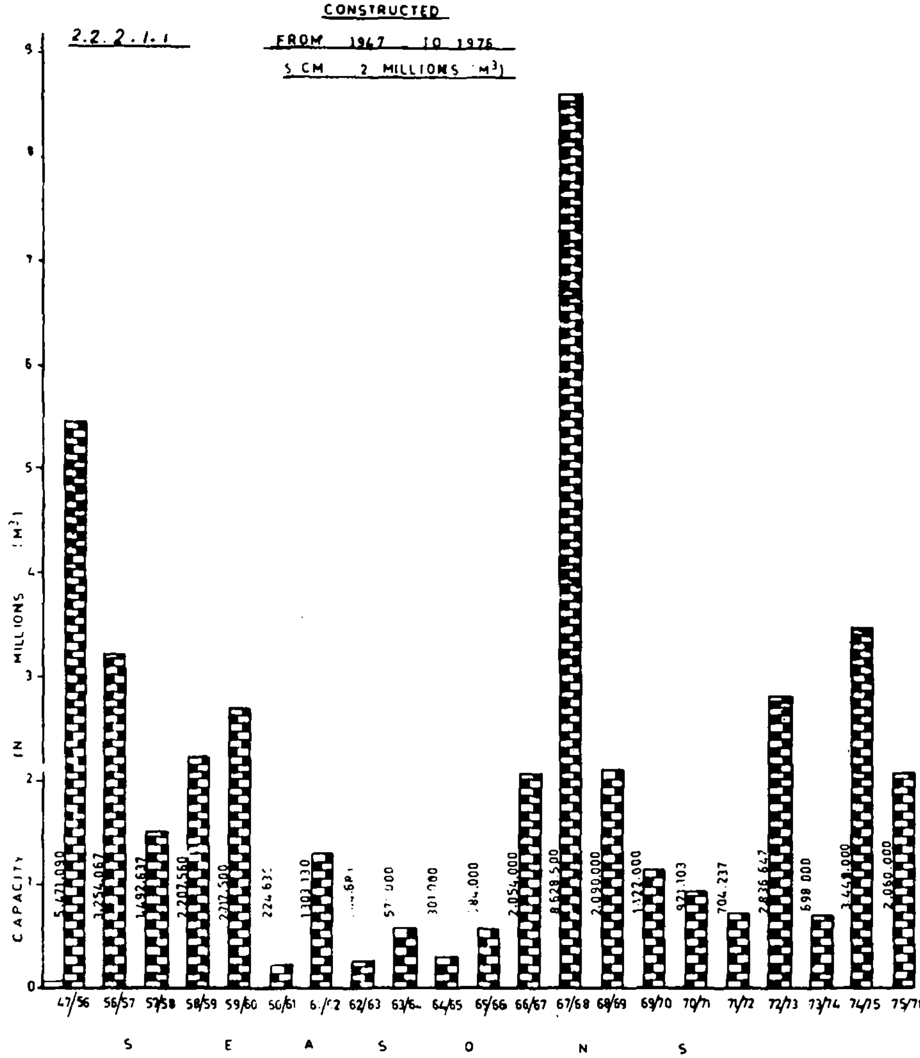
ii.Off-stream hafirs: these are sited away from the course and they are filled by a feeding canal connected to the stream. Many of these hafirs can be fed from one stream at a time. a small weir may be needed to raise the level at the intake.

2.2.2.3. Other types of hafirs

As more hafirs are excavated. sites for traditional hafirs became rare and new approaches have to be adopted. As the traditional requirements are both favourable soil and availability of stream : these are not always met. so when the soil is good for storage and no defined course is present the hafir can be sited near a hill or a jebel (jebel catchment) and the run-off from this high spot can be collected by guiding walls with canals on the side facing the jebel to fill the hafir.

CAPACITIES OF HAFIRS & DAMS

CONSTRUCTED



MASS CURVE

1 cm. = 2 Millions (M^3)

Fig 2.2.2.1.2

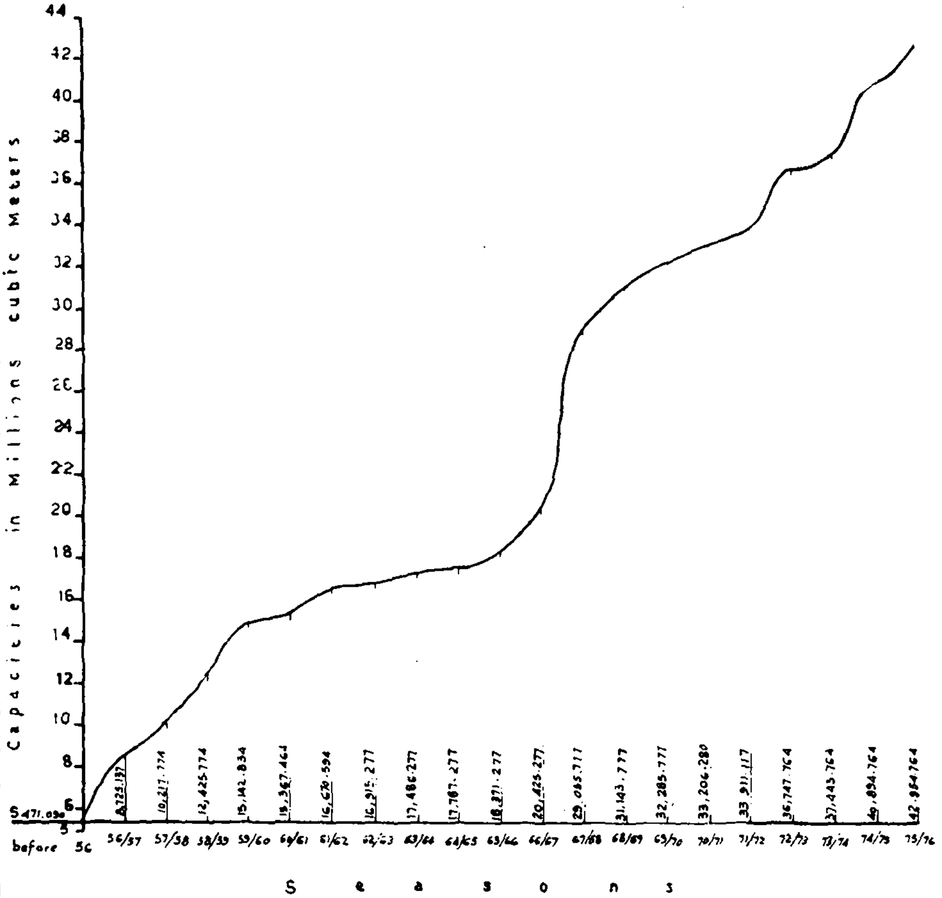


Table 2.2.2.1.1. Dams and hafirs in Sudan

Serial No.	Province	Hafirs Total	Capacity m	Dams Total	Capacity m^3	Embankments Total	Capacity m^3	Wiers Total	Capacity m^3	W spreading scheme Total	Watered area m^3
1	Red sea	1	60,000	-	-	-	-	-	-	8	16,230,316
2	Kassala	127	3,307,294	3	401,137	1	120,000	-	-	-	-
3	White Nile	33	727,621	-	-	-	-	-	-	-	-
4	Northern Kordofan	89	2,782,913	1	2,000,000	1	60,000	2	181,000	-	-
5	Northern Darfur	56	2,359'210	22	14,254,000	-	-	-	-	-	-
6	Blue Ninle	139	3,284,993	1	650,000	-	-	-	-	-	-
7	Southern Kordofan	238	4,348,028	3	4,771,500	-	-	-	-	-	-
8	Southern Darfur	45	376,549	1	480,000	-	-	-	-	-	-
9	Upper Nile	78	803,539	-	-	-	-	-	-	-	-
	Total	806	18,050,147	31	22,556,637	2	180,000	2	181,000	8	16,230,316

Some precautions are to be made since the run-off come under high velocity due to the slope and the high velocities make a lot of erosion ; so siting of hafirs of this fastly expected. Other types are self catchment hafirs where some artificial drainage is made to collect and guide the water to the hafirs.

2.2.2.4. Lined hafirs

In some parts of rural areas (i.e. Hamer) where ground water is scarce and the soil is very sandy other techniques are introduced for lining the hafir to minimize the seepage losses. Some lining materials are used such as asphalt, clay and P.V.C. membranes; the later was attacked by termites and hence discarded, butyl lining and polythene membranes are used in some hafirs but a definite assessment is not yet arrived at.

In 1970 (HTS and MMP) in their project of Darfur water resources established an experimental yard under the supervision of the institute of hydraulic research in England (Lunya Experimental hafirs). The experiment was done on 6 hafirs(3) ined with polythene membranes and (3) with a clay and one unlined hafir as a control. Measurements of evaporation and water use and levels are recorded daily. In 1973 in their report they concluded that the membrane use is preferred although 20 (percent) seepage was recorded compared with that from the unlined hafir. They recommended that the experiments should continue for another three seasons and their final report is due now. Another experiment was done by the same firm and its purpose was to provide water for small communities using sausage-type polythene tanks. The aim was to investigate both the efficiency of the catchment and that of the tank itself (Suwellinga village tank). They concluded that 18 (percent) of the total volume was lost by capillary evaporation through the back fill of the tank. The experiment continued for another three seasons at their request because the tank developed some leakage as well. Again the problem of termites damaging the membrane was serious and using insecticides should be studied so as not to mix with the drinking water.

2.2.2.5. Overground storage hafirs

Another approach which is practiced in some areas and where clay depths are limited to 2 - 3 meters is to use some overground storage. This is done by raising the embankment to store adequate quantity which is transmitted by pumping and a check valve is needed so that water will not drain back. Attendance is needed in this case which might be a problem in some remote areas, since in conventional hafirs no attendance is required during the rainy season.

2.2.2.6. Efficiency of hafirs

Four problems are faced which affect the efficiency of hafirs.

i. evaporation
ii. seepage
iii. silting
iv. mis-use.

(i) Surface water evaporation : is the main problem in open hafirs and dams, evaporation at Ghazalla Gawazat showed 2366 mm annually (Fenman) and 2374 mm (Piche). If we exclude the evaporation in the wet season (about 700 mm), the net evaporation from these areas is 1674 and for a hafir of 5 m depth the evaporation loss is 33.5 (percent) for a vertical hafir, as the hafir is sloping the losses is about 3 (percent) more; about 37 (percent) is lost by evaporation in an average hafir. This figure increases as the depth decreases. Some measures are taken to reduce these losses, a good example is used in Khor Bagara scheme which supply El Obeid town. Three hafirs are constructed at the side of the dam and as the level drops the water is diverted to the hafirs, to reduce the evaporation area. Then the water is pumped from one hafir to the other two as consumption goes on and finally the water is stored in one hafir.

(ii) Seepage losses: although the soil is tested before construction, a perfect impervious layer is not practiced. Seepage detection is not easy in hafirs since no reservoir operation is carried out but an average of 10 (percent) losses due to seepage and leaks is expected in hafirs. The seepage losses decreases with the life of hafirs as fine particles settle on the bed and the slopes of the hafir. These fine sediments tend to seal the pores.

(iii) Silting of hafirs: in hafir design some silt traps and stilling pools outside the hafir are considered to minimize the silt entering the hafir. They are quite efficient but still the hafir get silted with a rate 10 - 20 cm. annually. Desilting is a common practice and it is normally done between 8 - 10 years when over a meter of silt is accumulated.

(iv) Misuse of water: the primitive methods used to withdraw water are quite inefficient. Quite considerable quantity of water is lost by splashing and leaking tins around the well. Hand pumps are used in some hafirs but the misuse always make them out of order.

From the previous analysis the efficiency of an average hafir expected is 40 - 45 (percent) By minimizing these losses by using closed hafirs or hafirs with intrnal compartments the efficiency can be raised up to 65 - 70 (percent). Some techniques are introduced in Australia using tiny rubber balls at the water surface which cut down the evaporation by more than 60 (percent).

2.2.2.7. Dams and embankments

Earth and masonry dams are quite common when conditions are favourable.

Unlike hafirs they need proper investigations and adequate data on hydrology, geology, topography, ecology together with land use and soil survey. In some places (Sinut in Kordofan) dams achieved permanent settlement of some of the Messerya tribe area. In Baw dam in Ingessana hills small irrigation schemes were designed as one of the purposes together with the water supply to Baw itself. Khor Baggara dam proved to be the cheapest solution for the crisis of El Obeid water supply. It's capacity is planned to be almost 5 million cubic meters when the project is completed. Problems facing design of small dams are inadequate data on hydrology and prediction of design floods, the short duration of records does not give a good estimate for extreme floods on which design of spillways is based. In some masonry dams this problem is not faced and the whole dam acts as a water way. Possibility of the reservoir getting polluted should be accounted for and prevented. Seepage is also serious when the strata underneath is fractured.

2.2.2.8. Water spreading schemes

People used to cultivate in a small scale on the slopes of the dams and even in the hafirs (which is not allowed). The idea of water spreading schemes born in 1970 was due to the great quantities of water flowing from the streams to the Red Sea. The rural water corporation started to build small check dams along the khor, so that these watered areas can be cultivated after the wet season. Although this field is starting but it proved to be quite useful for development of these areas. Vast areas of fertile lands are available on the courses of the streams together with large quantities of water flowing in these streams. Proper studies are needed so that the water can be distributed fairly along the course. These complications of distributing water should be solved and a control and monitoring system for the wadi flows should be established. 8 series of dams were constructed with a total watered area of 4000 feddans.

2.2.2.9. Purification plants

The idea of improving the quality of water conducted from urban areas to rural areas is starting now. It is now considered to supply pure water to the people instead of that with poor quality. In the rural water corporation about 20 filter plants were constructed as follows:

i. 8 slow sand filters with capacities up to 20,000 gallons per day.
ii. 12 pressure filters with capacities varying from 500 gallon per hr. to 5000 gallons per hr.

2.2.2.10 Lakes and depressions

Very few of the rural streams contribute to the Nile tributaries as direct surface flow. Some of them just flow in flat deltas or disappear as subsurface runoff or ground water recharge. The third type of streams terminate in lakes or depressiens. No proper studies have been initiated for the different scattered lakes which contribute to the water resources in Sudan. Khor Abu Habil in Northern Kordofan contribute to El Rahad Turda by 56 million cubic meters which is used for irrigation and water supply for El Rahad village. This turda has been deepened and a proper feeding canal is connected to the main stream. Turdat Abu Zabad (Doxiadis 1969) receives over a million cubic meters which infiltrates and recharge the shallow wells scattered in the bed of it. Lake Keilak in Southern Kordofan receives more than 40 million cubic meters from El Berdab as subsurface flow and from Khor El Batha. There are many others which need quantitative survey and water levels to evaluate their water resources.

2.2.2.11. Domestic use (human and animals)

The rural water corporation adopted an estimate of daily water consumption in rural areas as follows (human consumption rate has to be increased as demand for water is increased):

Human	**- 4 gallons per head per day**
Cattle	**- 6 gallons per head per day**
Horses and donkeys	**- 5 gallons per head per day**
Sheep and goats	**- 2 gallons per head per day**
Camels	**- 5 gallons per head per day**

(Camels drink at intervals of 2-10 days according to temperature).

The total human population of the nomadic and rural areas is 9 millions (1973 census) with 2.8 rate of growth say 10 millions now and 11.5 in 5 years time. If we assume that 10 (percent) will use water from the Nile and its tributaries then 70 millions cubic meter of water is needed annually.

The animal population (taken from Ministry of Natural Resources):

Cattle	13.89	millions
Sheep and goats	27.79	
Camels	2.63	millions

Using the above rate of consumption the annual water needed for livestock is about 250 millions cubic meters. Assume 20 (percent) of the livestock will be watered from the Nile and its tributaries and 60 per cent are watered from stagnant waters during the wet season (say 4 months) then 160 millions will be required by livestock. The total for human and animal will be 230 millions cubic meters of water annually.

2.2.2.12. Available water from hafirs and dams

Assume 45 (percent) efficiency of hafirs as estimated before (losses due to evaporation, seepage, silting and misuse) and 20 (percent) of water of dams is used for domestic supply then water available is:

18 x 0.45 = 8.1
24.4 x 0.2 = 4.9 i.e. 13 millions cubic meter

Ground water abstracted 62.64 millions
Hand dug wells 1.20

The total of water available is about 76 millions cubic meter. The water which should be provided is 153 million. It is liable that 40 (percent) of this deficit should be provided by surface water points then the number needed will be about 3000 surface water points ultimately.

2.3. GROUND WATER RESOURCES OF THE SUDAN

2. 3. 1. Introduction

Knowledge about the geology of the Sudan started to appear as unpublished reports since 1904 Grabham (1909) published a report about wells of North-Eastern Sudan and in 1934 he discussed the water supplies of the Sudan. In 1948 a comphrehensive account of Sudan geology with the first geological map for the country was published by Andrew (in Tothill 1948). More detailed geoloical maps of different scales were published in 1950s. after independance systematic regional mapping with special emphasis on ground water supply was carried out by Sudan Geological Survey Department.
dophysical surveys were accomplished in many areas. Many published and unpublished reports were written by the geologists of the Geological Survey dealing with ground water all over the country.

Land use and rural water development (1956-1966) drilled hundreds of wells for water supply in the rural areas.
In 1966 Rural Water Corporation was created. Thousands of boreholes were drilled in the rural areas for water supply. Foreign companies were contracted to execute drilling programmes and hydrogeological investigations especially in the western part of the country. By now a wealth of hydrogeological data is available and much work is needed to use these data in the evaluation of the ground water resources of the country.

2. 3. 2. SUMMARY OF GEOLOGY OF THE SUDAN

the geologicAL FORMATIONS WHICH HAVE BEEN DISTINGUISHED WITHIN THE COUNTRY ARE: 1 The basement complex of the pre-cambrian age, 2. The Paleozoic Sandstone of late Paleozoic age, 3. The Nawa formation of pre-Mesozoic age, 4. The Nubian Sandstone formation of Mesozoic age, 5. The Yirol beds of mesozoic age, 6. Hudi Chert of Oligocence age, 7. The Volcanic rocks of tertiary age, 8. The Umm Ruwaba and El Gezira formations of Plio-Pliestocene age, 9. The Red Sea marine deposits of Quarternary age, and 10. The superficial deposits of Pleistocene to recent age (Fig. 2.3.1.).
The basement complex rocks are the oldest and most extensive rocks. They consist of igneous and metamorphic rocks such as granites, gabbros, schists gneisses and marbles. Since the basement rocks were formed they have been subjected to structural deformation. A long period of quiescence followed the evolution of these rocks during which erosion took place and uneven surface was formed. In the Paleozoic time shallow seas invaded the western part of the country where the Paleozoic sandstone and Nawa formation were deposited.Before the close of the Paleozioc time uplift took place and most of the Paleozoic sandstone and Nawa formation were removed by erosion. At the Mesozoic time shallow

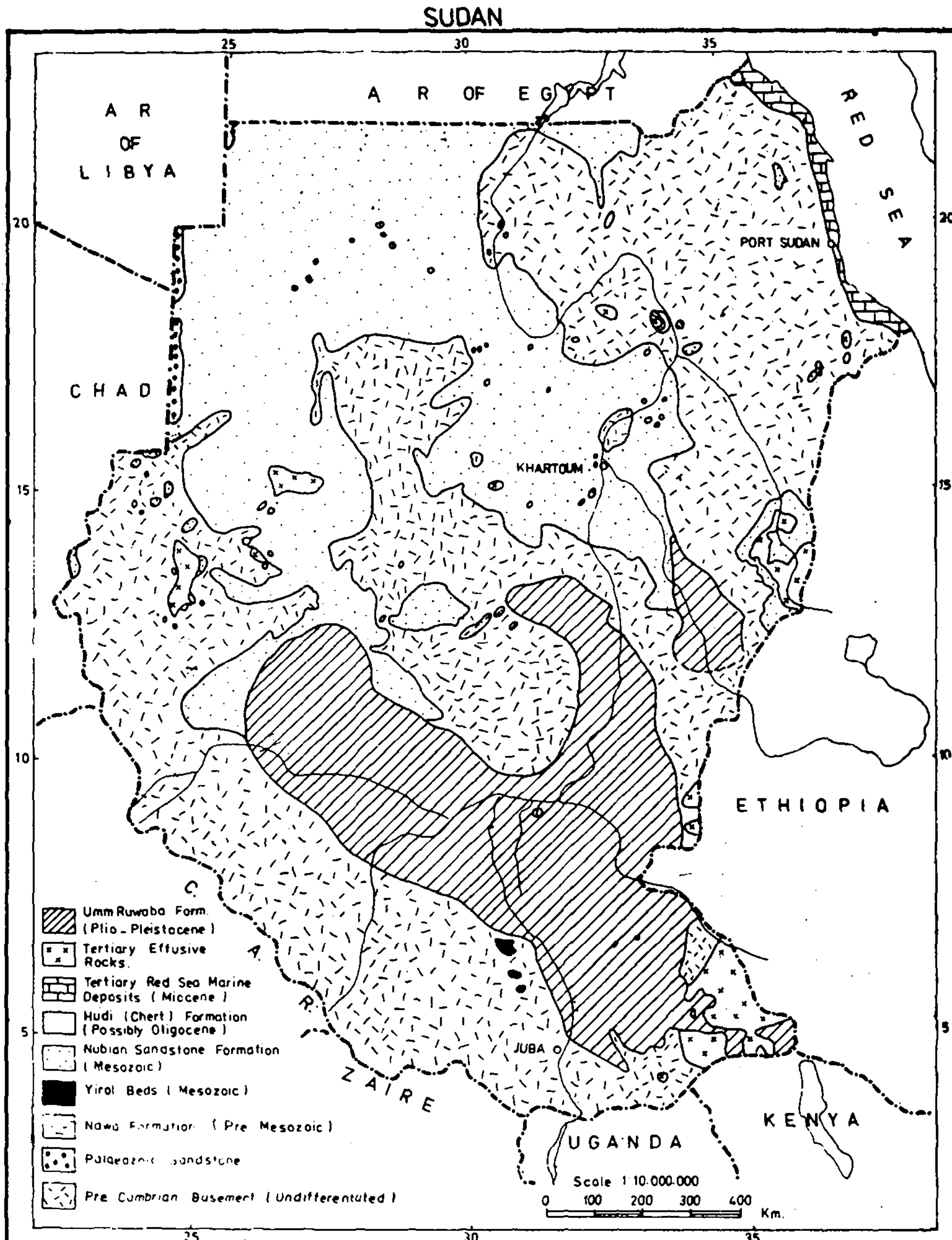


Figure 2-3-1 Geological Map of the Sudan

continental sea covered many areas in the country. During this time the sediments of the Nubian sandstone formation were laid down in a continental and -or shore marine environments. In the middle or late Tertiary time.tectonic movement in eastern Africa took place resulted in the formation of several structural basin in the basement rocks and Nubian sandstone formation. Such basins are bara-Umm Ruwaba, Kosti-Malakal and Juba- Abu Gabra basins. This movement was associated with volcanic activities which formed Jebels Marra and El Meidob in Western Sudan, Bayioda area in the Northern province, Jebel El Toriya South of Omdurman, and in some areas along the eastern boundaries between Sudan AND Ethiopia.

During Plio-Pleistocene time the above mentioned basins were filled with fluvial, lacustrine and deltaic sediments of Umm Ruaba formation.
several types of superficial deposits were laid down to include aeolian Qoz sands, lateritic ironstone, dark heavy clays and alluvial deposits.

2. 3. 3. MAJOR WATER BEARING FORMATION OF THE SUDAN

The main aquifers of the Sudan in order of importance are:
The main aquifers.of the Sudan in order of importance are.

1. Nubian sandtone formation
2. Umm Ruwaba formation
3. El Gezira formation
4. The alluvium
5. The basement complex rocks.

The geology and hydrgeology of these aquifers will be discussed in details:

2. 3. 3. 1. NUBIAN SANDSTONE AQUIFER

i. Geology of the Nubian sandstone formation:

a. Historical background

Russeger (1837)used the term "Nubisher sandstone" to the brownish sandstones resting unconformably on the basement complex in the Nubian area in southern Egypt.

Said (1962) used the term Nubian sandstone to include "the brownish highly dissected and almost horizontal sandstone beds covering parts of Egypt and Nubian and also to include any non-fossiliferous sandstones in the entire Paleozoic and Mesozoic succession". He suggests that the Nubia sandstone should be retained as formation names. In this respect, Said followed Hume (1906), Shukri and Said (1944), Shukri (1945) who described this formation in Egypt.

In Sudan, Beadnell (1909) first used the term "Nubian Series", Edwards (1926) identified some cretaceous plant fossils from a basal cilicified sandstone capping Jebel Dirra cast of El Fasher, Darfur province.

Sandford (1935) adopted the "Nubian Series" term and aplied it to the rocks in the northwestern Sudan which he thought to be of post-Paleozoic and pre-T ertiary age.

Andrew (1948) used the term "Nubian Series". Kleinworge and Zecheked (1958); Rodis et al. (1964) and Karkanis (1965) also used the term "Nubian Series".

Andrew (op cit.) describeb the "Nubian Series" as consisting of brown, buff, reddish, pink, and white sandstone interbedded with variegated mudstones, with silicified sandstone particularly present towards the base of the series. The sandstone are poorly cemented and friable, but hard ferricrete (ferruginous) beds often cap the hills. The Nubian series is characterised by the general absence of basal conglomerates except for isolated occurances found resting on the Basement Complex. According to Andrew the Nubian series is of Mesozoic age, probably Cretaceous and rests on an uneven and irregular crystallino floor.

Whiteman (1965,1971) used the term "Nubian Sandstone Formation" to include these bedded and usually flate-lying conglomerates, grits, sandstones, sandy mudystones, and mudstone that rest unconformably on the Basement Complex and Paleozoic sandstones and are older than the Hudi Chert formation (early Tertiary) and the "Early Tertiary" lavas.

Kheiralla (1966) recognised the following lithological types in the Nubian formation in the Shendi-Khartoum area:

1. Pebble conglomerates
2. Intraformational conglomerates
3. Merkhiyat sandstone
4. Quartzone sandstones
5. Mudstone.

According to Kheiralla (Op cit.) the Merkhiyat sandstones form the bulk of the Nubian Sandstone Formation and are characterized by (1) high clay-silt content, (2) abundance of white specks, probably kaolinized feldspar fragments, (3) pebbly nature, (4) occurence of interbedded intraformational conglomerates, pebble conglomerates and mudstones, (5) well developed cross-s tratification, and (6) abundant fossil wood.

The quartzose sandstones are well-bedded, non-pebbly, clean, well sorted, composed of pure quartz, coated with iron oxide and contain fossil ripple marks and furrow structure.

Pomeyrol (1968) suggested that the term "Nubian Sandstone" must be abandoned because it has been used too loosely.

Whiteman (1970) proposed that "the Nubian Sandstone Formation" should be designated to the Nubian sandstone group. He proposed that the Merkhiyat sandstones and the quartzone sandstones of Kheiralla (1966) which previously considered as members should be elevated to Omdurman and Shendi Formation respectively.

b. Lithology

Surface geological work and subsurface data show that the Nubian stone is composed of the following lithological types: 1. Sandstone, 2. mudstones, 3. intra-formational conglomerates, 4. conglomerates and 5. basal conglomerates:

1 - Sandstones

The sandstone component of the Nubian sandstone formation includes the poorly cemented sandstones, ferruginous sandstones, silicified sandstones, and silicified ferruginous sandstones.

The bulk of the Nubian sandstone is formed of poorly cemented sandstones sandstones which include medium and coarse - grained sandstones (abundant) and comparatively few beds of fine grained sandstones. Characteristically these sandstones are poorly cemented, highly porous and permeable. Almost all the boreholes drilled in the Nubian sandstone in central Sudan show this type of the sandstone. The cement is mainly silica, clay minerals, calcium carbonates and iron oxide. The interpreted data of size analyses indicate that the poorly cemented sandstone would generally be described as very coarse,to coarse - grained poorly to moderately sorted, near - symmetrical to coarse skewed, platykurtic to mesokurtic sand (Saeed, 1974).

The ferruginous sandstones mainly occur as prominent thick beds capping the Nubian sandstone hills, in some cases, as thin bands at some intervals within the Nubian sequence. The silicified sandstones are common in the Nubian sandstone formation. These beds, in most cases, are found to cap some of the Nubian hills and also, in very few cases, occur at the bottom of some hills. They show all variation in grain size and colour.

2 - Mudstones

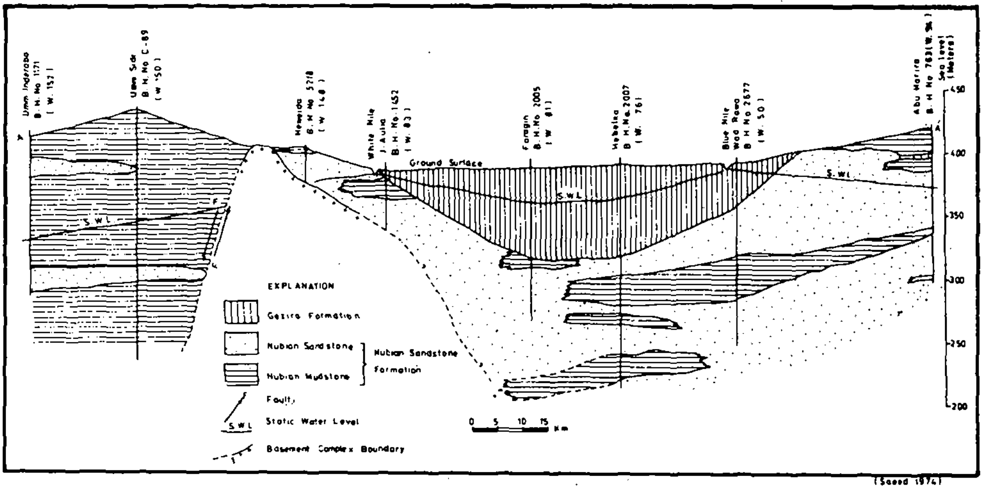
The mudstones include claystone siltstone and their sandy mixtures. The most common variety is the sandy mudstone. The mudstones occur as lenses interbedded in the poorly cemented sandstones and exhibit wide vertical and lateral variation in thickness. The colour of the mudstones, in most cases, depend upon the degree of ferrugination. It ranges from buff, yellow, pink, purple grey to black. From the surface and subsurface data different varieties of mudstones are recognized and include: white mudstones, forruginous mudstones, silicified ferruginous mudstones and grey carbonaceous mudstones. The mudstone lense-shaped beds are found at different horizones. The lenses extend for several kilometers. Their thickness varies from few meters to more than 120 meters. In some places, mudstone may be prominent in the Nubian sandstone formation. Figure 2.3.2. is a geological cross-section in the Nubian sandstone formation at Khartoum province.

3 - Intra-formational conglomerates

The inter-formational conglomerates, like the mudstones, are intercalated in the poorly cemented sandstones, they show a great variation in areal and vertical distribution. The intra-formational conglomerates are composed of mudstone frag ment incorporated in a sandy matrix. The mudstone fragments have different shape and sizes.

4 - Conglomerates

The Nubian sandstone hills are in few cases found capped with



(Saeed 1974)

Figure 2.3.2 Geological Cross Section at Khartoum Province

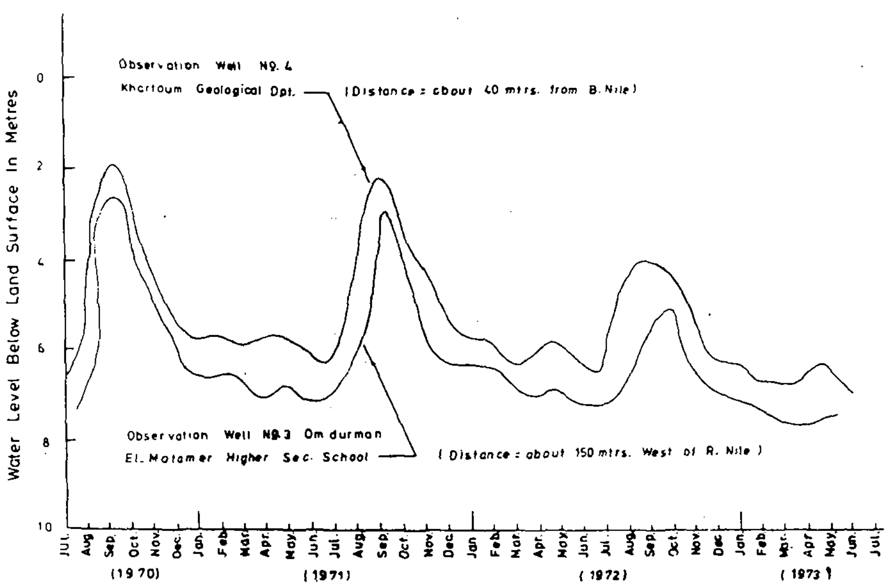


Figure 2.3.3 Seasonal Water Level Fluctuations in Khartoum and Omdurman Towns

(Saeed 1974)

conglomerates beds. Data from boreholes indicate that conglomerate also occur as intercalations within the poorly cemented sandstones. The conglomerates are composed of well rounded, rather elongated pebbles, predominently made of quartz, quartzites and few phyllites in sandy matrix. The average size of pebbles ranges from 3 to 5 cm in diameter. Sorting is poor to moderate and cementation is controlled by the degree of forrugination and silicification.

5 - Basal conglomerates

The basal conglomerate forms the lowermost bed of the Nubian sandstone formation, but it is not uniform and continuous throughout the base of the formation. It is composed of boulders, cobbles, and pebbles randomly embedded in a very ferruginous sandy matrix. The boulders, cobbles and pebbles are well to very well rounded, disc-shaped or elongated and composed of quartz quartzites, colloidal silica and few phyllites. The basal conglomerate defines the unconformably contact between the basement complex and the Nubian sandstone formation.

(c) Distribution and thickness of the Nubian sandstone formation

The Nubian sandstone formation occupies about 28 (percent) of the total surface area of the Sudan. Most of this formation is situated north of 12 N. (Fig. 2.3.1.). The formation is either cropping cut or covered by superficial deposits, Gezira formation, Umm Ruwaba formation or Tertiary lavas as shown in Fig. 2.3.1. The formation is usually flatlying or very gently dipping.

The thickness of the Nubian sandstone formation ranges from few meters near the basement complex rocks to more than 2000 meters at its deep trough. The maximum thickness recorded from the borehole data is not exceeding 500 m below land surface, but geophysical surveys carried out in the Nubian sandstone formation in different areas indicate that its thickness is more. Example of these are: Mula (1971) postulated a thickness of 1680 meters at Dagal basin which lies north of Jebel Aulia, Khartoum Province. The geophysical surveys carried out at Darfur Province, by Hunting and Sir Machdonald (1970) indicate that thickness in some places (Sg el Niam) reach up to 1200 meters. Strojexport (1971 - 1976) carried out geophysical and hydrogeological investigations at the western part of Kordofan province, eastern part of Darfur province, several basins, depressions and grabens filled with Nubian sandstone sediments of different thicknesses were recognized as follows:

	Area	Thickness of the Nubian Sandstone formation in meters
1.	Debbat Abeid depression	100-200
2.	El Fula depression	100-1500
3.	Dam Gamada depression	100-200
4.	Adat Umm Santa Hamrat El Sheikh depression	100-300
5.	Sugaa El Gamal basin	100-3000
6.	El Nuhud basin	100-500
7.	Babanusa basin (Umm Ruwaba Nubian basin)	100-3000
8.	Iyal Bakhit North braben	100-200
9.	El Rmil post graben	100-300
10.	Siderat graben	100-500

ii. Hydrogeology of the Nubian Sandstone Formation

(a) Occurrence of ground water

Ground water occurs mainly in the intersticies of the sandstones, conglo merates and basal conglomerates of the Nubian sandstone formation. However jointed and fractured mudstones may contain water within the saturated zone. Due to the existence of the mudstone intercalation, more than one aquifer are found in the Nubian sandstone formation. Ground water is found as water table conditions or as artesian conditions. The artesisn conditions depend upon the presence of the overlying impormeable mudstone beds of the Nubian formation or the clays of the Umm Ruwaba or El Gezira formation. Flowing water from a drilled well was recorded in Idd El Teen well at Gedaref district (borehole No.2134). The height of the rushing water was about 50 m above ground surface. The ground water crops out at the groumd surface as springs at Nekhila Oasis and Natron well in the northwestern part of the country.

Many boreholes were drilled in the Nubian sandstone aquifer. The depths of these wells range from about 60 to about 600 meters. The rest water level in the Nubian sandstone aquifer varies from a basin to another but generally ranges from few meters in the basins having sources of recharge (mainly in Nile and its tributaries), to more than 120 meters in the basins remote from or have no sources of recharge.

(b) Movement of ground water

Many workers dealt with hydrogeology of the Nubian sandstone aquifer in certain areas of the country constructed piezometric or water table contour maps as a part of their studies. The most important of this work was carried out by Rodis et al. (1964) at Kordofan province. . Karkanis (1965) at Darfur province, Kheiralla (1966) at Khartoum and Shendi region. Sulliman (1968) in Gedaref district. Hunting and Sir MacDonald (1970) at Northern and Southern Darfur provinces. Ahmadana (1973) at Darfur province. Iskander (1973) for the Nubian and Umm Ruwaba aquifers. Saeed (1974) at Khartoum province. Mukhtar (1975) in Shagra Basin. N. Darfur province and A. Latif (1976) at Blue Nile province. The Rural Water Corporation (1976) published piezometric contour map for the Sudan (Plate 2.3.1). This map shows that the ground water north of El Malha at the Northern Darfur province moves towards the Northeast. The elevation of the piezometric level ranges from 750 to 600 m above sea level. South of El Malha the ground water moves towards the south. The piezometric level ranges between 850 to 400 m above sea level. Ground water in the Nubian sandstone aquifer at Blue Nile. Gezira. Khartoum. the Nile and Northern provinces moves towards the Northwest. The ground water elevation ranges from 420 to 180 m. above sea level near the international boundaries between Sudan and Egypt. At El Gedaref area ground water moves towards the Northwest. The piezometric elevation ranges from 500 to 400 m above sea level.

The velocity of the ground water in the Nubian sandstone aquifer varies from 0.16 to more than 25 meter per year and the hydraulic gradient range from 9×10^{-4} to 1×10^{-3} meter per km. (Salama 1976).

(c) Recharge

The Nubian sandstone aquifer is recharged either from direct precipitation falling on the Nubian outcrop especially in the areas where the rate of precipitation exceeds of evapotranspiration or by water seeping from river Nile and its tributaries. wadies and Khors. The recharge is either taking place at present or took place in the past especially during pleistocene pluvial period when rainfall was more abundant than it is today.

Evaluation of environmental isotopes in ground water from El Nuhud Nubian aquifer and Umm Ruwaba Nubian aquifer of western Sudan indicates that there is no recharge to these aquifers for the last 5,000 years (Kheiralla, 1971). At Khartoum province along the river Nile and its tributaries, Blue and White Niles. it has been proved that the Nubian sandstone aquifer is hydregeologically connected with water of the Niles. These are indicated from the water level fluctuations in the wells (Fig. 2.3.3.) and also from the environmental isotopes determination.

Hunting (1970) calculated recharge from the alluvium south of Kutum -T agabo - Meidob divide to the Nubian sandstone aquifer lies between 21 to 80 million cubic meter per year to Umm Kaddada, Alauna and Shagera basins.

Saeed (1974) estimated the annual recharge from the Niles at

Khartoumprovince to be about 100×10^5 cubic meter. Mukhatar (1975) estimated theannual recharge to the Nubian aquifer at Shagera basin. N. Darfur province as 240×10^5 cubic meter a gallons per year (1.08×10^6 cubic m). Iskander (1976)mentioned that the amount of recharge to the Nubian sandstone aquifer at the order of 10^9 cubic m. every year and he indicates that this amount takes place in semi-arid and subarid areas. Salama (1976) basin receive annual recharge as follows:

1. Shahara Nile basin	136.0	million cubic metre.
2. Sahara Nubian basin	20.6	million cubic metre.
3. Central Darfur provice	46.6	million cubic metre.
4. Nuhud basin	15.4	million cubic metre.
5. Sag El Naam basin	14.8	million cubic metre.
6. River Atbara basin	3.0	million cubic metre.
7. Gedaref basin	41.3	million cubic metre.
8. Shagera basin	1.1	million cubic metre.
Total	299.2	.million cubic metre.

From the above mentioned works one can conclude that the recharge potentiality of the Nubian sandstone aquifer is high and it may be several milliards cubic meter. This potentiality is highly recommended to be evaluated using environmental isotopes techniques and the other hydrogeological methods.

(d) Hydrogeologic parameters of the Nubian Stone Aquifer

Pumping tests were carried out at different areas in the country. The results obtained indicate wide variation in transmissivity, T, and permeability, k, and storage, S, coefficients. The parmeability values range from 0.5 to 30 meter per day, the transmissivity coefficient range from 100 to about 2000 cubic meter per day and the storage coefficient varies from 0.15 to 0.0001. According to Ferris et al. (1962) the last twofigures characterize both water table and artesian conditions aquifers. The variation in the above parameters of the Nubian sandstone aquifer is due to lateral and vertical variation in the lithology of the Nubian sandstone formation, the presence of intercalation of the mudstones reduces the saturated thickness of the sandstone, type of cement, grain size and compaction and silicification of the sandstone.

(e) The hydrochemical characteristies of Nubian Sandstone Aquifer

Generally the Nubian sandstone aquifer is characterized by low dissolved mineral salts. The total dissolved solids mostly range between less than 200 to about 800 ppm. In certain areas the ground water quality is poor. These areas are, Jebel Hilla at Northern Darfur province, where the total dissolved solids vary from 3000 to 18000 ppm. At Sheikh El Amin Balla in Khartoum province the total dissolved solids reach up to 5000 ppm. In the Gedaref area where the

Basalt rocks overly the Nubian sandstone formation, the salinity of the water varies betwwen 1000 to 3000 ppm. Plate 2.3.2. is water quality map published by the Rural water Corporation (1976) shows the distribution of the total dissolved solids in parts per million in the Nubian sandstone and the Umm Ruwaba aquifers. Fig. 2.3.4 is a map showing the distribution of the total dissolved solids in part per million for the Nubian sandstone aquifer at Khartoum province and Northern El Gezira (Saeed, 1974).

The groumd water in the Nubian sandstone aquifer is suitable for domestic uses and livestock except at the proviously mentioned areas.

(f) Suitability of the Nubian Sandstone Aquifer for Irrigation

No detailed studies were carried out to evaluate the suitability of ground water in the Nubian sandstone aquifer for irrigation except at Khartoum province, Sag El Naam and Shagara basins. Saeed (1974) applied the U.S. salinity laboratory staff (1954) classification of irrigation waters to the Nubian sandstone aquifer in Khartoum province. He recognized nine types of classes within the Nubian sandstone aquifer as shown in the map (Fig. 2.3.5). The dominant type is C_2-S_1 (medium salinity water, low sodium adsorption ratio); Sheikh El Amin Balla area is characterized by very high salinity water and very high sodium adsorption ratio (C_4- S_4). This water is unsuitable for irrigation.

Boron is an important element for plants growth, but its presence in excess of 0.5 ppm is harmful to plants. Survey for boron concentration was carried out at Khartoum province and El Gezira area. The mazimum concentration recorded for the boron is 0.2 ppm which is within the limit of the sensitive crops (Saeed, 1976). Mukhtar (1975) classified ground water at Shagara basin as fresh water chemically fit for drinking and irrigation pruposes. The ground water at Sag El Naam basin is suitable for irrigation (classes C_1 - S_1 to C_2 - S_1).

In the other areas where the Nubian sandstone aquifer has total dissolved solids up to 800 ppm the water seems to be suitable for irrigation if compared with the water in the Nubian sandstone aquifer at Khartoum province and Sag El Naam and Shagara Basins.

(g) Storage capacity of the Nubian sandstoes aquifer

The ground water storage capacity is defined as volume of water that can be drained by gravity or can be pumped from materials underlying a designated ground water unit. No detailed works has been done to estimate the storage capacity of the Nubian Sandstone aquifer except in few areas as follows:

1 - Hunting (1970) estimated the water in storage in Umm Kaddada basin, Alauna and Shingil Tobaya (Sag El Naam) basin, and Shagara basin as $300x10^9$ m^3, $100x10^9$ and $20x10^9$ respectively.
2 - Dafalla estimated the storage capacity for Sag El Naam basin as $48x10^9$ m^3.
3 - At Khartoum province, Saeed (1974) estimated the storage capacity of the Nubian sandstone aquifer up to the depth of 150 meters in an area of

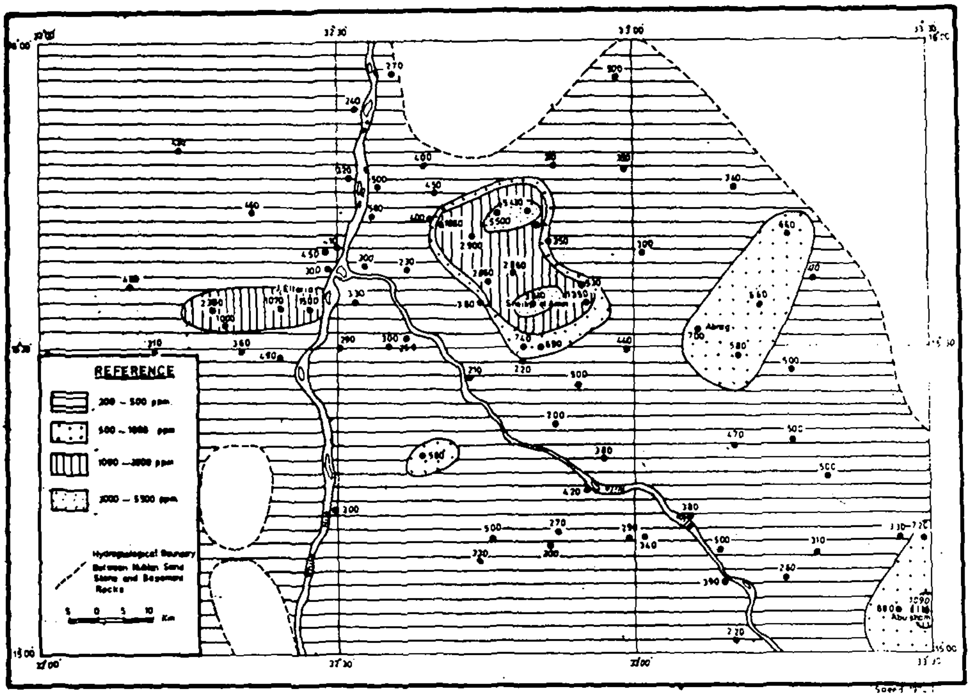


Figure 2.3.4 Map Showing Distribution of the Total Dissolved Solids Within the Nubian Sandstone Aquifers at Khartoum Province

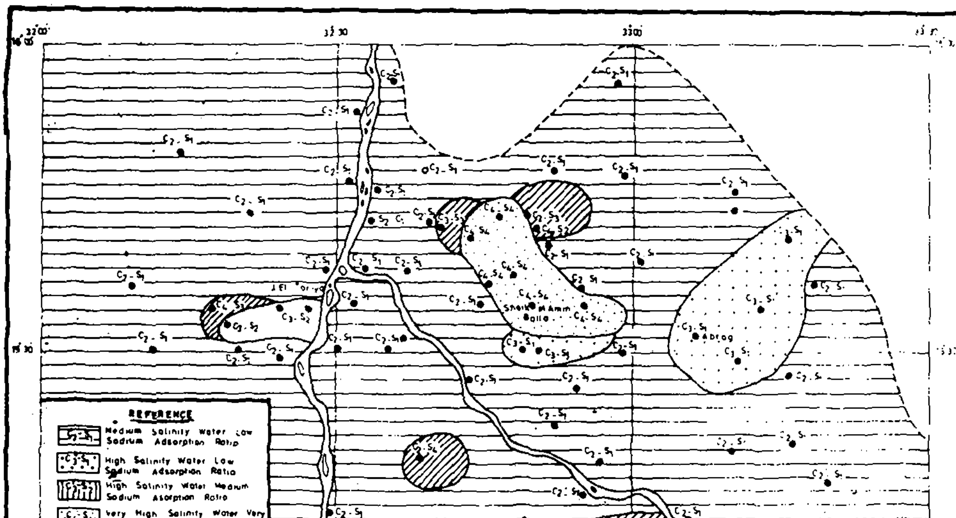


Figure 2.3.5 Map Showing the Distribution of the Major Classes of Ground Water for Irrigation Within the Nubian Sandstone Aquifers at Khartoum Province

about 19,000 km^2 as $77 \times 10^9 m^3$.

4 - Mukhtar (1975) estimated the storage capacity of Shagara basin, N. Darfur province as 1.0×10^9 gallons ($4.5 \times 10^6 m^3$).

5 - Salama (1976) estimated the storage in six Nubian basins as $16,544 \times 10^6 m^3$.

Salama's figure is too low if compared with the figures obtained from Khartoum and Darfur provinces.

From the above mentioned figures, it is clear that the storage capacity of the Nubian sandstone aquifer is very huge. It is the time to think about using this water for irrigation beside the other uses especially in the areas where the rest water level is shallow (Khartoum, El Gezira, Blue Nile and Northern province).

2.3.3.2. Umm Ruwaba Formation Aquifer

(i) Geology of Umm Ruwaba Formation

The Umm Ruwaba formation covers all Upper Nile province and the most part of Junglei, Eastern Equatorial, Lakes Provinces and parts of Bahr El Ghazal, Northern and Southern Kordofan and Darfur provinces. It covers about 20 per cent of the Sudan. It rests largely on an irregular surface in the basement rock. In Southern Kordofan and Darfur provincesUmm Ruwaba formation is underlain by the Nubian sandstone formation (Fig. 2.3.1.).

According to Edmonds (1942), The boreholes for water were drilled in 1914 along the railway between Kosti, and El obeid, these boreholes were laid down in a depression formed at the same time as the uplift of the Nuba Mountains. Andrew and Karkanis (1945) suggested the name ' Umm Ruwaba Series ' for the thick superficial deposits that occur on the central Sudan plain, Kurmuk - Ingessana - Moya ridge and surround the Nba Mountains on the eastern, southern and western sides. According to Andrew (1948) the Umm Ruwaba sediments consist of unconsolidated sands, clayey sands and sometimes gravelly. The clay are mostly buff, but greyish - white and greyishgreen clays occur. The sediments are generally undorted, but some of the sand beds are devoid of clay. The mineral feldspar, biotite are undecayed. Andrew (Op. cit.) mentioned that the finer sediments occur under clay - plain east of Sudd and White Nile. According to Rodis et al. (1964) the Umm Ruwaba strata in Kordofan province are composed of mudstones, sandstones and conglomerate. Facies and bedding change within relatively short distances are very common. The sandstone and conglomerate are often silty and the mudstone sandy. The mudstone is in many areas and is the dominant rock type. The Umm Ruwaba attains thickness of more than 335 m.

Shafie (1975) studied the minerology of Umm Ruwaba formation and he concluded that the sand of this formatinon is characterized by the presence of high per cent of feldspar which varies from 10 to 40 per cent. He found that the clay mineral is montmorilonite. Shafic (Op.cit) recognized three thicknesses in

Umm Ruwaba formation according to the distribution of the heavy minerals content as follows : (1) Lower thicknesses are charactorized by ilemenite - lemonite minerals. The thickness of this division is more than 99 m. (2) Middle thicknesses are characterised by ileminite -epidote. The thickness is 149 m. (3) The upper thickness is characterised by ilementie -limonite - epidote. The thickness is 157 m. The typical section of the studies is Umm Ruwaba Borehole No. 5444.

In the Southern Sudan Umm Ruwaba formation is characterized by prodominent clays. Iron ore concretions of varying size and at varying depths were recorded in some boreholes. In the Upper Nile provice the thickness of Umm Ruwaba reaches up to 1711 ft (552 m) (Salama, 1973).

Rift valley feature has been recognized by gravity survey at N.E. Kordofan which is consisted of three anomalous zones. The Bara depression has its axis passing the towns of Bara and Umm Ruwaba with deepest point of about 400 m. The valley fracture has a fractured and faulted zone immediately below the depression. The third zone is a block which sunk in the lower part of the crust. The rift feature runs in NW -SE direction and probably joins the White Nile (Mitwalli, 1969).

Hunting (1973) estimated the thickness of sedimentary rock up to 3.9 km between El Dien and Babanosa towns. Shafie (1975) nominated three rift zones controlling the structure of Umm Ruwaba formation.

1 - Bara rift zone stretching from Bara - Umm Ruwaba to White Nile with sedimentary cover reaching up to 500 m in depth.
2 - Malakal - Kosti rift zone. The rift zone dislocation extends along the White Nile valley.
3 - Juba - Abu Gabra rift zone mainly of north-west direction which joins Malakal-Kosti rift zone at right angle.

Recently (1976), Chevron Oil Company carried out geophysical survey for Umm Ruwaba formation. The results obtained indicate that the magnetic depth in the Northern area between Kosti and El Obeid never exceed-1.4 km and generally in the range of -0.3 to + 0.3 km. In the central area which occupies the White Nile valley approximately between Kosti, Malakal, Akobo, the basin has three deep areas separated by highlands. In the two northern deep basement is approximately 2.0 - 2.5 km sub-sea, In the southern basin is generally between 2.5 to 3 km sub-sew and may be deep as 3.5 to 4 km. In the southern are which is lying north-west straight lines extending from Torit to Buram, two adimentary basins of considerable size and depth have been discovered. The smaller one extends to some 335 km north south near the eastern edge of the central area, with width varying between 50 to 130 km and is up of about 3 km deep. The longer basin extend some 630 km north west the White Nile, in the southern area. It varies from 80 to 180 km in width and is up to 6 km deep.

Locustrine and fluviatile orign for Umm Ruwaba deposits were suggested by Rodis et al. (1964). Whiteman (1971) was of the opinion that Umm Ruwaba sediments were laid down in a series of land deltas.

(ii) Hydrogeology of Umm Ruwaba formation

Many workers contributed to the hydrogeology of Umm Ruwaba formation. Among them are Rodis et al. (1964) in Kordofan province, Mabrok (1972) in North East Kordofan próvince. Hunting (1973) and Strojexport (1972-1976) in Western Sudan. Ahmadana (1973) and Shafie (1975) in the central part of the Sudan. Salama and Macrol (1976) in Southern Sudan. From these studies the hydrogeology of Umm Ruwaba formation could be summerized as follows:

Ground water in Umm Ruwaba formation is found in the sand and conglomerate beds lie within zone of saturation. The aquifer generally confined. Two flowing boreholes were recorded in Northern Kordofan province (Umm Balgei B. H. No. 4842 and El Ghesheim B. H. No. 2836). In the eastern part of Northern Kordofan province the depth to water varies from about 46 m to more than 150 m. In southern Darfur province it varies from 30 to 75 m. In the Southern Provinces the depth to the water ranges from 10 to 25 m.

The Umm Ruwaba aquifer is charactorized by wide range of transmissivity and permeability values which in general range from less than 10 to more than 300 m^2 perday and less than one to more than 15 meter per day respectively.

Water level fluctuation in Umm Ruwaba aquifer was recorded in some areas during the rainy season indicating that this aquifer receives some recharge from the rainfall.

Ground water moves in different directions (Plate 1). In North Eastern Kordofan area ground water moves from NW to SE towards the White Nile valley. In Southern Darfur province the ground water moves towards south-east. In the Southern region ground water flowing towards the Sudd area in a close basin. The water is flowing from all directions to the centre of this basin indicating the possibility of the discharge from aquifer to the stream and lakes in Sudd area (Salama, 1976).

The chemical quality of the ground water in Umm Ruwaba aquifer is variable. Generally the total dissolved solids is low at the peripheral zones between Umm Ruwaba-basement rocks and Umm Ruwaba-Nobian sandstone formation which generally range between 100 - 500 ppm (Plate 2). The total dissolved solids generally increase in the direction of ground water flow and in depth where in some areas are more than 7000 ppm. The most saline water in Umm Ruwaba aquifer is located in the central part of Umm Ruwaba formation in the area of White Nile valley between Kosti-Malakal-Bentio-Fankog, where the total dissolved solids range between 1500 to about 3000 in Bentio-Fankog-M alkal area to more than 7000 in the area east between Kosti-Malakal. Shafie (1975) attributed the high mineralization of ground water in this region- in spite of the presence of the White River Nile - to the Malakal - Kosti, rift valley. Ground water in Umm Ruwaba formation in many areas east and west of White Nile and in some areas in the Southern provinces is unsuitable for domestic uses as well as for irrigation.

Evaluation for under flow, recharge, basin storage and abstraction for

Umm Ruwaba basin and Nubian Umm Ruwaba basin estimated by Salama (1976) as shown below:

Underflow	85.8 m cubic metre per year.
Recharge	582.3 m cubic metre per year.
Basin storages	22090.0 m cubic metre per year.
Abstraction	39.9 m cubic metre per year.

2.3.3.3. El Gezira formation Aquifer

(i) Geology of El Gezira Formation

El Gezira formation has been investigated by various workers. Abd El Salam (1966) described El Gezira formation as mainly consisting of unconsolidated clays sily, sands and gravel. He divided the formation into three members as: i) Upper clay, ii) Lower sandy member and iii) Mungata member. The upper clay member consists mainly of sand, occasional gravel silt and clay lenses. Saeed (1974) described the sand of El Gezira formation as medium grained, moderately sorted, nearly symmetrical to coarse skewed, mesekurtic sand.

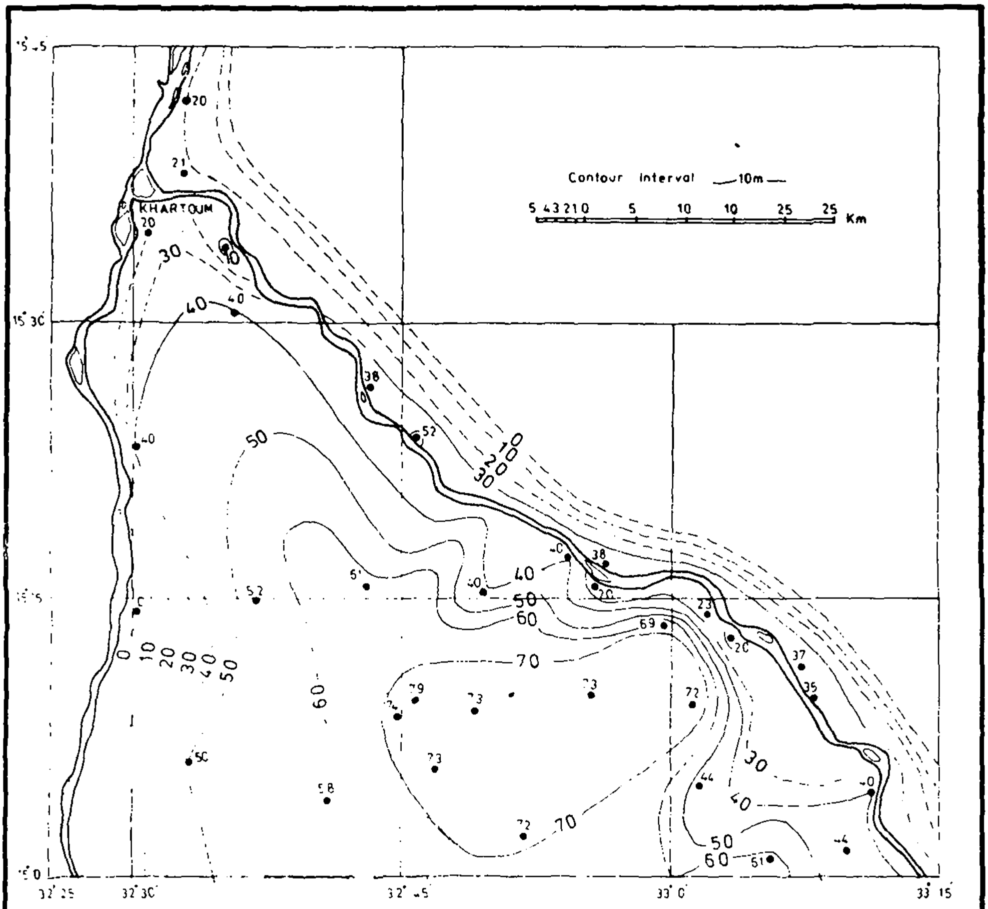
El Gezira formation is found in the area between the Blue and the White Niles and on the right bank of the Blue and River Niles. The thickness of El Gezira formation varies from zero at Jebel Aulia to about 79 meters at the centre of El Gezira area. Fig. 2.3.6 is an isopack map showing the thickness pattern of El Gezira formation. It is difficult to correlate El Gezira sediments over long distances due to the fact that it was deposited as lens-shaped and inter-fingering units. Abrupt changes in the texture of the sediment and pinch out often occur. The fine materials (clay and sandy clay) are predominant in the northern (Soba) and south-eastern land stretches (Gemeiabi, Edied El Bashagra), while the coarse materials (sand) are developed in the middle and south-western part of El Gezira (Saeed, 1974). The age of El Gezira formation is probably Pleistocene.

ii. Hydrogeology of El Gezira Formation

(a) Occurrence of ground water

Ground water occupies the interstices of the sand. gravel. sandy clay and silt of El Gezira formation within the zone saturation. El Gezira formation aquifer is unconfined. so the water occurs under water table conditions. However. confined ground water occurs at some places due to the presence of a confining bed overlaying the aquifer. The confining bed is mainly composed of clay which is somewhat permeable or leaky.

The depth to the saturated zone at El Gezira formation aquifer varies from about 8 meters in the area near the Niles and increases in the directions southeast the White Nile and southeast the Blue Nile where the maximum depth is about 35 meters at the southern centre of El Gezira. The thickness of the saturated zone of El Gezira formation



(Saeed 1974)

Figure 2.3.6 Isopach Map of El Gezira Formation aquifer varies from few meters up to about 40 meters. It is thin at Khartoum area and due west of El Gezira area near the White Nile, while it thickens at the centre of El Gezira area.

(b) Movement of ground water

Ground water in El Gezira formation aquifer moves from Blue and White Niles towards the centre of El Gezira area. This has been indicated by Abdel Salam (1966), Boushi (1973) and Saeed (1974). Fig. 2.3.7 is a water level contour map for El Gezira formation aquifer. The elevation of the ground water near the Blue Nile varies from 370 to 390 above sea level, while near the White Nile and at Khartoum the elevation is about 370 m above sea level. At the centre of El Gezira area the elevation of the ground water ranges from 350 to 360 m above sea level. The average hydraulic gradient of El Gezira formation aquifer varies from 0.3 to 0.7 m per km.

(c) Recharge

Saeed (1977) estimated the recharge to El Gezira formation aquifer between lat. 13° 00 N and lat. 15° 00 N along the Blue Nile as 100×10^6 m^3.

(d) Hydrochemical characteristics of El Gezira formation aquifer

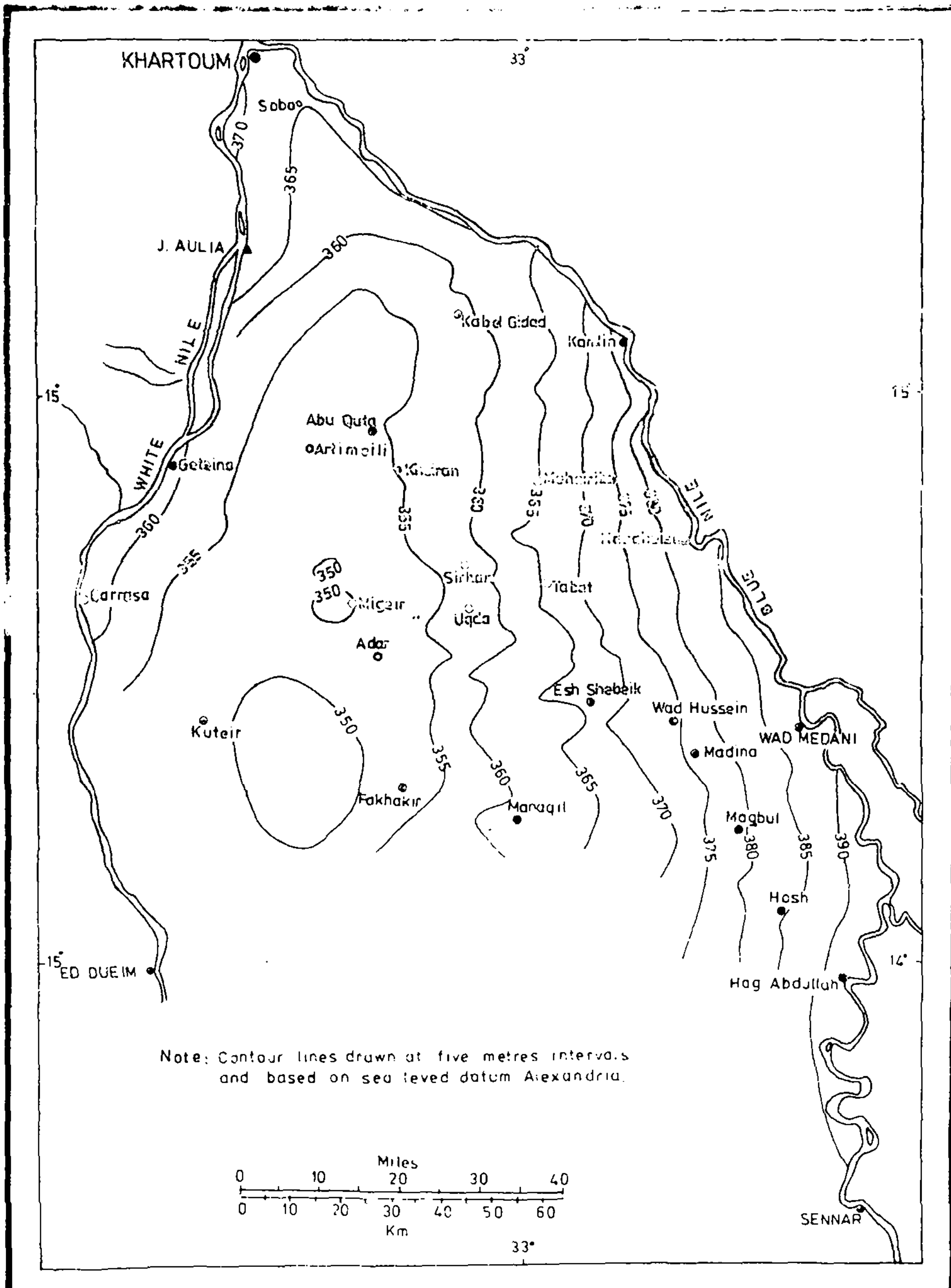
The salinity of El Gezira formation aquifer ranges from 200 to 2000 ppm at the northern part of El Gezira. Fig. 2.3.8 illustrates the distribution of the total dissolved solids which shows a tendency to increase towards the centre of El Gezira (Saeed, 1974). In the southern part of El Gezira Abdel Salam (1966) found that the total dissolved solids vary from 300 to about 1500 ppm. Highly mineralized water was found at the Managil area where the total dissolved solids vary from 5000 to 20,000 ppm (Fig. 2.3.9). The ground water in this area is unsuitable for human and animal consumption.

(e) Suitability of Ground Water of El Gezira Formation for Irrigation

El Gezira formation aquifer shows wide variation in the sodium adsorption ratio (SAR), which ranges from 0.3 to 132 (Saeed, 1974). Fig. 2.3.10 shows the distribution of the major classes of ground water for irrigation in El Gezira aquifer. Class C_2 - S_1 (medium salinity water, low sodium adsorption ratio), is located at El Garadat - Udied El Bashagra area. The other types are found as pockets at the centre of El Gezira. The boron concentrations in El Gezira formation aquifer are found within the limit of the sensitive crops (less than 0.5 ppm; Saeed, 1976).

(f) Storage Capacity of El Gezira Formation Aquifer

Saeed (1974) estimated the storage capacity of El Gezira formation aquifer in the area between Khartoum up to lat. 15° 00 N. (area about 3112 square km.) as 8.31 milliards cubic meter. By extending



(Abdi Salaam 1966)

Figure 2.3.7 Standing Water-Leved Contour Map, El Gezira

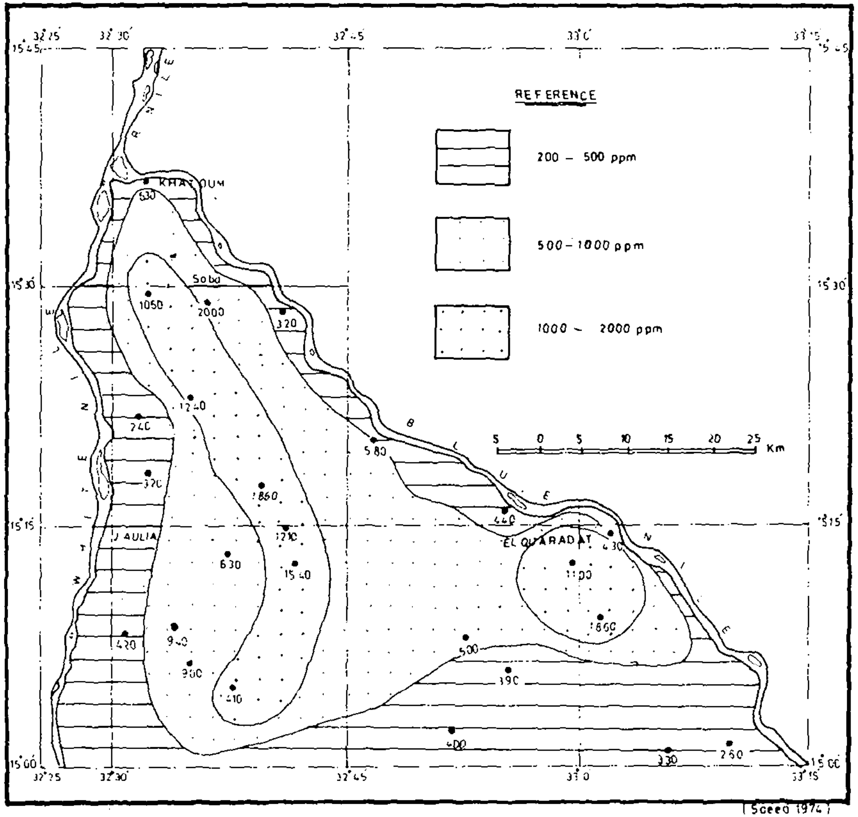


Figure 2.3.8 Map Showing the Distribution of the Total Dissolved Solids Northern Part of El Gezira Formation Aquifer

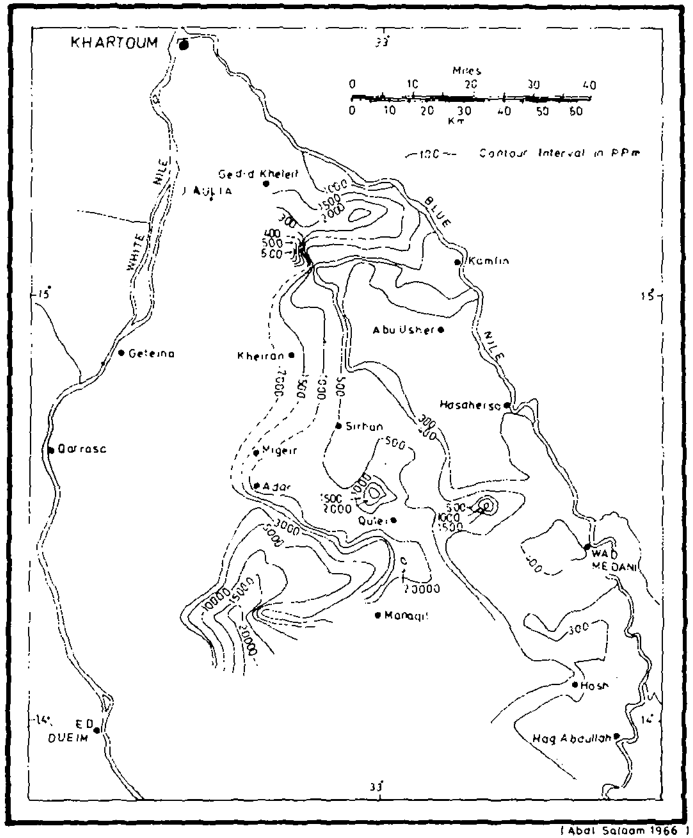
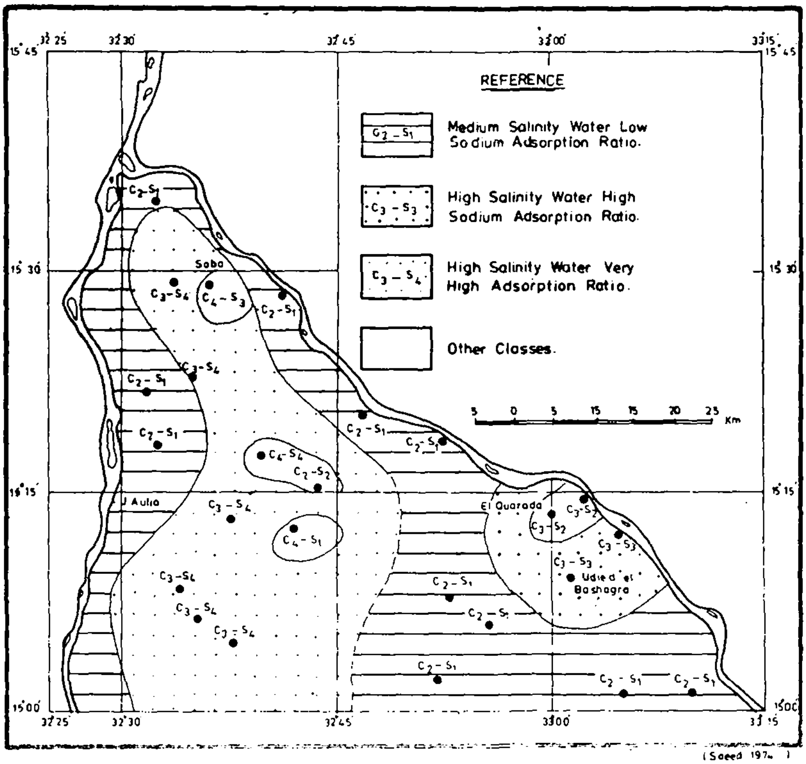


Figure 2.3.9 Total Dissolved Solids, p.p.m Map, El Gezira



(Saeed 1974)

Figure 2.3.10 Map Showing the Distribution of the Major Classes of Ground Water for Irrigation in El Gezira Formation Aquifer

this study to include the Gezira formation between lat. 14.00 to 15 00 N and long. 32 30 up to Blue Nile the ground water in storage for El Gezira formation be more than 30 milliards cubic meter.

(g) Discharge

Hundreds of tube wells were drilled in El Gezira formation aquifer to supply the towns and villages of El Gezira province. No accurate estimation has been done to account for the water pumped from the aquifer. The figures available from Gezira Board and Public Electricity and Water Corporation seem be more tha 5 million cubic meter.

2.3.3.4. Alluvial Aquifers

Ground water in the alluvial aquifers are characterized by:

1 - The depth to the water level is shallow.

2 - The aquifers recharged annually from the River or the wadi or khor from the run-off or directly from the rainfall.

3 - The permeability and the transmissivity values are high. water table

conditions are prevailing and the specific yield is high.
4 - The water quality is good and suitable for irrigation and domestic uses.
5 - The vertical and horizontal extensions of the aquifers are limited.

The most important alluvial aquifers are the Gash River. Khor Arbaat. Khor Baraka and Wadi Arab. in Kassala and Red Sea provinces. Wadi Nyala. Wadi Kutum and Wadi Azum in Northern and Southern Darfur provinces. Khor Abu Habil. Khor El Afin. Khor Shalingo and Wadi El Galla at the Nuba Mountains. Wadi Howar. Wadi El Milk and Wadi El Mugaddam in the north - western part of the country. The hydrogeology of these aquifers will be discussed briefly.

i. Hydrogeology of the Gash River Basin

(a) Occurrence of Ground Water

The alluvial deposits of the Gash River basin are the principal sources of the ground water in Kassala area. The thickness of the alluvial deposits range between 30 m upstream to about 60 m downstream. The alluvial deposits are composed of intercalating beds of unconsolidated coarse to fine-grained gravel. and. silt and clay. The fine materials such as silt and clay show a tendency to increase downstream. The sand and gravel cover a wide range in both lithological composition and grain size, Lithologically, the gravel is composed mostly of angular to subangular quartz pebbles; however, volcanic felspathic and grantic gravel are present.

The gravel grain sizes range from 2 mm to more than 10 mm. The sand is mostly well rounded and medium to coarse granined, Fine sand was found in several localities. The sand is mostly composed of quartz; however felspathic micaceous and volcanic sand are present.

It is difficult to correlate the sediment in this area over long distances due to their deposition as lens-shaped and interfingering units and abrupt change in texture of the sediments.

The alluvial aquifer of the Gash River basin is unconfined, so the water occurs under water table conditions. however. confined ground water occurs at few places in the valley fill owing to the presence of confining bed overlying the aquifer. The average saturated thickness at Kassala area is about 30 meters. The depth to the water varies with the time and place. depending on the time of the year and the relative altitude of the ground surface. It ranges from less than a meter near the Gash River to about 25 meters at the fringes of the aquifer.

(b) Seasonal Ground Water Level Fluctuations

During the period between December 1969 and February 1971 regular measurements for the rest water levels have been taken in 23 observation wells distributed to cover a great part of the area of the Gash River aquifer at Kassala area (Fig. 2.3.11). All the observation wells show seasonal ground water fluctuations. The records of the water levels in the observation wells near the Gash River show that the ground table starts to rise during July, August and September when the Gash River is flowing. It reaches its maximum in September and October. This indicates that the Gash aquifer is recharged by infiltration from the Gash River when the stream flows during the flood season. The observation wells which lie far away from the Gash River attain the maximum rise of water level in November and December. The water levels in the observation wells decline as the Gash River becomes dry. During the period between December 1969 and February 1971, 7.80 meters was recorded as the maximum water level fluctuations.

From the water level fluctuation in the observation wells, it was found that the average water fluctuation within the area of the observation wells during the flood of 1970 is 3.6 meters. The storage change for the entire area of the aquifer at Kassala, was estimated to be 75.35 x 10^6 m^3 (Saeed, 1972).

(c) Long Term Ground Water Level Fluctuations

(1) Saeed (1972) estimated that the water required to irrigate about 7000 acres of land cultivated by bananas, onions,citrus, mango and vegetables at Kassala area is about 76 x 10^6 m^3. In 1969 he accounted 12 x 10^6 m^3 of water for evapotranspiration and domestic uses. Therefore the annual discharge from the ground water reservoir is about 88 x 10^6 m^3.

(2) The continuous discharge of the ground water from the Gash aquifer for irrigation and domestic uses at Kassala area has been reflected in the water table level especially in the north-western region where most of the wells are concentrated there. The records of the water level measurements during February of the years between 1966 and 1974 show a continuous decline in the rest water level (Fig. 2.3.12). In the observation wells No. 5, 8, and 11 the drop in the water level is 2.45 m, 4.05 m and 3.35 m respectively. It can be concluded that

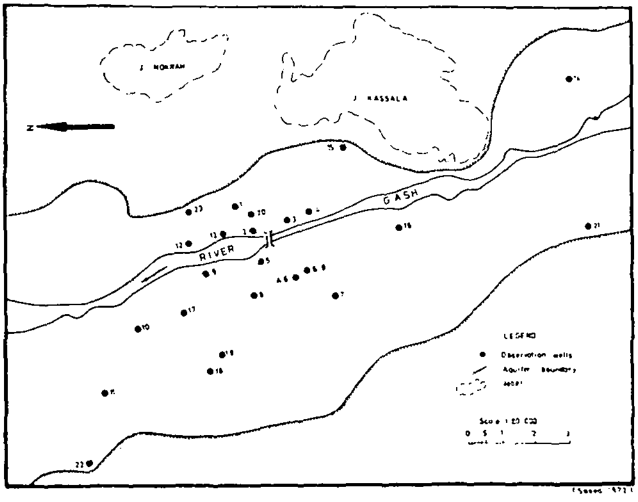
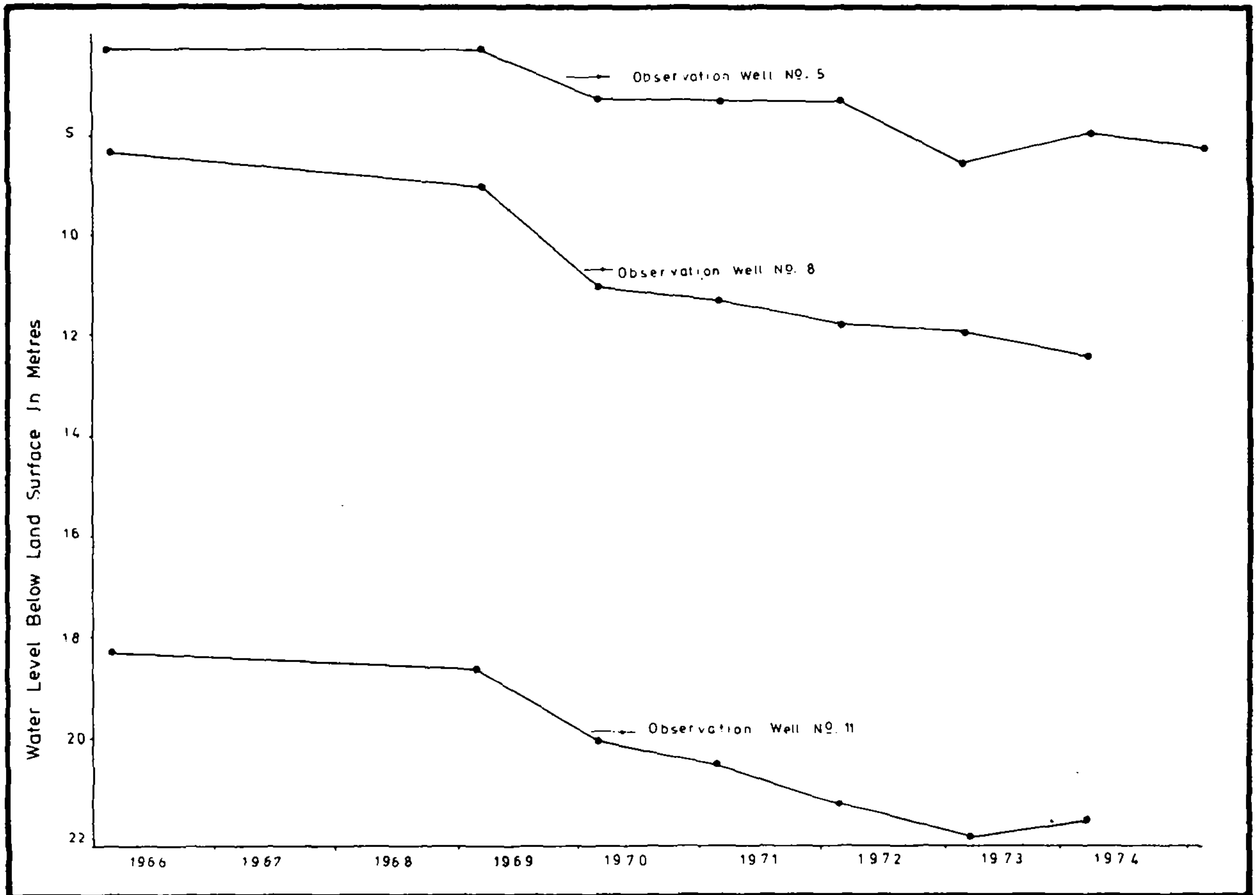
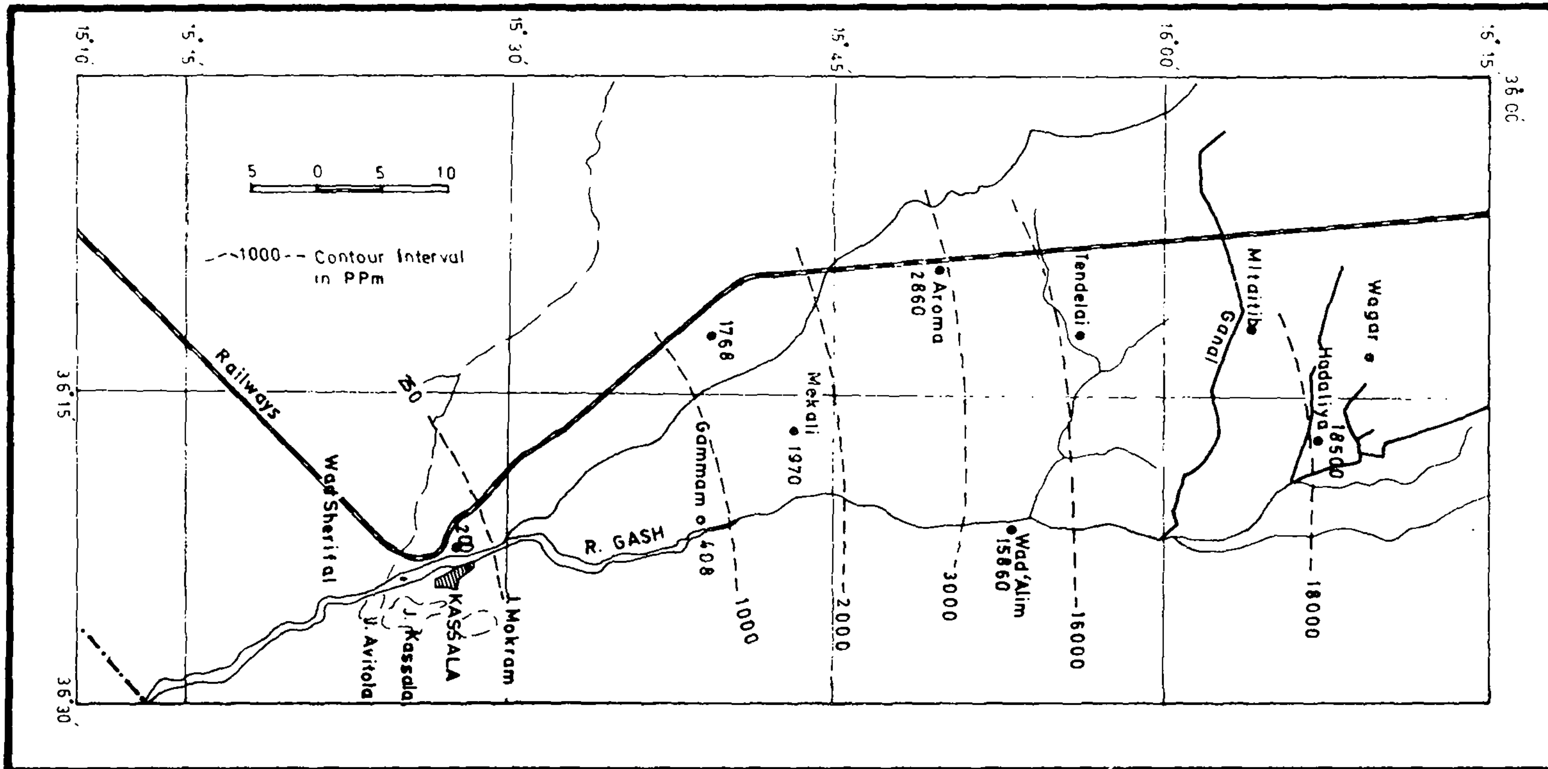


Figure 2.3.11 Map Showing Aquifer Boundaries and Location of the Observation Wells at th Gash River Basin at Kassala



(Saeed 1976)

Figure 2.3.12 Rest Water Level Situation in the Observation Wells Nos. 5,8 and 11 in February of the Years 1966 1974 in the Gash River Basin at Kassala



(Saeed 1972)

Figure 2.3.13 Map Showing the Distribution of the Total Dissolved Solids in P.P.m. at Gash Dalta there is an overdraft in the aquifer in this particular area (Tukruf west).

(3) At the eastern part of Kassala town the water table is more or less stable.

(d) Movement of Ground Water

At Kassala area the ground water moves towards the north-west. The elevation of the water table in February 1970, varies between 500.8 meters above mean sea level in the south to 467.4 meters to the northwest. The average hydraulic gradient is about 2 meters per kilometer. The elevation of the water table in September 1970 between 504.5 above mean sea level in the south to 467.15 meters to the northwest. The average hydraulic gradient is about 2 -3 meters per kilometer (Saeed, 1972).

(e) Hydrologic Properties of the Aquifer

Pumping test was conducted in different localities at Kassala area. The transmissivity values were found to be ranging between 3.6×10^4 gpd to 2.1×10^5 gpd. The average specific yield was found to be 13 (percent).

(f) Storage Capacity of the Gash Aquifer at Kassala area

Saeed (1969) estimated the storage capacity of the Gash aquifer at Kassala area by about 600×10^6 m^3.

(g) Quality of Water

The total dissolved solids in the Gash aquifer at Kassala area range from 180 to 260 ppm. The water is of an excellent quality for irrigation and domestic purposes (Saeed, 1969).

ii. Ground Water of the Gash Delta

At the Gash delta several wells were drilled to supply the region with potable water. The trials of drilling failed (except at Gammam). This was due to either that the drilling struck basement rocks at shallow depths or the water is brackish. Several shallow open dug wells are located near Balags (area in the Gash delta used for silt deposition prior to use of flood water for irrigation). The open wells produce potable water for domestic uses.

The quality of the ground water in the Gash delta shows remarkable variation in its chemical constituents. The total dissolved solids show tendency to increase towards the Gash delta. The total dissolved solids vary from 400 ppm at Gammam area to about 18,500 ppm at Hadaliya area (Fig. 2.3.13).

iii. Hydrogeology of Khor Arbaat

Khor Arbaat lies about 30 km northwest of Port Sudan, Red Sea province. Port Sudan town gets its water supply from the ground water in Khor Arbaat. The results of the hydrogeological investigations for this khor published by the Geological and Mineral resources Department in Bulletin No. 28 by M. T. Hussein (1975): the following is the summary of this work :

(a) Occurrence of Ground Water

The ground water in khor Arbaat basin is contained in a mass of permeable material mainly boulders, pebbles, gravels, sands and minor amount of silt and clay. The ground water is under water table conditions. The depth to the water in the khor varies with time and place. It ranges from less than one meter to more than 15 meters. The thickness of the aquifer ranges from 8 to 30 meters and the average thickness is about 20 m. The area of the aquifer between the upper and lower gates is about 12 square kilometre.

(b) Seasonal Ground Water Level Fluctuations

The water-table reaches its maximum elevation during the flood season (July - September). During the dry season the water table declines. The average water level fluctuation within the basin is about 2 meters.

(c) Hydrologic Properties of the Aquifer

The transmissivity of the aquiter as computed from the pumping test ranges from 4×10^{2} m^{2} per sec. to 2×10^{-3} m^{2} per Sec. (346 square meter per day to 17.3 square meter per day). The effective porosity was found to be ranging from 15 to 20 (percent).

(d) Recharge and Discharge

The mean annual recharge recorded for the surface flow at the upper gate is about 10×10^{6} m^{3}. The discharge by pumping to Port Sudan water supply is about 6×10^{6} m^{3}, the underground flow is about 1 to 3 million cubic meter and the evapotranspiration is about 0.24×10^{6} m^{3} per year.

(E) Water in Storage

The storage capacity of Khor Arbaat basin between the upper and lower gates was estimated between as 36 to 48 million cubic meter.

(f) Quality of the Water

The total dissolved solids of Khor Arbaat aquifer range from about 800 to 1100 ppm. The salt contents in water decrease after the flood period and the quality of water improves greatly.

iv. Hydrogeology of Tokar Delta

Tokar town gets its water supply from Krimpit area which is located at about 18 km south of Tokar town. The present wells field was located and developed since 1926. Up to date no remarkable change in the quality of the water or drop in the rest water level observed. The total dissolved solids recorded at Krimbit in March 1926 were 780 ppm. In November 1976 the total dissolved solids were 780 ppm. as recorded by Saeed. In 1954 borehole No. 495 was drilled near Tokar town, the total dissolved solids of the water from this well were 16448 ppm. The water is unsuitable for human and animal comsumption.

Several shallow open dug wells are found in the Delta but mostly their water are saline.

El Natiq (1975) worked on the hydrogeology of Tokar Delta. He found that the average saturated thickness is 18.5 m.

The average transmissivity of the aquifer is 2500 square meter per day and its storage coefficient is about 0.01. The flow of water is seaward. From the chemical composition of the ground water El Natiq (Op cit.) recognized three water zones in Tokar Delta aquifer as shown in Plate 2.3.3.

1 - Zone of fresh water :
This comprises the area between Dolabiai and Krimbit.

2 - Zone of interface :
This comprises the area between Tabelinai and Eglim.

3 - Zone of sea water :It comprises the area from the sea and dipping in the land direction.

From the flow net analysis he computed that dialy flow and flow through the gap passing to the sea are 72×10^3 and 77×10^3 square meter per day respectively.

Water consumption for Tokar town for the year 1975 was estimated at 504×10^3 per m^3.

No work has been carried to study the storage capacity. the fresh water in the delta aquifer and recharge from Khor Baraka.

v. The Alluvial Aquifers in Northern and Southern Darfur province

(a) Wadi Kutum

The hydrogeology of Wadi Kutum was investigated by Hunting (1970). The average thickness of the Wadi is about 10 m. It rarely exceeds 15 m in depth and is commonly less than 10 m. The permeability was estimated to be 14 meter per day and its storage was determined to be 20 per cent. Annual ground water flow was found to be 5×10^6 m^3 per year. and ground water in storage is 10×10^6 m^3. The total dissolved solids of the water vary from 198 to 232 ppm. The water is suitable for irrigation and domestic uses.

(b) Wadi Azum

Iskander (1973) reported the following about Wadi Azum. near Zalangi town. the average saturated thickness is about 30 m. Water in storage in an area of 29 sq. km. is about 85×10^6 m^3. The total dissolved solids of the ground water range between 174 to 216 ppm. UNFAO (1968) estimated the annual ground water discharge from Wadi Azum alluvium at 375×10^6 m^3.

(c) Wadi Nyala

Nyala town gets its water supply from Wadi Nyala. The thickness of the Wadi fill at the town wells site reaches up to 18.5 m and at the railways wells site the thickness of the sediment reaches up to 30 m. Hunting (1970). Dafalla (1973) reported that the annual recharge in Wadi Nyala aquifer is about 0.5 x 10^6 m^3 per year.

vi. Ground Water in the Nuba Mountains

The Nuba Mountains area geologically is composed from the basement complex rocks. No major sedimentary formation aquifer is present. The principal sources of ground water supply as worked by Mansour and Samuel (1957) are:

1 - Water issuing as Springs (Saraf)

The joints fissures and some geological structures carry a considerable amount of water. The presence of the above geological structures may cause water to issue by gravity as springs. This all around the hill masses at Rashad. Tallodi. Heban, etc. water is present as issuing from springs. The water of these springs is permanent all over the year but the yield is not sufficient to meet the domestic uses and livestocks of the major towns on the area e.g. Rachad. and Tallodi towns.

2 - The zone of Coarse shallow soil around Hills

The main hill masses being made of massive granitic rocks are mostly found to be surrounded by an aureale or residual soil. This is mostly made of porous and highly permeable material underlying by impermeable rocks. Rain water stored in this zone yield plentiful water from the shallow wells around the hill masses e.g. Jebel Heiban. Tallodi Delass.

Another water bearing formation similar to sureoles is the clay of plains in the area. The yield of ground water in this formation is not sufficient and the quality is inadequate.

3 - Khor Beds (alluvial sediments)

The alluvial deposit of the Khors constitutes the important water bearing formation at the Nuba Mountains area. The thickness of the khor beds are variable. They range between less than one meter to more than 20 meters. The sediments are composed of different sizes of sand, gravel boulders and clay. These beds are underlain by the basement rocks. The water level on the khors varies from few centimeters during the rainy season to few meters below the khor beds just before the rainy period. The following is a brief description for the water supply in different areas at the Nuba Mountains.

(a) Rachad Area

Around the hills masses the water is present as issuing from springs (Saraf). The most important sarafs are Saraf Um Gisir. Saraf Kabus and Saraf El Fallata.

Khor Tandit is a good supply of ground water all over the year. At Rachad town boreholes drilling failed to yield any water and the geophysical traverses did not recommend any site for borehole drilling. A dam was constructed on a water coarse at Tasba from which the Rachad town gets its water supply.

(b) Umm Berembeita Area

This is a typical of clay flats. The clay is dark grey cracked and calcareous. Ground water is available in Khor Umm Berembeita. The yield of the wells is all over the year. However water is available from the hot springs (60° C) west Umm Berembeita.

(c) Abu Gibeiha Area

This area is mainly composed of vast clay plains with scattered insleberage. Khor Tandik is the main source of water to Abu Gibeiha village and for most other villages along this khor. Khor Muweilih is the main source of the ground water supply to Muweilih village.

(d) Heiban Area

At Heiban area no water problems exist there. There is plentiful water supply in the whole area. The khors sandy beds are the main source of water. Heiban village gets its water supply from Khor El Ghor. The other important khors west and southwest of Heiban village are Khors Esh Shawi, K. Dinga, K. Taborei and K. Siri. In northwest Heiban area K. En Nabaq, K. El Sibaia, and K. El Awar are the important khors for ground water sources in that area. The water level range between few cms to about 7 meters. The production of the wells is good all over the year.

(e) Talodi Area

At Talodi village and its surroundings the ground water is found in several modes of occurrences which are mainly springs, shallow wells in coarse soil around the hills and water outcrops at the periphery of the shallow soil where it merges in clay plains where water pools are formed. The water level is shallow and the productivity of the wells is high all over the year.

(f) El Liri Area

Water is found as perennial streams from the sarafs found all around the mass of Jebel Liri. All these Sarafs are gravity springs where the water found in the granite intra-joint spaces is dammed either by quartz reefs or dykes or by the contact of fine grained amphibolitic rocks, Mansour (1957). The Sarafs of J. El Liri are found at Umm Shatta, Khor and Teiru villages.

(g) Kadugli town water supply

The water supply of Kadugli obtains from boreholes tapping weathered basement rocks. The water level in the wells varies from 10 to 15 m. The total dissolved solids range between 200 to 400 ppm.

vii. Major Khors in the Nuba Mountains

The major khors in the Nuba Mountains area which constitute good aquifers potentialities are: (1) Khor Abu Habil. (2) Khor El Afin. (3) Khor El Berdab. (4) Khor Shelingo and (5) Khor Wadi El Galla :

(a) Khor Abu Habil

Khor Abu Habil is the longest intermittent stream. It originates from the central part of the Nuba Mountains. The weathered zone of the basement rocks and the Wadi fill sediments are the principal water bearing formation for Khor Abu Habil. The average thickness of the alluvial sediments near El Dilling town is about 25 meters.The wells are highly productive.

(b) Wadi Shelengo

Wadi Shelengo lies in the western part of the Nuba Mountains. It originates from Nyma Jebels. In 1971 - 1972 Strojexport carried out ground water investigations in Wadi Shelengo in the area between lat. 11° 50 - 11° 05 N. At Debat Abat Abeid (Lat. 11° 21 long. 28° 56 E).

The alluvium thickness is 22 m. underlain by the Nubian sandstone formation which attains thickness of 138 m. The basement complex rocks met at the depth of 160 m as recorded in the borehole No. 3369. The rest wate level is 64.25 m. and the yield of the well is several thousands gpd. North Debat Abeid, the alluvial sediment thickness ranges between 17 to 30 m followed by the basement complex rock.

The rest water level varies from 44 to 47 m as recorded in the boreholes No. 5570 (Lat. 11° 35 N. long 28° 58 E) and No. 5568 (Lat. 11° 26 N long 28° 58 E) respectively. This indicates that the weathered basement complex rock is the main source of ground water in above mentioned localities.

(c) Wadi El Galla

Wadi El Galla is found in the western sector of the Nuba Mountains. It originates near Abu Zabad area and flows towards southwest. In 1971 - 1972 Strojexport carried out geophysical survey in some areas lying between lat. 12° 45 - 11° 0^0 N along Wadi El Galla. The thickness of the Wadi sediments in the area between Abu Galb and Abu Zabad varies from 40 - 50 m. The thickness between Bordia and Kutna wells is about 10 m. At Abu Zabad the thickness of sediments is predicted to be about 80 m. At Adra the thickness of the alluvial sediments is about 20 m underlain by the Nubian sandstone which its thickness is more than 435 m (as recorded in the well No. 5560. lat. 11° 3^3 N. Long. 28° 2^0 E). The depth to the water level is 68.8 m.

viii. Wadi Hawar, Wadi El Milk and Wadi Mugaddam

The three above wadies lie west of long. 32° 00 E. and south of N. No hydrogeological investigations have been carried out to these three major wadies. but it seems that those wadies are of good potentialities especially in the Nubian sandstone territories. Saeed 1974 indicated that there is a ground water flow from Wadi Mugaddam towards the northeast within the Nubian sandstone aquifer. He concluded that this Wadi constitutes a source of recharge to the Nubian sandstone aquifer.

2.3.3.5. Ground Water in the Basement Complex

The basement complex rocks cover about 45 (percent) of the total area of the Sudan. Ground water locates only in the deeply weathered zone of the basement complex rocks. however ioints and fractures zone are productive in many cases. Generally. the deeply weathered zones are associated with the well developed drainage along the wadies. khors and rivers. The basement complex aquifer has limited potential. The aquifer is thin and in many areas especially in the northern part of the country. the recharge is unreliable and the water is commonly salty. In many areas open dug wells are productive only during and shortly after the rainy season and they get dry in summer. The basement complex aquifer practically impermeable and it is of local rather than regional importance.

In some areas in Khartoum. N. Kordofan and N. Darfur provinces the deeply weathered zone of the basement rocks reach up to 50 m. The yield of the productive wells varies from 0.1 to 7 cubic metre per hr. The total dissolved solids vary from 200 to about 4000 ppm.

In the Southern provinces the weathered zone of the basement complex in many areas extends in depth to more than 50 m. The water level is shallow and generally it ranges from 5 to about 20 m. In some areas it exceeds 30 m. The total dissolved solids in the water is low. It is usually ranging from 140 to 300 ppm. The yield of the wells vary from 5 to about 14 cubic meter per hour.

2.3.4. Summary for ground water Potentialities of the Sudan

Table 2.3.1. shows estimations for ground water in storage. annual recharge and annual abstraction for the major aquifers in the Sudan. These estimations are based on the compilation of different figures computed by different writers. The writer is of the opinion that the actual figures for ground water in storage and the annual recharge are more than that has been mentioned in table 2.3.1.

From this table the annual ground water abstraction from the major aquifers equals about 14 (percent) of the estimated annual recharge. and equals about 0.04 (percent) of the estimated ground water in the storage. About 54 (percent) of the abstracted water is used for irrigation purposes in the Gash River area and Khartom province.

2.3.5. Recommendations

The above hydrogeological studies indicate that the ground water potentialities of the Sudan are huge. Only about 0.04 (percent) of ground water in the storage is abstracted annually from the different aquifers. This abstracted water represent only about 14 (percent) of the annual renewable water. It can be safely concluded that more ground water could be used in future for irrigation. industry and domestic uses.

Table 2.3.1. Estimations for ground water in storage annual recharge and annual abstraction for the major aquifers in the Sudan.

Major Aquifer	Basin or Area	G.W. in storage mm^3	Annual Recharge mm^3	Annual abstraction
(a) Nubian sandstone	1. Umm Kadada basin	300,000		5.60
	2. Alauna Shingil Tobaya basin (Sag El Naam basin)	100.000	80	1.50
	3. Shagara basin	20.000		0.70
	4. Khartoum province	77,000	100	70.00
	5. Nuhud basin	.136	15	2.50
	6. Sahara Nubian basin	5.500	21	1.20
	7. River Atbara basin	.240	23	0.50
	8. Gedaref basin	.700	42	4.20
Total (a)		502.576	381	86.20
(b) Umm Ruwaba	Sudd, Eastern Kordofan, Baggara and Blue Nile basins	22.090	582	39.90
(c) El Gezira	Area between Khartoum to lat. 14 00 N.	38.310	100	5.00
(d) Alluvial	El Gash, Arbaat, Kutum, Nyala, Azum, Baraka etc.	1.000	500	96.00
Total (a+b+c+d)		563.976	1.563	227.10

Source : Figures in this Table are quoted from references Nos. 17, 19, 37, 38, 39, 41 and 44 of Section 2.3.

To exploit such ground water resources economically for long term policy, the following points are highly recommended.

1. Geological Studies

Surface and subsurface geological mapping are highly recommended to determine the dimensions of the different ground water basin, lithological textures, vertical and lateral changes etc. This can be done by compiling and interpreting the existing geological and boreholes data and can be accelerated by using aerial- photographs, remote sensing techniques (ERTS imagries), air born and ground geophysical surveys.

2. Hydrogeological studies

(a) It is very necessary to identify the hydrogeologic parameters of each aquifer and the individual horizons of the same aquifer and to study the water quality of each bearing-horizon especially in Umm Ruwaba and

El Gezira aquifers where in many areas bad water quality is met. Scaling the saline water- bearing horizons of El Gezira aquifer and getting good water quality from the underlain Nubian sandstone aquifer was succeeded in many localites at El Gezira area.

(b) Since recharge to ground water occurs either directly from rainfall by seepage or through the beds of rivers ephemeral streams, wadies, and khors. So, records of precipitation, streams gauging are very essential.

(c) Uses of tracing techniques especially the environmental isotopes to detect areas of recharge velocity and directions of ground water flow is very important.

(d) Establishing a net of observation wells to record the changes in ground water strorage especially in the developed aquifers.

(e) Records of boreholes data and chemical analyses of ground water should be stored on standard system.

(f) Wells design to give the maximum yield is necessary.

2.4. CONSERVATION OF WATER LOST AT THE SWAMPS

2.4.0. Introduction

At the end of the 19th century it became a well known fact that Egypt. and very recently the Sudan too. would not be able to go further with its agricultural expansion without finding means by which it could increase the Nile discharges and smoothing out its annual and century fluctuations. Two solutions were thoroughly investigated at that time: the first was to even out the annual and century fluctuations of the river by building storage facilities (i.e. dams. barrages. etc.) and the second was to reduce water losses in the swampy upper reaches of the River (Fig. 2.4.1.). These reaches can presently be divided into three basins. namely. the Equaterial lakes basin. Bahr El Ghazal basin and Ethiopian plateau basin.

For the sake of presentation of the above three basins. it would be treated briefly in separate sections. More emphasis would however be put on the equatorial lakes basin since more attention had been directed towards it resulting in the present Jonglei Canal Project.

A reference list is also attached at the end of this Report so as to help as a guide for further investigation on the topic.

The efforts of the P.J.T.C.* for collecting the previous works that had been done on these basins and for drawing and carrying out plans for investigating these regions are also acknowledged.

(* P.J.T.C.» The Permanent Joint Technical Commission for Nile Waters.)

2.4.1. Equatorial Lakes Basin

The equatorial lakes basin broadly consists of the following sub-basins:

1 - Lake Victoria and Kioga basin which are the main sources for the Victoria Nile.

2 - Lakes George and Edwards basins. and River Semiliki basin which links lakes Edwards and Albert.

3 - Lake Albert basin. a source of the Albert Nile which runs up to Nimule. a town in the Southern frontier of the Sudan.

From Nimule. Bahr El Jebel (which is the new name given to the River up to Lake No) reaches Mangalla. after collecting the water of numerous torrents. with normal acceptable losses. From Mongalla to Malakal the River would. however. loose almost half of its average annual flow (over 14 billion cubic meter) on the swamps of Bahr El Jebel (Sud region)

i. Losses on Bahr El Jebel Swamps

From the River sources and up to Mongalla the losses are normal. while further down stream the losses in the swamps are terrific. Examples of such losses

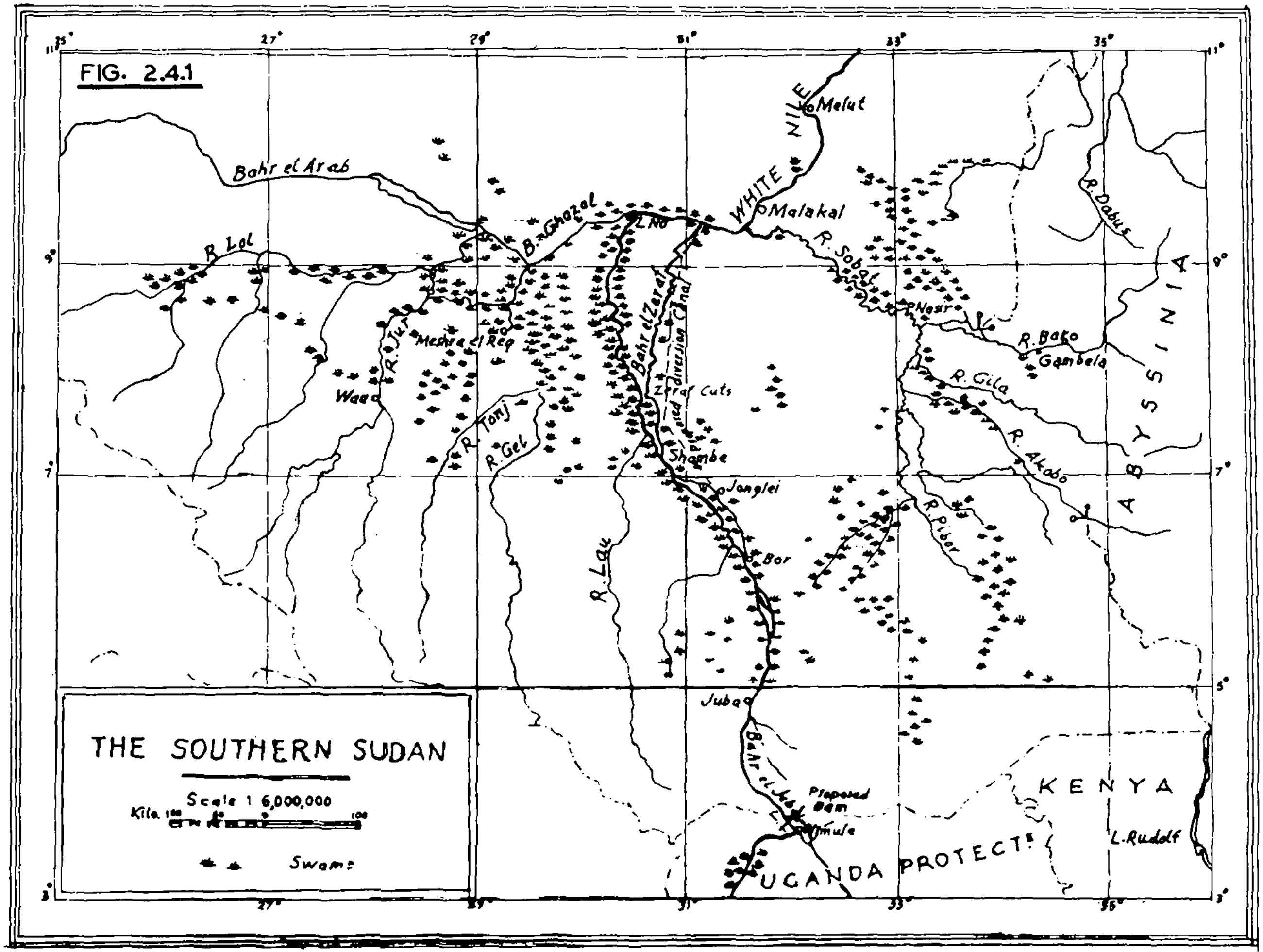

THE SOUTHERN SUDAN
Scale 1 6,000,000
Kilo.
Swamp
Bahr el Arab
R. Lol
B. Ghazal
L. No
WHITE NILE
Melut
Malakal
R. Sobat
Nasr
R. Baro
Gambela
R. Gila
R. Akobo
R. Pibor
R. Dabus
ABYSSINIA
Meshra el Req
R. Jur
Wau
R. Tonj
R. Gel
R. Lau
Bahr el Zeraf
Proposed diversion Canal
Zeraf Cuts
Shambe
Jonglei
Bor
Juba
Bahr el Jebel
Proposed Dam
Nimule
KENYA
L. Rudolf
UGANDA PROTECT^TE

FIG. 2.4.1

would be broadly demomstrated, for the period 1905 - 66, as follows:

Maximum annual discharge at Mongalla	65.5	billion cubic meter
Maximum annual discharge at Malakal	33.0	billion cubic meter
Minimum annual discharge at Mongalla	15.0	billion cubic meter
Minimum annual discharge at Malakal	10.3	billion cubic meter
Average annual discharge at Mongalla	29.0	billion cubic meter
Average annual discharge at Malakal	14.7	billion cubic meter

Hence the rate of losses in case of the average annual discharges approaches 50 (percent).

The percentage losses are reasonable up to a rate of flow reaching 30 million metric cube per day (mm^3 per day) at Mongalla then increases as shown below:

Discharge at Mongalla (mm^3/d)	Percentage losses (%)
30	17.0
40	22.5
50	32.0
60	40.0
70	45.7
80	50.6
90	54.0
100	57.0
110	59.5
120	61.7

It was also demonstrated from previous works that the only basic reason for these losses is the incapability of the River banks to hold discharges beyond a certain capacity.

ii. Proposals for Reducing these Losses

Ideas for reducing water losses on the upper reaches of the White Nile had appeared since 1898, while investigations work and recording of the River behaviour has started in 1904. The necessity for reducing the losses in the swamps of Bahr El Jebel was first discussed by Sir Williams Garastin in 1904 and has continued to be an important topic for discussion up to the present time.

The following projects had been discussed and proposed:

1. Projects with headwork beyond Jonglei (prior to 1930)
2. The Veveno-Pibor project
3. The Jonglei Canal Scheme(of 1936)
4. Bahr El Jebel Banking scheme
5. The modified Egyptian project
6. The modified Jonglei Canal scheme
7. Engineer Mohd. Khalil Ibrahim proposal
8. The P.J.T.C. proposals.

iii. Comparison between the abovementioned proposals

1 - Proposals with headworks starting beyond Jonglei point point were excluded for many reasons, most important of which were:

i. Water cost-benifit analysis had demonstrated that any southwards extention of these words, beyond Jonglei point, would give very little increase in the water benifit at a relatively very high cost.
ii. Topographic works had also indicated that the Jonglei line would be the safest latitude in case of high years, since excess water would find an easy access to the swamps area.
iii. The aerial survey of 1930 had proved the suitability of the Atem river at Jonglei for the execution of such head-works.

2 - The superiority of the Jonglei scheme to the Veveno-Pibor proposal was mainly based on the following :

1. The Jonglei scheme would give the same water benifits at rather a lower cost.
ii The Jonglei canal project could be expanded in a much cheaper way than the Veveno-Pibor scheme.

3 - Although for the same water benefits the banking scheme was found to be cheaper than the Jonglei project, the latter has been chosen for the following reasons:

i. Maintenance of the banking scheme would have been more difficult.
ii. The safety of the bank's structural works could not be guaranteed.
iii Secured navigation might have required special precaution in case of the banking scheme.
iv Adverse effect on the livelihood of the inhabitants were greater in case of the banking scheme.

4 - The above version of the Jonglei canal has been a subject of many revisions, most important of which are:

i. The Jonglei investigation team revision to the operation of the scheme.

ii. Dr Khalil's proposal which has added new suggestions.
iii. The P.J.T.C. proposals which is finally adopted as the Jonglei scheme.

Table 2.4.1. Water benefit

Bahr El Jebel discharges after the execution of the project	Phase 1 mm per d.	Phase 11 mm per d.
Mongalla at main course of Bahr El Jebel	75	75
Jonglei latitude	66	71
Jonglei at head of the canal	20	20
Bahr El Jebel at Jonglei latitude	46	51
Jonglei canals tail	19	19
End of Bahr El Jebel and Zeraf	32	45
Total after project execution	51	64
Total before project execution	38	39.5
Water benefit mm per d.	13	24.5
Water benefit in billion m^3	4.7	9.0
Water benefit in billion m^3 at Aswan	3.8	7.0

2.4.2. Swamps of Bahr El Ghazal basin

i. Bahr El Ghazal:

The boundaries to this basin are:

(a) The Sudan Congo frontier in the south.
(b) The Sudan Central African frontiers in the southwest direction.
(c) Marra hills in the north.

Rivers collecting from these boundaries flow towards Bahr El Ghazal swamps in the north eastern corner of the basin.

The total area of the basin is roughly estimated as 526000 square kilometer of which 40000 square kilometer is covered by the swamps.

ii. Main Rivers in the basin

The main rivers in the basin are:

1 - Bahr El Arab and tributaries
2 - River Lol and tributaries
3 - River Jur and tributaries

4 - River Tong and tributaries
5 - River Gel or Maridi and tributaries.

iii. Hydrological investigations

Run-off gauging on this basin had started as early as 1904 with a station on River Jur at Wau town. Intensification of hydrological gauging stations in the basin has slowly continued with the ultimate goal of covering the whole basin with reliable and adequate network.

Table 2.4.2. shows the total discharges of these rivers calculated from records on the period 1942 - 43 to 1951 - 52. At present it is believed that from the total of about 13 billion meters cube of water in Bahr El Ghazal Rivers only 0.5 billion meter cube reaches Lake NO and the remaining amount is lost in the swamps. Reclamation of this water is one of the aims of the P.J.T.C.

Table 2.4.2. Bahr El Ghazal basin Recorded discharges 1942-43 to 1951-52

Location of gauging	Average total discharge at floodseason		Average total discharge at the hydrological yr.	
	Billion m^3	Percentage	Billion m^3	Percentage
River Lol, at Nyamlall	4.00	31.7	4.10	31.1
Pongo River, behind Wau-Aweel bridge	0.60	4.8	0.60	4.6
Jur River, at Wau city	4.40	34.9	4.70	35.6
Tonj River, at Tonj town	1.10	8.7	1.10	8.3
Gel or Maridi River	0.40	3.2	0.40	3.0
Naam River, at Mvolo	0.40	3.2	0.50	3.8
Yei or Lau River, at Mundri	1.70	13.5	1.80	13.6
Total	12.60	100	13.20	100

2.4.3. Ethiopian Plateau Basins

Mention in this Plateau would be confined to the basins of Rivers Sobat and Machar Marshes (Fig. 2.4.1.)

2.4.3.a. Basin of River Sobat

Pibor and Baro Rivers are the main tributaries of the Sobat River. After their confluence point the unified stream (River Sobat) continues a journey of about 350 km before it reaches the White Nile, very close to Malakal. The eastern sub-tributaries of both Rivers collect their water from the Ethiopian highlands very near to the Sudan frontier.

The total area of Sobat River basin is estimated as about 187200 square kilometer of which 41400 square kilometer is River Baro basin, 109000 square kilometer is River Pibor basin and the remaining 36800 square kilometer is the main River Sobat basin.

The annual rainfall on the basin varies from 800 mm on the plains to 2000 mm at the highlands, while evaporation at Malakal and Gambeila is estimated as 1420 mm per annum.

Measurements of the average annual discharges of the Baro River had indicated that out of 13.3 billion cubic meter (1928 - 1956) at Gambeila, only 9.2 billion cubic meter (1929 - 1957) were recorded at about its confluence with the Pibor. In other words, the losses in the swamps of this River are èstimated as about 4 billion metre cube per annum.

The above losses are mainly due to inadequacy of the River channel to carry discharges beyond certain values. Investigations of these reaches has indicated that spillage over the natural channels would occur, on the different ranges, as in Table 2.4.3.

The P.J.T.C. is undertaking the responsibility of investigating the topographical, hydrological and other relevant aspects for the development of this lost water.

Table 2.4.3. Natural capacity of the River Baro channel, at different reaches.

Reach	Length km	Discharges million m^3 per day
Gambeila to branching of River Al ador	106	61
Branching of River Aladora to Gekaw mouth	13	60
Gekaw mouth to Khor Machar	23	30
Khor Machar to confluence of River Aladora	34	40
From confluence of River Aladora to Khor Makair	10	50
From Khor Makair to Baro mouth	15	45

2.4.3.b. Basin of Machar Marches

This basin is located between, Sobat basin to the south, White Nile to the west, Melut-Palokich road and Khor Yabus to the north, and the Ethiopian highlands to the east (Fig. 2.4.1.).

The swamps of Machar probably receives its water from Khor Ahmar, Khor Tombc, Khor Yabus, Khor Daga, Khor Lau, spillage from River Baro, Khor Machar, and from direct rainfall.

The area of these swamps is estimated as about 20000 square kilometer, while the average annual rainfall is estimated as 800 mm.

The annual average volume of water reaching Machar Marshes is estimated as about 4.4 billion cubic meter, of which only about 0.5 billion cubic meter reaches the White Nile through khors Adar and Wol.

2.4.4. Summary

Table 2.4.4. gives a summary of the potential capacity of the water conservation plans. These figures are taken from the P.J.T.C. 1960 - 61 annual report. Other sources show slightly different values. From the Nile water agreement of 1959 these quantities of water should be equally divided between Egypt and the Sudan.

Investigations aiming at reclaiming these losses are currently undertaken by the P.J.T.C.

Table 2.4.4. Summary of the results

Swampy region	Approximate average annual losses x 10^9 m^3	Annual average conservable water x 10^9 m^3	Remarks
Bahr El Jebel basin	14.3	4.7	Phase I
			as at Malakal
		4.3	Phase II
Bahr El Ghazal basin	13.2	7.0	
River Baro	4.0	4.0	
Machar Marshes	14.0	4.0	
Total	35.5	24.0	

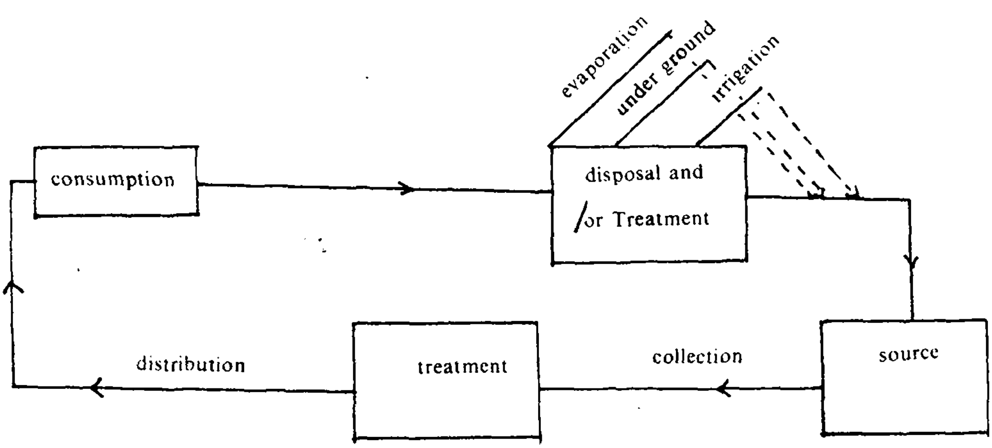
2.5. WATER RECYCLING

Throughout the country standards of living are rising, urbanization and industrialization are intensifying, and also new agricultural schemes are on the way. All these activities result in an ever increasing demand for water and correspondingly result in production of more waste water. Hence these two factors namely: the requirement of more water and the production of more waste water ask for good management in terms of quality and quantity of the existing water resources, and for the development of new water sources. Therefore the sources which a few years ago would have been considered unsuitable must now be utilized The two potential new sources are:

1. Recycling or reuse
2. Desalination (Section 2.6)

Each of the above sources has its potentialities and limitations, although the recycling has in many times proved to be more economical.

The recycling in principle is not invented by man, but it is actually an imitation of what is happening in nature. The only differences are : the shortening of the time factor required to decompose the contaminents, and the efficiency increase of the process which helps nature to cope more efficiently with unnatural contaminents introduced into the cycle (supply-consumption-treatment-reuse) as indicated in Fig. 2.5.1.



The recycling is practised around the world for different purposes and in different scales. For example in the USA the total water usage from the Verdigis River in Kansas was recorded as seventeen times the flow in the river. The recycling is usually practiced in the following order of preferences:

1 - for industrial and agricultural purposes, thereafter
2 - for cattle and recreation purposes, and finally
3 - for human consumption.

(It is to be noted that the requirements regarding quality are the least for industrial and agricultural activities). The following are typical types of water use in industry which could be satisfied through recycling:

1 - cooling
2 - steam generation
3 - processing including washing and transport
4 - potable.

Cooling being the largest demand which could easily be satisfied with recycled water. As to steam generation,this does not consume much water, as long as the condensate is recycled, but when water is a necessary part of the product, little can be done to affect its requirements.

The need for recycling is decided usually through the cost per benefit ratio analysis.

The limiting factors for recycling being the deterioration of water quality with respect to:

1 - chemical toxicity
2 - mineralization, generally and salinity in particular

Generally speaking the gradual build up of the dissolved substances is considered to be the main drawback of recycling. Table 2.5.1. demonstrates the gradual build-up of dissolved salts due to recycling.

The final effluents from municipal sewage works represents a potential for recycling. In this country the effluents from the municipal sewage works are used for irrigation purposes on a limited scale such as that practised in the green belt area of Khartoum. For the case of Khartoum North sewage works, due to the existing problems in the plant, the effluents produced cannot be used for irrigation. Yet,

Table 2.5.1. Contamination of water after five months reuse [2]

Analysis	original water	After about 10 cycles
pH	8.4	8.6
NO_3 -N ppm	1.9	2.7
Cl	63	520
SO_4	101	89
Na	59	379
Total solids	305	1139
NH_3 -N	-	10
COD	-	43
ABS	-	4.4
P.V.	-	3.9

it is hoped that after the second phase completion, the quaiity of the effluents will be of reasonable standards and hence it may be used for irrigation. Typical analysis of these effluents are shown in Table 2.5.2.

The capabilities of recycling technology are however more than that, and the industrialization of some parts of the country such as the eastern and western parts of the Sudan can only be viewed in the spectrum of recycling.

Table 2.5.2. Typical raw sewage and final effluent quality

Constituent	Raw water White Nile A	Raw water Blue Nile A	Treated water B	C	Final effluents D
pH	8.2	8.0	7.2	6.5 - 8	6.5 - 8
Turbidity	0.0	0.0	0,0	--	--
Conductivity	280	240	300	--	--
Total solids	140	120 ppm	120 ppm	200-300	16 - 44 ppm
Valuable solids	--	--	--	--	--
A validity	120	90 ppm	80 ppm	--	--
Hardness	70	80 ppm	70 ppm	--	--
U	10	10 ppm	10 ppm	--	--
NH -N	0.0	0,0	0.0	35-40	5.4 - 12 ppm
NO	0.0	0.0	0.0	4 - 12	12 - 22 ppm
GOD	--	--	--	--	--
BOD	1.3	0.6	--	150-200	8 - 20
P.V.	--	--	--	--	--
ABS	--	--	--	--	--
Coliform	--	--	--	--	--
Dissolved oxygen	8.9	9 ppm	0.2 ppm	--	--
Residual chloride					

C and D are at the inlet and outlet of El Goz sewage works A, A from White and BlueNiles, and B from Khartoum water works after treatment (Stack Lab.)

The success of using recycling as a water source will depend generally on the efficiency of treating the used water, the availability and quality of the existing water resources and the use for which the recycled water will be put.

The existing practice of evaporating the industrial effluents, for example as practiced in the Friendship Textile Factory, can not continue for long. This is because evaporation means loosing water and polluting the ground surface and consequently the underground water.

One should think of treating these industrial effluents so that it could be recycled in order to reduce the water demand and the pollution hazards because the discharging of industrial effluents on land, either for irrigation, subsurface disposal or evaporation may result in a long term pollution effects.

2.6. WATER DESALINATION

2.6.0. Introduction

The shortage of fresh water resources may in future call for processes enabling sea-water, brackish water or waste water with a high salt content to be used both for human consumption and for industry.

The necessary treatment includes removing salts or extracting pure water from the natural liquid which, in fact, is an aqueous solution.

Certain techniques are already in standard use, others are quite recent. The best known method involves evaporation in several alternative ways. The conventional method of distillation using source of heat from combustion of fuels, electricity, etc. is either very uneconomical or impracticable in remote arid areas. Recently the process of water distillation using solar energy has been adopted in many countries especially in north Africa, Latin America and Asia. In the Sudan favourable conditions exist for solar energy as the sun shines over 90 per cent in most regions.

The costs for evaporation processes do not decrease in proportion to the salinity. Two processes of desalination using membranes, electrodialysis and reverse osmosis, have been adopted and it is possible to adopt the process to the degree of salinity of the water to be treated.

In the article four methods of desalination will be summarised:

1 - sea water desalination by distillation
2 - solar distillation of water from saline boreholes
3 - electrodialysis
4 - reverse osmosis.

2.6.1. Sea water desalination by distillation

There are several competitive distillation processes depending on the source of power which is required to convert the water (fossil or nuclear fuel, solar or geothermic energy) and on the daily capacity required:

- staged expansion or MSF (multi-stage flash recirculation)
- the multiple effect process
- steam compression
- solar distillation process

The steam produced by sea water evaporation is sufficiently pure to produce distilled water containing less than 30 mg of salt per litre. The sea water can be evaporated at various temperatures depending on the pressure in the evaporation chamber. Under vacuum conditions, evaporation occurs at very low temperatures (Fig. 2.6.1).

In the multi-stage flash recirculation the brine is heated under pressure inside the tubes of heat exchangers. After the brine reaches the maximum temperature in the input heater, it is injected into a series of flash chambers. Each chamber works at a successively lower pressure, and flash vapour is released in

Fig. 2.6.1

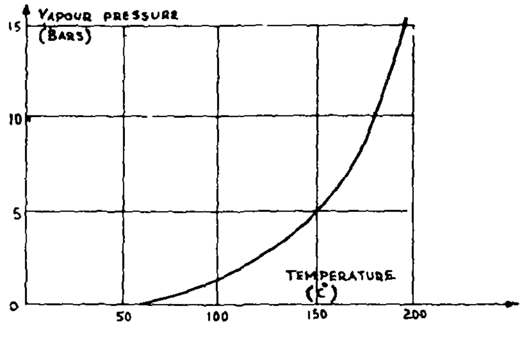


Fig. 2.6.2

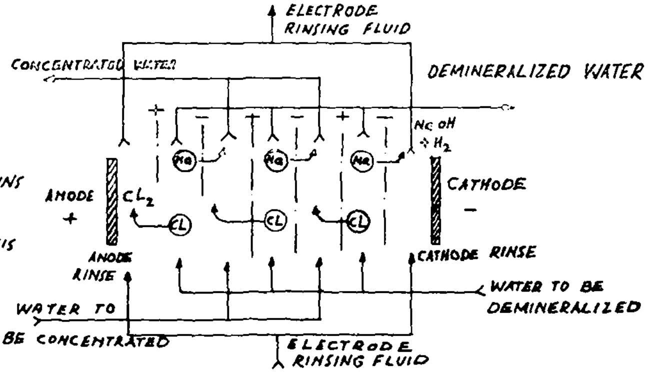
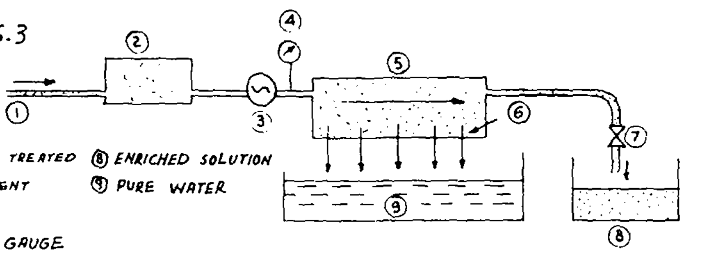


DIAGRAM EXPLAINS PRINCIPLE OF ELECTRODIALYSIS

Fig. 2.6.3



① WATER TO BE TREATED
② PRE TREATMENT
③ PUMP
④ PRESSURE GAUGE
⑤ MEMBRANE SUPPORT
⑥ MEMBRANE
⑦ REGULATING VALVE
⑧ ENRICHED SOLUTION
⑨ PURE WATER

PRINCIPLE OF REVERSE OSMOSIS

each. This vapour is condensed on the outside of the heat exchange tubes through which the brine flows, and regenerative recovery of heat takes place. A point is reached in the cycle when the temperature of the vapour is insufficient to transfer heat economically to the brine in circulation, and the last few stages are separately cooled.

In the multiple effect process the low pressure steam is used to heat the first effect. The vapour produced being used to heat the next effect and so on. Vapour from the last effect is used largely in preheating the feed, the rest being condensed by cooling water.

In the plants used for the mechanical vapour compression the vapour produced is mechanically compressed and then acts as the heating steam. Because no cooling water is required it was possible to install this type of plant without providing sea water intake facilities.

Solar distillation process is a recent technique and current researches concentrated in increasing the yield of potable water from brackish water. The process may be developed in the future to cover desalination of sea water.

Sea water distillation is an area of continuing technical development and the characteristics of a desalination plant are obtained by striking a balance between the investment costs and the operating cost in order to obtain the lowest possible cost price per cubic metre of fresh water produced. The more important characteristics are:

The performance or economy ratio (number of cubic metres of fresh water produced per metric ton of steam). This ratio will vary from 7 to 13 depending on the fuel costs.

The sea water pre-treatment methods related to the maximum temperature of the brine at the head of the plant, (pre-treatment prevent scaling which results from presence of dissolved salts in the sea water). The higher this temperature, the lower the cost of the evaporation unit. However, pre-treatment using polyphosphates (limited the temperature below 90^{o} C) is much simpler and less expensive to run than acid injection pre-treatment (limited to temperatures below about 120^{o} C). The use of polyphosphates is generally recommended when sea water salinity is high (45 g per l or more) and when a cheap power source is available (low economy ratio).

2.6.2. Solar distillation of water from saline boreholes

It is a recent technique adopted for removing the impotability of water. It is experimented and applied successfully in many countries and many researches are going on to improve the implementation of the method. Being a simple and economical method great attention has been devoted to adopt the method for distillation of brackish borehole water water in the Sudan - Researches and experiments are carried out in Faculty of Engineering at the University of Khartoum in small scale production plant and many alternative designs are tried to step up the the maximum yield of potable water.

Two main systems of solar distillation have been used during the last 10 years:

1 - distillation by natural circulation of water vapour

2 - distillation by forced circulation of water vapour.

The first method is done by a simple glass house consisting of a metal. wooden or masonary basin with a glass roof. and a black-painted floor covered with a reasonable depth of water. Evaporation and condensation are stimulated by natural convection and natural atmospheric draft respectively.

In the second method mechanical means are introduced both for increasing the rates of evaporation and condensation and hence higher yield is expected.

Although the solar energy method seems to be promising for solving the problem of saline boreholes in the Sudan. yet feasible and economical design for large production is not justified.

2.6.3. Electrodialysis

It is simply an electrolysis process in which a specially arranged series of membranes is placed between the electrodes:

- same membranes being negative and permeable only to the cations.
- and the other being positive and permeable to the anions.

By this means. both the cations and the anions can pass through the membranes while liquids and non-ionized molecules are retained (Fig. 2.6.2). However. salinity can hardly be reduced by more than 50 (percent) by movement through one electrodialysis cell without a loss in efficiency. Consequently. most units comprise several stages in series. and the required reduction in salinity is achieved by successive stages.

Raw water must be pre-treated before being introduced into the electrodialysis cells:

- turbidity must be eliminated
- the ion content must be reduced to a fraction of a milligram per litre.
- for raw water containing calcium bicarbonate. treatment by acidification is quite suitable for limited output units while removal of carbonates by means of ion exchangers is suitable for large installations.

Investment costs with the running costs increase rapidly with the salinity of the raw water as an increase in the number of stages is required. Hence electrodialysis is particularly suitable for waters of low salt content and present technical development states that brackish water with a salt content of about 3 g per L can be easily treated by this method to produce drinking water.

2.6.4. Reverse Osmosis

The difference in pressure between solutions of different concentrations is the osmotic pressure. It can reach high values. for example 25 atmospheric pressures for sea water containing 35 g per L salts. 31 g per L of which is sodium chloride

Conversely, if pressure in excess of the corresponding osmotic pressure is applied to an aqueous solution in contact with semi-permeable membrane, pure water will pass through the membrane. Using simple equipment as shown in Fig. 2.6.3, it is possible to apply the method to desalination or demineralization of brackish or sea water.

Principle of reverse osmosis

Membranes used are mostly of a specially treated cellulose acetate. Applying pressure for example 70 atmosphers, it is possible to obtain water containing less than 1 - 2 (percent) of the original salinity of sea water at a rate of

about 150 - 200 l per d per square meter.

Production of drinking water from brackish water is easier than from sea water, because osmotic pressure is lower and less salinity reduction is required. However extensive pre-treatment is necessary for brackish water containing calcium sulphate or bicarbonate to prevent formation of scale on the membranes.

The special nature of this process, which extracts pure water from a solution of aqueous suspension, where as other techniques like electrodialysis extract impurities, lends reverse osmosis as a possible method for final recovery treatment of waste water.

Current researches are concentrating to find out suitable membranes of longer performance and with higher capability of producing purer water.

Process water for food industry can be produced by reverse osmosis, because the membranes are impermeable to bacteria and the various organic substances. This possibility is of great interest as water is becoming increasingly polluted.

2.7. SUMMARY

Table 2.7 summerizes in a very broad way the present available and the foreseen future conservable water supply in the Sudan. It must, however, be noticed that sea water, which represents an appreciable potential supply for many uses, is deliberately excluded from this table due mainly to difficulties in estimating quantitatively its contribution:

Table 2.7. Potentiality of water supply in the Sudan

Source of supply	Presently available x $10^9 m^3$	Futurely conservable x $10^9 m^3$	Remarks
From Nile water agreement (at centre of the Sudan)	20.35	20.35	In future, this quantity is subject of constrains from the 1959 water agreement.
Water conserved from the swampy regions		12.0	Water from Bahr El Jebel, El Ghazal, R. Baro and Machar swamps.
Non-Niletic streams		8.0	Only minor part of this water is utilized by Hafirs and dams (including Baraka and Gash).
Annual recharged ground water	0.3	2.0	From all the ground water resources in the country.
Water conserved from improved irrigation efficiency		2.0	Assuming a 10 improvement in efficiency
Total annual amount	20.65	43.35	This is the quantity of water that may be obtained annually.
Water from ground water		564.0	Water in storage without annual recharge.

CHAPTER 3

WATER NEEDS

3.1. DRY LAND FARMING

3.1.1. Introduction

Unlike traditional agriculture and irrigated farming which have been practiced in the Sudan for many centuries. mechanized rainfed agriculture is relatively new. Only about 40 years ago this type of farming was unknown in the country and it was only during the mid-forties that it was introduced in Gedaref area.

Like all other new innovations large scale mechanized rainfed agriculture was faced in the beginning with operational difficulties but it was rapidly established during the mid-forties especially when private enterpreneurs were allotted land to be developed wholly by them.

The rate of expansion was slowed down during the early sixties but during the last five years plan rapid horizontal expansion took place. In contrast to the expected slow rate of expansion in areas under perennial irrigation. projections for mechanized dry land farming indicates that a huge expansion will take place in that field. The obvious reason for this contrast is the fact that development deals with limited amounts of accessible areas for perennial irrigations and that most of these areas were already underdeveloped. Moreover most of the available arable land can safely and cheaply be put under rainfed agriculture.

3.1.2. The role of rainfed agriculture - productivity and areal dimensions

Although Sudan is one of the few leading countries in Africa in the field of irrigated agriculture. one should not overlook the fact that it is also the leading country in the field of mechanized rainfed agriculture.

Together with traditional rainfed farming. mechanised dry land farming contributes to a large extent on the attainment of the country's self-sufficiency in food crops such as sorghum. millet and it also contributes substantially in foreign exchange earnings through the production of oil seeds such as sesame. ground nuts and cotton seeds. Compared to traditional farming. mechanised rainfed agriculture covers about 55 (percent) of the cultivated rainfed areas but productivity-wise it contributes much more.

As far as the main crops are concerned the following tables give the areas under crops for the last nine years. A quick look to these tables will give a clear indication of the role played by mechanised rainfed farming in the economy of the country.

Although date limitations do not permit the presentation of a full picture of the situation in traditional rainfed agriculture. Table 3.1.4. will. nevertheless. give a rough guide.

Table 3.1.1. Areas under Dura (sorghum) in the mechanized rainfed farming areas in the Sudan 1967/68 - 1975 / 76 (units in feddans).

Season	Kassala	Blue Nile	S.Kordofan	Upper Nile	White Nile	S.Darfur	Total
1967/68	1,600.000	189.368	200	40,000		-	1.829.568
68 / 69	676.330	145.300	200	30,450		-	852.280
69/ 70	1.243.988	187.001	685	60,000		-	1.491.674
70/ 71	1.688.742	257.520	15.714	65,000	14.367	-	2.041.343
71/72	1.467.970	298.174	76.510	127.260	43.765	-	2.013.679
72/73	1.082.935	366.131	85.358	177.530	33.620	-	1.745.574
73/74	1.390.500	598.500	124.155	253.755	53,070	1.400	2,420,902
74/75	1.635.000	695.850	159.528	225.600	48.400	4.380	2.768.758
75/76	2.000.000	499.361	182.442	316.805	51.020	5.700	3.055.328

Table 3.1.2. Area under cotton in the mechanized rainfed farming area in the Sudan 1967/68 - 197576 (units in feddans)

Season	Kassala	Blue Nile	S.Kordofan	Upper Nile	White Nile	S.Darfur	Total
1967/68	36,720	-		-	-	-	36,720
68/69	34,650	-		-	-	-	34,650
69/70	63,640	-	50	-	-	-	63,690
70/71	20,528	-	300	-	-	-	20,828
71/72	5,600	-	798	-	-	-	6,398
72/73	16,050	-	6,445	-	-	-	22,495
73/74	20,550	1,600	12,033	-	-	-	34,183
74/75	8,200	12,020	7,813	-	-	-	28,033
75/76	15,000	11,184	3,000	-	-	-	29,184

Table 3.1.3. Area under sesame in the mechanized rainfed farming areas in the Sudan 1967/68 -1975/76 (units in feddans)

Season	Kassala	Blue Nile	S.Kordofan	Upper Nile	White Nile	S.Darfur	Total
1967/68	321,506	22,025			-	-	343,531
68/69	298,900	29,690		5,800	-	-	334,390
69/70	321,924	26,065	98	8,000	-	-	376,086
70/71	278,578	25,735	2,700	11,705	-	-	318,718
71/72	278,454	33,056	2,776	10,510	-	-	324,796
72/73	370,472	101,281	7,667	31,520	4,200	-	515,140
73/74	441,500	224,914	10,386	49,820	5,300	-	731,920
74/75	374,000	177,568	24,444	45,285	6,150	300	627,747
75/76	300,000	142,835	20,984	45,110	2,500	400	511,829

Table 3.1.3. Area under sesame in the mechanized rainfed farming areas in the Sudan 1967-68 - 1975-1976 (units in feddan)

Season	Kassala	Blue Nile	S. Kordofan	Upper Nile	White Nile	S. Darfur	Total
1967-68	321,506	22,025	--	--	--	--	343,531
68-69	298,900	29,690	--	5,800	--	--	334,390
69-70	321,924	26,065	98	8,000	--	--	376,086
70-71	278,578	25,735	2,700	11,705	--	--	318,718
71-72	278,454	33,056	2,776	10,510	--	--	324,796
72-73	370,472	101,281	7,667	31,520	4,200	--	515,140
73-74	441,500	224,914	10,386	49,820	5,300	--	731,920
74-75	374,000	177,568	24,444	45,285	6,150	300	627,747
75-76	300,000	142,835	20,984	45,110	2,500	400	511,929

Table 3.1.4. Cultivated areas in traditioanal sector

Province	Areas 1961-62	1971-72	1976-77
Northern	31,500		
Khartoum	30,000	235,000	
Blue Nile	1,049,000	3,811,000	520,000
Kassala	1,740,000	94,000	350,000
Kordofan	2,407,000	1,126,000	2,463,000
Darfur	240,000	339,000	1,197,000
Upper Nile	213,000	42,000	175,000
Bahr El Gazal	106,000	212,000	300,000
Equatoria	146,000	85,000	353,000

To give a clear picture of the upward trend of development in the field of mechanised rainfed during the past years. the above information can be represented in the following diagrams which give the situation for dura as an indication for other crops. (Fig. 3.11 - 3.1.5).

Apart from what has been developed in the past years. the six - years plan proposes the following horizontal expansion in the field of mechanised rainfed agriculture.

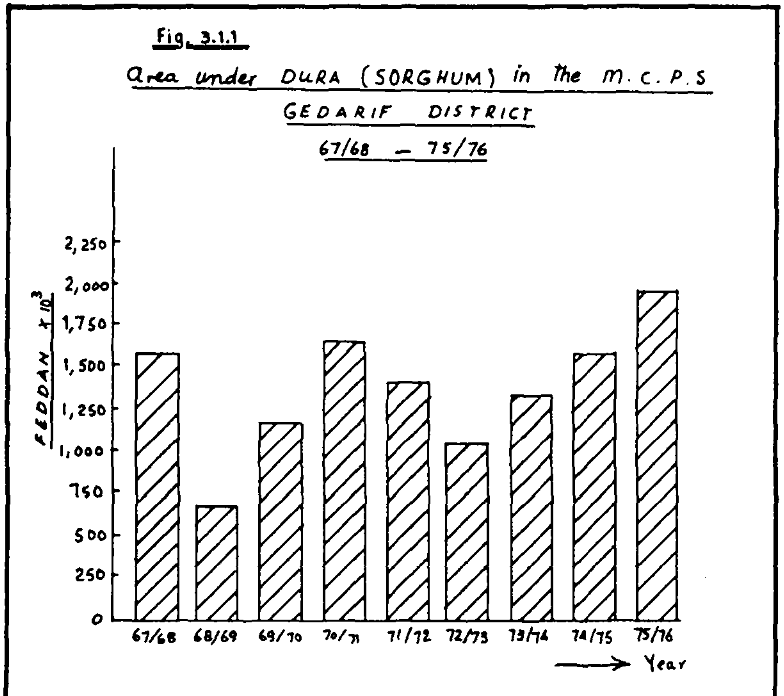


Fig. 3.1.1
Area under DURA (SORGHUM) in the M.C.P.S
GEDARIF DISTRICT
67/68 — 75/76
FEDDAN x10^3
2,250
2,000
1,750
1,500
1,250
1,000
750
500
250
0
67/68
68/69
69/70
70/71
71/72
72/73
73/74
74/75
75/76
Year

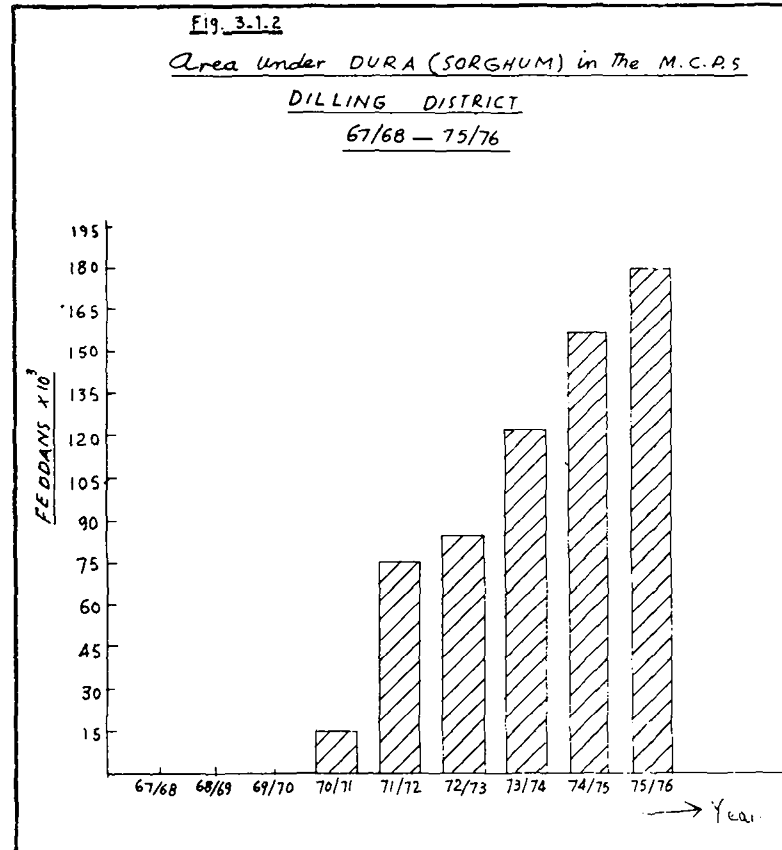


Fig. 3.1.2
Area under DURA (SORGHUM) in the M.C.P.S
DILLING DISTRICT
67/68 — 75/76
FEDDANS x10^3
195
180
165
150
135
120
105
90
75
60
45
30
15
67/68
68/69
69/70
70/71
71/72
72/73
73/74
74/75
75/76
Year

Fig. 3.1.3

Area under DURA (SORGHUM) in the M.C.P.S

DAMAZIN DISTRICT

67/68 — 75/76

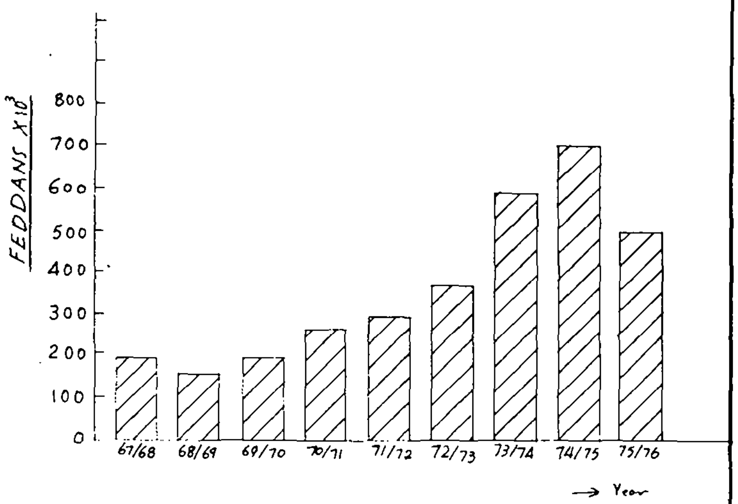
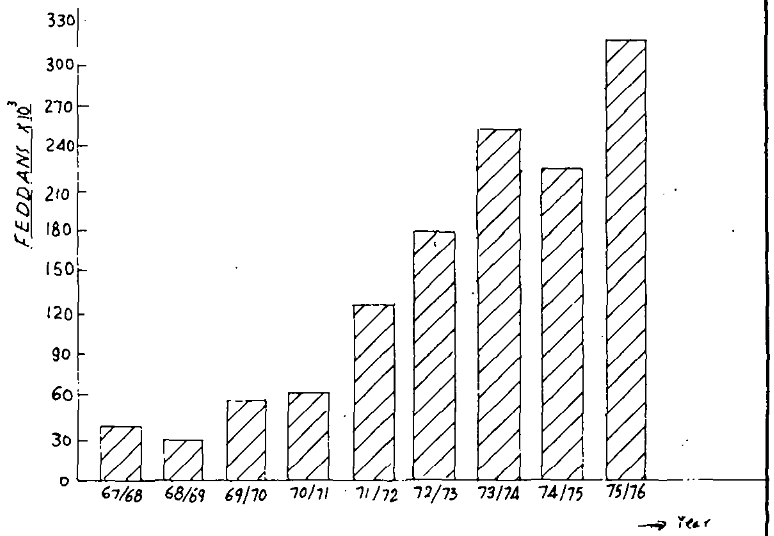


Fig. 3.1.4

Area under DURA (SORGHUM) in the M.C.P.S

RUNK DISTRICT

67/68 – 75/76



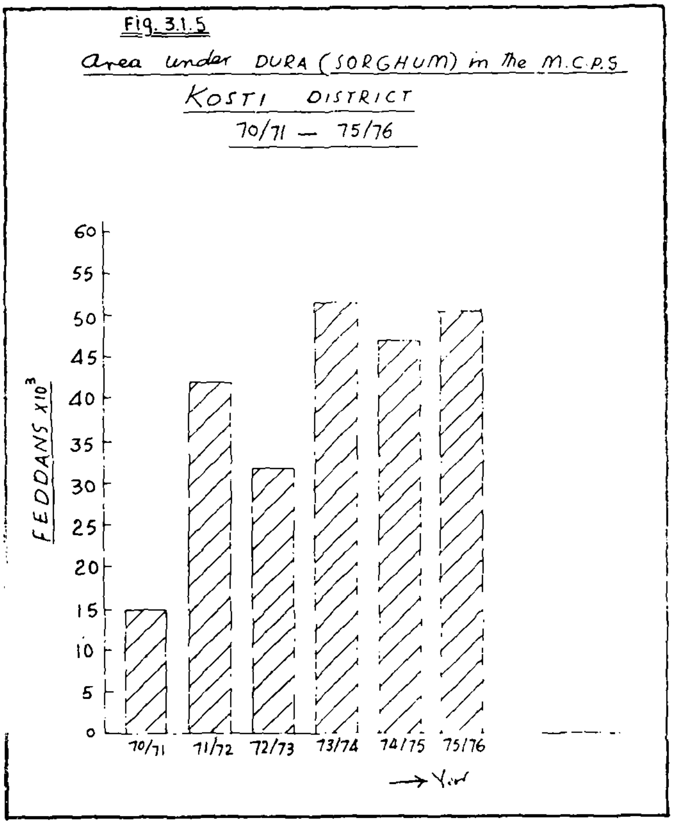


Table 3.1.5. Area to be developed during the six years plan

1. private sector	area - feddan
Bahr El Ghazal province	600,000
S. Darfur province	375,000
Blue Nile province	500,000
Southern Kordofan province	425,000
Upper Nile province	250,000
Equatoria	250,000
Kassala	100,000
Total	2,500,000

To this will be added areas which are already allocated or under allotment for large agricultural companies, the total extent of which is about 3 million feddans. Thus the private sector share is about 5.500.000 feddans.

2. Public sector	area - feddan
Southern Kordofan	225,000
Blue Nile	250,000
Northern Darfur	30,000
Equatoria	30,000
Bahr El Ghazal	30,000
Total	565,000

So the overall target of the six years plan is around 6 million feddans.

3.1.3. Implications of mechanised rainfed farming on available water resources

Despite the huge part of present expansion in the field of mechanised rainfed farming and despite the vast area to be developed in the future, areas under dryland farming do not make any appreciable demand on the permanent water supply available for the country's consumption.

All crops grown on these vast areas depend entirely on rainfall for their growth. Almost all of the areas under rainfed agriculture lie on the central dry plain between isohytes 500 - 750 mm. Such quantity of rainfall is quite adequate for the growth of the main crops.

Even the provision of domestic water supply for those working in the fields depend almost entirely on rainfall. In most schemes and projects in rainland artificial water ponds or haffirs with varying capacities are excavated and when they fill during the rainy season they provide the only source of water for those working in the fields.

In very few cases where some sandstone rocks are met some deep wells were dug but this is usually in very limited areas.

Water requirement for farm labourers and other categories working in the fields certainly vary appreciably and this could be judged from the following rough estimates of the number of workers in a farm-unit of 1000-1500 feddan:

Tree clearance	**100**	**labourers**	**for**	**5 months**
Weeding	**80**	**labourers**	**for**	**1 months**
Harvest	**125**	**labourers**	**for**	**1 months**
Sack handling	**30**	**laboureres**	**for**	**2 months**

In addition to this there are about 10 permanent staff half of which stays all the year round. Multiplying thesefigures with the present per capita for water consumption, one could imagine the huge quantities of water required for domestic use in the rainfed areas which covers millions of feddans (see attached plate 3.1.1.).

To stress this point some data pertaining to the number of haffirs and their capacities, in different mechanised farming projects have been collected. Such data although incomplete can nevertheless give some indication of the quantities of water consumed domestically in the rainfed mechanised schemes. The information is given in the following table:

Table 3.1.6. Water sources in mechanised rainfed areas.

Area	No. of haffirs	Total capacity m^3
Damazine area	96	1,898,000
Gedarif	120	3,815,000
Renk	3	200,000
Dilling	13	350,000
Megennis project	5	80,000
Total	237	6,343,000

3.1.4. Summary and conclusions

From what has been mentioned previously the following conclusions can be drawn:

1- That agricultural activity in the rainlands by far exceeds the activity in the irrigated areas and that the country depends to a large extent for its food consumption and foreign earning on dry land farming. It is also evident that dry farming occupies large tracts of land many times the area under perennial irrigation.

2- That mechanised dry farming, although it makes valuable contributions to the country's economy, it nevertheless does not make as much demand on the country's available water resources compared to other agricultural industries. Even if it does, considering the overall water balance situation, such demand is modest and can be easily and cheaply fulfilled.

3- That although a number of haffirs and water points have been established in these areas, there is still an acute shortage of water in many parts, and that even the available water does not meet the minimum hygienic standards required.

4- That future development will continue to be in the dry farming areas not only because it is cheap and less demanding but simply because we have very limited available water resources for perennial irrigation.

3.2. IRRIGATION WATER REQUIREMENTS

3.2.1. Introduction

It is well demonstrated in section 2.1 of this study that over 90 (percent) of the Sudan's area lies within climatic zone where the total annual evaporation exceeds the annual rainfall. It is also indicated in that section that even in areas where the seasonal rainfall is adequate for cultivation on a total quantity base, its distribution in time is somewhat inadequate for reliable production. On the other hand, landwise Sudan has one of the greatest potentialities for the world's food production, a fact that has been firmly recognized in Roma's International Conference on Foods Problems. That recognition has put on the Sudan, among other few countries, the responsibility of increasing their agricultural yields.

To boost up its agricultural production the Sudan is hence expanding both its irrigation and rainfed cultivation. Though rainfed cultivation is undergoing a vast expansion (Section 3.1.) its productivity is far below that of an equivalent irrigated area due mainly to unreliability in the distribution and quantity of rainfall.

Table 3.2.1 shows the irrigated area and the annual rate of increase of that area as per head of population in few selected countries that are famous for practicing irrigation. Though the gross irrigated area in the Sudan lies well below many of these countries, its average annual rate of increase stands as one of the highest in the world. The vast expansion in the Sudan's irrigated area, as developed in the last few decades, is clearly demonstrated in Fig. 3.2.1. That expansion was unfortunately coupled with almost the total consumption of the Sudan's share of the Nile water, the sole traditional source (Fig. 3.2.1.).

To go further with its proposed future irrigation development, the Sudan has to look for water from, and to optimize between more expensive sources. These sources may include conservation of water from swampy regions, improving various utilization efficiencies, controlling of non-Nilotic streams, recycling and desalination processes.

Furthermore due attention must be paid to other uses of water such as in power generation, industrial, domestic, navigation, fishing, and recreation sectors. In this respect it is relevant to mention that the amounts of water needed for mining, manufacturing and thermal power production already surpass agricultural requirements in some countries and may soon do so in many more (Table 3.2.4).

Review of all available vast wealth of literature on irrigation was found impossible in this brief study, yet its great importance calls for a whole project devoted primarily to that aim. Hence the aim of this short note will deliberately be confined to briefly reviewing the history, methods, efficiency and problems of irrigation improvement, since by such improvement an appreciable amounts of the lost water can be made available for further use.

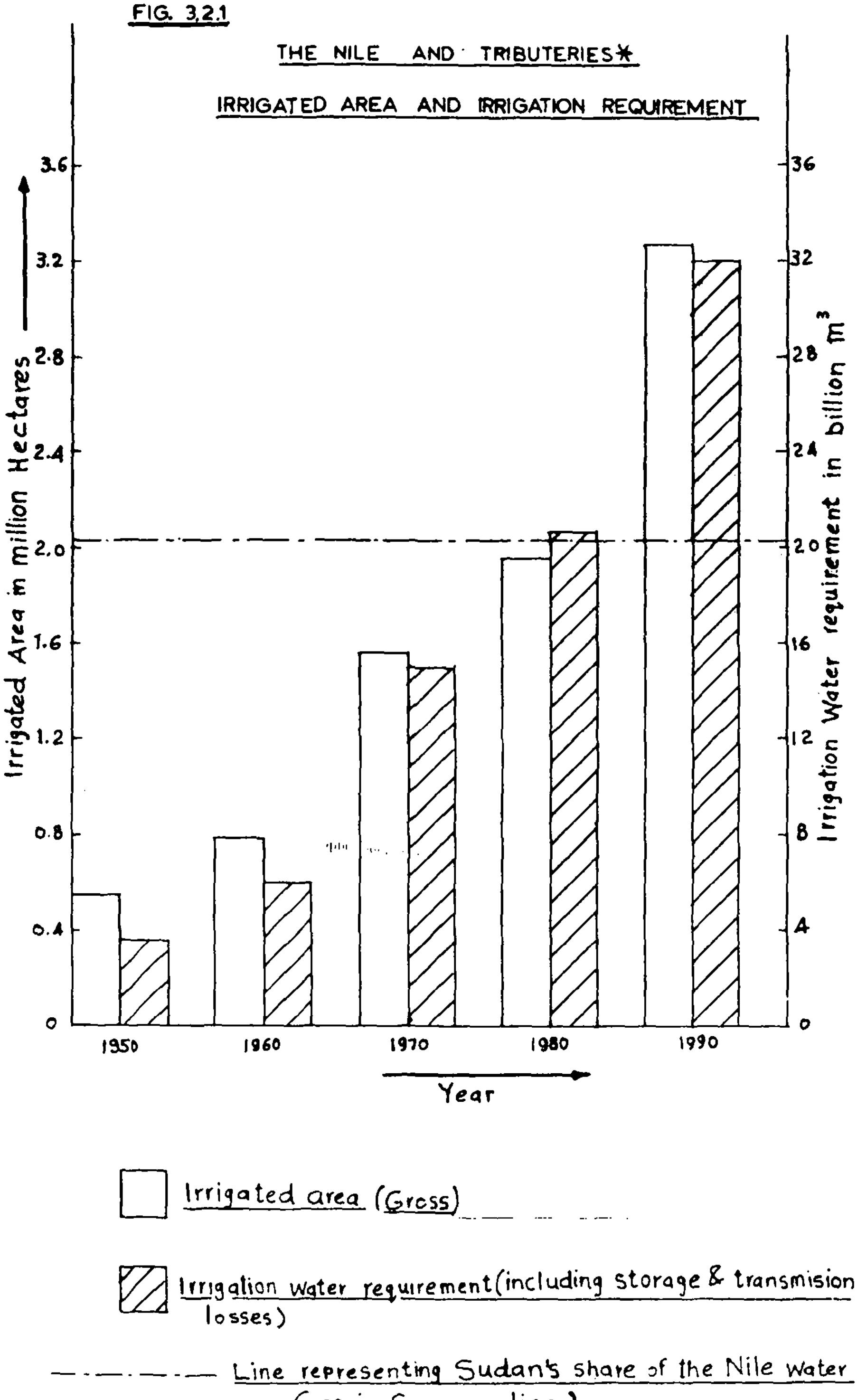
Table 3.2.1. Irrigated area per head of population in few selected countries.

Country	Period	Population x 10^6	Total irrig.area ha. x 10^6	Irrig. area per capita ha/capita	-average annual rate of increase m^2/capita
China (main land)	1960	640.0	74.0	0.116	
India	1960	442.0	23.4	0.053	+ 8.0
	1964-65	460.0	26.2	0.057	
U.S.A.	1960	184.0	16.6	0.090	
	1968	200.7	17.8	0.089	- 1.3
West Pakistan	1960	43.0	6.0	0.160	+ 111.3
1968	47.0	11.7	0.249		
Russia	1966	233.0	9.9	0.042	
Mexico	1966	44.0	3.3	0.075	
Iran	1967	25.1	3.1	0.124	
Egypt	1960	26.1	2.5	0.096	+ 1.3
	1968	30.0	2.9	0.097	
Sudan	1960	12.7	0.8	0.066	
	1978	17.0	1.9	0.112	+ 25.6

FIG. 3.2.1

THE NILE AND TRIBUTERIES*

IRRIGATED AREA AND IRRIGATION REQUIREMENT



* Numerical Figures for this diagram were taken from reference (7)

3.2.2. Brief history

Irrigation in the Sudan had been practiced in the northern part of the country since the time of the oldest known civilization. In the remainings of these civilization numerous indications such as revervoirs, swimming and distribution facilities had alread been discoverd[4]. Striking similarities were also observed between these findings andthose discovered in Egypt. Such similarities should surprise nobody since the two civilizations were long proved to have great links between each other. Though it is not easy to state exact dates of constructing these irrigation works, yet there are beliefs that the world's ever oldest dam had been built in Egypt for the purpose of drinking and irrigation some 5000 years ago[3]. Whatever differences could be made on the accuracy of the age of these works, no doubt basin irrigation had been practiced along the Nile since 3000 B.C.

Along the centuries primitive methods for lifting irrigation water has also been introduced in both Egypt and Northern Sudan (sagia and shadouf). These methods were sometimes used to subsidize basin irrigation and to provide water at low river flow. Strange enough that these methods are still in practice at many places along the Nile valley.

These forms of irrigation had however continued as the sole practice up to 1904 when William Garsten (an engineer in the Egyptian Ministry of Works) wrote his famous report on the suitability of the Gezira land for modern methods of irrigation. Two years later cotton was actually irrigated in the Zaydab area. It is worth mentioning, however, that prior to that project, cotton had already been undercultivation in the Gash and Baraka Deltas.

In 1910, however, a group of English weaving companies formed the well known Sudan Plantation Company who had started their first irrigation activities by a pump scheme at Taiba area. The amazing yield obtained from that scheme encouraged the company, to extend its irrigated area in 1914 by a bulk of 2520 hectores, at Barakat. Such extensions were continued by developing: in 1921 the Haj Abdalla pump scheme of 8190 hectares and in 1921 Wad El Nau pump scheme of an area of 12600 hectares have been established.

After the end of the first world war the work was continued on Sennar Dam which was officially opened in 1925 to irrigate an area of 126,000 ha. in the Gezira. That date marked a sharp development in the gross irrigated area of the Sudan. Since then the Gezira scheme continued to expand reaching, at the time of independence, an area of over 400,000 ha.

Soon after its independence the Sudan Government had embarked on the execution of the Managil scheme which ultimately inflated the gross irrigated area in the Gezira to over 840,000 ha. At that time the Sudn had managed to work out an agreement with the Egyptian Government so as to use their reservoir at Jebel Aulia for extra storage for meeting the country's water need at low flow period.

The restriction on the Sudan's use of the low flow period water was finally resolved after the famous 1959 water agreement between the Sudan and Egypt. Soon after that agreement the country embarked on the execution of Roseiris and Kashm El Girba Dams. While the completion of the first dam has facilitated crop intensification in the Gezira and the development of numerous pump schemes (famous of which are El Suki, N.W.Sennar, Abu Naama, Rahad, etc.), the completion of the second one in 1966 has led to the irrigation of another 173,000 ha. in Kassala province.

Other than the above mentioned schemes, vast development in pump irrigation (over 420,000 ha.) has similtaneously been witnessed, along the main Nile, Blue Nile and the White Nile.

All the abovementioned schemes are prepared and drawn, by the Government, in a comprehensive map (plate 3.2.1) showing in addition to the presently and futurely irrigated areas, the present and future rainfed projects, as well as the hydropower projects. The total water requirements for these irrigation schemes are compiled in Table 3.2.2 a. and 3.2.2 b. It must however be over emphasised that the numerical figures in these tables are meant to give an order of magnitude for the purpose of this work only, and hence it should not be taken as typical. That is because wide variation, on these values, were found in different reports.

3.2.3. Systems of Irrigation

According to the means by which water is transfered from the source to the conveyance system, irrigation in the Sudan can broadly be classified as follows:

i. Gravity irrigation from rivers
ii. Pump irrigation from surface and ground sources
iii. Flood irrigation
iv. Traditional irrigation (sagia and shadouf).

Table 3.2.2.a. Committed shemes and their water requirements

River system - present schemes	Gross area in ha x 10	Total annual water req. for each	Total water req.x10 m
Blue Nile			
Rosieris reservoir (evap. after heightening		510	
Pump scheme U. S Sennar	126	791	
Abu Naama scheme (Kenaf)	13	109	
El Suki scheme	36	310	
N. W. Sennar	16	382	
Sennar Reservoir losses		298	
Gezira and Managi schemes	876	7517	
Rahad scheme phase 1	126	1139	
Pump schemes D %S Sennar	33	431	
Guneid scheme	36	545	
TotaL	1262 (1247)		12032 (11977)
White Nile			
Pump schemes	223	1910	
Kenana Sugar Scheme	34	757	
Hajar Asalaya	15	363	
Melut	13	310	
Evaporation losses (Jebel Aulia)			
Total	285 (260)		3340 (2840)
River Atabara			
Kashm El Girba scheme (plusevaporation)	173	1970	1970
	(156)		(1839)
Main Nile			
Pump schemes	125	1152	
New pump schemes	22	201	
Basin irrigation	29	250	
Total	176	1603	1603
Ground water			
Kassala area	3	76	
Khartoum area	2	46	
Other area	--	3	
Total	1884		19070

Table 3.2.2.b. Proposed schemes and theirwater requirements

River system - proposed scheme	Gross area in ha x 10	Annual W. req. m x 10	Total W. req.
Blue Nile			
Kenana	336	3040	calculated as Rahad (1)
Rahad Phase 11	218	1970	"
S. Khartoum projects	42	541	"
Total	596 (596)		5551 (4800)
White Nile			
Renk, Jalhak (sugar)	84	2080	(calculated as Melut)
Jonglei irrigation scheme	84	300	
Pengko scheme	210	750	
Extension on pump schemes (Kenana) S. Khartoum, etc.	42	370	
Total --	420 (118)		3500 (2300)
River Atbara			
Seti scheme (reserv. evaporation)	260	2500	2500
Total	(261)		(2190)
Main Nile			
Extensions (dr Smith 's revised soilsurvey)	42	385385	
Total	(0.0)		(0.0)
Non-Nilotic extensions			
i.e J. Marra, Wadi El Khaw, Sag El Naam, Kassala, etc.	250	2000	
	(223)		
Total	1568		13936

Note:

(1) Numerical figures in this table are primarily estimates prepared by S. Elzein and Abdin M.A. Salih (ref. 7) some of the recent publication of the Ministry of Irrigation show slightly different values.

(2) Figures between brackets are taken from the National report to the 1977 United Nations Water conference (8).

(3) The numerical fig. in tabe 3.2.2.a are rough estimates which may not necessarly represent the actual consumption of water preliminary compilation of the total water actually consumed by some of these schemes indicates much lower values.

i. Gravity Irrigation

Examples for this system of irrigation are:

(a) Gezira and Managil

(b) Kashm El Girba

(c) Rahad Scheme. after the barage site.

Gravity irrigation is the largest system of irrigation in the Sudan. The total irrigated area by this system is estimated as over one million hectare. excluding the Rahad scheme.

ii. Pump irrigation

Pumping of irrigation water could either be from surface source such as river. lakes or haffirs or from ground water sources.

Pumping from rivers is the largest of these practices. ranking second to gravity irrigation. The total irrigated area by this system is estimated as about 0.87 million hectare. including the Rahad scheme (Phase 1).

Pumping from lakes. haffirs and ground water is practiced in smaller areas as compared to the above mentioned.

iii. Flood irrigation

This system of irrigation is practiced in the Sudan under two names. flush system and basin system.

Flush irrigation is the system practiced in the Delta. of Baraka and Gash. The total areas irrigated by this method depend mainly on the characteristics of the annual flood. but can be estimated between about 30.000 ha. to about 82.000 ha.

Basin irrigation. on the other hand. is practiced along the main Nile at Shendi. Marowe. and Dongola districts. As in the flush irrigation the area in this system varies widely with annual flood characteristics. It can vary from about 4.200 ha. in a bad year to 42.000 ha. in a good year.

iv. Traditional Irrigation systems

Sagia and shadouf systems are quickly disappearing with the introduction of small relatively cheap pumps. Up to the midsixties there were about 10.000 registered sagias.

3.2.4. Methods of Irrigation

A method of irrigation is defined in here as the way by which water is delivered to the field. The following are some of the methods utilized in the Sudan irrigation practice:

i. Furrow irrigation
ii. Wild flood irrigation
iii. Basin irrigation
iv. Sprinkler irrigation
v. Drip irrigation.

i. Furrow irrigation

This method of irrigation is adopted almost in more than 90 (percent) of the Sudan irrigated area. The classical furrow dimensions would however be modified in the Rahad scheme (Phase 1) so as to comply with new practices.

ii. Wild flood irrigation

This method of irrigation is applied in the Sudan under two names: basin irrigation in the main Nile reach and flush irrigation in the deltas of Baraka and Gash.

iii. Basin irrigation

This method is applied in the Sudan for most of the irrigated horticultures, irrigated rice, wheat vegetables and other crops.

iv. Sprinkler and drip irrigation

These two methods are used on a very limited scale in the Sudan. Among these limited scales are university, research centres and few individual practices.

3.2.5. Efficiency of Irrigation

Total irrigation efficiency can be defined as:

$$\eta = \frac{M'' \times 100}{M} \quad (\text{ as percentage })$$

where M'' = the actual quantity of water consumed by the crop in the irrigated area.

and M = the actual quantity of water abstracted from the source over the corresponding period of irrigation.

The total efficiency can further be defined as:

$$\eta = \eta' \times \eta''$$

where η'' = application efficiency $= \frac{M''}{M'} \times (100)$

M' = the actual quantity of water delivered to the field over the corresponding irrigation period. On the other hand,

η' = conveyance and storage efficiency $= \frac{M'}{M} \times (100)$ where M' and M are as defined above.

These definitions can better be understood through Table 3.2.3. where in some cases in the United States the total irrigation efficiency can deteriorate to a value of only 32 (percent).

Although a survey like that done by U.S.A. has not yet been published (to the writer's knowledge) in the Sudan, a highly optimistic values have been estimated in column (5) of Table 3.2.3. The conveyance and storage efficiencies have been calculated from Table 3.2.4. while an average application efficiency of 60 (percent) is adopted.

It can thus be seen that by increasing the irrigation efficiency an apprecirable part of the water can be saved. A selected committee in U.S.A. has found in 1960 that by increasing the irrigation efficiency in the year 2000, the 1954 gross irrigated area will almost be doubled with insignificant increases in the stored and applied irrigation water.

Similarly if the total irrigation system in the Sudan is improved by 10 (percent) then the country could save from its present irrigation water requirement an amount almost equal to its share from the Jonglei Canal Project (Phase 1).

Table 3.2.3. Irrigation efficiency

Region	USA East. States (averages)	USA West. States (averages)	USA Upper Missouri	Gezira and Managil (Sudan)
On farm				
Net required by plant cubic m. per ha.	1035	2146	1336	4385
Efficiency of application %	60	45	45	60
Total required cubic m. per ha.	1725	4769	2980	7309
Stored - diverted				
Stored and delivery efficiency %	60	52	40	80
Total required cubic m. per ha.	2875	9171	7500	9136
Estimated recovery of losses	20	55	55	0.0
Total irrigation requirement cubicm. per ha.	2507	5307	4104	9136
Net required / total requirement x100	42	40	32	48

Table 3.2.4. Estimated annual water requirement for United States and Union of South Africa.

Country and type of Use	United States x 10^9 cubic meters		Union of South Africa x 10^9 cubic meters (out of VaalRiver) x-	
	1950	1975	1950	1975
Irrigation	138	238	0.31	0.37
Domestic and public-water	26	51	0.13	0.27
Industrial and Electricpower	116	339	0.13	0.31

x quoted from United Nations publications on water for industry.

In fact there are already very encouraging findings from researches that have been carried out by research centres and University on the plant water relations. Quoting from a discussion by Mr. N. R. Fadda (9).

The aim of these studies was the discovery of the most economic use of irrigation water either through water saving or better returns per unit volume. In general, work proceeded along three lines:

1 - The reduction of the amount of water given in any one irrigation.
2 - The prolongation of the interval between irrigations.
3 - The shortening of the period during which plant was watered. One should also acknowledge the recent contributions of Mr. H.G. Farbrother and Dr. H.S. Adam of wad Medani Agricultural Research station.

Similar works are highly needed in the field of conveyance and storage.

3.2.6. Irrigation as compared to other uses

Since the water in the Sudan is fastly becoming a precious commodity, its utilization must be a subject of careful and scientific optimization between the different uses (agriculture, power, industry, navigation.etc.).

Most developing countries vastly depend on agriculture, and the Sudan is no exception. Over 90 (percent) of the country's water resources is utilized in that purpose.

It is however well known that irrigation from all the other uses has the poorest efficiency in water use. Researches in the United States (3) has shown that about 98 (percent) of the water used in industry can be reused (non-consumptive) while the other non-consumption figures are 90 (percent) for public use, and 40 (percent) for irrigation.

In the Sudan figures of these sorts are not readily available at present but from the data compiled in this work the following preliminary figures for non-consumption are estimated as: below 10 (percent) in irrigation, over 95 (percent) in industry, less than 50 (percent) in public supply.

Evaluation for the relative production values of water for the different uses can not be reached in this preliminary work, yet other countries may be quoted.

While one source in the U.S.A. has assessed the return from 1000 square meter of water asfrom 36.5 to 40.6 S for irrigation as compared with 3700 to 5000 S for industry, another source gives the figures for irrigation as 17 - 22 S as compared with 1500 - 4000 in industry[3]

These examples are mentioned here only to show the importance of giving due weight to the selection of the right scheme. Such a selection would mostly require an optimization between engineering, economical, social, and political factors and constrains.

Problems in Irrigation

It is not an easy task to sum up all the problems that face the irrigation practice in the Sudan, yet the following points would give a brief listing of these problems:

i. Problems at storage and conveying systems

(a) Losses due to evaporation, evapotranspiration, seepage, breakage and weeds both at reservoirs and canals.
A classicial example for high evaporation losses can be taken from Jebel Aulia reservoir where evaporation losses reaches an amount comparable to the stored water.

(b) Scouring and erosion problems downstream of dams, some irrigation works, and meandering reaches of rivers. Examples of these problems can be taken from Roseiris, Kashm El Girba dams, Gash and Nile rivers.

(c) Silting problems at reservoirs and canals.
The size of this problem is well demonstrated at Kashm El Girba reservoir, canals linking the Blue Nile to various pump stations (i.e. Suki, N.W. Sennar, Kennaf, Rahad, etc.), and conveyance canals (especially the night storage minors).

(d) Night storage versus continuous flow in minor canals.

(e) Accuracy in water measurements.
It is well known that the calibration of gates and hydraulic structures at both dams (i.e. Sennar) and conveying canals has an accuracy well below the anticipated required standard, specially when the Sudan utilizes its full share of the Nile water.

(f) Conflicts between demands of different uses.

Most of the presently available and future planned dams in the Sudan are of multipurpose nature. Conflicts between the need of water for each of these purposes will soon become very acute specially with the presence of many dams, complicated needs, and complete utilization of the total share of the country's Nile water.

(g) Working out an efficient system for the coordination between the operation of the numerous dams and controlling works in the Nile and its tributaries.

(h) Time lag between the different reaches of the river and at different flow conditions.

Items (g) and (h) are very much related and their importance would be more noticeable as the country approaches the full utilization of its share from the Nile water.

(i) Development of an efficient system of annual or monthly (or even daily) recording of the actually irrigated area and the amount of water delivered to that area. Such a system must also record the escapage through irrigation drainage systems. The importance of this work will soon be very noticeable specially when the country's share of the Nile water is theoretically fully utilized.

(j) Working out an efficient system for planning, operations, recording and documentation.
Such a system is vitally needed at a time where the country's readily available water is fully utilized. That system must be capable of optimizing between demands that varies widely in time and in space, especially when the country's annual share of the Nile water is below the average amount.

ii. Problems at the field

Work in this side should generally concentrate in improving the application efficiency. Such improvement may require the cooperation and good will between research institutes, irrigation engineers, agriculturists, and the farmers.

Among other directions, researches may concentrate on the following:

(a) Reduction of losses in farm distributers and subdistributers. (i.e. through lining, use of pipes, etc.).
(b) Reduction of field application losses (through wider appreciation of the physical characteristics of the soils, etc.).
(c) Timing and depth of application (i.e. time of starting and ending the irrigation period, interval between irrigations, etc.).
(d) Uniformity of application (lack of uniform distribution of water on the field leads to reduction in application efficiency and uneven crop yields).
(e) Proper drainage and conservation of excess water.
(f) Introduction of new methods of irrigation (i.e. sprinkler, drip, etc.) or improvement of present methods (through change in slopes, furrow lengths, etc.).

3.2.8. Brief summary

It has been established from this section that:

i. Irrigation had been, still is and will continue to be one of the basic consumers of the Sudan water resources.
ii. On completing the present and committed schomes the country will consume about 19 billion m^3 out of its share of the Nile water (20.35 billion m^3 at Sennar) (Table 3.2.2.).
iii. The proposed schemes would require about 11 billion m^3 of water over the present Sudan's share of the Nile water. (Table 3.2.2b).
iv To meet these requirements sources other than the Nile should be investigated.
v. Uses other than irrigation (power, industry, domestic, navigation, etc.) should carefully be considered.
vi. Optimization between water sources and water uses is extremely important.
vii. An increased irrigation efficeency may save an appreciable amount of water.
viii. Numerous problems deteriorate the efficiency of irrigation in the Sudan. These problems should be given considerable attention.

Table 3.2.5. Gezira standards for delivery and escapage losses[5]

Period	Minor canals	% losses assumed main-major canals	Escapage	Total
July to December	3	5	5	13
January to June	3	5	2	10

Table 3.2.6. Storage losses in the present storage reservoirs[5]

Name of reservoir	Storage capacity 10^9 m^3	Evaporation losses 10^9 m^3	Purpose of storage
Sennar	0.93	0.30	Irrigation and power
Jebel Aulia	3.50	2.0[6]	Irrigation
Reseiris	3.02	0.51	irrigation and power
Kashm El Girba	0.85	0.29	Irrigation and power
Aswan high dam	90	10.0	Power Irrigation and flood control.

3.3.1. WATER NEEDS IN INDUSTRY

3.3.1.1. Introduction

Before proceeding into deep discussion on industrial water requirement it seems necessary to define the word industry since it has recently been very widely and vaguely used. To avoid such vagueness, the meaning of industry would be confined in this paper to the activites of manufacturing works and factories, mines and quarries. Under this definition lies very wide range of industries such as, manufacture of chemicals, iron and steel, oil refining, pulp, paper and board, textile manufacturing and finishing, food processing and preservation, etc. Activities such as thermal power stations and hydroelectric power generation would be treated in a separate part of this report.

No doubt the fastly growing industrial development in Sudan would have an appreciable demand for water arising primarily from the large and ever-increasing requirements of various industries specially in cooling, processing and steam generation. Industrialization also leads to urbanization and concentration of population which consequently leads to higher demand for water at geographically concentrated spots. Furthermore, attention would have to be paid to ways of minimizing industrial water use and disposal to avoid wastage and health problems.

Internationally, industrial use of water is normally gauged and optimized against other needs, such as agriculture, power generation, domestic, etc. Such optimization against other needs is very much necessary in a country like the Sudan where the agricultural sector consumes over 90%of its almost completely exhaustel readily available water resources.

Unfortunately the quantity and quality of water demanded in industry varies widely from commodity to another, or even for the same commodity it varies from country to country and from plant to another. That variation is mainly due to differences in the manufacturing process. It is also unfortunate that data on industrial water requirement, both in the Sudan and many places abroad, are scarce and rarely recorded.

Due to the above mentioned limitations the nature of this work would be of preliminary and general character. In most of the places that had been visited, no recording of the actual requirements were readily found. Guesses and estimation work were often used to reach the numerical figures presented in this report.

3.3.1.2. Quantity of water needed in industry

a. Consumptive and non-consumptive uses of water

Before embarking into quantitative analysis of the water demanded by industry it would be appropriate to distinguish between two types of uses, namely the consumptive and non-consumptive. Consumptive use is defined by the American Water Association as the water used in connection with vegetative growth, food processing, or incidental to an industrial process, which is discharged to the atmosphere of incorporated in the product of the process [(4)]. As defined above, consumptive use is thus means the elimination of that water from water resources in the concerned area.

Non-consumptive use, on the other hand, means that such used water would be available for reuse, with or without certain reconditioning processes. Luckily the amount of consumptive usage is very small in industrial use in comparison with other uses (i.e. agriculture). According to sources from the United States of America (2), only 2 (percent) of that country's industrial use is of a consumptive nature.

b. Type of uses

Uses of water in industry may be broadly classified under two types of uses:

a. domestic needs and

b. manufacturing purposes.

The domestic needs arc casy to estimate and its supplies are usually provided from public sources. Depending on the number of employees and conditions of living, the quantity of such water can easily be estimated.

Manufacturing purposes, on the other hand, require water for the following broad uses:

1- Boilers (quality of water varies with type of industry).
2- Coolling (temperature is the main quality demand).
3- Proccessing such as in washing, dissolving and diluting, conveying substances, scrubbing industrial gases, etc. (cheap water is advisable).
4- Water incorporated in a product (high quality water is needed).
5- Fire fighting (quantity and pressure are important, but quality is seldom considered).

Great variations are found in the percentage of water needed for these different uses, specially as between industry and the other, or even plant and the other.

c. Evaluation of water quantity in the Sudan

It is unfortunate that no internationally accepted criterion is available for evaluating the water quantity needed by industry. Many authorities in the world estimate industrial consumption as per head of population per day. Such a criterion, would not be of great use for the purpose of this work, since it widely varies from place to the other. A more appropriate criterion is that published by the United Nations (Department of Economics and Social Affairs) under the name 'Water for Industrial Use'[5] .

In that book water used by different industries is compiled as per unit product for few countries in the world. The publishers have however, issued a warning that the figures on their book should not be taken as typical since a unit product for the same commodity may require a highly different quantity of water in another country. Table 3.3.1.1. which is compiled by the writer of this paper clearly demonstrate the importance of that warning. As an example from this table, one ton of sugar may require an amount of water in the Sudan 111 times that in the United States and 12 times that in the Union of South Africa.

The main reasons for these high variations could be due to one or all of the following factors:

1 - While some authorities estimated that water as per unit of raw material, others estimate it as per unit of the finished product.

2 - In countries with shortage in water resources the manufacturing process would be designed for mimimum water use.

3 - Some countries estimate only the consumptive use versus unit product.

In spite of the above limitations, the data on that book was used, when actual data is not available, to give rough estimates of the amount of water needed by some industries in the Sudan, both at present and at the end of the commencing six year plan (Table 3.3.1.2). The data compiled in that table has either been collected from the responsible department or estimated from the report on the six years plan[1] .

The writer would, like to issue the following warnings:

(a) The figures on Table 3.3.1.2 should be taken as broad guide lines.

(b) Complete compilation of industrial activities was found impossible in such a general type of work. Hence Table 3.3.1.2 is far from being a complete survey of all industrial activities.

(c) Industrial activities where no estimates for its water requirement are available in the United Nations Report, their water needs are left blank.

(d) Though mining and quarries were found to have great potentialities in this country, yet statistics on the required water for these purposes was found difficult to forcast, and hence were not compiled in Table 3.3.1.2.

Table 3.3.1.1. *Comparison between local industries water requirement and that of similar industries in other countries.*

Type of industry	United Nations Publication		Similar Industry in the Sudan		Sudan Requirements (others not required)
	Water required per ton of product (m.cube)	Country	Water required per unit of product (m^3)	Source	
Sugar	4.2 40.0	United States Union of South Africa	465	For Sennar-Assalaya-Malut Guneid - Girba (Eng. Ahmed El Bushra)	110.7 11.6
Canned Vegetables and Fruits i.e. Tomato products	20.5	United States	300	Karima Factory (Director Mohd. Osman)	14.6
Leather Tanning	67.0 50.0 - 125.0 50.1	United States (raw hide) Finland Union of South Africa	114.0	Khartoum and White Nile Tanneries (Engs. Osman Yousif, Juda El Sheikh and Gorashi)	1.7 2.3 - 0.9 2.3
Milk Powder	200	Union of S.Africa	200	Babanosa Milk Factory (Khidir Osman Bashir)	60
Portland Cement	2.5	Finland	0.05	Atbara Factory (this low value is due to circulation reuse) (A/Wahab Doka)	0.02
Cement	3.1	United States			0.02

Table 3.3.1.2. Water quality for industry in the Sudan

Type of industry	Product (76-77) ton.s except as specified.	Water requirement (million m. cube)	Product (82-83) tons. except as specified	Water requiremen (million m.cube)
Sugar (465)	240.000	111.6	780.000	362.7
Soap (6.0)	37.000	0.2	74.000	0.4
Alcohols (40.0)	4.600 c. m.	0.2	9.200	0.4
Shoes	14.0 (109 pair)	--	--	--
Portland cement (3.1)	217.000	0.7	1.050.000	3.3
Flour mills (3)	380.000	1.1	470.000	1.4
Beer (20.0)	10.000 c.m.	0.20	20.000 c.m.	0.4
Cigarette	515.000 kg	--	600.000 kg	--
Matches	220.000	--	--	--
Vegetable oil	80.000	1.8	4.000.000	88.0
Biscuits and cakes	--	--	--	--
Textiles	11.365.6000 y.	3.4	308.500.000 y.	9.3
Straches (15)	6.037	0.1	(12.074)	0.2
Textile (steeping)	--	--	20.680.000	0.9
Kenaf ( )	10.000.000	7.3	over 2.000.000	15.0
Kenaf ( )	1.000	--	over 2.000	--
Canned vegetables	2.000	0.6	6.000.000	1800
Fruits (300)				
Karima dates factory	109	--	--	--
Onion drying (Kassala)482	--	--	--	
Babanosa milk drying (200)	87	0.02	174	0.04
Raia and Krikab and Saaad				
Sweets (16)	5.000	0.08	10.000	0.16
Oils (10)	1.415.000	14.0	2.830.000	28.0
Paper packing	8.000	0.3	16.000	0.6
Glass products (68)	4.000	0.3	8.000	0.6
Tanneries ( )	--	1.2	--	1.4
Pipe line	600.000	--	--	--
Fertilizers (urea)	--	--	100.000	27.0
Asbestos pipes and plates (100)	--	--	60.000	6.0
Steel rods and pipes (100)	--	--	12.800	1.3
Dry battaries	40 (million)	--	--	--
Brick manufactory and buliding industry	--	--	--	--
Mining and quarries	--	--	--	--
Total estimated quantity		143.1		2,341.7

3.3.1.3. Quality, waste treatment and disposal of industrial water

An internationally accepted measure to the quality of water is its chemical, physical and biological characteristics. Water quality in industry has very wide range of specifications that vary from a product to another and from process to proccess. For example water for the manufacture of antibiotics, and photographic materials must have a high degree of purity, while at the other extreme, quality requirements are somewhat relaxed in cooling processes. It is however, impossible to present here a complete list of specific quality standards for the numerous uses to which water is put in industry. Such specifications may be found in many mannuals and handbooks.

As indicated previously water used in industry is almost completely non-consumptive. However, in order to be able to re-use that water certain reconditioning processes may be necessary. The reconditioning or treatment process can sometimes be very costly. Hence the disposal system and the reuse of water is a matter subject to optimization between the need to that water, the cost of treating it to the specified level, and the health hazards constrains.

Dr. El Sharkawi (2) has written a report on the treatment of industrial wastes in the Sudan. In that report numerous industrial areas were visited and their water treatment and disposal systems were inspected. In many of these areas polluting effects were discovered and water wasted by evaporation were found. The study was not a complete survey and by its nature gave no suggestion towards an optimiztion approach. Though it gave very good recommendations an local problems, it lacked, the unitary or global look.

3.3.1.4. Cost of water in industry

As in the cases of quantitative and qualitative statistics, it is impossible to present here a list of the cost of water in industry. That is because the demand varies greatly in quantity and quality for different manufacturing processes, while treatment cost would also vary widely depending on the nature of the raw water.

In the absence of any local data, the following statistics from other countries are presented just for sake of demonstration. Table 3.3.1.3(5) shows water use per unit of a south African pound market value in industry and agriculture. The table clearly demonstrates the higher return from using water in industry than in agriculture. For example from the same market value lucerne would require an amount of water more than 300 times that needed by leather. Sources for the United States (3) have also assessed the return for 1000 m3 of water as from 17 - 40.6 for irrigation and 1500 - 5000 for industry.

The message that could be received from these examples is that in a country like the Sudan with limited water resources the allocation of water to different uses should be reached through optimization between these uses.

Table 3.3.1.3. Union of South Africa: water use per unit of market value in industry and agriculture

Product	Water required to yield Ls. 1' Market value (imperial gallons)
Leather	70
Sugar, refined	200
Paper pulp	300
Electricity	500
Oil from coal	800
Steel	1200
Butter } cows depend on grazing	300
Cheese }	200
Milk powder	300
Milk, fresh	4,400
Potatoes, irrigated	3,500
Rice, irrigated	6,000
Wheat, irrigated	14,000
Lucerne, irrigated	22,000

3.3.1.5. Location of industry

It is becoming an acceptable practice, in many countries, to locate certain industries near the water supply source. That practice is particularly clear in cases of large using water industries, such as nuclear power plants and others (4).

3.3.1.6. Sources of water for industry in the Sudan

Depending on the quality of the needed water for the particular process, the following are the potential sources in the Sudan.

a. Red Sea waters.
b. Nile and tributaries, and other surface water sources
c. Lakes, haffirs and dams.
d. ground water.

From the above sources ground water and the Nile and tributaries are the mostly used sources at present. The red sea water is used in limited industries for cooling purposes.

3.3.2.2. Cooling water Evaluation

All thermal power stations use closed system of cooling except Port Sudan "A" Station which uses on open system (Sea water as cooling medium)

If the compensation and make up water is estimated as 1 % of the cooling water then by assuming that; the thermal efficiency of power station to be around 40 %, 70 % of heat is rejected to the cooling water, the rise in water temperature is about 15^{0} k and the average load factor of all power stations as about 0.3, then:

a. The annual quantity of cooling water needed by the available stations would equal »234,440 cubic m.

b. Similarly the annual water needed for the committed stations would equal » 300,000 cubic m.

c. And the annual water quantity needed by the proposed schemes would equal » 534,500 cubic m.

3.3.2. WATER COOLING IN THERMAL POWER GENERATION

3.3.2.1. Electricity supply in Sudan

Table 3.3.2.1. shows a list of electricity supply in the Sudan, in order of size and showing the type and capacity of each generating plant:

Table 3.3.2.1. Size of P.E.W.C. system installed capacity x

		Diesel	Hydro	Steam	Gas turbine	Total
1.	Blue Nile grid	32.3	107.0	30.0	15.0	184.3
2.	Eastern grid	4.8	12.6			17.4
3.	Atbara	10				10.0
4.	Port Sudan	8.1				8.1
5.	Kassala	3.9				3.9
6.	El Obied	1.9				1.9
7.	Nyala	1.5				1.5
8.	Umm Ruaba	1.3				1.3
9.	Shendi	1.2				1.2
10	Juba	1.0				1.0
11	Eddien	0.9				0.9
12	Malaka	0.9				0.9
13	Wau	0.9				0.9
14	El Gurashi	0.7				0.7
15	El Fasher	0.7				0.7
16	Dongola	0.4				0.4
17	El Geteina	0.2				0.2
Total		67.9	119.6	30.0	15.0	232.5

x Installed capacity does not mean the available capacity, the average available may be considered as 60 (for thermal plants) of the installed capacity.

On the other hand table 3.3.2.2. gives a list of PEWC'S committed generation developments in the Sudan, while Table 3.3.2.3. shows the proposed schemes

Table 3.3.2.2.

Station	NO. and size MW	Total		commission date
Burri	3 x 5	15.00	diesel	1978
Rosieris	1 x 40	40.00	hydro	1978
Gorrashi	2 x 0.17	0.34	diesel	1977
Atbara	1 x 3	3.00	"	1978
Port Sudan	2 x 3	6.00	"	1978
Khashm El Girba	1 x 3	3.00	"	1978
Kassala	1 x 1.2	1.20	"	1978
Juba	5 x 1	5.00	"	1978
El Obeid	5 x 1.0	5.00	"	1978
Total		78.54 MW		

Table 3.3.2.3. Six years plan 1977/78 - 1982/83 proposed PEWC's Schemes

Station	No. and size	Total
Atbara	4 x 5	20
Dongola	2 x 1	2
Shendi	3 x 1	3
Umm Ruaba	3 x 0.5	1.5
Al Fasher	2 x 2 1 x 1	5
Nayala	3 x 0.5	1.5
Malakal	1 x 0.5	0.5
Wau	3 x 0.5	1.5
Port Sudan	3 x 5	15
Juba	1 x 1	1
Khasm El Girba	3 x 3	9
Kassala	2 x 3	6
Blue Nile Grid	2 x 5	10
Edduiem	4 x 1	4
El Getina	3 x 0.5	1.5
Total		121.5

3.3.3. HYDROELECTEIC POWER GENERATION

3.3.3.1. Introduction

The idea of building dams across the main Nile had long been discussed and studied by the Egyptian Ministry of Works[6]. The purposes for these dams were however, basically aimed at solving Egypt's problems of increasing irrigation water demand and flood protection. To that aim a group of investigators were commissioned in the period of 1895 - 1897 to inspect the suitability of some of the Nile's cataracts as dam sites. As a result of their report, Sir William Garisten had put favourable arguments for Aswan dam which was actually built in 1902. By 1906 the Egyptian had already discovered that Aswan dam could not meet their water demand and hence another group of investigators were assigned the job of investigating the following four sites:

(a) Second cataract (Dal).
(b) Fourth cataract (Cheri Island).
(c) Fifth cataract.
(d) Sixth cataract (Sabaloka)

In spite of these investigations a decision was taken in favour of heightening Aswan Dam in 1907. A second heightening of that dam was again executed at later time.

However, in the early forties these studies were reviewed again with special concentration on the fourth cataract[3]. The investigation on that site has included relatively more detailed cross and longitudinal sections.

In the early fifties the irrigation advisor[4] of the Sudan had written a report on the development of the main Nile for the benefits of Egypt and for the first time the Sudan too. Further, more purposes other than irrigation and flood protection (i.e. hydro-power) started also to appear for the first time. In that particular report the advisor had recommended that the main purposes for which the main Nile can be developed are as follows in order of their importance:

1- irrigation
2- flood protection
3- hydro-electric power
4- navigation.

The following sites were prepared as the best dam sites to provide power and annual storage for the use of the Sudan:

1 - The Sabaloka gorge
2 - The fifth cataract
3 - The tail of the fourth cataract, at the site which had been previously investigated by the Egyptian Irrigation Department.
4 - The second cataract, near Gemai.

The power generated from such multipurpose projects could be utilized for:

(a) Domestic and industrial supply to the towns of Khartoum, Khartoum North and Omdurman.

(b) Electrification of Sudan railways starting with Khartoum, Atbara section.

(c) Electrification by means of grid, the pumps and sagias in the Northern Province.

(d) Power supply for a factory to manufacture artificial fertilizers in the form of ammonium nitrate.

The Report was however a rough preliminary survey of such potentialites. A more detailed plan was the one that had been prepared by Morrice and Allan who were commissioned by the Ministry of Irrigation and Hydro-Electric power in 1958[1]. Their report mentioned the following locations as the main power sites in the Sudan:

(a) Roseiris and Sennar on the Blue Nile.

(b) Sabaloka, fifth cataract, fourth cataract, and Semna on the main Nile.

(c) Nimule, Juba reach in Bahr El Jebel (Bedden).

That report has also mentioned useful studies on the fourth cataract reservoir contents and evaporation losses (Table 3.3.3.1), Semna reservoir contents and evaporation losses (Table 3.3.3.2.), and relative proportions of evaporation losses from the main Nile reservoirs (north of fourth cataract).

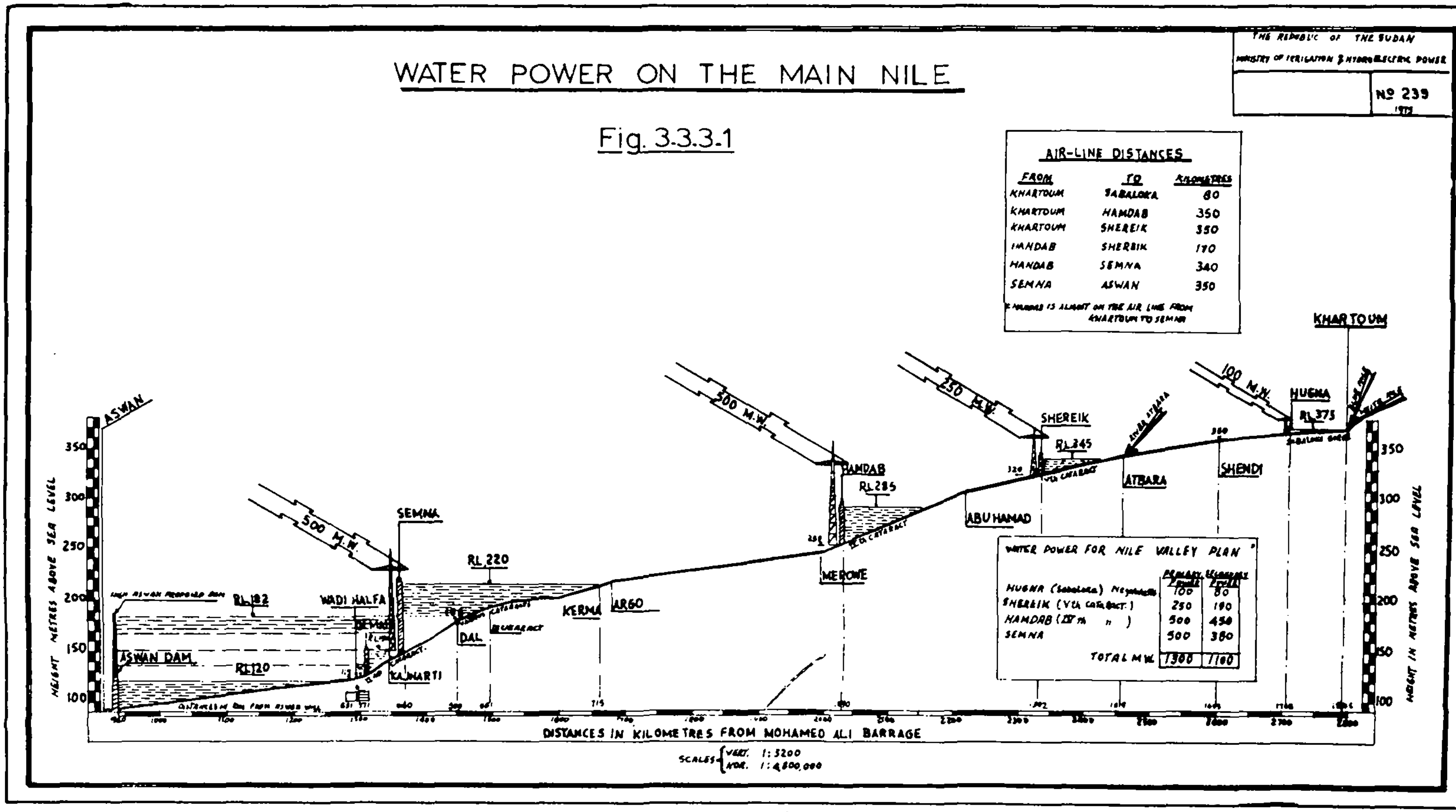
A comprehensive report, prepared by Engineer Sigayroon El Zein, on the optimum way of utilizing River Atbara's water had revealed the relatively high potentiality of that River for hydro-power generation. Hydroelectric power is at present seasonally generated at Kashm El Girba dam, but the report advises for another dam at El Showak since it will greatly help in generating large scale power.

A very recent study had also been carried out by the Ministry of Irrigation on Sobaloka hydro-power project[2]. It is proposed to maintain an impounded constant head water level of 374.0 m. The contents and evaporation losses for that dam are shown in Table 3.3.3.3.

Water power on the main Nile was lately compiled by the Ministry of Irrigation and Hydroelectric power in a diagramatic way as shown in Fig. 3.3.3.1.

While this work was under preparation a report has been published by the Sudan National Preparatory Committee for the United Nations Water Conference. In that Report, the actually installed capacity and the short and long term planned capacity from the Nile system were prepared as in Table 3.3.3.4.

To the present writer all the above efforts worth to be considered provided that basic factors, are given their right weight. These factors are:



WATER POWER ON THE MAIN NILE

Fig. 3.3.3.1

(a) Generation of power from water sources should be optimized with its generation from other sources (i.e. thermal, nuclear, wind solar, etc.).
(b) The whole country's water resources development must be looked at as an integrated unit which forms a part from the national master plan.
(c) A multipurpose project looks at this preliminary stage as superior to a one purpose scheme.
(d) The operation of these dams should be optimized for minimum water losses and maximum power generation.
(e) Evaporation per unit benefit must be minimum. (minimization in water use would very soon be an important constrain in any national plan for the Sudan water resources).
(f) That rate of sedimentation of these reservoirs per unit benefit must also be considered.

The last point requires a great care when designing the dead storage for these dams so as to avoid experiences similar to that of Khashm El Girba reservoir.

3.3.3.2. Quantity of Water Needed for Hydro-electric Power

The previous review of literature reveals the wide potentiality of hydroelectric power generation from the rivers of the Sudan. Huge amount of water would however be needed in order to meet that purpose. Two types of needs should be considered:

(a) Water untilized in power generation
(b) Water lost in storage, transmission and cooling systems.

(a) Water untilized in power generation

The water needed for the generation of all the abovementioned power potentialities is of a vast quantity that could be many times the country's available water supply. Luckily such a type of water is completely of non-c onsumptive nature and it can be reused for as many times as possible. The limiting end for such a reuse is either the transportation of the water outside the region or its allocation to a new consumptive purpose.

It is impossible and of no use in this type of work, to estimate the total amount of water for this purpose, since it varies with many complicated and interconnected factors. Most obvious of these factors are, the optimization between power and other needs (irrigation. navigation, etc.),optimization between the different sites, number of turbines at each site, etc.

(b) Water lost in storage, transmission and cooling systems

1. Water lost in storage

To generate the above mentioned amount of power a huge quantity of water must be stored in reservoirs. Such storage consequently leads to losses, specially evaporation, that may demand an appreciable part of the country's water resources. For example a reservoir at Semna will gernerate 500 MW at the cost of 3.69 billion cubic meter (Table 3.3.3.2.) while a reservoir at the fourth cataract will generate the same amount of power with only 2.02 billion cubic meter of water lost in evaporation (Table 3.3.3.1.). Furthermore it can be noted from these tables that the reservoir content, giving the same amount of power, varies widely between the two sites.

No doubt evaporation losses must have a deciding role in the selection of any or all of these sites, provided that the following factors are given their due weight:

(a) Variation in evaporation with different geographical sites and climatic conditions.

(b) Variation in evaporation with reservoir content (i.e. tables 3.3.3.1. and 3.3.3.2.).

(c) Methods of estimating evaporation losses.

Evaporation in the Sudan is, in most instances, estimated by multiplying the Piche's value by a factor of 0.5. As has been shown in section 2.1 great differences in evaporation magnitude can be obtained if Penman's method is used instead of the previous procedure. Table 3.3.3.5 demonstrates the appreciable differences in monthly evaporation losses, from Sabaloka reservoir, if the Pitche's method is used instead of Penman's method as introduced in section 2.1.

Other than evaporation losses storage through these reservoirs may lead to other losses such as seepage, etc.

n. Transmission Losses

As a result of power demand, water may be transported to remote areas (i.e. Semna) where additional losses due to such transmission must be considered when optimizing between different sites and different uses.

3 - Cooling system

This is a minor part of the total lost water, utilized primarily to compensate the evaporation losses in the turbine units.

3.3.3.3. Summary of the total water lost in evaporation

Table 3.3.3.6 give a very rough estimate of the amount of water bound to be lost in evaporation at present and future dam sites. It is obvious from the table that these losses may increase from less than a billion cubic meter at present to over 12 billion cubic meter in future. Adding to this the transmission losses the figure would be of a terrific magnitude.

It must however be remembered that the numerical figures on that table are estimated under very rough circumstances and the writer warns from taking them as typical. More elaborate topographical, climatological and hydrological surveys are needed so as to come out with a more reliable estimation for these losses.

Table 3.3.3.1. Fourth cataract reservior -contents and evaporation losses

contents in bill. cubic m.	reduced level in m.	exc ess surface area in km^2.	Annual evaporation in billion cubic. m.	Relative evaporation in mm^3 per year/ bill. m^3 per-store.	Rmarks
0.1	259.4	29	0.09	900	
1.0	270.3	132	0.42	420	
2.0	275.5	209	0.65	325	
3.0	279.3	275	0.85	280	
4.0	282.2	333	1.03	260	
5.0	284.7	385	1.19	240	
6.0	287.1	439	1.36	225	
7.0	289.3	487	1.51	215	
8.0	291.2	542	1.68	210	
9.0	292.9	602	1.87	205	
10.0	294.5	653	2.02	200	(this level gives about500 MW of power)
11.0	296.0	701	2.17	195	
12.0	297.6	749	2.32	190	

Table 3.3.3.2. Some reservior-contents and evaporation losses

contents in bill. cubic m.	Reduced level in m.	Excess surface area in km^2	Annual evaporation in billion m^3	Relative evaporation in mm ^{3} per year/ bill. m^3 per store.	Remarks
0.2	159.6	29	0.08	400	
1.0	173.6	85	0.25	250	
2.0	182.0	142	0.41	205	
4.0	192.3	310	0.91	230.	
6.0	199.2	486	1.41	235	
8.0	203.4	610	1.78	220	
10.0	206.4	698	2.04	205	
12.0	208.9	784	2.29	190	
14.0	211.1	869	2.54	180	
16.0	213.1	951	2.78	175	
18.0	214.9	1021	2.98	165	
20.0	216.4	1091	3.19	160	
22.0	217.8	1161	3.39	155	
24.0	219.1	1231	3.59	150	
25.0	219.7	1265	3.69	150	(this level give-sabout 500 MW ofpower).

Table 3.3.3.3.Proposed Sabaloka dam reservoir evaporationlosses

Month	Piche evaportion in mm	Open water surface evaporation in mm	Evaporation at impounded level 374 m in $10^6 m^3$ per day
January	14.5	7.3	0.642
February	17.1	8.6	0.757
March	20.2	11.1	0.889
April	22.0	11.0	0.968
May	21.0	10.5	0.924
June	20.4	10.2	0.898
July	15.7	7.9	0.695
August	12.1	6.1	0.536
September	14.3	7.2	0.634
October	16.9	8.5	0.748
November	16.8	8.4	0.739
December	14.1	7.1	0.625

Note: 1. data taken from Khartoum climatological normals, 1941

2. reservior surface area - 88 km.

Table 3.3.3.4. Hydroelectric power in the Sudan

	Planned capacity MW Short term	long term	Actually installed capacity MW
1. Blue Nile			
a. Roseiris dam	120	-	90
b. Sennar dam	15	-	15
2. White Nile			
a. Jebel Aulia dam	25	-	-
3. Bahr El Jebel			
The rapids in the Nimule-Juba reach, a drop of 162 m in 168 km length	100	400	-
4. The main Nile			
a. Sabaloka gorge, 90 km from Khartoum	107	-	-
b. Fifth cataract at 435 km north of Khartoum	-	250	-
c. Fourth cataract, 750 km north of Khartoum	-	250	-
d. The Dal and third cataracts, 1170 km north of Khartoum	-	200	-
5. River Atbara			
a. Khasm El Girba dam	-	-	13
b. Upper Atbara dam	20	-	-
Total	387	1100	118

Table 3.3.3.5. Proposed Sabaloka dam reservoir evaporation losses

Month	Piche evaporation in mm	Open water surface evaporation in mm using a factor 0.5	Open water surface evaporation in mm (Penman's method)x
January	14.5	7.3	5.8
February	17.1	8.6	6.8
March	20.2	11.1	8.7
April	22.0	11.0	8.8
May	21.0	10.5	8.4
June	20.4	10.2	10.2
July	15.7	7.9	9.4
August	12.1	6.1	10.9
September	14.3	7.2	10.0
October	16.9	8.5	8.5
November	16.8	8.4	6.7
December	14.1	7.1	5.6
Total		102.9	99.2

xAfter Dr. Adam's paper (section 2.1).

Table 3.3.3.6. Evaporation losses x

Site	Present capacity MW	Future capacity MW	Present evapor. losses x 10^9 m^3	Future evapor. losses x 10^9 m^3
1. Blue Nile				
a. Roseiris	90	210	0.3	0.5
b. Sennar dam	15	30	0.3	0.3
2. White Nile				
a. Jebel Aulia	-	25	-	2.5
3. Bahr El Jebel	a. Nimule-Juba reach (half of that at 4th. cataract)	-	500	1.0
4. Main Nile				
a. Sabaloka	-	100	-	0.3
b. Fifth cataract (evaporation is estimated as half of the forth cataract)	-	250	-	1.0
c. Forth cataract	-	500	-	2.0[1]
d. Semna	-	500	-	3.7[1]
5. River Atbara x x				
a. Khasm El Girba	13	13	0.2	0.2[5]
b. El Shawak	-	20	-	0.8[5]
Total	188	2148	0.8	12.3

x Figures in this table are of a very rough character and should not be taken as typical.
x x The tendency is now running towards constracting two dams at Setit and Atbara branches.

3.4. DOMESTIC WATER SUPPLY (HUMAN AND ANIMAL)

3.4.0. Introduction

It is rather unfortunate that no documented history has been found for the industry of domestic water. What is recorded here is mainly to project the present situation for the production and distribution of water in big towns under the control of the water department of Public Electricity and Water Corporation. Most of the data presented is extracted from monthly or yearly reports found in the archives section in P.E.W.C.

There are two main sources of water used by P.E.W.C.:

(a) Surface water which is either from rivers, canals or haffirs. Here the water is treated in waterworks mostly passing through the processes of initial setting, coagulation (by addition of aluminium sulphate), filtration (rapid or pressure filters) and disinfection (by the addition of chlorine).

(b) Ground water. Water is pumped from boreholes and in most cases disinfected by the addition of chlorine.

3.4.1. Waterworks

The waterworks now operating in the country are as shown in Table 3.4.1. which shows the production capacity of each station in the year 1975.

Since Khartoum province is the biggest consumer of domestic water, it is taken as an example. Table 3.4.2. for the combined waterworks of Khartoum, Mogran, Burri, Omdurman and Khartoum North, illustrate the production of water and chemicals used during three different months for three consecutive years, 1974, 1975, 1976. The months chosen are May, August and December. May is to represent the high consumption months, August for the months of high dosage of chemicals due to increase of the total suspended solids due to surface run-off from rains and December is the representative of the low consumption months.

3.4.2. Ground Water - boreholes

Towns supplied by boreholes are given in Table 3.4.3. Boreholes are also used in Khartoum province to augment the supply in the capital three towns and in many detached villages in the province.

Table 3.4.4. shows the location of boreholes in Khartoum province and the average output in Cu. m. per hour.

3.4.3. Combined Production of Waterworks and B. H. in Khartoum province

Table 3.4.5 gives a summary for the production of domestic water from waterworks and boreholes in Khartoum area for the period July 1973 to June 1974, and the period July 1975 to June 1976. Quantities of chemicals consumed and electricity used are also given.

3.4.4. Water Consumption at Houses

An experiment has been made by the Water Department of P.E.W.C. to show the monthly consumption of domestic water in the three different classes of housing i.e. first. 2nd and third class houses. Three houses are taken in each class and the selection is made to represent the variation in the consumption of water according to the water installations and the type of buildings. Houses in each class are graded as low, average or high consumer. The experiment ran for eleven months. (Tables 3.4.6, 3.4.7. and 3.4.8).

It is important to note that the averages given include the water used for watering the garden. In first and second class areas, the garden constitutes the major consumer of water. Now let us make a comparison between the high consumer in the third class, which is a modern house with a siphon system and small garden, with the averages of the 2nd and 1st class houses which had very big gardens:

a.	2nd class monthly average	88 cubic m.
	-monthly average for third class high consumer	40.1 cubic m.
	Water used in the garden per month	47.9
		1.59 cubic m. per day
		351.26 gallons per day
b.	1st class monthly average	102.26 cubic m.
	-monthly average for 3rd class	40.1 cubic m.
	Water used in the garden per month	62.26 cubic m.
		2.07 cubic m. per day
		456.57 gallons per day

The comparison shows that most of the domestic water goes for watering the gardens in first and 2nd class areas.

3.4.5. New Waterworks

The new waterworks under construction is Khartoum North new waterworks. Total capacity of the station is 40 mgd (181,818 cubic meter per day) and it is going to be executed in four stages.

Stage 1	8 mgd (under construction)
Stage 2	8 mgd
Stage 3	12 mgd
Stage 4	12 mgd.

Stage (1) is expected to be completed by the beginning of 1978. 3 mgd will be supplied to Omdurman through Shambat bridge, the remaining 5 mgd is consumed at Khartoum North.

New waterworks at Rabak, Roseiris, Rahad and Abu Hamad, capacity about half mgd are about to be started.

For other towns, the general trend is to extend the existing waterworks and improve the distribution system. Juba and El Obeid are given top priorities due to their increasing demand for water.

Towns supplied by boreholes are also under an improvement programmes for the distribution system and for drilling more boreholes to meet the demand. Among these towns, Port Sudan has got an acute problem of domestic water. Studies are now made to gain the maximum out of the existing water resources.

3.4.6. Summary and Recommendations

1 - It is clear that the per capita daily consumption of water is evidently big in the three categories of houses. The per capita in an average third class house without a siphon system is 0.156 cubic meter. Now let one assume that drinking, cooking, plate washing and laundry consume 50 l per day per person, 106 l per day per person are left mostly for personal washing and showering. The figure indicates a very wastefull usage of water.

2 - First and 2nd class daily averages per person are likewise extremely high and huge amounts of water (2.07 cubic meter per day in first class, 1.59 cubic meter per day in 2nd class) go for watering the gardens. There is a lot of money and effort put behind the purification, disinfection and distribution of potable water which is primarily intended for domestic use. Gardens could be watered directly from the rivers through a separate system of raw water.

3 - It is obvious that a great majority of the citizens are wasteful in their water consumption. Taps are left open for a considerable time, defects and leaks are not repaired. It is high time now to think of other fellow-citizens who put their buckets and wait for hours to fill it.

4 - The evaluation of the distribution systems in the different towns of the country has not been touched in this report due to the complexity of the problems and scarcity of records. However, its importance calls for an urgent investigation on its adequacy (i.e. size, pressure, quantity and economy, etc.).

5 - Separate figures were not given for animal consumption in the towns, yet their demand is implicitly included in the total quantities that appeared in this work.

Table 3.4.1. Waterworks

No	Waterworks	Capacity in cu.m. per year	No	Waterworks	Capacity in cu.m. per year
1	M o g r a n (Khartoum)	26,542,800	14	Duiem	1,014,412
2	Burri (Khartoum)	6,205,00	15	El Fasher	928,880
3	Omdurman	5,803,500	16	Khasham El Girba	876,000
4	Wad Medani -- B.H.	4,466,500	17	Sennar	816,600
5	Khartoum North	4,146,400	18	El Ghorashi	816,00
6	Atbara	4,111,800	19	Gezira Abba	816,600
7	Gedarif	2,481,216	20	Maridi	519,300
8	Wau	1,760,000	21	Torit	519,300
9	El Obeid -- B.H	1,566,560	22	Renk	518,500
10	Kosti	1,546,832	23	Damazein	298,704
11	Juba	1,437,000	24	Bour	254,500
12	New Halfa	1,151,050	25	Karima	71,652
13	Malakal	1,119,000			
	Total	62,337,658			7,450,448
	Grand total			69,788,106 cu.m. peryear	

Table 3.4.2. Combined woterworks, Mogran, Burri, Omdurman and Khartoum North

Description	May 74	Aug.74	Dece.74	May 75	Aug.75	Dece.75	May 76	Aug. 76	Dec. 76
Crude water pumped from Riverincu.m. per month	3,089,525	2,939,110	2,422,670	3,346,360	3,007,905	2,533,540	3,584,735	3,311,965	2,993,580
Water lostin treatment, filter washand at premises in cu.m. per month	151,285	284,995	123,200	207,655	322,750	195,380	291,065	345,040	293,510
Water pumped to distribution systemin cu.m. per month	2,938,240	2,654,115	2,299,470	3,138,705	2,685,155	2,438,160	3,293,670	2,966,925	2,700,070
Day of maximum draw-off during the month in cu.m.	123,245 (23-5)	108,055 (26-8)	100,395 (3-12)	131,795 (31-5)	113,650 (2-8)	104,835 (1-12)	131,285 (8-5)	118,715 (26-8)	103,705 (18-12)
Aluminium sulphate used during themonth in kgs.	189,000	415,500	129,410	169,550	462,825	131,650	152,400	537,800	165,400
Chlorine used during the month inkgs.	1,925	1,679	1,585	2,241	1,836	1,823	2,228	1,323	1,937
Average Aluminium dose (ppm)	50	141	53	50	153	52	42	162	55
Average chlorine dose (ppm)	0.61	0.62	0.68	0.70	0.66	0.77	0.67	0.49	0.83

Table 3.4.3. Towns supplied by boreholes

No:	Location	Production in cu.m. per year	No	Location	Production in cu.m. per year
1	Khartoum province	15,731,500	14	Nuhud	360,000
2	Port Sudan	6,051,740	15	Geneina	286,000
3	Kassala	2,784,585	16	Damar	269,804
4	Shendi	1,868,000	17	Getaina	256,060
5	Dungola	954,200	18	Kadogli	207,936
6	Singa	834,096	19	Deling	207,936
7	Berbar	790,000	20	Kawa	185,200
8	Nyala	764,760	21	Bara	153,480
9	Tukar	504,000	22	Helaliya	122,040
10	Rufaa	504,000	23	Abu Aushar	88,536
11	Hasaheisa	490,440	24	Sinkat	36,096
12	Kamlein	439,448	25	Sawakin	17,853
13	Umm Ruaba	360,850			
Total		32,077,622			2,200,941
Grand total		34,278,563 cu.m per year			

Table 3.4.4. Boreholes in Khartoum province

Location or No.	Average output cu.m per hr.	location or No.	Average output cu.m. per hr.
El Kadaro	40	Borehole No. 1149	60
El Khogalab	30	Borehole No. 1152	50
Faki Hashim	40	Borehole No. 1153	70
El Kabashi	30	Borehole No. 1413	70
El Sagay	30	Borehole No. 1410	
El Naya	40	Borehole No. 1409	30
Um Doum	30	Borehole No. 1408	50
El Gaily	40	Kkartoum Residential area	70
El Eilafoun	30	New Mahadiya	80
Um Dawa Ban	30	El Sababi	70
El Eisalat	30	Khartoum North industrial area	40
El Kalakla El Guba	40	El Hagi Yousif(1)	60
El Kalakla El Galaa	40	El Hag Yousif(2)	40
El Kalakla Sangaat	40	El Dubasien	70
Jebel Aulia	60	Salamat El Basha	100
Tuti Island	30	El Gereif East	60
El Gazera Slang	30	El Gereif West	60
El Sorourab	40	Shambat	60
Borehole No. 1026	60		

Table 3.4.5. Summary of domestic water produced from waterworks and boreholes inKhartoum area (July 1973-June 1974). and July 75- June 76)

NO.	Description	Quantities for the period July 73-June 74 cubic m.	Quantities for the period July 75-June 76 cubic m.
1	Plant capacity (waterworks)	42,616,670	42,616,670
2	Boreholes capacity 9	15,731,500	15,731,500
3	Total capacity (1 _ 2)	58,348,170	58,348,170
4	Water purified	29,618,175	33,432,235
5	Water pumped from boreholes	9,385,335	10326,615
6	Total (4 _ 5)	39,003,510	43,758,850
7	Water used in waterworks	873,240	444,335
8	Water pumped to distribution systems (6 - 7)	38,130,270	43,314,515
9	Aluminium sulphate used	2,073,800 kg	2,558,200 kg
10	Lime hydroxide used	36,515 kg	125,065 kg
11	Chlorine used	18,365 kg	23,245 kg
12	Electricity used	10,729,715kwh	9,066,380 kwh

Table 3.4.6. Third Class Houses: area chosen, Imtidad Nasir: monthly consumption for three houses

Grade of house	consumption in cu. m. per month								
	75:Feb.	March	April	May	June	[illegible]	Aug.	Sept.	Oct.
High consumer, house with siphon system	42	41.7	41.3	57	43	44	44	35	38
Average consumer, house with small lawn	20	26.4	32.6	35	34	32	31	31	26
low consumer, Jalous house	12	13.8	15.9	21.3	22	19	15	12	12
	Nov.	Dec.	Average						
High consumer, house with siphon system	33	22	40.1						
Average comsumer, house with small lawn	23	19	28.2						
Low consumer, jalous house	15	13	15.5						

If we take the average house and assume that there are six persons per house, since the Sudanese family is usually big, then the average consumption per person in a third class residence can be taken as follows:

Average monthly consumption per person $= \frac{28.2}{6} \approx 4.7$ cubic meter

Average daily consumption $= \frac{4.7}{30} \approx 0.156$ cubic meter

≈ 34.47 gallons per day.

Table 3.4.7. Second Class Houses: area chosen, second class old extension, Khartoum, block 9. Monthly consumption forthree houses

Grade of house	Consumption in cu . m. per month										
	75:Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
High consumer	152	157	211	218	245	191	170	161	162	223	127
Average consumer	78	87	108	110	114	98	86	58	77	90	62
Low consumer	74	69	80	84	81	75	87	66	116	91	79

	Average
High consumer	183.4
Average consumer	88.0
Low consumer	82.0

It could be noticed that there is no big difference between the average and low consumer, hence the size of 88 cu.m. per month could be established as an average consumption for the 2nd class area. The average for the high consumer is excluded since the habits of living in one locality are expected to be similar.

$$\text{Average monthly consumption per person} = \frac{88}{6} = 14.67 \text{ cubic meter}$$

$$\text{Average daily per person} = \frac{14.67}{30} = 0.49 \text{ cubic meter}$$

$$= 107.6 \text{ gallons per day}$$

Table 3.4.8. First Class houses: area chosen old first class area, Khartoum, blocks 10, 11 and 12. Monthly consumption for three houses

Grade of house	Consumption in cu. m per month										
	75-Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
High consumer (swimming pool and big lawn)	51	64	91	51	109	147	24	110	148	266	94
Average consumer	115	138	147	147	210	165	145	93	202	136	97
Low consumer	64	58	74	93	82	50	47	62	48	54	43

	Average
High consumer	105.0
Average consumer	143.4
Low consumer	61.4

It was reported that the high consumer used the water only for filling the swimming pool and watering a big lawn, the connections in the house are supplied by another meter, hence this house was excluded. The average for the other two houses ≃ 102.36 cubic meter.

Average monthly consumption per person ≃ $\frac{102.36}{6}$ ≃ 17.06 cubic meter

Average daily per person ≃ $\frac{17.06}{30}$ ≃ 0.57 cubic meter per day

≃ 125 10 gallons per day

3.5. INLAND NAVIGATION IN THE SUDAN

3.5.1. Introduction

The Nile had vastly been utilized as a means of transport as far back in history as the time of the first recongnized civilization (few thousands years ago). From the old times and up to nowadays various forms of ships were built and so many different types of traffics had been handled. However, it was only in the present century that regular and relatively large steamers were introduced along long-reaches of the Nile and tributaries.

Fig. 3.5.1. indicates the present active river navigation lines in the Sudan. These lines represent only a minor part of the potentiality of the Sudan's waterways.

Although river transport is generally the least expensive means of transport as far as capital outlays and operating expenses are concerned, yet its development in the Sudan was handicaped by so many shortcomings that would briefly be reviewed in this section.

3.5.2. Review of Reports

Inland navigation in the Sudan has received considerable attention in the last ten years. Though many good reports have been written on that topic, only few of them would be reviewed in here.

The Luckheed's report (1) of 1968 has optimized between the different modes of transport (rail, road, water and air) adopting the system analysis approach. It has also made comparison between that approach and the traditional methods for planning.

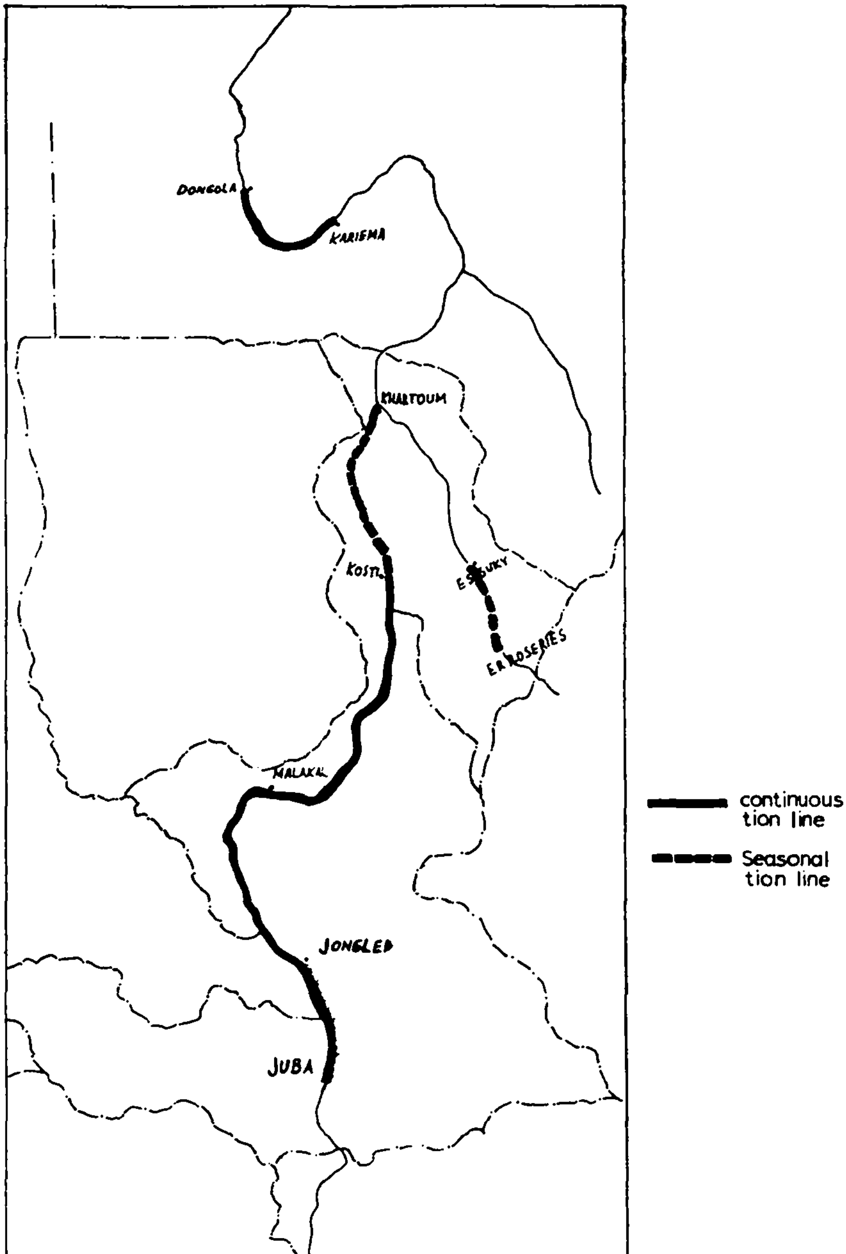
The Romanian's report(2) has the advantage of being concentrated on the problem of navigation in Southern Sudan. Though vast amount of data on the different aspects of river transport, has been collected in that report, the final recommendations were considered as expensive and unrealistic. That was why the river Transport Corporation (RTC) was reluctant to adopt that plan.

Quoting from a report by the RTC "the Romanian analyses lacked the alternative modes of transport,.. their study is an implementation plan rather than an evaluation alternatives".

While the German's report (5) has dealt with the same problem as that of the Romanian's report (navigation between Khartoum and Juba), it has the advantage of having made use of the Romanian's data. It has also given more realistic evaluation and anticipation to the future of navigation in that reach. Most of the report's recommendations have been adopted in the present national six-year-plan (1976-77 - 1982-83).

The Adar's report (4) had the merits of being an optimization between the different modes of transport, (rail, road, river, air). Its data seems to have been more carefully collected and appears to be quite up to date. The recommended 3 phases plan in their report has been rationally and systematically reached.

Fig. 3.5.1 PRESENT NAVIGATION LINES IN THE SUDAN



3.5.3. Navigation as compared to other modes of transport

Facilities for transport in the Sudan broadly consist of:

1 - 5493 km length of railways.
2 - 1723 km length of river ways (utilized length).
3 - 10223 km length of roads (only 823 km are with asphalt)
4 - 19 airports.
5 - 1 seaport (Port Sudan at the Red Sea).

Prior to 1969 - 70, railways and water ways were the main modes of transport. Roads transport has, however, vastly increased between the years 1970 - 1977, while the growth of the railways and river transport was less than anticipated in the same period.

Table 3.5.1. indicates the size of traffic between cities, in millions, for the period 1969 - 70 to 1976 - 77, while table 3.5.2 shows the financial situation of these modes of transport. Except for seaports these systems of transport are running at losses that are more obvious in the case of river transport. The reasons for these losses are diverse and interconnected, but most obvious of which is that most of the barges return empty from their Southern Region trip.

Table 3.5.3. indicates the six year plan anticipated growth in the different modes of transport in the coming six years (1977 - 78 - 1982 - 83). For the river transport the table indicates a rate of growth in cargo reaching a maximum value of about 224 (percent).

The Adar's report(4) has however exhibited a rational optimization between these modes of transport and has recommended a three phase plan.

3.5.4. The River Transport Corporation's Fleet

Including the new ships, the RTC fleet consist. more or less of the following units.

1 - 31 old pusher boats
2 - 6 new pusher boats (1974)
3 - 19 motor ships
4 - 140 old lighter (80 - 100 tons)
5 - 16 old lighters for liquid cargo (60 - 80 tons)
6 - 28 new lighters (500 tons)
7 - 6 new tank lighters (300 tons)
8 - 7 new passenger vessels (1974)
9 - 10 smaller vessels and launches and 3 ferries
10 - 4 new passenger vessels (1977).

Such a fleet is considered to be one of the largest in Africa and is capable of meeting the country's present demand with minor improvements(3). For more detailed information on the topic references (2), (3), (4), as well as the RTC Headquarters should be consulted.

3.5.5. Present Navigation Problems

Among others inland navigation is hindered by the following problems:
(i) Navigability of channels:

a. Lack of signalling system.
b. Existence of some rapids with small depths.
c. Existence of sharp bends (Malakal - Juba reach).
d. Inadequate depths specially at low flow periods.

Forty years of record in the Malakal - Juba reach has shown depths as small as 0.61 m(3), while the Karima - Dongola reach has been very much affected by the vastly expanding abstraction rate from the upstream reaches (specially the Blue Nile). The present RTC's fleet requires a draught depth of up to 1.22 m. Unfortunately these depths are not met at these reaches, specially at low flow period.
e. Inadequate widths (i.e. Malakal - Juba reach, Jebel Aulia lock).
f. Water hyacinth.

(ii) Inadequate harbours and shipyards.

(iii) Economical difficulties.

Table 3.5.2. shows that the river Transport is operating with deficit both in 1969 - 70 and 1974 - 75 seasons. The southern reach line was running at losses for all the period 1958 - 59 to 1973 . Among other reasons,these losses could be due to the following:

(a) Over 90 (percent) of the traffic is from the North to the South (10 (percent) from South to North)
(b) The high HP required to move one ton of payload (0.85 to 1.2) and to the low capacit(5) . In USA the above ratio is about 0.18.
(c) Inadequacy in navigability, shipyards, harbours, peration adds to these difficulties.

It must however be noted that the River Transport Corporation has only been constituted as an independent entity in 1973. Prior to that time it was merely a tributary to the Sudan Railways. The available studies (1, 2, 3, 4) together with the ambitious plans of the RTC indicate an encouraging future for inland navigation in the Sudan. The success of these plans requires, in addition to the optimization of the different modes of transport, a similar optimization with the other utilizers of Sudan water resources (namely, irrigation, power generation, industry, domestic, etc.).

Table 3.5.1. Inter-cities traffic movement (in millions)

Mean of:	1969-70		1974-75		anticipated plan		Actual achievement		67-77 (expected)		Rate of growth in the modified 5 yr.	
transport:	ton-km	pass-km	ton-km	pass-km	ton-km	pass-km	ton-km	pass-km	ton-km	pass-km	ton-km	pass-km
								%			%	%
Railways	2697	1014	2274	1102	4000	1170	57	94	2800	1150	4	13
Roads	922	3480	2464	5840	--	--	--	--	3787	6000	311	72
River ways	80	72	82	88	117	101	70	86	83	88	4	22
Airways	2	134	8	286	--	190	--	150	8	570	300	325
Total	3701	4700	4828	7315	4117	1461	117	--	6678	7808	80	66

Table 3,5,2, Financial situation

different sectors	1969 - 70 earnings	cost	ratio of cost to earnings %	1974 - 75 Earnings	cost	ratio of cost to earnings %
Railways	18.85	16.13	86	22.81	24.24	106
River transport	1.08	1.70	157	2.20	3.06	139
Sudan Airways	3.09	4.01	130	11.37	12.03	106
Sea ports	2.94	1.55	53	7.15	3.22	45

Table 3.5.3. Six year plan, 1982-83 (transport section)

Unit	Year: 1974-75 (actual)	1976-77 (expected)	1977-78	aimed 78-79	achievement 79-80	80-81	81-82	82-83	Rates of growth 77-82-83 %
Railways									
10^9 ton-km	2.274	2.800	3.00	3.200	3.500	3.000	4.200	4.500	86
Pass.-km x 10^9	1.102	1.150	125	1300	1.350	1.000	1.450	1.500	30
Roads									
Ton-km x 10^9	2.46	3.787	3.80	4.000	4.100	4.000	4.500	4.980	31
Pass.-km x 10^9	5.84	6.00	6.20	6.500	7.000	8.000	9.000	10.070	60
River transport									
Ton-km x 10^9	0.08	0.083	0.08	0.100	0.120	0.050	0.175	0.194	224
Pass.-km x 10^9	0.08	0.088	0.05	0.095	0.100	0.005	0.108	0.110	25
Pipe lines									
Ton-km x 10^9	(0.270) by railways	(0.278) by railways	0.3	0.320	0.350	0.380	0.400	0.420	--
Airways									
Ton-km x 10^9	0.007	0.008	0.010	0.015	0.020	0.022	0.022	0.032	30
Pass-km x 10^9	0.286	0.570	0.600	0.700	0.850	0.950	1.000	1.131	98
Total									
Ton-km x 10^9	4.827	6.678	7.195	8.535	9.170	10.002	10.875	11.872	78
Pass-km x 10^9	7.315	7.315	7.808	8.140	9.300	10.455	11.558	12.811	64

3.6. FISHERIES

3.6.1. Nile Potentialities

As many tropical rivers the Nile basin is not only rich in species but extremely productive of fish. It is still far from fully exploited. Valuable fisheries exist in the Southern Sudan which annually exports 2.000 tons of dried fish to the Congo. White Nile, Jebel Aulia dam reservoir, Roseiris dam and the Nuba lake are of very high fish potentialities of more than 50 species. It is regretting that no statistical survey on this wealth is available but hydrobiological studies are done on different areas in the Sudan with special attention to Roseiris lake, Jebel Aulia, Nuba lake and the Red Sea. In the 6 years development plan a strategy for development of the fisheries resources is based on the optimum utilization of the resources and modernization of the industry. The plan recommeded 10 projects:

1 - Development of central Sudan fisheries which includes the following reservoirs:(i) Jebel Aulia, (ii) Roseiris, (iii) Sennar and (iv) Kha sh m El Girba.
2 - Development of lake Nuba fisheries to increase the production of fish to 3.000 tons per year.
3 - Improvement of fresh fish marketing facilities and the main markets to be improved are Khartoum, Kosti, Wad Medani, El Duiem, Atbara, Damazin, Sennar, Kassala.
4 - Fish culture experimental and demonstration project to lead to the initiation of fish culture on large commercial scale.
5 - Promotion of fishing industry statistics which quantify the fish resources all over the country and their promotion.
6 - Development of fisheries resources in southern region and establishment of research centres.
7 - Re-establishment of oyster farming in the Red Sea (Dongousate bay).
8 - Development of marine fishing resources with the provision of mechanised fishing boats and equipments.
9 - Development of fisheries research objectives to determine potential of major water bodies and improve the methods of their utilization.
10 - Strengthening of fisheries training centre to provide the efficient technical personnel.

In Jongolei canal project the fisheries component was quite important for the overall programme of the project. One of the many supposed primary effects of the canal is the socio-economic effects on the people of the area resulting from changes in their pastoral habits, to agricultural traditions and fishing practices. In the report of Dr. G. Dunen 1976 he called for actual predictions of the primary hydrological changes that will result from the Jonglei scheme before the ecological predictions can be finalized. Hydrobiological studies are to proceed irrespective of the hydrological studies, and an integrated approach to the problem as a whole. The programme of investigations into the hydrobiological effects of the Jonglei canal is to be established (Sudd hydrobiology effect). The proposed investigation is a comprehensive programme of hydrobiological impact assessment which must include the study of major processes and organisms which are likely to be affected by a planned human activity. The framework might include studies of the major physical-chemical processes, as well as the plants and animals which are affected by them.

The main project recommended for the study of fisheries as the most economically important aquatic animals and is likely to be significantly altered by the construction of Junglei canal. This project includes:

1 - Identification of seasonal movements population.
2 - Investigation of relevant biological aspects of dear fish groups and an assessment of the effects of changes in the hydrological regime on these groups.
3 - Pilot schemes to form artificial drainage basins in compartments to trap fish at flood tides and to exploit by controlled harvesting.
4 - Investigation of the optimum use of earth barrage reservoirs and similar waters for fish production.
5 - Investigation of use of aquatic weeds in fish farming.
6 - Investigations of aquatic invertebrate population from the aspect of fish foods, and as indicators of water quality changes.

On fisheries development three projects are suggested by Dr. Dunn to be executed by FAO:

1 - Inventory of present status of fisheries which is essential before any fisheries development is contemplated.
2 - Fisheries resources survey which concern with the assessment of the commercially important fish populations, their location, seasonal movements, breeding, producticn, techniques of catching and market possibilities.
3 - Fisheries development project which concentrate on training of fishermen, the introduction of improved methods of fishing, treatment of the catch, transport and marketing.

3.6.2. Effect of Engineering works on Fisheries

On many rivers fisheries are an important economic asset and it is obvious and essential that when planning and designing engineering projects the direct and indirect effects of such project, on fish potentialities should be considered. River board regulations in England are considering the life of fish in streams, when water is abstracted, damped or diverted upstream. In such cases a minimum of 21(percent) of the average daily flow of the stream should be maintained to secure fish life (maintained flow) in small streams and 17 (percent) in large streams. In dams the maintained flow is preferred to be discharged from the upper levels of the reservoir to avoid the discharge of cold and possibly deoxygenated water. Dams may constitute physical barriers to migration of fish both upstream and downstream; their effect will always be unfavourable unless they may act as barriers to harmful fish. On the other hand they may create reservoirs of greater productive capacity for a different fauna. Fluctuations of reservoir levels will also affect fish life.

Fish ways, fish ladders, fish locks or fish lifts should be considered when **migratory fish** exist. (**One of the** main criticisms of Roseiris dam that it does not **have any of these and had** its **direct** effect on fish population in the resérvoir). **Fish locks and** fish lifts have the **advantage of** avoiding waste of water. Fish screens devices which are necessary in hydro-electric work and sometimes provided to check suction of fish in diversions and water supply schemes. The choice of such types of structures, location and design should be carefully considered and Engineers are requested to get advice from fish experts. The capacity of the reservoir should be such that the lowest calculated level is ample for the reservation of fish. Sub-impoundments with independent water level control may sometimes be desirable.

The transport and deposition of sediments and nutrients is an important function of any water way. Changes in the hydrologic regime will undoubtedly affect these processes and obviously affect the fish life pattern, so any water resources project should include together with the hydrological studies a simultaneous or separate hydrobiological investigations (Jonglei canal).

In the area of Jebel Aulia reservoir zoo plankton is characterised by considerably diversity of forms especially in the pre-dam portion of the reservoir. Decrease in the current velocity, reduction in the quantity of suspended sediments and development of submerged vegetation, all these are favourable conditions for the increase of this fish food.

Another example of dam effects is the poverty of the pre-dam area from Benthos and this is probably caused by change in hydrological regime of the reservoir liable to the effect of water discharge through the bottom sluices of the dam as in Jebel Aulia dam.

3.7. RECREATION PURPOSES

3.7.0. Introduction

The presence of a natural clean water attracted our early ancestors to form settled life and hence most of the old civilizations had flourished on the banks of the rivers. Naturally clean surface water, had been appreciated by many artists, poets and writers a long time ago. It is generally known that the sight of stretching water, and the sound of falling water soothes the nerves. Now with the spread of education and the general promotion of the public thinking, there is an increasing appreciation for the preservation of the natural environment, especially surface water as it is enjoyable to sit beside, walk along, look into or be in direct contact with the water through, bathing, swimming, sailing or fishing. The need for these numerous recreational potentialities in the surface water is now increasing, putting in mind the congestion of people in big towns and their search for an out-door recreation.

3.7.1. Surface water recreation potentiality

In our country, there is a huge number of rivers and fortunately they are still clean and unpolluted and hence they offer a valuable public amenity which can be used for recreation beside other usages. Despite the fact that many of these rivers run in scarcely populated areas, but still many pass through densely populated towns and they became a source of pleasure and recreation for the inhabitants. Surface water recreation can be divided into two categories:

1- Indirect contact with the water.
2- Direct contact with the water.

Indirect contact with the water includes: (a) sitting beside (b) looking into the water, (e) walking nearby, (d) picnicing or playing on the bank and (e) making ornaments with the water like fountains and man made lakes.

To encourage the above types of recreation, the surface water should be of such qualities that would appeal to the human senses. Although it is very difficult to change the inherit qualities of the water, but control measures should be made to stop any discharges or wastes that would seriously affect its colour, turbidity, taste, odour. Or generally hamper the aquatic life whether in rivers, lakes or the sea. Here in our country a special attention should be paid to the proper banking of the rivers so as to attract the public. It is the right of the public to have safe and easy access to his beautiful sceneries.

Direct contact with the water can be further subdivided into : (a) primary contact and (b) secondary contact.

The definition given in the report of National Technical Advisory Committee to the Seceretary of the Interior (U.S) in April 1968, is ' in which there is prolonged and intimate contact with the water involving considerable risk of ingesting water in quantities sufficient to pose a significant health hazard '. Examples are swimming, diving, bathing or wading. The definition given by the committee for secondary contact with water, (sports including those in which contact with the water is either incidental or accidental and the probability of ingesting appreciable quantities of water is minimal) example is fishing.

The same quality requirements as for indirect recreation apply here, but strict control should be made for faecal pollution through actual determination of the colliform count.

3.7.2. Money return from surface water recreation

For the indirect recreation, no direct money return is expected and as we have stated before the public should have free access to his beautiful surface waters and enjoy them.

For direct contact recreation the writer thinks that charges should be imposed on group contact recreation like sailing, fishing and swimming clubs.

3.8. SUMMARY OF RESULTS

Table 3.8.1. gives a preliminary estimate to the present and future demand for water in the Sudan. The numerical figures in this table should not be taken as typical and are presented here only to demonstrate in a very broad way the order of magnitude of these demands.

Uses such as navigation, recreation, fisheries are deliberately not included in the table since their demands are quantitatively unclear at the moment:

Table 3.8.1.

Type of use	present demand billion m^3	future demand billion m^3	Remarks
Irrigation	19.8	33.7	
Hydro - power generation	--	12.0	present demand for hydro-power generation is included with irrigation
Industry	over 0.1	over 2.3	1. mining, quarries, and other numerous industries are not included. 2. The figures can be consumptive or nonconsumptive.
Domestic	0.4	2.0	Future need is calculated for a population of 32 million with 40 gpd requirements.
Total	20.2	50.0	
Percentage of different uses	irrig. 98 %	irrig. 67.4 %	In future uses such as power generation, industry and domestic will have an appreciable increase in their water demand.

4.1. SUDAN AND INTERNATIONAL AGREEMENTS

4.1.1.

The 1904 agreement between the United Kingdom and Ethiopia stipulated that Ethiopia undertakes not to construct any works on the Blue Nile or its distributaries which may obstruct the flow without the prior consent of the Sudan Government.

4.1.2.

In 1920 the Egyptian Government issued a programme for the Nile control and appointed an International Commission which endorsed the proposals to construct Gezira Scheme, Jebel Aulia reservoir and Naga Hamadi barrage. The commission estimated the ultimate water requirements for Egypt as 58 milliards, but could not fix a quota for the Sudan. Consequently the Egyptian postponed all irrigation projects awaiting agreement on the political future of the Sudan.

4.1.3

In 1925 a new International Commission was formed and the 1925 Nile Water Agreement was based on the recommendations of that commission. The agreement restricted the construction of any works on the Nile, its tributaries and the lakes from which it flows without the previous agreement of Egypt. The agreement specified that the natural flow of the river should be reserved for the benefit of Egypt from January to mid-July subject to certain pump irrigation - rights in the Sudan covering 25.000 hectares, while the Sudan water requirements during the low flow period were to be provided entirely from Sennar dam storage. The details of this agreement are as follows:

The 1929 Nile Water Agreement

This agreement which defined the Nile water for both Egypt and the Sudan until 1959 can be summarized as follows:

1 - The period 16th July to 31st December shall be referred to as the period of surplus, whereas the period from January 1st. to July 15th. during which the Sudan was obliged to maintain a debit and credit water account, was referred to as the restricted season.

2 - The natural flow of the river during the restricted season was absolutely reserved to Egypt, subject to the sanctional pumping rights.

3 - During the period of surplus, the Sudan was entitled to draw water into the Gezira Canal, to fill the Sennar reservoir, to flood the area under basin irrigation in the Northern Province and to irrigate by pumps, all as follows:

(a) First filling of Sennar dam from level 409 to 417.20 in 10 days time to ensure command in Gezira canal and to store 333 million cubic meter, should not be affected earlier than 15th. July, criterion being that the combined Malakal plus Roseiris discharges with a ten day lag for Malakal, have averaged not less than 160 million cubic metres per day for the preceding five days. The second filling of the reservoir was effected between 27th. October to 30th. November to 420.70 corresponding to a storage of 781 million cubic meter, and which remains thus up to January 18th Later in 1952 it was agreed to raise the reservoir level to 421.70 to store 929 million cubic meter.

(b) Taking water in the Gezira canal, at the maximum rate of 84 cumecs during August 1st. to November 30th, 80 cumecs during December 1 to January 15 and 52 cumecs during the period January 16 to 18. Thus from January 1 to 18 the total Gezira canal consumption shall be 117 million cubic meter. It was also agreed that the Sudan should accept a limited rate of progress so as to afford Egypt the opportunity to overtake the effect of development of the Sudan by construction of works and barrages according to a predetermined programme, and subject to this the maximum discharge drawn in the canal after August 1st. to November 30th. can be gradually increased from 84 cumecs in 1929 to 168 cumecs by the year 1936, the corresponding increase in December was up to 160 cumecs.

(c) Further water requirements should be met entirely from stored water, and the water used on all additional areas under pumps is replaced in the river by the release of corresponding quantities of water from Sennar reservoir in compensation at the rate of 800 cubic metres per feddan per month.

(d) As for pump irrigation the area under pumps covered by the 1929 agreement and which was established before 1925 has been stated above as 22,500 feddans perennial, irrigated throughout the year and 16,000 flood area irrigated from July 15th. to end of February.

Hence, in accordance with the 1929 Nile Water Agreement the debit items from January to July were:

i. Losses from Sennar reservoir
ii. Gezira canal discharge
iii. Compensation water for pumps
iv. Domestic supply.

The credit items were :

i. Reservoir contents at January 1st. = 781 million cubic metres at 420.70.
ii. From 1 - 18 January the Gezira canal consumption was 117 million cubic metres and the reservoir loss at 1.35 million cubic metres per day was 24 million cubic metres, bringing the total to 141 million cubic metres, which when added to the content totals 922 million cubic metres.

(e) Save with the previous agreement of Egypt, no works should be constructed or measures taken on the Nile or its branches or on the lakes through which it flows, in the Sudan or in territories under British administration, which would affect the flow of the river in such a way as to cause prejudice to the interests of Egypt.

Application of the 1929 Nile Water Agreement

(1) It was stated in the 1929 Nile Water Agreement that the final volume debited must not under any circumstances exceed the volume at credit during the restricted period. This condition limited the irrigation development in the Sudan as it was strictly adhered to the development continued from 1929 onwards in the light of this agreement, and following are examples showing the rate of progress in the water use up to the sixth decade of this century:

i. For example up to the fifth decade and particularly if one takes a year like 1944 the volume debited did not exceed the volume at credit:

Credit:

Sennar content at January 1	781 million cubic metres.
Abstraction from River 1 - 18 January	141 million cubic metres.

Total credit	922 million cubic metres.

Debit :

Gezira canal consumption January to April	578 million cubic metres
Evaporation losses January to July	135 million cubic metres.
Domestic supply May to July	15 million cubic metres.
Compensation for pumps	49 million cubic metres.

Total debit	777 million cubic metres.

Hence 145 million cubic metres was surplused downstreem.

(2) In the sixth decade of the century viz. 1950 to 1960 considerable progress in irrigation development was achieved. Hence an agreement was worked out in 1952 to raise Sennar dam by one metre to ensure a storage of 929 million cubic metres and to increase the storage at Jebel Aulia dam gradually by 400 million cubic metres with reservoir level at 377.40 to allow for the development of Managil extension in the interest of the Sudan, to be repaid by the Sudan when more stored water is available from the next project to be developed.

As an example of the stage of development in the fifties, let us take the mode of development in the agricultural year, say 1953.

(a) Entitlement of the Sudan during the restricted period January to mid July:

i	Sennar reservoir contents at the new storage level of 421.70	929 mm^3
ii	From river 1 - 18 January plus reservoir losses	141 "
iii	Extra storage in Jebel Aulia	200 "
iv	Sanctioned pumping rights from as before 1925 from 1st. January onwards	143 "
	Total entitlement	1413 "

(b) Consumption during the period of surplus:

It is evident that the limitations imposed during the restricted period determine the extent of area to be cultivated perennially. Water use in the period of surplus before 1959, say in 1953 was approximately as follows:

(i) 1,000,000 feddans at Gezira at 1600 cubic metres per feddan	= 1600 million cubic metres.
(ii) About 400,000 feddans under pump irrigation at 2,000 cubic metres per feddan	= 800 million cubic metres.
(iii) 70,000 feddans under basin at 5,000 cubic metres per feddan	= 350 million cubic metres.

Total during the period of surplus	= 2750 million cubic metres.
Total during restricted period as before	= 1413 million cubic metres.

Total annual consumption by Sudan	= 4163 million cubic metres.

Hence the Sudan consumption before the 1959 Nile Water Agreement was of the order of 4 milliard cubic metres.

(3) Let us take another example which demonstrates further how the credit during the restricted period is consumed leaving a surplus released downstream Sennar dam. The year 1954-1955 is considered:

(a) Credit :

(i) Storage at Sennar	= 929 million cubic metres.
(ii) From natural river 1 - 18 January	= 141 million cubic metres.
(iii) From Jebel Aulia storage	= 400 million cubic metres.
(iv) Pumps after 1 January as before 1929	= 142 million cubic metres.

Total credit	= 1612 million cubic metres.

(b) Debit :

(i) Compensation for pumps	= 547 million cubic metres.
(ii) For sugar trials in the South	= 35 million cubic metres.
(iii) For rice trials at Malakal	= 6 million cubic metres.
(iv) For Abger Pumps	= 6 million cubic metres.
(v) Small pump schemes	= 81 million cubic metres.

Total pumps	675 million cubic metres.
(vi) For Gezira canal	600 million cubic metres.
(vii) Evaporation losses	137 million cubic metres.

Total debit	1412 million cubic metres.

Hence the unused surplus is 200 million cubic metres, which accounted for more development between 1955 and 1959.

4.1.4.

In 1932 an Agreement was concluded between Sudan and Egypt, under which Jebel Aulia Reservoir was constructed to give additional water supplies to Egypt.

Agreement regarding Jebel Aulia dam

The construction of Jebel Aulia dam was completed in 1937 with a storage capacity of 3.5 milliard cubic metres at full supply level of 377.20 m. Its first filling was determined by the date when the flow at Atbara would suffice the irrigation requirements in Egypt, that in sometimes in July and the first filling would continue to level 376.50 by 20th. August.

The second filling would start in September and completed in October to level 377.20 or 377.40 or 377.50.

The gap between the end of the first filling and the beginning of the second filling, that is from 20th. August to September 1st. corresponds with the expected peak of the Blue Nile flood.

Emptying of Jebel Aulia dam occurs from 1st. of February to 1st. of March. It was agreed that a minimum of 55 million cubic metres to be released downstream the Jebel for pumps on the main Nile and that the level should not fall below 376.25 before 1st. March in the interest of Dueim schemes. Emptying used to be completed up to mid April per mid May, depending on the irrigation needs in Egypt. It should be noted that the operation of both dams is prior to 1959.

4.1.5.

In 1935 and 1946 an agreement with Ethiopia to construct an over-year storage dam at lake Tana was proposed, but not finalized.

4.1.6.

In 1946 Egypt proposed the future conservation of the Nile involving over-year storage in lake Tana, lake Victoria and lake Albert, the Jonglei canal, and the 4th. cataract reservoir. Modifications were suggested by the Sudan, but no further action was taken at the time.

4.1.7.

In 1949 an agreement was reached between Egypt and Britain on the construction of Owen Falls dam at the outlet of lake Victoria which was completed in 1954.

Agreement on Owen Falls dam

An agreement was concluded between Egypt and Britain in 1949 allowing Uganda to construct Owen Falls dam to store 200 milliard cubic metres in lake Victoria if necessity demands and to generate 150 MW. The dam was completed in 1954 whereupon Egypt was to pay 4.5 million pounds to Uganda.

4.1.8.

In 1952 Egypt and the Sudan agreed to raise Sennar dam by one metre and Jebel Aulia dam by ten centimetres.

Agreement on raising Sennar dam

In 1952 Egypt and the Sudan agreed that the Sudan can raise Sennar level by one metre and would provide facilities towards the construction of the 4th. cataract dam by Egypt and that the Sudan would draw 200 million cubic metres from Jebel Aulia dam in low years.

In 1952 Egypt proposed the construction of the over-year storage dam of El Sad El Ali.

4.1.9.

In 1959 the Nile Water Agreement was concluded between the two countries. whereby the net benefit from Aswan High Dam would be divided at the ratio of 14.5 milliard cubic metres for the Sudan and 7.5 milliard for Egypt and as a result the Sudan share has become 18.5 milliard cubic metres and that of Egypt 55.5 milliard cubic metres leaving 10 milliard cubic metres for evaporation from Aswan high dam reservoir.

The agreement stipulated the formation of a permanent joint technical commission to undertake the gauging of the Nile. to draw plans for the increase of the Nile yield. to draw up the working arrangements for any works to be constructed on the Nile. and to consider and reach a unified view regarding the other riprarian countries claims and any such accepted claims shall be deducted from the shares of the two countries. Details pertinent to this agreement are as follows:

First. the present acquired rights

1- That the amount of the Nile waters used by the United Arab Republic until this agreement is signed shall be her acquired right before obtaining the benefits of the Nile control projects and the projects which will increase its yield and which projects were referred to in this agreement. The total of this acquired right is 48 milliards of cubic metres per year as measured at Aswan.

2- That the amount of the waters used at present by the Republic of the Sudan shall be her acquired right before obtaining the benefits of the projects referred to above. The total amount of this acquired right is 4 milliards cubic **metres per year as measured at Aswan.**

Second. the Nile control projects and the division of other benefits between the two republics

1- In order to regulate the River waters and control their flow into the sea. the two republics agree that the United Arab Republic construct the Sudd El Aali at Aswan as the first link of a series of projects on the Nile for over year storage.

2- In order to enable the Sudan to utilize its share of the water. the two republics agreed that the Republic of the Sudan shall construct the Roseiris dam on the Blue Nile and any other works which the Republic of the Sudan considers essential for the utilization of its share.

3- The net benefit from the Sudd El Aali reservoir shall be calculated on the basis of the average natural river yield of water. at Aswan in the years of this century. which is estimated at about 84 milliards of cubic metres per year. The acquired rights of the two republics referred to in article 'First' as measured at Aswan. and the average of losses of over-year storage of the Sudd El Aali reservoir shall be deducted from this yield. and the balance shall be the net benefit which shall be divided between the two republics.

4- The net benefit from the Sudd El Aali reservoir mentioned in the previous item. shall be divided between the two republics at the ratio of 14 and half for the Sudan and 7 and hafl for the United Arab Republic so long as the average river yield remains in future within the limits of the average yield referred to in the previous paragraph. This means that. if the average yield remains the same as the average of the previous years of this century which is estimated at 84 milliards. and if the losses of over-year storage remain equal to the present estimate of 10 milliards. the net benefit of the Sudd El Aali reservoir shall be 22 milliards of which the share of the Republic of the Sudan shall be 14 and half milliards and the share of the United Arab Republic shall be 7 and half milliards. By adding these shares to their acquired rights. the total share from the net yield of the Nile after the full operation of the Sudd El Aali reservoir shall be 18 and half milliards for the republic of the Sudan and 55 and hafl for the United Arab Republic.

But if the average yield increases. the resulting net benefit from this increase shall be divided between the two republics. in equal shares.

5- As the net benefit from the Sudd El Aali (referred to in item 3 article 'Second') is calculated on the basis of the average natural yield of the river at Aswan in the years of this century after the deduction therefrom of the acquired rights of the two republics and the average losses of over-year storage at the Sudd El Aali reservoir. it is agreed that this net benefit shall be the subject of revision by the two parties at reasonable intervals to be agreed upon after starting the full operation of the Sudd El Aali reservoir.

6- The United Arab Republic agrees to pay to the Sudan Republic 15 million Egyptian pounds as full compensation for the damage resulting to the Sudanese existing properties as a result of the storage in the storage Sad El Aali reservoir up to a reduced level of 182 metres (survey datum). The payment of this compensation shall be effected in accordance with the annexed agreement between the two parties.

7- The Republic of the Sudan undertakes to arrange before July 1963, the final transfer of the population of Halfa and all other Sudanese inhabitants whose lands shall be submerged by the stored water.

8- It is understood that when the Sudd El Aali is fully operated, for over-year storage, the United Arab Republic will not require storing any water at Jebel Aulia dam. And the two contracting parties will in due course, discuss all matters related to this renunciation.

Third. Proiects for the utilization of lost waters in the Nile basin

In view of the fact that at present. considerable volumes of the Nile basin waters are lost in the swamps of Bahr el Ghazal. Bahr el Jebel. Bahr el Zeraf. and the Sobat river. and as it is essential that efforts should be exerted in order to prevent these losses and to increase the vield of the River for use in agricultural expansion in the two republics. the two republics agree to the following:

1- The Republic of the Sudan in agreement with the United Arab Republic shall construct proiects for the increase of the River vield bv preventing losses of waters of the Nile basin in the swamps of Bahr El Jebel. Bahr el Zaraf. Bahr el Ghazal and its tributaries. the Sobat river and its tributaries and the White Nile basin. The net vield of these projects shall be divided equallv between the two republics and each of them shall also contribute equallv to the costs.

The Republic of the Sudan shall finance the above mentioned projects out of its own funds and the United Arab Republic shall pav its share in the costs in the same ratio of 50 (percent) allotted for her in the vield of these projects.

2- If the United Arab Republic. on account of the progress in its planned agricultural expansion. should find it necessarv to start on anv of the increase of the Nile vield project. referred to in the previous paragraph. after its approval bv the two governments and at a time when the Sudan republic does not. need such projects. the United Arab Republic shall notifv the Sudan Republic of the time convenient for the former to start the execution of the project. And each of the two republics shall. within two vears after such notification. present a date-p hased programme for the utilization of its share of the waters saved bv the project. and each of the said programmes shall bind the two parties. The United Arab Republic shall at the expirv of the two vears. start the execution of the projects. at its own expense. And when the Republic of the Sudan is readv to utilize its share according to the agreed programme. it shall pav to the United Arab Republic a share of all the expenses in the same ratio as the Sudan's share in benefit is to the total benefit of the project. provided that the share of either republic shall not exceed one half of the two total benefit of the project.

Fourth. Technical cooperation between the two republics

1- In order to ensure the technical cooperation between the governments of the two republics. to continue the research and studv necessarv for the Nile control projects and the increase of its vield and to continue the hvdrological survev of its upper reaches. the two republics agreed that immediatelv after the signing of this agreement a permanent joint technical commission shall be formed of an equal number of members from both parties: and its functions shall be:

(a) The drawing of the basic outlines of projects for the increase of the Nile vield. and for the supervision of the studies necessarv for the finalizing of projects, before presentation to the governments of the two republics for approval.

(b) The supervision of the execution of the projects approved by the two governments.

(c) The drawing up of the working arrangements for any works to be constructed on the Nile, within the boundaries of the Sudan, and also for these to be constructed outside the boundaries of the Sudan by the agreement with the authorities concerned in the countries in which such works are constructed.

(d) The supervision of the application of all the working agreements mentioned in (c) above in connection with works constructed within the boundaries of Sudan and also in connection with the Sudd el Aali reservoir and Aswan dam, through official engineers delegated for the purpose by the two republics, and the supervision of the working of the upper Nile projects, as provided in the agreements concluded with the countries in which such projects are constructed.

(e) As it is probable that a series of low years may occur and a succession of low levels in the Sudd el Aali reservoir may result to such an extent as not to permit in any one year the drawing of the full requirements of the two republics, the Technical Commission is charged with the task of devising a fair arrangement for the two republics to follow. And the recommendation of the Commission shall be presented to the two governments for approval.

2- In order to enable the Commission to exercise the functions enumerated in the above item and in order to ensure the continuation of the Nile gauging and to keep observations on all its upper reaches; these duties shall be carried out under the technical supervision of the Commission by the engineers of the Sudan Republic and the engineers of the United Arab Republic in the Sudan and in the United Arab Republic and in Uganda.

3- The two governments shall form the joint technical commission, by a joint decree, and shall provide it with its necessary funds from their budgets. The Commission may, according to the requirements of work hold its meetings in Cairo or in Khartoum. The Commission shall, subject to the approval of the two governments, lay down regulations for the organization of its meetings and its techical administrative and financial activities.

Fifth, General provisions

If it becomes necessary to hold any negotiations concerning the Nile waters, with any riparian state, outside the boundaries of the two republics, the governments of the Sudan Republic and the United Arab Republic shall agree on a unified view after the subject is studied by the said Technical Commission. The said unified view shall be the basis of any negotiations by the Commission with the said states.

If the negotiations result in an agreement to construct any works on the river, outside the boundaries of the two republics, the Joint Technical Commission shall after consulting the authorities in the Governments of the states concerned, draw all the technical execution details and the working and maintenance arrangements. And the Commission shall, after the sanction of the same by the governments concerned, supervise the carrying out of the said technical agreements.

2- As the riparian states, other than the two republics, claim a share in the Nile waters, the two republics have agreed that they shall jointly consider and reach one unified view regarding the said claims. And if the said consideration results in the acceptance of allotting an amount of the Nile water to one or the other of the said states, the accepted amount shall be deducted from the shares of the two republics in equal parts, as calculated at Aswan.

The Technical Commission mentioned in this agreement shall make the necessary arrangements with the states concerned, in order to ensure that their water consumption shall not exceed the amounts agreed upon.

Cooperation with Nilotic Countries

4.1.10.

Following a series of discussions, Egypt, Uganda, Kenya, Tanzania and UNSF agreed in 1967 to construct the hydrometeorological survey of the catchments of lakes Victoria, Kyoga and Albert. Burundi and Rawanda joined this project in 1972 and Ethiopia joined the Technical Committee of this project as an observer. The first phase of the project was accomplished in 1975 and thereafter the second phase has started with the object of formulating a mathematical model presenting the Upper Nile system to assist in the conservation, control and development of the Nile water resources taking into consideration the optimum benefit of the riparian countries.

Main objectives of phase 1

The project for the hydrometeorological survey of the catchments of the lakes Victoria, Kyoga and Albert which commenced in August 1967 had for its objective the collection of meteorological and hydrological data of the Upper Nile system in the countries of Kenya, Tanzania and Uganda. According to the purposes specified in the plan of operation, 'the data collected and the study are expected to assist the participating countries in the planning of water conservation and development and to provide the ground for work for inter-governmental cooperation in the storage, regulation and use of the Nile".

The specific task assigned to the project in the original plan of operation were:

(a) Setting up additional data collecting stations (24 hydrometeorological, 156 rainfall including 6 rainfall records, 67 hydrological and 14 lake level recording) and upgrading some of the existing stations, in order to complete an adequate network from which basic hydrometeorological data can be collected and analysed.

(b) Establishing of seven small index-catchments for intensive studies of rainfall - runoff relationships for application to other parts of the catchment area.

(c) Aerial photography and ground survey of these sections of the lake shore areas which are flat and which will be most subject to change with variations in levels of the lakes. Since only a few contours above and below lake water level will be required, aerial photography will be used to prepare planimetric maps and the contours will be properly located by topographic survey. A hydrographic survey of lake Kyoga particularly the portion where depths are shallow and not well measured will be carried out.

(d) Devising and proposing analytical procedures for the various parameters involved in the water balance of the lakes, using the data collected from the new and existing stations and from the index catchments. The analysis carried out should among other things lead to the development of maps of mean monthly and annual evapotranspiration, precipitation, stream flow and evaporation during specially wet and dry years, isohytal maps of severe storms, and various graphical representations of precipitation data.

(e) Training staff of the participating governments in hydrmeteorological work.

The duration of the project was five years.

Objectives of phase 11

A. Long-range objectives

The project is intended to assist the participating governments in the planning of conservation and development of the water resources of the Upper Nile basin, and to provide the groundwork for intergovernmental negotiations for the storage, regulation and use of the Nile.

b. Immediate objectives

1 - The immediate objectives are as follows :

(a) To formulate a mathematical model representing the Upper Nile system including all lakes and rivers in all the riparian countries, which will help in the future in the development of the water resources of the Upper Nile.

(b) To evolve various alternative patterns of regulation of lakes Victoria, Kyoga and Albert singly and as a system taking into account the objectives of optimum benefits.

(c) To continue work on aspects pertaining to evaporation determination by energy budget methods, evapotranspiration, index catchments, collection, publication and analysis of data.

(d) Training the staff of the participating countries in system analysis, regulation and use of rivers and lakes.

2 - This project does not have a direct investment potential.

4.1.11.

Contacts have been indicated with Ethiopia and the UNDP to formulate agreements aiming at conducting joint hydrological studies on the upper catchment areas of River Gash and Baraka, but no progress has been made yet.

4.1.12.

The UNDP has proposed a joint project between Ethiopia and the Sudan to conduct hydrometreorological studies in the Blue Nile catchment area within Ethiopia to study the flood forecast of the Blue Nile, and still no progress has been made yet.

4.1.13.

The UNDP has proposed a joint project to study the environmental impact of the Aswan High Dam reservoir together with the limnological, hydrogeological, hydrological and meteorological aspects. Formulation of the plan of operation is expected in 1977-78.

4.2. WATER LAWS AND REGULATIONS IN EXISTENCE IN SUDAN

These include the current legislations, regulations and general principles pertinent to the various aspects of water resources.

4.2.1. Constitutional

The constitution of the democratic Republic of the Sudan has provided for the conservation, and efficient exploitation of the available water resources.

4.2.2. River Control Regulations

There are adequate regulation rules for all the river control works in the Sudan comprising the reservoirs of Sennar, Roseiris, Jebel Aulia, Khashm El Girba and the stretch of the high dam reservoir within the Sudan. These rules have been set out in accordance with the provisions for the control of the flows of the Nile which include the working arrangements for the operation of river works embodying the hydrologiol aspects relating to the natural flows, time lags, transmission and other losses, reservoir characteristics, as well as the principles of the filling, emptying, hydraulic control and the aportionment of usage for irrigation, hydropower, water supply taking into account the downstream rights and the minimum acceptable flows.

4.2.3. Reservoirs compensation ordinances

When a new reservoir is constructed, the normal practice is the enactment and enforcement of an ordinance for compensation. As an example of this, there is, the Jebel Aulia compensating ordinance of 1937 which makes provision for the award of compensation in respect of damages to property caused by the raising of the level of the White Nile consequent upon the construction of the dam. The ordinance defines the compensation to be determined, the appointment of the commissioner and assessors and the date at which the final dam conditions are reached. Similar ordinances have been enacted in case of all the other reservoirs in the Sudan.

4.2.4. Irrigation regulations

There are ordinance and regulations governing irrigation schemes.

For example the Gezira scheme ordinance and regulations contain rules for the control, regulation, distribution and other technical directions to ensure the safe and efficient operation of the canal system. It defines the relationship between the water control irrigation authorities and the agricultural authorities. According to these regulations the supply of water, its control and distribution is mainly a weekly indent by the block agricultural inspector on the sub-divisional irrigation engineer expressed in cubic metre per day based on water factors at the sub-divisional engineer above him and finally the last one indents upon the head works engineer (dam engineer). The regulations also define the measures related to wide spread and local flooding, drainage of rainwater and escapage of the surplus canal water as well as the operation of the regulators and other structures.

4.2.5. Nile pumps control board ordinance

This ordinance issued in 1939 aims at controlling the pumping of water and water renting licences from the River Nile for irrigation, including the extent of land to be cultivated, the canalization, the methods of cultivations, etc. The ordinance stipulates the establishment and the powers of the Nile pumps board, the main duties of which include the equitable distribution of the available waters amongst riparian owners and allotting from time to time specified proportions of water to any particular province or district and making regulations consistent with the requirements of public health. According to such regulations the board would issue water renting licences, prescribe penalties, fix conditions of land tenure, lay down rules for making canals and drains, and regulates the crop rotation on the land irrigated by pumps. In accordance with the above ordinance of 1939, new regulations were issued by the Nile Pump Control Board in 1951. Later in 1960 regulations for the land tenancies were issued for the prupose of the distribution of tenancies and pertinent issues.

4.2.6. Taxation Ordinance

Such ordinances are issued from time to time with respect to the land watered from rivers, ground water or rainfall. Examples of such ordinances are:

(a) In the case of lands watered by sagia, matara wheel or shadouf, a rate is fixed by the government.

(b) The rainlands watered periodically by rain or rivers; all crops grown on rainlands shall also be liable to a tax.

The organs responsible for water supply for irrigation, domestic use, industrial use, or generation of power issue legislations from time to time fixing water rates to be paid by the public or government units.

4.2.7. Ordinances pertinent to other Uses of Water Channels

1 - The fresh water fisheries ordinance:
This ordinance issued in 1954 regulates and controls fishing in fresh water fisheries, and it applies to all fresh water rivers and lakes in the Sudan.

2 - There is another similar ordinance regulating marine fisheries in the Sudan.

3 - River transport in the Nile and inland waters ordinance:

This ordinance enacted in 1907 comprises river navigation regulations. boat regulations and harbour and shipping regulations within the territorial waters or on the shores of the Sudan

4.2.8. Water Pollution Control Ordinance

This ordinance lies in section three of the environment health ordinance issued by the Sudan Ministry of Health in 1975. The main clauses of this ordinance aim at preventing the addition of any solids. fluids. industrial wastes. chemicals. sewage.refuse. and remains of animals on the water supply sources or inside rivers. canals. haffirs. wells natural ponds or into the sea to avoid causing harm to the health of man and animals. The ordinance stipulates the control and supervision measures to be undertaken by the provincial authorities on the water supply sources and water works and the collection of water samples therefrom as well as inspection of rural and urban water supply net-works.

The ordinance also includes the conditions of the storage and supply of water which ban the supply of water to the public before analysing it by the appropriate technical authorities to ensure its freedom from pollution. The ordinance provides. as well. protective measures against the spread of epidemic diseases. the collection of water samples for bacteriological analysis. treating the water supply source and conducting medical examination for employees on water supply systems until the absence of pollution is confirmed.

Finally. the ordinance regulates the disposal of sewage and industrial wastes in water courses and specifies the proportion of biochemical oxygen and suspended material in ppm by weight of water conveyed by canals which are used for conveying treated sewages and irrigation water.

4.2.9. The Water Hyacinth Ordinance

This was enacted in 1960 and is cited as the ordinance for the combatment of water hyacinth and the control of its spread in Sudanese rivers and water ways. According to this ordinance the areas infested with hyacinth should be published in the Gazette. Observation and control points should be established in the infested reaches. Any vessels passing a control point should be cleared from the hyacinth. Owners of pump schemes should install mesh screens in inlet channels and should notify the concerned authorities of the appearance of any water hyacinth in their schemes. The ordinance bans the transference of water hyacinth from place to place and it permits the concerned authorities to enter into any land with the object of controlling the spread of the water hyacinth. Regulations should be issued from time to time to help in the implementation of the context of this ordinance. Any person who breaches the ordinance shall be liable to penalty.

4.2.10.

The continental sea shelf governing the use of the territorial sea waters was enacted in 1970. It defines the base line and the extent of the coast as well as the rights of sovereignity and the legal status of the superjacent waters.

4.3. NOTE ON THE RELATION BETWEEN WATER SUPPLY AND SEWAGE

4.3.1. The water cycle

The water cycle in nature is a continuous process. Elements of the cycle are evaporation, transpiration, precipitation, surface runoff, infilteration and percolation. They are all interconnected to form a loop and whatever is lost from one element is added to another.

With development the need of man for more water became tremendously big, that he was obliged to revise his consumption of water, specially when the available water resources are limited and at the same time to reconsider the utilization of his used water. Of course he has already got the example for recirculation from the natural water cycle. Hence in this paper the writer is trying to establish the relation between water supply and sewage.

4.3.2. Relation between water supply and sewage

Before establishing the relation, it is important to verify whether the sewerage system is separate, combined or partially separate. In separate systems, foul sewage and surface water have two independent systems. In combined system both foul sewage and surface water are carried in the same sewer. In partially separate, also two independent systems are used but here some surface water is allowed into the foul sewer.

4.3.3. Separate system and water demand

Referring to Table 4.3.1. taken from Tebbutt (Principles of Water Quality Control) which shows the domestic demand in U.K. in 1966 and in future (2000), it could be noticed that most of the water used goes to the sewer. Water used in industry is also mostly referred to the sewers. Hence the estimates for sewage volume is really comparable to the domestic and industrial demand. Percentages given for temperate climate are within the range of 80 - 90 (percent) (Public Health Notes. Imperial college. Asst. Prof. F. E. Bruce) - In warmer climates the ratio is between 70 - 80 (percent) (Tebbutt) as some water is expected to be lost in evaporation or garden watering. In very hot countries like the Sudan, the writer thinks that the percentage may be as low as 50 (percent) since most of the water goes to watering the gardens or otherwise showering the empty areas in the house for cooling as illustrated in Chapter 3.4.4. The above percentage together with the infiltration from ground water through poor jointing, cracks in the pipe or man holes is generally known as the dry weather flow (d.w.f.).

4.3.4. Combined system

Here it is important to estimate the surface run-off which depends on the intensity and frequency of rainfall, impermeability of the soil and topography of the area. As it is not practical to design a sewer whcih can accommodate any storm, relief devices are installed in the system to divert the storm sewage to storage, waste or a recipient body of water and creating pollutional hazards. Here in Khartoum the system is separate which is a great advantage from the point of view of river pollution.

Table 4.3.1. Domestic water demand

Use	Estimated consumption/l/head /day 1966	2000
Drinking and cooking	5	5
Dish washing and cleaning	14	18
Laundry	14	23
Personal wasing and bathing	45	59
Closet flushing and refuse disposal	50	63
Car washing	-	4
Garden use and recreation	5	27
Waste in distribution	23	36
Total	156 (34.32 gallons)	235 (51.7 gallons)

In either system huge amounts of water are involved and should be reclaimed especially in countries where the water resources are limited. The reclamation necessitates special quality standards to suit the expected usage of the reclaimed water. The standards are laid down by the governmental authorities responsible for the water resources together with the public health specialists and should be enforced on all water users with the national objective that no water is unduely lost and at the same time ensuring that no determental effects are added to the environment.

4.3.5. Quality requirements for used water

Used water whether from industry, agriculture or effluents from sewage stations should be under very strict quality control measures, if it is to be returned to the natural water resources. In this country, rivers, at first sight represent an attractive recipient for used waters, but not to forget that many of our citizens drink water from the rivers raw without any sort of treatment.

Tables 4.3.2., 4.3.3. and 4.3.4. illustrate the chemical analysis for the white Nile, the Blue Nile and tap water during the year 1971-1972 taken from the report of the Government Analyst 1961 - 1972, Ministry of Health.

Our rivers are clean and it should be the concern of everybody in this country to see that they are kept clean. If ever any used water is returned to the river, very strict quality control measures should be implemented. Factors leading to rivers pollution can be summarized as follows:

1 - Faecal pollution from sewage stations.

2 - Organic materials that exert a high biochemical oxygen demand (B. O. D) and consume the dissolved oxygen (D. O) in the water.

3 - Substances that form a film on the surface of water like oils and detergents and can deter the oxygenation of water from the atmosphere.

4 - Hot discharges from industrial waste water that leads to reduction of D.O. by raising the temperature of water.

5 - Discharges with huge volumes of suspended and dissolved solids.

6 - Toxic materials from industrial effluents like cyanides and phenols.

4.3.6. Recommended exploitation for the used waters

Industrial and sewage effluents could easily be used in irrigation since great areas of the Sudan are hot and dry for most of the year. If the quality of the effluent is bit below the requirements, raw water from the river could be added for dilution, even ground water could be resorted to, if there are no rivers or canals in the neighbourhood. It has been a very wise idea to use the effluent from Khartoum sewage plant in irrigating the green belt to the south. The same idea could be applied to the effluent from the industrial area sewage plant at Khartoum North according to the recommendation of Dr. Fahmy. M.El Sharkawi, the WHO consultant in his assignment report October - December, 1975.

Table 4.3.2 White Nile. chemical analyses - 1971 / 72

Date:	3.7.71	2.8.71	4.9.71	2.10.71	2.11.71	8.12.71	3.1.72	5.2.72	2.3.72	4.3.72	1.5.72	1.8.72
Water temperature C	23	23	25	29	25	24	17	17	20	23	25	28
PH	8.2	8.0	8.3	8.1	8.2	8.2	8.0	8.2	8.2	8.2	8.3	8.2
Conducivity micromho cm	250	185	210	260	180	250	230	240	310	250	250	250
T. dissolved solids dried at 180c mgl	200	160	180	200	160	200	200	200	200	240	210	240
Total hardness as Ca_3Co_3	115	80	70	70	85	75	80	90	80	80	80	80
Total alkalinity as Ca^3Co_3	100	90	120	110	110	120	120	130	160	200	190	150
Excess akalinity as Na^2Co_3	Nil	10	55	45	15	43	40	45	85	125	115	75
Calcium as Ca	30	20	20	15	25	15	15	20	20	20	15	10
Magnesium as mg	10	10	10	5	5	10	10	10	5	5	10	15
Chlorides as c_1	15	15	30	35	30	20	25	15	25	10	10	10
Sulphate as so_4 25	25	25	40	15	25	15	25	25	25	25	25	25
Nitrate as No_3	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Fluorite as F	0.70	0.60	0.50	0.80	0.50	0.50	0.50	0.50	0.40	0.40	0.50	0.40
Amooonia as N	0.40	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0.39	0.5-	Nil	0.10
Albuminoid as N	-	-	-	-	-	-	Nil	Nil	Nil	Nil	-	0.30
Sodium as Na	15	20	23	25	20	40	20	30	15	15	20	45
Potassium as K	5	10	15	15	10	10	10	15	5	5	20	15
Dissolved oxygen	7.10	7.30	7.40	6.60	7.20	7.80	9.20	8.90	7.60	4.00	6.00	6.00
Biochemical oxygen demand	2.10	2.30	3.50	2.20	4.20	1.90	1.50	1.00	1.00	1.00	0.20	2.50
Suspended solids	Nil	Nil	0.05	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Settleable solids	Nil	Nil	0.07	0.10	Nil	Nil	Nil	Nil	Nil	Nil	Nil	

Table 4.3.3. Blue Nile, chemical analyses - 1971/72

Date		3.7.71	2.8.71	4.9.71	2.10.71	2.11.71	8.12.71	3.1.72	5.2.72	2.3.72	4.3.72	1.5.72	1.8.72
Water temperature C		24	23	23	23	24	25	18	18	22.5	23	24	30
pH		8.2	8.0	8.0	8.2	8.0	8.2	8.0	8.0	8.2	8.0	8.2	8.1
Conductivity micromhe-cm		250	180	160	180	1140	180	160	180	220	190	210	250
T. dissolved solids dried at 180 C	mg-l	200	160	140	150	120	160	120	140	160	160	140	240
Total hardness as $CaCo^3$	''	90	100	80	80	100	85	85	100	110	90	120	120
Total alkalinity as	'	130	90	90	70	80	90	80	90	110	120	130	150
Excess alkalinity Na_2Co_3	''	45	Nil	10	Nil	Nil	5	Nil	Nil	Nil	35	10	30
Calcuim as Ca	'	30	20	20	20	25	20	25	25	25	30	25	30
Magnesuim as Mg	'	Nil	10	5	5	10	10	5	10	10	5	15	10
Chlorides as Cl	''	30	10	15	90	15	25	20	15	20	10	10	5
Sulphate as So_4	''	25	15	35	40	15	25	15	25	35	40	60	35
Nitrite as No_3	''	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Fluoride as F_3	''	0.60	0.40	0.50	0.80	0.50	0.50	0.50	0.50	0.50	0.40	0.60	0.40
Ammonia as N	''	0.40	Nil	Nil	Nil	Nil	Nil	Nil	0.4	Nil	Nil	Nil	0.07
Albuminoid as N	''	-	-	-	-	-	-	Nil	Nil	Nil	Nil	Nil	0.2
Sodium as Na	''	30	30	5	10	10	10	10	25	15	10	60	20
Potassium as K	''	20	20	3	5	5	5	5	15	5	5	5	5
Dissolved oxygen	''	6.90	4.90	6.50	6.60	7.70	7.60	9.50	9.00	7.90	4.50	6.70	5.90
Biochemical oxygen demand	''	2.70	1.40	3.10	1.30	1.10	1.70	2.10	3.60	2.00	1.00	2.00	1.50
Suspended solids	''	Nil	Nil	3.40	0.25	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Settleable solids	''	Nil	Nil	0.10	Nil	Nil	Nil	NIl	Nil	Nil	Nil	Nil	Nil

Table 4.3.4. Tap water, chemical - 1971-72

Date		3.7.71	2.8.71	4.9.71	2.10.71	2.11.71	8.12.71	3.1.72	5.2.72	2.3.72	4.3.72	1.5.72	1.8.72
Water temperature C		-	-	-	-	-	-	-	-	-	-	-	-
pH		8.0	7.8	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.1	8.0
Conductivity micromho-cm		220	160	200	195	160	250	240	250	235	300	200	250
T. dissolved solids dried at 180 C	mg-l	180	140	160	160	140	200	200	200	160	200	190	240
Total as hardness as $CaCo_3$	"	110	140	100	85	90	80	75	90	90	70	50	60
Total alkalinity	"	100	60	60	160	70	100	100	100	100	150	160	130
Excess alkalinity Na_2Co_3	"	Nil	Nil	Nil	80	Nil	20	25	10	10	85	85	75
Calcium as Ca	"	30	30	30	25	30	20	20	20	25	20	15	15
Magnesium as Mg	"	10	15	5	5	5	10	5	10	5	5	10	5
Chloride as Cl	"	15	10	30	50	30	30	35	30	25	10	10	10
Sulphate as So_4	"	40	65	50	40	25	35	25	25	25	40	60	35
Nitrate as No_3	"	Nil	Nil	Nil	Mil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Fluoride as F	"	0.60	0.60	0.40	0.80	0.50	0.50	0.50	0.50	0.50	0.40	0.60	0.40
Ammonia as N	"	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Albuminoid as N	"	-	-	-	-	-	-	-	-	-	-	-	-
Sodium as Na	"	15	15	5	5	5	20	10	10	10	10	20	25
Potasium as K	"	5	5	3	5	5	10	5	5	5	5	20	25
Residual chlorine	"	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

4.4. WATER QUALITY CONTROL

The conservation of water quality means the prevention of water pollution and contamination which necessitates the creation or strengthening of bodies responsible for the control of water abstraction, treatment and disposal.

Generally speaking water could be polluted through:

1 - Industrial waste,

2 - Agricultural waste,

3 - Domestic waste and

4 - Miscellaneous wastes. The waste generated from the above sectors should not be permitted to find its way into water courses unless treated to a certain standard, otherwise it will damage the quality of the existing water resources.

Worldwide experience have shown that vastly developing countries like the Sudan can no longer rely on the self-purification mechanism because of the excessively increasing quantities of waste and the chemical composition of the polluting substances i.e. non-biodegradable, synthetic materials, fertilizers, insecticides, etc.

The present practice in this country is to strictly prevent the discharge of any waste treated or untreated to water sources as indicated by the environmental health ordinance of 1976. This is because most of the people drink water directly from sources without any treatment. Nevertheless, that ordinance seems to be severe and not practical specially when considering the presently vast industrial and agricultural development and the wide scale urbanization taking place in this country. Such development asks for more water and produces an increasing quantity of waste. Hence it might be difficult from a practical point of view to stick to that ordinance. For example one could see many cases where this ordinance seems not adhered to:

1- During the rainy season washing of wastes from various activities finds its way to surface and underground water resources.

2- The existing type of domestic waste disposal installations in individual houses, being septic tanks or pit latrines, are probably polluting the water sources and contradicting the existing ordinance.

3- The disposal of the final effluents from the existing and projected sewage treatment works in view of expanding economy represents a problem when viewed in terms of this ordinance.

4- Accidental cases of pollution.

5- Future tightness in the country's water resources may inforce the return of used water to sources rather than evaporating it.

Hence the conservation and improvement of the existing quality of water resources in the Sudan can be achieved only through realistic pollution control measures which reflect the need for more water with good quality, and the conservation of the existing water quality.

To be able to control and prevent the pollution one should know the pollutants which are likely to damage the sources, and the mechanism or their actions based on their properties.

Pollutants

1- Inert matter in suspension (clay-silt)
2- Substances toxic to aquatic life (acids - alkalis - salts of toxic-metals).
3- Biological oxidizing matter in solution or suspension
4- Non-biodegradable materials (i.e. detergents).

The effect of these pollutions are detrimental to water purification for various uses and to aquatic life.

The quality of water sources in Sudan as it stands now is fairly good although it is expected to deteriorate if no realistic pollution control measures have been devised.

Generally speaking any successful policy for water pollution prevention necessitates the provision of adequate waste handling and processing facilities specially in case of large concentrations or population. The cost of pollution prevention could be large but it is a worthwhile investment. (British experience shows that for each 100 pounds spent on water treatment and supply about 125 pounds should be spent on sewage).

It is not a good policy to prevent disposal of waste without working out the ways and means for:

1- The satisfaction of the increased water demand

2- The provisions of disposal facilities for the increased waste production

3- The adoption of cheap methods for waste treatment and disposal regarding domestic use and industry.

4- Considering disposal facilities in view of the natural, physical, topographical and climatological factors which will affect the effluent disposal (e.g. slopes, saturation of soil, blockage of voids, etc.)

Hence the need is felt for national standards (reflecting the country's habits and environmental conditions) regarding:

1- Drinking water quality

2- Final effluent quality, and quality control facilities for:

(a) Systematic monitoring of water resources quality.
(b) Systematic control of produced effluents from the various sectors.

All of the above activities regarding pollution control measures can be achieved through the creation of a national body such as the American Environmental Pollution Control Agency or the British Water Boards, where the interests of all consumers are catered for. Through the usages of water one could list the interested bodies who are likely to be involved in this body as follows:

1. Water is a food source (Fishing Department)
2. Water is a transport medium (Transport Department)
3. Water is a recreation medium (Tourism Department)
4. Water is for domestic supply and industry (Local Governments and; (Ministry of Industry).
5. Water for agriculture and animal (Irrigation, Agriculture and Natural Resources, Department)
6. Water is a source of power (Hydroelectric Department)
7. Water could be used as a medium of waste disposal ; (Research Institution and Local Governments).

Hence the body to control the water quality shall not be a section of any department or ministry as it should represent and protect the interests of different departments which sometimes could be of conflicting interests.

4.5. RIVER AND RIVER BASIN PLANNING

4.5.1. Morphology of a River

The word 'river' is a modification of the word riveire which is in turn derived from the Latin word Ripa meaning banks. When rain falls on to the ground some of it sinks in the ground but a great part of it gather together to form streams which in turns give rivers. The streams cut their way by forming valleys which are deep and narrow at the head. The rain washes away a good portion of the banks material, thus the valleys get wider and wider by time. The energy of the running water is sufficient to pick up a great part of the material on the banks, but the loosening effect due to material carried by the water in forms of stone, sand or rocks, tends to prepare the bank surface for the moving water to increase still further its attack on the banks. As a result the stream carries a lot of the material from the high lands where the streams are initiated to be deposited later in the flat parts of its course.

River water, like rainwater, dissolves certain rocks such as limestone as well as wear them away mechanically. The salinity thus acquired will determine the suitability of the water to the different uses such as drinking, irrigation, etc. Similarly the fine suspended particles will cause turbidity of the water.

In general rivers may carry materials sometimes for thousands of miles, to be deposited when the river has not enough energy to keep it in suspension and motion. There are two modes of sediment transport:

1- **Suspended load :** This load is kept in suspension by upward components of velocity fluctuation. When that component is dissipated the particles settle out.

2- **Bed load :** is defined as that part of the total load which moves near to or in contact with the bed most of the time. Its mode of motion is mainly rolling and saltation. The particles knock against one another and are thus gradually reduced in size.

As mentioned above the picking up of material and keeping it in suspension depends on the turbulent energy of the water, in particular the upward component, which in turn depends on the instantaneous velocity of the stream; similarly deposition depends on the same. As the velocity is a function of the slope, erosion takes place at the steep slopes and deposition at flat slopes. The later-deposition takes place at two points along the course of the stream when the stream enters that ground from the highlands e.g. the sudd area of the Southern Sudan, and when it reaches the sea, thus forming its delta.

As the velocity drops, the section of the river should increase to pass the same discharge. The only way for the section to increase is by spreading as the river has little energy to scour thus spills over its banks forming swamps. In these swamps a lot of water is lost by evaporation and transpiration. Also the area becomes invested with grass, trees, insects, etc. For example, in the Sudan the Nile loses about 14 milliards annually in the swamps area of Bahr El Jebel and Bahr El Zeraf.

Material deposited by streams form alluvial plains that are rich and good for agriculture. Those alluvial plains such as Nile plain are the most fertile land in the world and on it the old civilizations started. But the action of deposition closes the waterway and forces the stream to change its course. As the slope is gentle or nil on these regions the stream wanders freely in any direction.

Some rivers overspill their banks during floods and consequently deposit a lot of good fertile soil such as in the North of the Sudan.

4.5.2. Behaviour of a river

A river behaviour can be identified in three stages:

i. In the swift high part. The river denudes or wears away its course.

ii. In the slower-moving middle part of the course the river keeps the suspended material in suspension.

iii. In the slow flat course and delta deposition takes place.

4.5.3. Falls and rapids

When a river passes over a ground formed of strata of different resistance e.g. soft shale followed by hard and then soft strata, there is a possibility of formation of falls. A good example of this is Niagara falls, Fourth Cataract, etc.

4.5.4. Classification of rivers

There are many ways by which a river may be classified:

i. by its type of flow. whether continuous or intermittent

ii. by its ease of navigation, navigable or non-navigable

iii. whether surface flow or ground flow

iv. by its orgin, whether from rain or melted snow in the highland or from lakes e.g. Victoria Nile, or from springs. As lakes and springs in absolute terms originate from the rain all rivers have their origin in precipitaion. Actually this is the way by which nature closes the hydrological cycle.

Rivers similarly discharge either in the sea, lake, river or vanish in the ground. The Nile finishes its long journey in the Mediteranean Sea while Khor Arab just disappears in the desert.

4.5.5. Uses of rivers

Rivers are put to many uses by man. One characteristic of river which is important is that it purifies itself of all types of pollution.

4.5.6. Some of the most important uses

i. drinking water

ii. irrigation

iii. generation of hydropower

iv. navigation

v. waste disposal area

vi. fish breading

vii. transportation of logs

viii. recreation

Unfortunately the requirement of these uses conflict and it is the job of the planner to optimise the benefit.

Rivers although are very useful, have their own problems:

1. meandering
2. bank erosion
3. pollution
4. sediment deposit
5. salinity
6. turbidity
7. obstacles to navigation
8. evaporation and transpiration by weeds: water hyacinth
9. disease borne e.g. bilharza in the Gezira canals
10. floods and droughts.

Each one of these problems can form a research topic of its own. Specially flood and droughts. In fact one cannot under emphasize the importance of constructing enough control works to minimize as much as possible the effects of flood and drought. It is however a part from the whole river basin planning, liable to optimization with theother parameters.

4.5.7. Meandering and desert creep

Examples of some of chronic problems of rivers can be found in the Nile whether meandering, bank erosion or desert creep mentioning some only.

Meandering is a common characteristic of all rivers in alluvial soil. So far there is no accepted explanation for its occurrence, yet its effects are well known. Most pump sites on the Blue Nile and the Main Nile are threatened one time by erosion and other by deposition, e.g. Bawga Island, Ganate pump site, Kitayab, Zeidab, Badeen Island, Salfarti, Shabana, Labab, Abu Dom scheme, Ganati Island, Korti Island, Nori.

The time between the occurrence of successive erosions or deposition at on site gives a full cycle of meandering. For the Nile it is of order between 40 and

50 years.

The idea of remedy for meandering is stabilization of the banks. This means stabilizing the bank between Khartoum and Halfa about 2 x 1500 kilometers. This is rather too expensive for a developing country.

Bank erosion is due to:

1- Erosive power of the swift current in the banks due to meandering effect.

2- Erosion due to the secondary currents.

3- Saturation of banks above low water level during flood creates a pushing effect on the particle after the flood passes.

4- Piping effect at the bed of the river due to high ground water pressure.

The remedy may consist of:

(a) Lining of the banks.

(b) Toe protection using mattress out of wire net and any filling material like branches of trees or grass.
This method had been used in El Kitaib in 1960.

(c) Repelling groynes are good but need to be designed through model investigation.

Desert creep is another problem. The continuous feeding of the Nile by drifting sand through the phenomenon known as 'desert creep' results in covering the fertile islands of the Nile by a layer of sand and at low level formation of sand bars which obstruct navigation. So far there are no perfect solutions but forestation and vegetation cover are of great help. The rate of desert creep is roughly estimated as 20 kilometers per year. If one assumes an average grain size of 9 mm ($_8$ inch) and the sand moves in one layer the Nile will receive $20 \times 10^3 \times 10^3 \times 9$ per 10^3 18000 cubic metres of sand per one kilometer of bank. For 1500 kilometers. $18 \times 10^4 \times 15 \times 10^2$ 27×10^7 cubic metres of sand will pour in the Nile annually. All of this material had to be deposited somewhere before reaching the High Dam.

Besides this the desert creep has a very serious effect on the fertile land on the banks of the river. It is buried under a layer of sand and this puts it out of use. Thus the people imigrate. It is said that 75 (percent) male population of the Northern Sudan imigrate because of lack of chances of making a decent living.

Forestation will slow down sand drift and may clear away area affected but the remedy should be global. These problems are concerned with river engineering, yet linked with it there are:

i. Political problems e.g. boundaries between countries crossed by a river.

ii. Social problems such as problems encountered when pumping is investigated or drinking zone are to be located.

iii. Economic problems such as stabilizing the whole of the Nile against meandering. This brings us to the point of suggesting the formation of board such as TVA (international) for all countries in on basin to tackle such problems. Its may be called for example Nile valley authority (NVA). Its main function is planning for the best use of the river basin.

4.5.8. River basin planning

The procedure of river basin planning consists of two main ideas;

i. Treatment of the basin as hydrological, economical and social identity (this shows the importance of revising the 1959 Nile agreement between the Sudan and Egypt).

ii Always design projects for multi-purpose use the steps to be taken are:

(a) To set out the broad outline of the river basin development policy. This is the task of the policy-makers.

(b) To identify the goals of the river development in accordance with the country's ambition and policy in (a). This is the function of subcomittee of the executive and legislative and representative of the experts.

(c) Design and numerization of projects for re-evaluation by the executive and legislative in step (d) to follow. This work is done by the experts and personnel of different interdisciplinary skills in accordance with constraints set by the subcommittee in step (b).

(d) As mentioned in (c), the final evaluation to be done by the policy-m akers before the green light is given. Cost benefit analysis, taking in consideration tangible and intangible benefits, is the measuring stick for the validity and usefulness of a project.

These steps when properly followed will give in the end an assured procedure for a successful River basin development.

4.6. AN APPROACH TO WATER RESOURCES MANAGEMENT

4.6.1. Acknowledgement

The writer would like to acknowledge that most of the definitions presented in this part were taken from reference (1). From the vast literature read in the subject these definitions were found as the best convey briefly what the writer wants to say.

4.6.2. Introduction

Regionally and internationally water resources studies are receiving at present, a considerable attention through universities, research centres, various United Nations Organizations and programmes (i.e. FAO, UNESCO, WHO, WMO, IHP, etc.) and national and international con ferences. Such studies are extremely important in arid regions where water becomes a vital element for the existence of almost every human activity. Like power consumption the gross water used by an inhabitant is nowadays frequently used as an index of the standard of living.

Although water is the most manageable of all the natural resources, being capable of diversion, transport, storage and recycling, its quantity, quality and distribution in time and space are highly variable. Hence man would be faced by many choices for managing his water resources. These choices should not be isolated from the hydrological, ecological, economical,sociological and political effects. Worldwide experiences have shown beyond any doubt, that a wrong choice may either be unrectifiable or it may need very high costs for its correction. Such experiences can be avoided if the management of the water resources is carried out in a rational scientific manner.

Many effective methods for treating this problem were developed and established by many countries in the world. Review of all these methods are not the purpose of this note, yet the system engineering approach would be briefly reviewed and recommended for adoption to the Sudan's water resources. Chapters 2 and 3 of this study clearly demonstrate the complexity of the problem, in quantity and quality, space and time, demand and supply.

4.6.3. Method of treatment

It is obvious from the previous chapters in this report that numerous interacting factors must essentially be considered in any short or long term management plan of the Sudan's water resources. Luckily in the last few decades new techniques have made remarkable and advantageous worldwide development in many complex engineering problems. The development of these techniques has been stimulated by various different factors, most remarkable of which is the availability of increasingly powerful computers.

This new field of study is called 'system engineering' or more generally 'system science'. Here, the study is understood as being the analytical and synthetic study of a system of associated entities to realize one or several predominating objectives. The reader is assumed to be well acqainted with simpler systems such as electrical, telecommunications, transport, economic, social, ecological, educational, bureaucratic, political systems.

The method of confronting problems of the above type is defined as the 'system approach'. The system approach concentrates on the system as a whole complex and not on components of the parts. Techniques such as system analysis, operation research, etc. may be used. In this technique mathematical, physical, statistical and probabilistic methods are often used for the preparation of decision criterion relating to the system at its different states.

In the cases where a basin or a hydrographically defined region are taken into consideration then a water resources system, hydraulic system, or water system is the frequent given name.

4.6.4. Water resources system

From the several definitions of a water resources system one can adopt the following definition : 'a limited finite whole of identifiable entities capable of interacting in such a way that the whole when functioning, achieves the determined objectives in order to obtain the chosen purposes'.

However, a water resources system has various variable characteristics such as:

(a) Its inter-connection and interaction with other complex systems (such as the economic, social, political,.. systems).

(b) A global water resources system is extremely complex and is by necessity divided into smaller complex subsystems. Considerable interactions between these subsystems usually exist.

(c) Every moment a system is found to be in a particular condition, called a state which is defined by the state of parameters, the relationship of interactions and the constrains which are at the same time characteristics of it.

(d) It must be considered as an integrated whole.

(e) It may serve several different objectives.

The system approach is being used more frequently for the study of this problem, since it provides a unitary vision of the different phenomena, involved. The basic activities necessary to formulate a water resource system in a unitary vision can be summarized as follows:

i. Forecasting i.e. outline of the objectives.
ii. Planning of the activities necessary to obtain the determined objectives.
iii. Programming, at the time of the stages of these activities.
iv. Coordination between the different actions relevant to these activities.
v. Control of the development of the activities of the system to obtain the determined objectives.

Thus forecasting, planning and programming are moments of different activities projected into a future, with systematic and fixed character. They produce objectives, plans, programmes, projects and norms of short, middle and long terms.

Control, on the other hand, indicates examination, confirmation and if necessary corrective action, dictated by the interpretation of the results. The whole process may be described as:

Forecasting + planning + programming + coordination = organization

While :

Organization + control = management.

Thus a definition of the management of water resources is reached. Such an approach which provides a rational procedure for the management of a water resources system and which is universally accepted, can be utilized successfully in the Sudan.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

5.1. Sources of Water

5.1.1. It has been established from section 2.1. that over 90 (percent) of the Sudan's area lies within climatic zone where the total annual evaporation exceeds the total annual rainfall.

5.1.2. It is also demonstrated that the largest portion of the country's surface water sources are fed from catchments located outside the Sudan's boundaries. The corresponding surface runoff (specially the Nile and tributaries) is consequently shared, by agreements, with some of those neighbouring countries.

5.1.3. The 1959 water agreement with Egypt has limited the country's average annual share of the Nile water to 18.5 billion cubic metres at Aswan, or about 20 billion cubic metres at the central part of the country. The above value is subject to many limitations, most obvious of which are, fluctuation in the Nile annual discharges, claims from other Nilotic countries, etc.

5.1.4. It has been estimated in section 2.4 that over 35 billion cubic metres of the Nile water is annually lost at the swamps of its upper reaches. Preliminary studies have revealed that about 24 billion cubic metres of that water can be conserved through projects similar to the popular project of Jonglei. According to the 1959 water agreement the Sudan would equally share that quantity of water with Egypt.

5.1.5. In section 2.2.3. of this work it has also been established that non-N ilotic streams can form a significant contributer to the country's annual water supply (roughly estimated as about 7 billion cubic metres).

5.1.6. The comprehensive review on the works that had been carried out on ground water (section 2.3) has revealed that the Sudan's ground water supply could be of an order of magnitude equalling over 2 billion cubic metres as annual recharge and exceeding 500 billion cubic metres as stored reserve.

5.1.7. This report has also dealt with the conservation of water by more efficient utilization. In that respect it has been established that by increasing the total irrigation efficiency by 10 (percent) an amount of water exceeding the country's share of the Jonglei project (Phase 1) can be obtained.

5.1.8. The report has also dealt with conservation of the country's water through reuse (recycling), optimum use, and desalination.

5.1.9. There are numerous problems, however, hindering the maximum utilization of these sources. Some of these problems are listed at the end of each section in this report. Nevertheless some of the basic common problems would briefly be mentioned in here:

(a) Absence of a unified plan for the meteorological, hydrological and hydrogeological gauging of these resources.

(b) Inadequacy and diversity in the available networks and in the methods of measuring these parameters.

(c) Inadequacy and diversity in the method of compilation and presentation of the data obtained from the present networks.

(d) Lack of coordination and systematic exchange of information between the many bodies dealing with these parameters.

(e) Lack of communication between the bodies mentioned in item (d) and the bodies that utilize the country's water resources.

(f) Lack of organized systematic plan for water technology transfer from highly developed worldwide sources to the different corresponding sectors inside the country.

5.2. Uses of Water

5.2.1. It has been established from section 3.2. that over 90 (percent) of the readily available annual sources of the country's water is consumed in irrigation (about 20 billion cubic metres). Furthermore, if the country developed all its proposed irrigation schemes, which most probably will be the case, then about another 14 million cubic metres of water will annually be needed for that purpose.

5.2.2. In section 3.3.3. the country high potentiality in hydropower generation has been established. From that study, however, it has been shown that about 12 billion cubic metres of the country's scarce water resources will be lost through evaporation, if reservoirs giving the suggested size of power are built at these sites.

5.2.3. The report has also dealt with water demand by industry and domestic uses which are found to have an increasing claim on the country's water resources (i.e. about 10 (percent) of the country's future water resources).

5.2.4. The report has included sections on uses such as navigation, fisheries and recreation.

5.2.5. The most important conclusions reached from that chapter are:

(a) The country's demand for water in the near future would be more than its annual readily replenishable potential water supply. This is a serious situation when one knows that even in countries where their available water is many times their requirement, management and planning of their water resources are becoming very vital elements.

(b) Point (a) becomes more severe when one realizes that the above values are annual average quantities. The variation of these quantities and their quality, in time and space is very great.

(c) Absence of adequate metering and recording system for the actual water consumed by these uses.

5.2.6. There are many problems which hinder the allocation [illegible] country's limited water resources to the most suitable use and with a maximum return. Some of these problems are summarized [illegible] section in this report. However, few of the most [illegible] will be briefly listed here:

(a) Absence of a national plan optimizing between [illegible] and maximizing the return per unit quantity of water.

(b) Poor utilization efficiency in almost all of these uses. For example total irrigation efficiency is estimated as [illegible] while costly treated domestic water is sometimes [illegible] gardens and in building constructions.

Miscellaneous Topics

5.3.1. Multi-national and international agreements on the Nile [illegible] briefly summarized in section 4.1.

4.3.2. Section 4.2. gives a comprehensive summary on [illegible] regulations in existence in the Sudan.

5.3.3. The quality control on the country's water resources [illegible] dealt with in sections 4.3. and 4.4.

5.3.4. The river, its behaviour, problems and uses are dealt with in section 4.5. The writer of that section has however, put special stresses on:

(a) The planning of a river basin

(b) The meandering behaviour of Sudan's rivers, erosion and deposition in relation to meandering, and river training problems.

(c) The desert creep.

(d) Flood and drought.

5.3.5. The urgent need for the management of the country's water resources has been called for in section 4.6. The system engineering approach is recommended for achieving that goal.

5.4. Recommendations

5.4.1. It is well established from the present study that the Sudan's water resources are approaching a critical situation that calls for very urgent solutions.

5.4.2. It is also established that the water issue contains numerous parameters and constraints each of which is of a complicated nature.

5.4.3. To the present writers the following recommendations need to be urgently fulfilled:

(a) The formation of an effective national body, coordinating between the various bodies directly involved in the field of water resources.
(b) Soon after the formation of that effective body, full-time technical committee must be formed to plan and supervise the following:
(i) Survey of the whole water resources in the country with the ultimate aim of drawing a national management plan on the countries water resources.
(ii) Outlining of a priority list to the researches or investigations that should urgently be carried out to fill the gaps needed to formulate the national management plan.
(iii) Establishment of research groups in the following fields or any other additional fields found necessary.

1 - Hydrometric group, to redesign the country's meteorological, hydrological and hydrogeological networks, collecting data from these networks, compil ing these dataanalysing it and presenting it in a publishable form.

2 - Ground water conservation group, to study the quality quantity and annual recharged of the various aquifers in the country.

3 - Alluvial hydraulics group. to study erosion, sedimentation, river training and sand movement (i.e. Kashm El Girba problem, desert creep, etc.).

4 - Water conservation group, to study the swampy areas, recycling, utilization efficiency, desalination, etc.

5 - Environmental and water quality group, to study ways and means by which deterioration in water quality can be treated, reduced or eliminated.

6 - Formation of a publication and information centre to carry out among others, the following functions:

1 - Publishing of all the centre technical works and information pamphlets (through current journals, pamphlets, etc.).

2 - Formation of a system for obtaining relevant technical works from world wide sources and transfering it to the corresponding bodies inside the country (through libraries, etc.).

3 - Improving the state of water culture among the different sectors of the population so as to reduce losses and misuse of the country's precious water resources.

7- Establishment of a well defined plan for the type and standard of educational institutes necessary to provide the country with the technical manpower needed in that field.

APPENDIX 1

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APPENDIX 2

Meteorological Data (average for the period 1941 -1970)

Table 2.1. Yambio (04 34' N -28 24' F -650 m)

	Max °C	Min °C	Sunshine	Wind speed mph	V. P. m. b. 1200	Rainfall mm per month	Piche evapora. mm per day	Penman evapora. mm per month
J	33.6	17.8	3.5	3	16.5	12	6.4	140
F	34.3	18.3	3.9	2	16.8	25	7.1	141
M	33.5	19.6	5.0	2	20.5	93	5.4	133
A	31.7	20.0	6.0	2	24.0	148	3.4	123
M	31.0	19.7	6.0	2	25.5	187	2.8	121
J	29.9	19.2	5.9	2	24.9	163	2.3	105
J	28.9	18.9	6.5	2	24.8	167	1.9	92
A	28.9	18.9	6.8	2	24.8	210	1.9	92
S	30.1	18.9	6.3	2	24.5	187	2.3	96
O	30.3	18.8	6.1	2	24.4	180	2.4	105
N	31.5	18.5	5.2	2	22.0	75	3.0	108
D	32.5	17.3	4.0	2	18.5	17	4.5	112
Year					1464		1368	

Table 2.2. Wad Medani (14 24' N -33 30' E -405 m)

J	33.6	14.0	92	5.6	9.2	-	13.3	160
F	35.1	14.8	93	6.1	7.7	-	15.9	221
M	38.4	18.2	87	6.0	6.8	-	19.5	236
A	40.7	21.1	86	5.8	7.9	-	21.7	251
M	41.4	23.8	80	7.0	10.8	14	20.4	266
J	39.7	24.6	72	9.5	15.7	29	18.6	269
J	35.8	22.8	60	9.6	20.0	118	11.8	236
A	33.4	21.8	61	7.5	23.6	140	7.0	209
S	35.2	21.8	76	5.4	21.7	48	7.8	212
O	37.8	21.6	85	4.0	16.3	19	11.2	197
N	36.4	18.0	92	5.0	11.7	-	14.0	191
D	33.8	14.5	94	5.1	10.5	-	12.6	178
Year					368		2635	

Table 2.3. Abu Naama (12 44' - 34 08' E - 445 m)

J	35.4	15.0	89	5	4.7	0	14.3	175
F	36.6	16.4	88	5	9.9	0	16.9	209
M	39.8	19.6	83	5	9.7	1	19.3	221
A	41.1	22.5	83	5	10.7	1	19.0	242
M	40.1	24.5	74	5	15.1	20	16.5	242
J	36.4	23.2	57	6	20.4	123	11.3	212
J	32.5	21.7	49	5	23.7	123	6.0	166
A	31.2	21.1	49	4	25.5	162	3.6	142
S	32.9	20.7	62	4	24.9	109	3.9	163
O	36.2	20.2	73	4	19.9	36	7.0	175
N	37.3	18.3	88	4	13.1	1	12.7	178
D	36.0	15.7	90	5	12.6	0	13.6	166
	Year					576		2191

Table 2.4. Khartoum m (15 36' N - 32 33' E - 380 m)

J	31.7	16.0	93	10	9.1	0	14.5	169
F	33.2	16.7	93	12	7.8	0	17.1	203
M	37.0	19.9	87	10	7.9	0	20.2	230
A	40.1	23.0	86	10	8.9	0	22.0	251
M	41.9	26.3	78	9	11.0	5	21.0	258
J	41.6	27.1	76	9	13.1	5	20.4	266
J	30.1	25.7	67	10	17.8	55	15.7	251
A	36.2	24.8	69	9	21.3	72	12.1	227
S	32.6	25.6	76	8	17.7	25	14.3	233
O	39.3	25.2	87	8	13.4	5	16.9	212
N	35.8	21.2	94	9	11.3	0	16.8	191
D	32.3	16.9	94	10	9.9	0	14.1	166
	Year					167		2 6 5 7

Table 2.5. Atbara (17 42' N - 33 58' E - 345 m)

J	30.5	14.7	92	8	9.9	0	14.1	152
F	32.0	15.3	94	8	8.0	0	16.7	170
M	35.9	18.4	89	8	7.0	0	21.0	220
A	39.3	21.9	89	7	7.1	0	23.5	228
M	42.1	25.8	83	6	9.1	3	24.1	233
J	43.0	28.0	73	6	10.1	2	23.7	219
J	40.4	27.2	72	6	14.1	27	19.4	226
A	39.4	25.8	75	7	16.1	31	17.6	220
S	41.0	27.1	80	4	13.1	5	20.0	198
O	39.3	25.6	82	5	11.6	1	19.1	180
N	35.0	20.5	93	6	12.1	0	15.7	162
D	31.4	16.0	93	6	10.9	0	13.6	146
	Year					69		2354

Table 2.6. Eddamazin (11 45' N - 34 24' E - 470 m)

J	35.5	16.7	86	5	9.8	0	13.5	157
F	37.1	18.1	87	5	9.0	0	16.3	188
M	39.6	21.7	18	5	9.6	1	19.4	203
A	40.2	24.6	77	5	11.1	19	18.7	209
M	38.6	24.9	65	6	16.3	40	14.9	200
J	35.1	22.8	54	7	20.4	119	8.4	175
J	31.7	21.5	42	6	23.2	181	5.0	139
A	30.8	21.1	45	5	25.3	203	3.1	133
S	32.5	20.9	57	4	24.9	129	3.6	148
O	34.9	20.5	67	4	20.5	41	5.3	154
N	36.6	18.6	83	4	13.0	3	10.1	163
D	35.9	16.3	91	5	10.0	0	12.0	154
	Year					736		2023

Table 2.7. Ennahud (12 42' N - 28 26' E - 565 m)

J	31.8	13.5	90	7	6.4	0	13.0	151
F	33.1	14.8	89	7	6.0	0	14.6	178
M	36.7	18.5	78	6	6.8	1	16.6	200
A	38.8	21.0	84	6	8.7	2	16.3	206
M	39.1	23.1	77	5	12.8	15	13.6	200
J	37.1	23.6	66	5	18.0	45	9.8	188
J	33.2	22.8	60	5	21.9	112	3.6	166
A	31.8	22.1	57	4	23.1	137	4.3	151
S	34.1	21.9	69	4	20.0	70	5.8	169
O	36.3	21.0	77	5	13.8	20	10.1	178
N	34.6	17.7	92	6	8.9	0	13.3	169
D	32.0	14.3	93	6	7.5	0	12.3	151
	Year					402		2107

Table 2.8. Ghazala Gawazat (11 28' N - 26 27' E - 480 m)

J	32.4	14.1	91	9	8.1	0	15.7	185
F	33.9	15.7	91	9	7.6	0	18.3	206
M	37.6	19.7	81	8	91	1	20.2	224
A	39.5	21.7	80	8	11.7	6	19.8	230
N	39.3	24.1	78	6	14.3	17	17.2	215
J	36.4	23.8	70	6	20.7	71	11.0	200
J	32.5	22.5	58	5	24.3	108	5.7	160
A	31.3	21.9	50	5	25.7	151	3.7	145
S	33.4	21.6	70	4	24.1	90	4.8	163
O	36.2	20.4	85	6	18.0	29	9.9	172
N	35.4	17.1	92	7	13.1	0	14.8	188
D	33.3	14.8	94	8	9.6	0	15.2	178
	Year					473		2266

Table 2.9. Karima (18 33' N - 31 51' E -250 m)

J	28.8	12.6	91	8	7.6	0	15.4	154
F	30.6	13.6	93	9	7.1	0	18.5	182
M	34.6	17.1	88	9	5.8	0	22.5	227
A	38.4	21.1	88	9	6.3	0	25.4	254
M	41.7	24.9	85	9	85	0	25.4	275
J	43.1	26.8	80	8	9.1	0	25.6	266
J	41.4	26.9	83	7	12.1	13	21.6	257
A	40.7	27.3	79	7	14.8	23	19.6	248
S	41.4	26.7	81	7	11.8	4	24.1	236
O	39.0	24.0	89	8	10.4	1	22.5	233
N	33.7	19.0	94	8	10.7	0	18.1	182
D	29.5	14.0	95	8	9.1	0	15.0	151
	Year					41		2665

Table 10. Kassala (15 28' N - 36 24' E - 500 m)

J	34.3	16.	90	4	13.4	0	9.1	139
F	35.4	16.4	90	4	12.5	0	10.4	163
M	38.6	19.2	85	4	11.0	1	13.4	191
A	40.7	22.1	86	4	11.6	4	15.0	203
M	41.7	24.8	82	4	13.5	12	15.2	206
J	39.9	25.2	77	5	16.9	27	13.1	212
J	35.6	23.4	65	6	21.0	97	8.7	191
O	38.9	23.2	87	2	15.9	9	10.6	178
N	37.5	20.6	88	2	14.2	3	10.5	151
D	35.0	17.0	88	2	13.8	0	9.1	130
	Year					314		2137

Table 2.11. Kadugli (11 00' N - 29 43' E - 500 m)

J	35.1	17.1	1.8	6	10.4	0	13.9	178
F	36.6	18.7	2.0	7	10.2	0	15.6	212
M	39.3	21.2	2.7	6	12.5	2	16.8	224
A	39.9	22.6	3.1	5	13.9	14	15.6	227
M	38.1	23.3	4.3	6	19.3	88	10.5	224
J	34.9	22.3	5.0	6	22.3	104	7.0	197
J	31.9	21.6	5.8	5	24.0	139	4.4	166
A	31.0	21.2	5.9	6	25.1	172	3.2	163
S	32.5	20.6	5.5	6	25.1	139	3.5	172
O	34.8	19.9	4.2	6	21.6	78	5.6	185
N	36.7	18.2	2.2	6	14.4	2	11.0	185
D	35.6	17.2	1.4	6	11.4	0	12.8	172
	Year					731		2305

Table 2.12. Abu Hamad (19 32' N - 33 20' E - 315 m)

J	28.8	13.1	1.4	7	8.6	0	14.2	145
F	30.4	13.8	1.2	8	6.6	0	16.6	185
M	34.4	17.2	1.5	8	6.5	0	20.1	218
A	39.1	20.9	1.0	8	6.5	0	23.1	251
M	41.7	24.8	1.4	8	9.3	1	25.4	272
J	43.4	27.3	1.6	7	8.8	0	26.4	269
J	41.7	27.1	2.8	7	11.5	6	22.7	263
A	41.4	26.6	3.0	7	13.6	7	21.8	257
S	42.1	27.3	2.5	7	11.1	1	24.2	245
O	39.2	23.7	0.9	7	10.4	0	21.0	215
N	33.8	19.6	1.1	7	11.8	0	15.9	169
D	29.7	14.8	1.4	7	10.3	0	13.3	142
	Year					15		2631

Table 2.13. Kosti (13 10' N - 32 40' E - 380 m)

J	32.9	16.7	90	6	10.8	0	13.3	151
F	34.5	17.4	90	6	9.4	0	15.1	185
M	37.3	20.2	84	6	9.1	1	17.7	203
A	40.5	22.5	83	5	9.4	2	18.8	209
M	40.5	24.9	66	5	14.3	16	16.5	209
J	38.1	24.9	66	6	18.7	39	13.5	197
J	34.6	23.3	56	6	22.2	111	8.2	178
A	32.4	22.5	56	5	25.2	142	5.1	160
S	34.5	22.5	68	5	23.7	63	6.2	166
O	37.2	22.9	79	4	18.4	21	10.2	175
N	36.2	21.0	88	6	13.4	1	13.3	169
D	33.3	17.6	92	6	11.8	0	12.6	148
	Year					396		2151

Table 2.14. Gedaref (14 02' N - 35 24' E - 600 m)

J	34.9	17.1	87	7	12.5	0	13.6	160
F	36.1	18.2	88	7	12.8	0	15.6	182
M	38.7	21.2	81	7	12.7	1	19.0	203
A	40.2	23.6	80	7	13.0	4	19.5	221
M	40.0	24.6	79	7	15.6	27	16.0	221
J	37.1	23.0	73	8	19.0	86	11.8	203
J	32.8	21.5	58	7	21.3	154	7.3	175
A	31.1	20.9	61	7	23.6	188	4.7	160
S	38.7	21.2	70	7	23.0	92	5.6	175
O	39.8	21.7	78	5	18.7	24	9.2	175
N	40.2	21.0	87	6	14.6	3	13.8	169
D	40.1	18.2	91	7	13.5	0	13.6	160
	Year					579		2204

Table 2.15. El Fasher (13 38' N - 25 20' E - 730 m)

J	30.6	9.5	89	5	7.5	0	11.9	136
F	32.1	10.8	89	6	6.4	0	13.9	157
M	35.3	15.2	81	6	7.7	1	15.4	185
A	37.5	18.0	80	6	7.9	1	17.9	203
M	38.5	21.1	79	6	10.0	9	17.1	212
J	38.1	22.8	72	6	13.1	16	15.3	206
J	34.8	22.4	61	5	18.0	86	9.6	178
A	32.2	21.3	60	4	21.2	132	6.0	157
S	34.9	20.5	72	4	16.6	35	9.1	1 7 8
O	36.0	18.4	83	5	11.9	6	13.5	178
N	33.1	13.4	92	4	9.1	0	12.9	163
D	30.7	9.9	91	4	8.3	0	11.4	163
	Year					286		2116

Table 2.16. El Obeid (13 10' N - 30 14' E - 570. m)

J	30.6	13.5	91	8	6.6	0	15.6	172
F	31.1	14.6	91	9	5.7	0	17.9	200
M	35.7	18.3	91	8	5.8	0	20.7	215
A	38.3	21.1	83	6	7.5	2	21.1	218
M	39.0	24.0	76	8	11.6	14	18.9	221
J	37.3	24.3	65	9	16.1	27	15.2	212
J	33.4	22.9	56	9	20.7	113	9.7	178
A	31.4	21.9	55	7	23.1	143	5.8	163
S	33.8	21.6	69	6	19.9	69	7.3	182
O	37.2	21.3	80	7	21.7	19	13.2	191
33.9	17.5	90	8	8.6	0	16.8	182	N
D	30.9	14.2	94	8	7.2	0	15.0	163
	Year					386		2297

Table 2.17. Geneina (13 29' N - 22 27 E - 805 m)

J	32.2	11.7	86	8	4.6	0	16.5	163
F	33.5	13.3	90	9	4.3	0	19.5	2197
M	36.3	17.1	79	8	5.2	1	21.2	209
A	37.8	19.7	79	7	6.8	3	21.1	215
M	37.8	21.2	75	6	10.2	24	18.1	206
J	36.2	21.6	67	6	14.0	43	13.5	200
J	32.0	20.8	55	5	19.9	168	7.0	160
A	29.6	20.0	54	5	23.0	236	3.5	136
S	32.5	18.6	65	4	19.1	74	5.8	169
O	34.9	16.8	77	6	10.7	10	12.2	178
N	33.7	14.2	89	8	6.9	0	15.2	172
D	32.2	11.6	90	7	5.6	0	14.9	157
Year					559		2162	

Table 2.18. Juba (4 52' N -31 36' E - 460 m)

J	36.7	19.7	78	2	13.5	4	11.0	163
F	38.2	21.1	69	2	13.9	8	11.8	169
M	36.8	22.9	58	4	17.5	51	9.9	166
A	34.9	23.0	54	2	21.8	95	7.0	154
M	33.1	22.2	63	4	24.4	156	4.7	157
J	31.9	21.4	60	4	24.3	112	3.8	139
J	30.4	20.7	48	2	24.4	136	3.0	127
A	30.5	20.5	56	2	24.7	150	2.9	139
S	32.0	20.6	64	2	23.8	114	3.7	154
O	32.2	20.7	62	2	22.9	115	4.4	151
N	34.7	20.3	66	2	19.9	38	5.9	157
D	35.5	19.5	79	2	16.6	9	8.7	160
	Year					988		1836

Table 2.19. Malakal (09 33' N - 31 39' E - 390 m)

J	35.4	13.4	83	8	9.5	0	18.5	188
F	36.8	19.8	82	9	9.1	0	20.8	203
M	38.6	22.4	23	6	10.7	7	19.4	200
A	38.3	23.8	70	6	15.1	21	14.9	194
M	35.7	23.4	60	6	21.1	102	9.5	166
J	32.7	22.2	45	6	23.2	109	6.2	139
J	30.7	21.6	39	5	24.8	149	3.8	118
A	30.5	21.6	45	4	25.8	167	2.9	130
S	31.7	21.8	50	4	25.7	144	3.2	139
O	33.3	21.8	60	4	24.0	82	4.5	148
N	35.0	19.7	79	5	15.4	6	10.2	166
D	34.9	18.1	89	8	10.7	0	15.5	178
	Year					787		1969

Table 2.20. Port Sudan (19 35' N - 37 13' E - 05 m)

J	27.3	19.9	61	10	22.9	6	8.9	115
F	26.3	18.9	73	10	22.6	1	9.0	143
M	28.7	19.5	78	9	23.2	0	8.9	166
A	31.3	21.0	83	9	24.7	1	10.0	197
M	35.1	23.3	83	8	26.4	2	12.6	212
J	38.7	25.4	77	7	26.1	0	15.2	224
J	40.6	27.9	73	8	28.4	10	17.3	227
A	41.1	29.2	77	8	29.3	3	17.0	227
S	36.3	26.7	82	7	29.3	0	12.4	206
O	33.8	24.9	85	7	31.0	6	8.3	172
N	31.1	23.8	74	9	28.6	57	8.2	136
D	28.5	21.4	65	9	24.8	25	8.7	112
	Year					111		2136

Table 2.21. Wadi Halfa (21 55' N - 31 20' E - 125 m)

J	24.8	8.2	93	9	6.9	0	12.3	139
F	27.1	9.5	91	9	5.9	0	15.4	142
M	31.4	13.3	86	10	5.8	0	20.2	216
A	36.2	17.7	86	10	6.5	0	24.9	257
M	40.4	22.2	86	10	8.0	1	28.3	284
J	41.7	23.6	90	9	8.8	0	27.2	284
J	41.6	24.3	89	9	10.3	1	26.7	284
A	41.7	25.7	86	8	12.0	0	26.9	260
S	39.8	23.2	88	9	10.7	0	28.1	260
O	37.1	20.3	91	9	10.0	1	23.9	248
N	31.0	15.0	94	8	9.1	0	16.9	160
D	26.1	10.2	91	7	8.7	0	12.2	118
	Year					3		2652

Table 2.22. Wau (07 42' N - 28 01' E - 435 m)

J	35.8	17.8	82	5	9.1	1	11.3	163
F	36.9	19.2	79	4	8.4	5	12.2	182
M	37.9	22.2	68	5	12.7	21	11.6	182
A	37.0	23.5	64	5	17.9	75	9.2	182
M	34.9	23.1	63	5	22.5	141	6.2	163
J	32.5	22.1	56	4	24.0	172	4.3	145
J	30.9	21.4	45	4	24.4	205	3.2	124
A	30.8	21.1	49	4	24.5	229	2.9	127
S	32.1	21.2	56	4	24.2	171	3.5	142
O	33.6	21.1	61	4	22.3	140	4.2	145
N	35.1	19.9	75	4	15.9	14	7.4	160
D	35.3	17.9	86	4	10.9	0	10.0	160
	Year					1174		1875