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WATER DEVELOPMENT AND MANAGEMENT

Proceedings of the United Nations Water Conference
Mar del Plata, Argentina, March 1977

(in four parts)

Part 4

425

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Published for the
UNITED NATIONS
by
PERGAMON PRESS
OXFORD · NEW YORK · TORONTO · SYDNEY · PARIS · FRANKFURT

E/CONF. 70/ABSTRACT 29 **CROP WATER USE IN IRRIGATED AND RAINFED AGRICULTURE IN THE SUDAN**

H. S. Adam and H. G. Farbrother
By the Government of Sudan

The seasonal patterns of evapotranspiration (ET) for most of the irrigated crops of the Sudan, when grown to good standards of husbandry, have been established at the Gezira Research Station at Wad Medani. (Rates of ET are taken directly from the slopes of soil moisture depletion curves within successive irrigation cycles, and estimates of actual crop-water use (CWU) are calculated over the relevant period.)

Optimum crop-water requirement (CWR) can be identified from the measured ET and the actual CWU, when the evidence from the soil moisture depletion curves confirms that available moisture in the rooting zone has not, in fact, been limiting under the best standards of growth and yield.

The methods of prediction of CWR for irrigated crops in the central Sudan are fully discussed, including the routine application of the "Penman Eo x crop-factor method" to meet the needs of both the irrigation engineers in forward planning and the field managements of the existing large-scale irrigation projects in the area.

Rain-grown crops are extensively cultivated over the more southerly areas of the central clay plains, but either the amount or the distribution of rain is everywhere the main factor limiting productivity. Actual CWU can approach CWR under the best combination of circumstances, but the relationship between rainfall data and CWU is much complicated by very variable losses from surface run-off.

The progress that has been made at the Gezira Research Station in the prediction of CWU for rain-grown sorghum, when only daily rainfall data are available, is described by way of example. The ratio of calculated CWU to optimum CWR subsequently becomes the basis for forecasts of likely yields.

The special form of the relationship between:

$$\frac{CWU}{CWR} \text{ and } \frac{\text{yield (actual)}}{\text{yield (potential}} \text{ where } Y_{pot} = 6000 \text{ kg/ha}$$

is the basic approach being followed in these applied research studies at the Gezira Research Station.

THE PROJECTS FOR THE INCREASE OF THE NILE YIELD WITH SPECIAL REFERENCE TO JONGLEI PROJECT

KAMAL ALI MOHAMED *

ABSTRACT

Considerable volumes of water estimated at 42 milliard cubic metres annually are lost in the swampy regions of the Upper Nile system within the Sudan encompassing the Basins of Behr El Jebel, Behr El Zeraf, Behr El Ghazal, Sobat and Machar Marshes. This paper gives a brief outline of the hydrology of each of these Basins and illustrates the anticipated conservation works comprising dams, diversion works and embankments that have to be constructed in order to reclaim part of the lost waters, thereby reducing the losses and providing extra yield of the Nile Waters to be utilized jointly by the Sudan and Egypt for future water resources development.

Although the Paper gives a brief account of both the Behr El Ghazal and the Sobat Machar Basins, it elaborates on the envisaged Jonglei Canal Project which is the major project intended for the mainimization of losses in the Behr El Jebel and El Zeraf Basin. In this respect the Paper outlines a general description of the Jonglei Project Area, the developmental prospects, the hydrology and engineering works incorporated in the Jonglei Project as well as the anticipated affects and water benefit derived subsequent to the completion of the Project. The Paper ends by highlighting the economic aspects of this Project with respect to Egypt, to the Sudan as a whole and to the Southern in Particular.

* NILE WATERS DEPARTMENT, SUDAN.

BACKGROUND

Considerable volumes of water are lost in the swampy regions of the Upper Nile system in the Sudan amounting about 42 milliard cubic metres annually.

Studies for the minimization of these losses and the subsequent utilization of the water yields derived from the reclaimed swamps have been initiated since the beginning of this century.

The Sudan's share of the Nile Waters as stipulated in the 1959 Nile Water Agreement between Egypt and the Sudan has been fixed as 18.5 milliard cubic metres (equivalent to 20,35 milliard M3 at Sennar) and that of Egypt as 55.5 milliard cubic metres).As for the utilization of the Sudan's share, the present total consumption by irrigation development projects including those under construction is of the order of 18.259 milliard cubic metres serving a total irrigated area of 1.84 million hectares, leaving only about 2.091 milliard cubic metres for further utilization. On the other hand the irrigable area adjoining the River Nile and its tributaries, and which is envisaged for development in the anticipated medium and long term economic plans, is estimated as 1.4 million hectares, which requires about 14 milliard cubic metres. As mentioned above, the irrigation development is limited by the present Sudan's share of Nile Waters. Consequently the Projects for the increase of the Nile Yield through the reclamation of the Upper Nile swamps is of vital necessity for the prospective water resources development in the Sudan.

In view of the fact that considerable volumes of the NIle Basin Waters are lost in the swamps of Behr El Jebel, Behr El Zeraf, Behr El Ghazal and Sobat River and as it is essential that efforts should be exerted in order to present these losses and to increase the yield of the River for use in agricultural expansion in the two Republic (Sudan and Egypt), the two Republics agreed to the following :-

1. Te Republic of the Sudan in agreement with Egypt shall construct projects for the increase of River, Yield by preventing losses of waters of the Nile

TABLE (1)

NORMAL DISCHARGES OF BAHR EL GHAZAL BASIN

TOTALS IN MILLIONS OF CUBIC METRES

Month	River Lol	River Kyom	River Pongo	River Geti	River Jur at Wau Siwl.+ Bussary	River Tong	River Makak	River Gell	River Gul-mar	River Wok-oko	River Sass-ary	River Khor-goya	River Naam	River Yel	Total for the basin	Total at mouth of basin	Amount lost in swa
Jan.	21.0	0	0	0	0	0	0	0	0	0	0	0	0	0	21.0		-
Feb.	10.0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.0		-
March	3.4	0	0	0	0	0	0	0	0	0	0	0	0	0	3.4		-
April	2.2	0	0	0	0	0	0	0	0	0	0	0	0	15.7	17.9		-
May	16.2	0	3.0	0	114	42.0	0	6.8	0	0	0	0	22.7	78.5	283.2	22.9	260.3
June	129	0	25.8	0	241	89.0	0	43.9	2.5	17.7	2.4	0	77.1	135	763.4	18.2	745.2
July	301	24.9	404	6.4	422	139	0	55.3	2.4	24.0	1.5	0	55.1	215	1287	22.1	1264.9
Aug.	829	12.6	74.4	19.0	776	198	0.2	66.6	7.3	40.6	4.1	3.2	122	479	2631	28.1	2602.9
Sept.	1280	12.5	134	31.9	1280	292	0.4	90.5	6.0	30.6	2.1	1.3	107	459	3727.3	19.0	3708.3
Oct.	1180	9.6	151	26.1	1340	283	0.1	71.5	4.0	16.2	1.2	0.5	69.8	316	3469	20.7	3448.3
Nov.	365	2.3	103	7.5	646	122	0	42.8	0.8	4.6	0.3	0	20.6	127	1441.9	16.3	1425.6
Dec.	71.7	0	15.8	0.7	169	22.9	0	1.0	0	0	0	0	2.0	32.2	315.3	13.4	301.9
Total	4207.5	61.9	547.4	91.6	4988	1187.9	0.7	378.4	23.0	133.7	11.6	5.0	476.3	1857.4	13970	160.7	13,800

Basin, the swamps of Behr El Jebel, Behr El Zeraf, Behr El Ghazal and its tributaries, the Sobat River and its tributaries and the White Nile Basin. The net yield of these projects shall be divided equally between the two Republics and each of them shall also contribute equally to the costs.

This Agreement also provided for the formation of a Permanent Joint Technical Commission for Nile Waters. Oneof the functions of this Commission shall be the drawing of the basic outlines of projects for the increase of the Nile Yield, and for the supervison of the studies necessary for the finalizing of projects, before presentation of the same to the Governments of the two Republics for approval. The Commission is also designated with the supervision of the execution of the projects approved by the two Governments.

I. THE BEHR EL GHAZAL BASIN SYSTEM

The total annual average discharge of Behr El Ghazal basin composed of about 14 major tributaries amounts to 13.970 milliard cubic metres, but almost all of this supply dies away in the swamps of Behr El Ghazal Basin, save for 0.16 of a milliard which finds its way to the White Nile through the main course of Behr El Ghazal(see table 1). The Behr El Ghazal swamps cover an area of 40,000 square kilometres which are subjected to an annual rainfall ranging from 900 mm. to 1130 mm and an annual rate of evaporation amounting to about 1200 to 1380 mm. (see table 2).

A programme for conducting hydrometeorological and hydrological studies in this Basin is currently under implementation with the object of finalizing the formulation of the Projects necessary for the minimization of losses in these swamps and the diversion of the water yield derived accordingly to the main course of Behr El Jebel and the White Nile. The anticipated projects include :-

(a) The construction of dams to store part of the flow of some of the major streams in their upper reaches during

TABLE (2)

WAU (ON BAHR EL GHAZAL)

CLIMATOLOGICAL NORMALS

ELEMENT	RELATIVE HUMIDITY %	RAINFALL (MM)	EVAPORATION PICHE (MM)
Month	0600	Total	
Jan.	46	1	12.0
Feb.	42	4	13.0
March	46	24	12.7
April	64	69	9.1
May	73	132	6.4
June	80	166	4.5
July	84	198	3.5
August	86	218	3.1
Sept.	83	181	3.7
Oct.	80	120	4.7
Nov.	70	13	7.9
Dec.	57	1	10.5
Year	68	1127	7.6

the flood abatement and which will be released during the low flow season. The storage sites identified hitherto include :-

i. A proposed dam on River SIWI at about 9 kilometres upstream the river mouth to store about one milliard cubic metres per year.

ii. A proposed dam on River Yei at Aga falls with a storage capacity of 0.33 milliard cubic metres. Another possible site is south of Mundri with a feasible storage capacity of 0.3 milliard cubic metres.

iii. A proposed dam on river Busseri 50 kilometres upstream of its mouth with a storage capacity which ranges from 0.5 milliards. On level 445 metres and 1.0 milliard on level 450 m.

(b) The construction of diversion canal to divert the flow of the south eastern streams of River Yei, Naam, Jel, Jelimar, Makak and Tong to Behr El Jebel south of Shambe. A similar canal or the remodelling of existing river channels is envisaged to divert the flows of the north western streams of Jur, Jeti, Pongo, Jol, Behr El Arab to the course of the White Nile.

The effect of such storage and diversion works on the downstream reaches of the White and the Main Niles shall be studied.

The anticipated net yield of this project is estimated at 7 milliard cubic metres.

II. THE RIVER SOBAT AND MACHAR MARSHES SYSTEM

The average total annual flow of River Sobat at Malakal amounts to 13.7 milliard cubic metres with the daily discharge fluctuating between 8 MM3/day in April to 66 MM3/day in November. The River Baro and Pibor are the two main tributaries of the Sobat in addition to other smaller tributaries such as Gila, Akobo.

The average annual runoff of River Baro at Gambeila is about 13.3 milliard M3 and that of the Pibor is 2.4 milliard M3 and of Jila 1.2 milliard M3. The runoff of the River Baro at its mouth is 9.4 milliard M3 and consequently there is a loss of the order of 4 milliard M3 between Gambeila and the junction of River Baro and Pibor (see table 3).

On the other hand the area of the Machar Marshes is of the order of 20,000 square kilometres and the average annual rainfall over the area ranges from 800 to 900 mm, and the annual rate of evaporation is about 1300 mm (see table 4 and 5). The Machar Marshes receives its waters from the eastern torrents, from Khor Machar, from the spill of the right bank of River Baro and from direct rainfall. The permanent area of the marches is 6,500 square kilometres. The annual discharge flowing into the swamps

of Machar is estimated as 2.75 milliards M3 from the River Baro spill and 1.75 milliard M3 from the eastern torrents, but out of this 4.5 milliard M3, the portion which flows into the White Nile through Khor Adar and Wool is of the order of 0.5 milliard M3 and the remaining 4 milliard M3 are lost in the Machar Marshes. The two major eastern torrents are Yabus and Daga whose annual flows are 0.4 and 0.45 milliards respectively.

The proposed Projects for the increase of the Nile yield in the Basin of the Sobat and Machar Marshes can be summarized as follows :-

(a) Proposed storage on the Upper Baro with the object of regulating its flows. This Project requires cooperation with Ethiopia as the Reservoir will extent within the Ethiopian territorial boundaries.

TABLE (3).

RIVER BARO.

NORMAL DISCHARGES.

MONTHLY TOTALS IN MILLIONS OF CUBIC METRES.

River Month.	River Baro at Gambeila	River Baro at its mouth	Amount Lost.
Jan.	251	256	-
Feb.	164	155	9
Mar.	148	129	19
Apr.	196	176	20
May.	462	429	33
Jun.	1200	926	274
Jul.	1980	1340	640
Aug.	2660	1480	1180
Sept.	3010	1430	1580
Oct.	2040	1410	630
Nov.	746	1080	-
Dec.	441	571	-
Year	13,298	9382	4385

(b) The banking of the Baro from the mouth of the Jikaw up to the offtake of Khor Machar, a distance of about 23 kilometres.

(c) The construction of a diversion canal from the Baro through Khor Machar and Adar to the White Nile.
The estimated net benefit from this Project is of the order of 4 milliard cubic metres (see map (2) and (3).

TABLE (4)

AKOBO (LAT. 07° 47'N LONG. 33° 01'E ALT. 400 M)

ON SOBAT BASIN

CLIMATOLOGICAL NORMALS

Element	Relative Humidity % (18 Yrs.)	Rainfall (mm)	Evaporation PICHE' (mm) (18 Yrs.)
Month	0600	Total	
Jan.	46	1	10.4
Feb.	39	4	12.2
March	47	21	11.3
April	61	56	8.8
May	74	127	5.8
June	82	119	4.0
July	87	179	2.8
August	88	229	2.4
Sept.	86	150	2.9
Oct.	81	79	3.7
Nov.	75	16	4.9
Dec.	59	3	7.3
Year	69	984	6.4

III. THE BEHR EL JEBEL AND ZERAF BASIN

1. The Behr El Jebel losses half its discharge in the swamps outflanking its banks between north of Mongalla up to Malakal. The Jonglei Canal project has been proposed to divert part of the Behr El Jebel flows with the object of minimizing the waters lost in these swampy regions and thereby increasing the yield of the river.

TABLE (5)

KIRMUK (LAT. 10° 33'N LONG. 34° 17'E ALT. 690 M)

MASHAR BASIN

CLIMATOLOGICAL NORMALS

Element	Relative Humidity % (18 Yrs.)	Rainfall (mm) (26 Yrs.)	Evaporation PICHE' (mm) (18 Yrs.)
Month	0600	Total	
Jan.	31	TR.	14.8
Feb.	31	2	15.5
March	31	9	15.7
April	46	31	11.9
May	63	109	7.3
June	74	164	4.4
July	81	165	3.1
August	83	214	2.5
Sept.	78	166	2.9
Oct.	70	104	3.5
Nov.	51	18	7.7
Dec.	38	1	12.4
Year	56	983	8.5

THE JONGLEI CANAL PROJECT

2. GENERAL DESCRIPTION OF THE PROJECT AREA

2.1. L O C A T I O N

The Jonglei Project Area lies approximately between latitudes 6° 30' and 9° 30' north and longitudes 31 45' and 30° 10' east.

2.2. THE INHABITANTS

Between the southern frontiers of the Sudan up to Jonglei latitude the Project does not effect the hydrological regime of the river. In this reach there are the Madi Tribes living on the east bank of Behr El Jebel between Juba and Nimule. They are mainly cultivators and some of them are engaged in fishing, but they live away from the river because of the tse-tse fly. Between Juba and Terkaka live the Bari tribes along both sides of the river. They are mainly engaged on agriculture and raising cattle during the dry season in the flood plain. The Mandari tribes settle on the highland between Terkaka and Tome and utilize the flood plain pastures for summar grazing.

2.3. LIVESTOCK RESOURCES

During the rainy season when mosquitos and biting flies are prevalent near the fringes of the swamps, the Dinka and Nuer move their cattle to the higher ground to graze the pastures of the high land. After the rains they drive their cattle to graze the grasses of the intermediate land. When this grazing is exhausted and water supplies run short during the dry season, the cattle is moved to the toiches of the main rivers and watercourses where they find plenty of toich grasses, water supplies and fishing.

2.4. AGRICULTURE

The inhabitants of the Project area are mainly concerned with animal husbandry. The inundation of the lands due to rain flooding for most of the year constitutes the major factor that has limited agricultural expansion in the Project area.

It is for this reason that we find agricultural production which mainly comprises food crops is restricted around the settlement of the local inhabitants. For example, the Dinka and Nuer grow maize and some tobacco while the Shuluks grow Dura, water melons, beans and tobacco.

2.5. IRRIGATION AND DRAINAGE

It would be an exaggeration to say that all the people in the Project area rely exclusively on animal husbandry as a source of livelihood, for rain-grown crops are of great importance in their subsistance economy. Yet the production of grain crops is on the whole a precarious undertaking.

In this region the mean annual rainfall is usually adequate, but its monthly distribution is extremely variable. While irrigation is essential for assured crop production in the semi-arid region of the country, it is also very desirable in the Jonglei area. Though the rainfall exceeds 650 mm. in the flood region, and cover the greater part of the area is round about 800 mm, its variations and consequent unreliability should be remembered. Practice in the region suggests that at the height of the growing season at least 100 mm, of rain per month are necessary if the crops are not to suffer excessively from lack of moisture and at least 130 mm, of rain per month are desirable at the height of the growing season for optimal yields. Examination of climatic data will show that in 25 out of 100 years, rainfall at Bor will not reach even the lower figure and will barely do so in Malakal. This clearly shows the need for irrigation.

In short it can be stated that high possibilities of irrigated agricultural development are available in the Project area and its vicinity provided proper flood control and drainage measures are implemented. The land west of the Jonglei canal is estimated to be about 3.7 million acres which is suitable for irrigated crops and pastures. As a first stage it is envisaged to irrigate about 200,000 acres by a canal having a capacity of 5 MM3/day and taking off from River Atem.

There are also other possibilities of irrigation in the Pengko area, the Mongalla Gummeiza flood plain east of Behr El Jebel and the Aliab Valley west of the River.

2.6. FISHERIES RESOURCES

The area of permanent water lakes, the main river channel and the adjoining watercourses provide the reservoir of fish stocks in the Project Area. The seasonal inundation of the flood plains is of vital importance for the distribution and yields of fish.

The Zone comprising Shambe, Kenisa and Upper Zeraf appears to be the most promising for fisheries resources, but it is almost entirely unexploited by the local inhabitants, as fishable waters are widely dispersed and problems of communications and marketing are a limiting factors South of Kenisa there are considerable potentialities and the Dinka have fishing camps widely dispersed over the area as they are largely dependent on fish for their livelihood.

THE JONGLEI PROJECT

3.0. HISTORICAL REVIEW

The investigations concerning the river training of Behr El Jebel and Behr El Zeraf, with the view to reducing the water losses experienced and hence increasing the Nile Yield, have been considered since 1898. The concept of the regulation of Behr El Jebel discharges is closely tied with the concept of storage in the Equatorial Lakes.

Several alternatives have been studied regarding the conveyance of Behr El Jebel flows across the Sudd Region with the view to achieving the maximum possible yield. The preliminary broad lines of the Jonglei Project were laid down in 1936 and submitted to the Sudan Government later in 1938 for study and comment. Originally the Equatorial Nile Project consists of a dam at the outlet of Lake Victoria at Awen falls (already built), a balancing regulator downstream of Lake Kyoga, and a dam at the outlet of Lake Albert, probably at Muti in deference to Uganda's wishes though an engineering and hydrological point of view it would be better at Nimule. It is intended that normally Lake Albert outflow would be regulated in the final stage to pass discharges at Mongalla of 90 million per day in the timely season (21st. Dec. to 30th. June) at Mongalla and 57 million M3 per day during untimely remainder of the year. In order to achieve this, a balancing reservoir dam would be required for the uncontrolled terrents joining the river between Lake Albert dam and Mongalla. This would probably be suited at Bedden.

In the Sudd plains, the first engineering works would be the banking of Behr El Jebel to prevent the losses which at present occur by spill when the discharge exceeds 65 mld at Mongalla. This banking would begin at Tombe and end at a barrage to be built on Behr El Jebel downstream of the River Atem head. The River Atem would be remodelled and banked from its head to Jonglei to carry 80 mld. At Jonglei there would be another canal regulator with a lock and a regulator without a lock across the lower Atem downstream the canal regulator and lock.

The Jonglei canal, twin channels each with a capacity of 27.5 mld. and connected by cross cuts, would leave the Atem here and rejoin the main river at the mouth of River Sobat. Various alignments have been considered and the most favoured of these is the direct line from Jonglei to Mogogh and hence to Sobat mouth. At the tails of the canals there would be regulator falls and one lock. A large cross-drainage work would be needed to Syphon Khor Atar under the canal north of Mogogh.

Distribution of water between the Jonglei canal and Behr El Jebel downstream of Jonglei would be according to the following discharges :-

	Timely season	Untimely season
Jonglei Canal	55 mld	17 mld
Behr El Jebel	30 mld	35 mld

With the works and operations described, the benefit or extra water available for irrigation farther north would be 7 milliards in a normal year.

After implementation of the scheme there would be periods when on the proposed regulation, excess flood water would need to be escaped from the Equatorial Lakes. The proposal is to pass this water in the Sudd area at the rate of 120 mld downstream the canal offtake.

The most important effect of the Equatorial Nile Project would be reduction in the area of riverain flood plain exposed in the dry season after inundation during the rains. The vital use made of this flood-plain by the cattle owing inhabitants of the area for the provision of dry grazing when inland pastures are dry and implatable has already mentioned.

South of the Atem barrage, the banking of Behr El Jebel and the reversal of the season, which change in the hydrological regime would bring about, would mean the estimated loss of 774 sq. km. of flood-plain, of which 400 sq.km., would probably still fulfil its present function of producing dry season grazing because of seepage and natural irrigation by run-off from high land streams.

Between the barrage and the Buffalo cape-Fangak line, below which point levels would be governed by backwater effects of River Sobat and Jonglei Canal tail discharges, the controlled water in Behr El Jebel would reduce the present swamp area of approximately 6500 sq.km. much of which is permanently flooded and produces no grazing, to about 360 sq.km. of seasonally inundated flood-plain.

North of Buffalo cape-Fangak, and along the White Nile to Jebelein, the present in-undated and exposed flood-plain areas would be reduced from 1,150 sq.km. to 1,120 sq.km. owing to the higher minimum flow in the White Nile during the dry season.

Other determental effects would be considerable reduction in fisheries resources.

In their task of estimating the cost of remedial measures to provide alternative livelihood for the people whose riverain flood-plains would be diminished or lost, the Jonglei Investigation Team, which was formed by the Government in 1946 recommended in 1954 a revised operation of the project which would obviate many of the difficulties described and reduce the adverse effects.

It was proposed by the team that the Equatorial Lakes should be regulated in such a way that the regime of the river entering Sudan would follow the present fluctuation being high in the rainy season and low in the dry season, so that inundation and uncovering of the southern flood-plains would take place as at present and in phase with grazing requirements. Flood escape discharges would be greater but would still follow the required

fluctuations. North of the barrage, discharges down the Behr El Jebel would be less than at present, but would consist of three instead of two channels. One would be run above ground level, so that gravity irrigation of the Eastern plain would be possible. The other two canals would carry a normal steady flow to the Sobat mouth, but would be one kilometre apart and have outside banks only. The "washlands" between the canals would carry flodd_ escape discharges. Under this regime, more water would be passed in the untimely season than under the original scheme. According to the proposed revised operation of the Project, the losses in riverain pastures could be reduced to roughly 19% of the total livestock dependent on the flood-plains of the main river, instead of 36%. Moreover under the revised method of operation there would be no losses in the fisheries resources required by the population, though there would be a reduction in the potential. The estimated cost of remedial measures would, according to estimates, amount to about Ls.6,600,000 plus 300 million M3 of water.

The main beneficial effect of the Equatorial Nile Project would be that large amounts of water which at present flood naturally compartively useless areas of swamps would be available for the controlled irrigation of crops. Other beneficial effects would be those upon drainage between the barrage and Buffalo cape latitude; upon communications, and upon hydro-electric power development in Behr El Jebel above Juba by assuring a firmer flow.

After the Sudan gained independence in 1956, the negotations which were conducted since then by the Sudan and Egypt to agree on the allocation of the Nile Waters between the two Republics culminated in the 1959 Nile Water Agreement. This agreement enabled Egypt to construct the Aswan High Dam for over year storage.

In April 1974 the final version of the same project was issued, as explanined in the forthcoming paragraphs which also include summaries of the relevant detailed studies conducted by the P. J. T. C. to clarify several points pertinent to the proposed project.

4. THE HYDROLOGY OF BEHR EL JEBEL AND BEHR EL ZERAF

4.1. BEHR EL JEBEL

The Albert Nile emerges from Lake Albert and flows over a distance of 225 kilometres with a water slope of 2.30 cm/kilo up to Nimule on the southern borders of the Sudan. After Nimule the Behr El Jebel flows in a rocky channel for a distance of 156 kilometres up to Rejaf with a slope of one mt. per kilometre and to Mongalla which is 57 kilometres away from Rejaf with an average slope of 30 cm/kilometre.

From Mongalla northwards Behr El Jebel traverse the swamps of the Sudd region which is thickly infested with papyrus. When Mongalla discharge exceeds 65 MM3/day some of the waters of Behr El Jebel spill into Aliab Valley on the western bank north of Tombe. North of Bor water from Behr El Jebel spills into six heads which form the river Atem which flows through the eastern swamps upto the eastern dry lands and then it flows back into Behr El Jebel through several channels.

4.2. BEHR EL ZERAF

The upper Zeraf which flows northwards is formed by waters from the downstream reaches of River Atem and also from the right bank of Behr El Jebel.

4.3. ESTIMATED DISCHARGES AND LOSSES

4.3.1. D I S C H A R G E S

The mean annual discharges reaching Behr El Jebel from both Lake Albert and the torrents are as follows :- 24.2 from the Lakes + 4.8 from the torrents = 29.0 milliards M3.

4.3.2. L O S S E S

- The mean annual discharge at Mongalla = 29 milliard.
- The corresponding mean annual discharge at Malakal 14.7 milliard M3.

It is evident from the above information that the average loss between Mongalla and Malakal is about 50%.

Comparing the Mongalla discharges with those at Malakal, it is realized that the losses remain within reasonable limits when Mongalla discharge is in the range of 30 MM3/day and the corresponding losses are of the order of 17%.

5. DESCRIPTION OF THE PRESENT PROJECT AND ENGINEERING WORKS

5.1. THE CAPACITIES OF THE PRESENT CHANNELS

5.1.1. The normal discharge of 75 MM3/day can flow from Mongalla to Jonglei provided that some unobjectionable measures to modify the channel are undertaken.

5.1.2. Between Jonglei and Peak's channel the discharge corresponding to 75 MM3/day overtops the adjacent land in certain reaches by about two metres on the average.

5.1.3. As far the reach between Peaks channel and Lake No, it would be necessary to divide the normal discharge of 66 MM3/day (which corresponds to a flow of 75 MM3/day measured at Mongalla) between Behr El Jebel and Behr El Zeraf as follows :

Behr El Jebel	45 MM3/day.
Behr El Zeraf	21 MM3/day.

6. THE OUTLINES OF THE PROPOSED PRESENT PROJECT

6.1. THE FIRST PHASE

The first phase of Jonglei Project based on passing natural river flows, whereas the storage projects in the Equatorial Lakes are considered as the second future phase of the Project.

On studying the various alternative proposals of the Jonglei Canal alignment, it was agreed that the best alignment would be the direct line which takes off from Jonglei and proceeds to the point of latitude 8° 30' longitude 31' 22' from where it continues with a bearing of 14° N.E, until it joins the Sobat near its confulence with the White Nile. The direct line was preferred on the merits of its being shorter, easily navigable, less eathwork is involved, the flow shall not be obstructed by weeds, easier to excavate, and moreover, its course is not interrupted by numerous Khors which involve cross drainage works. Consequently, the first phase of Jonglei Project comprises the following works :-

6.1.1. Excavation of Jonglei Canal with a cross section adequate to convey a discharge of 20 MM3/day.

6.1.2. The construction of the following control works :-

(a) A Regulator at the efftake of the Canal.

(b) A Regulator at the outfall of the Canal.

(c) A Regulator on the lower Atem at Jonglei latitude.

6.1.3. The necessary training and banking works on river Atem from its head up to the proposed lower Atem regulator at Jonglei latitude.

6.2. THE SECOND PHASE.

The second phase shall incoperate the following works:-

6.2.1. The use of the Equatorial Lakes (Victoria, Kyoga and Albert) for long term over year storage to equalies their natural outflows.

6.2.2. The improvement of the carrying capacities of the channels of Behr El Jebel north of Mongalla as well as of Behr El Zeraf to enable them to convey the Mongalla normal flow of 75 MM3/day. This includes also the completion of studies in respect of the improvement of Aliab Valley as it carries a considerable portion of Behr El Jebel discharges.

6.2.3. The excavation of a new canal or alternatively the widening of the first phase canal so that the total discharge diverted by the canals will add up to 43 MM3/day.

7. THE EFFECT OF THE FIRST PHASE OF THE PROJECT ON THE NATURAL RIVER CHANNELS DOWNSTREAM JONGLEI LATITUDE

The next table illustrate the extent of the effect of the diversion of 20 MM3/day through the proposed Jonglei Canal on the river channels downstream Jonglei latitude, taking into account the times of travel of discharges and their transmission lossess between the respective reaches, namely.

Mongalla - Jonglei latitude.
Jonglei latitude-Downstream Peak's channel
Jonglei - Downstream cut 2 on Behr El Zeraf.

8. THE WATER BENEFIT RESULTING FROM THE PROJECT

Table 7 hereunder shows the prospective water benefit that shall be derived after the completion of the construction of the 20 MM3/day canal. The water benefit in each V case is estimated at Aswan on the basis of a mean daily flow of 75 MM3/day passing at Mongalla.

Table 8.2 and 8.3 show the annual water benefit on the basis of the monthly mean discharges at Mongalla and their corresponding values at Malakal during two average years (1912 and 1960) prior to and after the construction of the first phase of the Project.

Computed on the basis of an average year (1923/24) representing 85% of the annual discharge of the present Century.

10. THE ECONOMIC ASPECTS OF THE PROJECT

10.1. WATER BENEFIT.

Tremendous volumes of water, estimated at 42 milliard cubic metres, are lost annually in the swamps of the

Table 5

THE EFFECT OF THE JONGLEI CANAL WITH 20 MM/DAY CAPACITY ON THE WATER LEVELS OF BEHR EL JEBEL AND BEHR EL ZERAF, DOWNSTREAM JONGLEI LATITUDE (NORMAL YEAR)

(TIMES OF TRAVEL TO BE TAKEN INTO ACCOUNT).

Month	Mongalla discharges MM3/day	Correspond discharg. at Jonglei latitude MM3/day	River Atem discharg. before the canal MM3/day	The Canal discharg. MM3/day	Behr El Jebel disch. D/S channel after const. of the canal MM3/day	Corresponding level in Metres	Behr El Zeraf disch. D/S the cuts after the constant of canal MM3/day	Corresponding level in Metres	Rem
JUL.	82	71.7	38.5	20	-	-	-	-	-
Aug.	94	80	45.5	20	-	-	-	-	-
Sept.	96	81.1	47.0	20	32(35)	26.56(26.85)	12(14.2)	26.47(26.68)	High
Oct.	92	78.4	44.0	20	-	-	-	-	-
Nov.	83	72.8	39.5	20	-	-	-	-	-
Dec.	74	66.1	34.5	20	-	-	-	-	-
Jan.	67	60.2	35.0	20	-	-	-	-	-
Feb.	63	56.8	27.5	20	-	-	-	-	-
Mar.	61	55.1	26.5	20	24(31)	25.76(26.46)	7.5 (11.7)	26.00(26.40)	Low
Apr.	65.1	51.0	29.0	20	-	-	-	-	
May.	77.0	68.0	36.0	20	-	-	-	-	
Jun.	76.5	67.9	35.5	20	29.5(33)	26.31(26.65)	10.5 (13)	26.33(26.57)	Avera.

TABLE 7

	After the first phase.	After the second phase(subsequent to storage in the Lakes.)
- Behr El Jebel discharge at Mongalla	75	75
- Upstream Jonglei Latitude	66	71
- D/S the canal head regulator	20	20
- Behr El Jebel D/S Jonglei latitude	46	51
- Discharge at the outfall of the canal	19	19
- Discharge after the tail of Behr El Zeraf and Jebel.	32	45
Total reaching Malakal after execution of the Project.	51	64
Total reaching Malakal before execution of the Project.	38	39.5
- Water benefit in MM3/day	13	24.5
-Water benefit in milliard M3/year at Malakal.	4.7	9
- W. benefit in Mld. M3/yr. at Aswan.	3.8	-

basin of Behr El Jebel, Behr El Zeraf, Behr El Ghazal, the Sobat and the Machar Marshes.

If the plans aiming at the reduction of these losses through the construction of dams and diversion works are implemented, considerable economic benefits shall be realized as a result of the prospective increase of the Nile yield that shall be utilized in agricultural and hydro-electric power development.

The Permanent Joint Technical Commission for Nile Waters has been conducting the technical investigations and studies necessary for the formulation of a number of projects for the increase of the Nile yield by reclaiming those swamps to realize an extra yield of 18 milliard cubic metres annually. The volume of water lost in the Behr El Jebel and Behr El Zeraf swamps is estimated at about 15 milliard cubic metres in addition to another 7 milliard cubic metres of direct rainfall on the swampy regions. The first Phase of Jonglei Project aims at achieving the minimization of these losses and the provision of a net benefit of 3.8 milliard cubic metres (4.7 milliard as at Malakal) which shall be divided equally between the Sudan and Egypt.

To throw light on the economic benefit that shall be gained from Jonglei Project, it is necessary to calculate the economic value of cubic metre of water based on the economic analysis of the Rahad Irrigation Project, as indicated hereunder :-

- The total anticipated benefit of the first phase of the Rahad Project = £.14,810,000
- The total area = 300,000 feddans and the annual consumption is of the order of 1.2 milliard cubic metres of water.
- This analysis indicates that the annual revenue of one cubic metre of water is 12 millimes which is equivalent to 12 million pounds for every milliard utilized for irrigation agriculture. Accordingly, the value of the volume of water lost every year in the swampy regions of the Upper Nile (42 milliards) is equivalent to 504 million pounds.
- Hence, the economic benefit of the anticipated extra yield of 4.7 milliard cubic metres resulting from the first phase of the Jonglei Project, is equivalent to about 56 million pounds, and as such, the benefit to be gained by the Sudan alone amounts to 28 million Pounds per annum. There are vast irrigable lands in the Southern and Northern regions of the Sudan where such extra water yield can be utilized for agriculture development. These areas include the Renk-Gelhak arable lands, the fertile clay plains bordering the Blue Nile and commanded by the Roseiries Reservoir, as well as the prospective Upper Atbara Setit irrigation development schemes. The anticipated water yield can also be utilized for further hydroelectric power production which should be given high priority as a result of the shooting prices of imported fuel for thermal generation.

Beside the use of the anticipated water benefit as investment in the contemplated agricultural expansion, the Jonglei Project yields several other benefits in the form of infranstructural elements as explained hereunder :-

10.2. The banking of River Atem shall protect the adjoining eastern plains which have always been isolated owing to spill from River Atem and overland runoff.

10.3. The diversion of 20 MM3/day through the canal shall reduce the Behr El Jebel and Behr El Zeraf discharges downstream the tail of River Atem by about 5 MM3/day; but this does not alter the seasonal fluctuation of the river. However, the water level in the swamps shall be reduced by 10% during flood time and 20% during the low river season, which shall result in the improvement of the riverain pastures. In addition the canal shall provide a perennual source of water supply, and consequently the pastures in the high and intermediate lands, amounting to millions of feddans, shall be utilized for grazing throughout the year. At present shortage of water in the dry season compels the inhabitants to drive their cattle down to the fringes of the swamps.

10.4. The canal shall protect the plains lying between the canal and Behr El Zeraf including Fangak district from the flood hazards; and in this respect it is to be recalled that Fangak has remained encircled by water since 1964.

10.5. The Jonglei Project shall help in developing the area lying between the proposed Jonglei Canal and Behr El Zeraf. This area which amounts to about 3.7 million feddans is suitable for agricultural and livestock development. An irrigation main Canal, with a capacity of 5 MM3/day, shall be excavated concurrently with the Jonglei canal to irrigate part of these vast plains.

10.6. The canal is designed to provide a new navigable route, which shortens the distance between Malakal and Juba by about 300 kilometres. This route which shall be additional to the existing navigation line along Behr El Jebel and the White Nile, will obviously expedite the rate of development in the Southern Region.

10.7. The compacted bank of the canal shall be used for road traffic for most of the year.

10.8. The canal will provide a new source of fisheries to be utilized by the people settling near the canal route.

10.9. The Jonglei Project will considerably expedite the agricultural, livestock and industrial economic development in this part of the Country, which helps in achieving the promoting of comprehensive, integrated socio-economic development on the national scale.

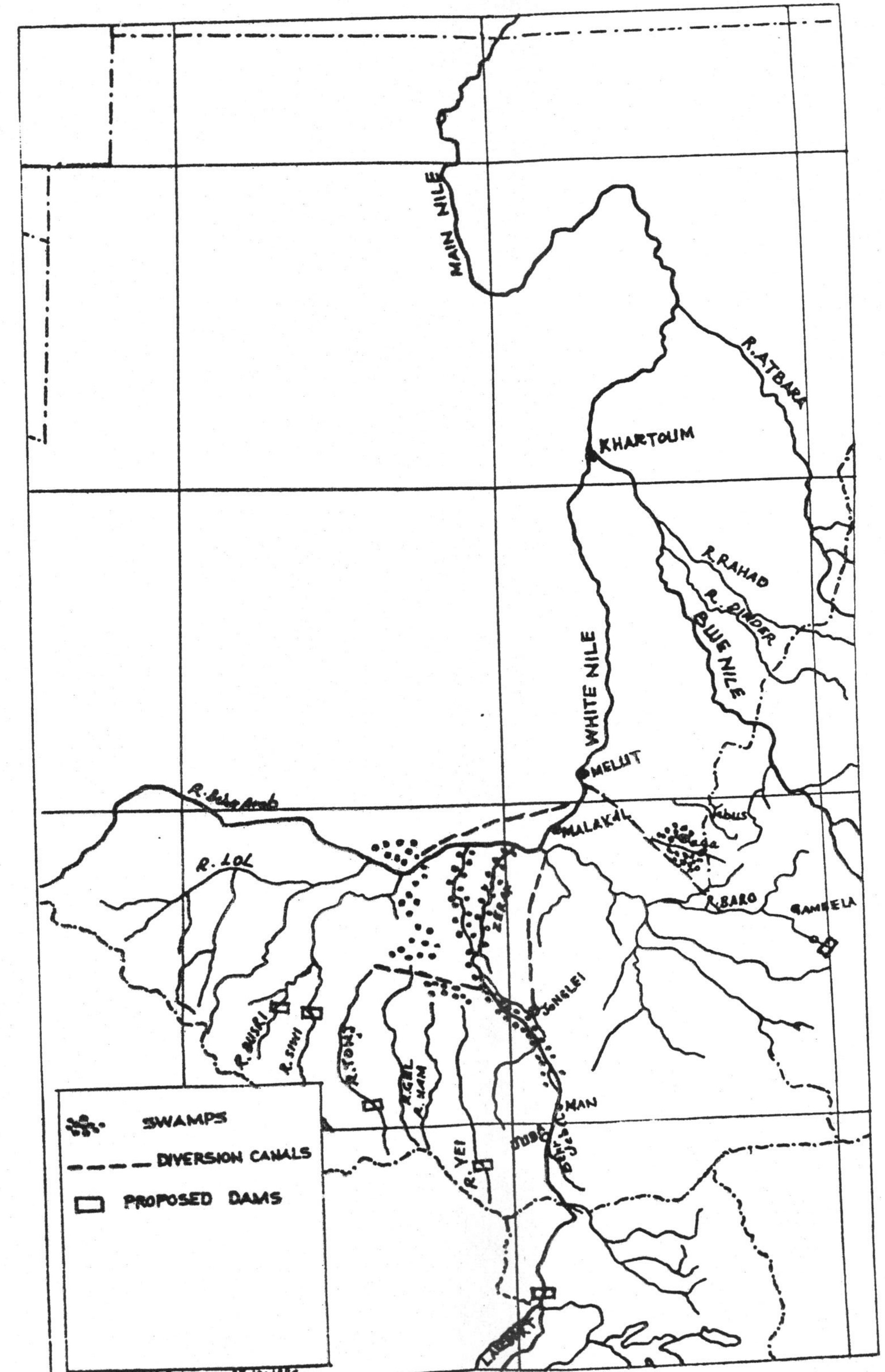
TABLE (8)

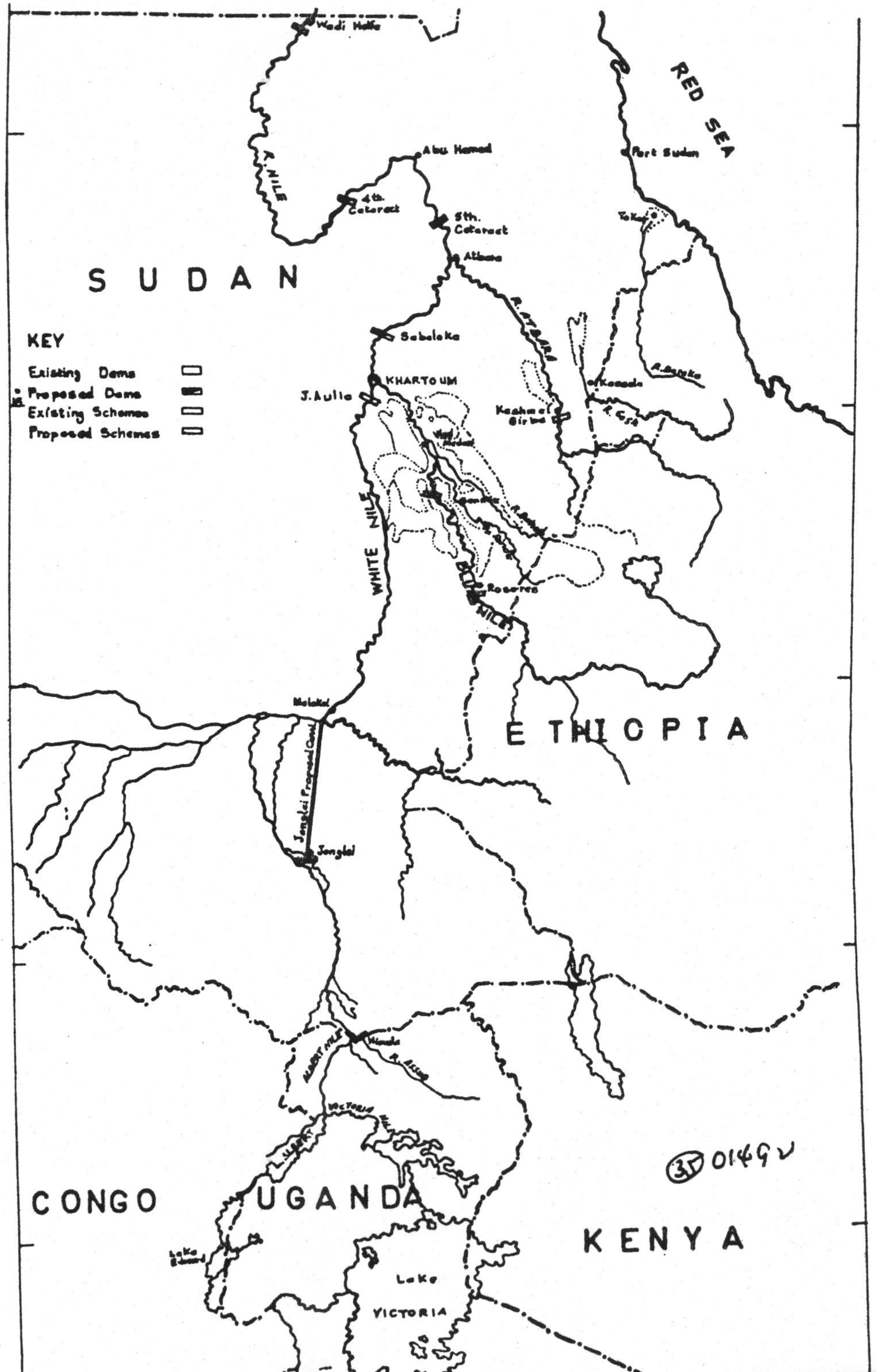
ANNUAL DISCHARGES OF THE UPPER NILE REACHES

IN MILLIARD M^3 PER YEAR

Year	Lake Victoria outflows	Lake Albert outflows	Torrent Discharges	Mongala 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	19.83	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	18.99	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	20.72	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

Year	Lake Victoria outflows	Lake Albert outflows	Torrent Discharges	Mongala Discharges	Discharges of Jebel and Zeraf as at Malakal
36	23.63	21.51	4.22	24.90	12.87
1936/37	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	18.87	3.39	21.58	14.27
41	24.32	21.29	4.21	24.78	14.31
1942/43	25.35	30.49	4.44	33.82	15.35
43	19.01	22.20	3.75	25.09	15.17
44	16.60	15.94	3.06	18.32	13.99
45	16.02	15.17	4.43	19.07	13.23
46	17.48	18.21	7.00	24.33	13.54
47	24.31	27.82	4.02	30.49	14.35
48	21.75	27.64	4.67	31.00	14.93
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	19.93	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	19.27
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	40.18	5.79	42.46	23.80
Means Disch.	22.49	25.30	4.83	28.99	14.74
Max. Disch.	51.36	56.92	9.77	65.51	33.00
Min. Disch.	12.71	13.54	1.78	14.98	10.29

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Abu Hamed
Port Sudan
4th. Cataract
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Atbara
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Existing Dams
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Proposed Schemes
Sabaloka
KHARTOUM
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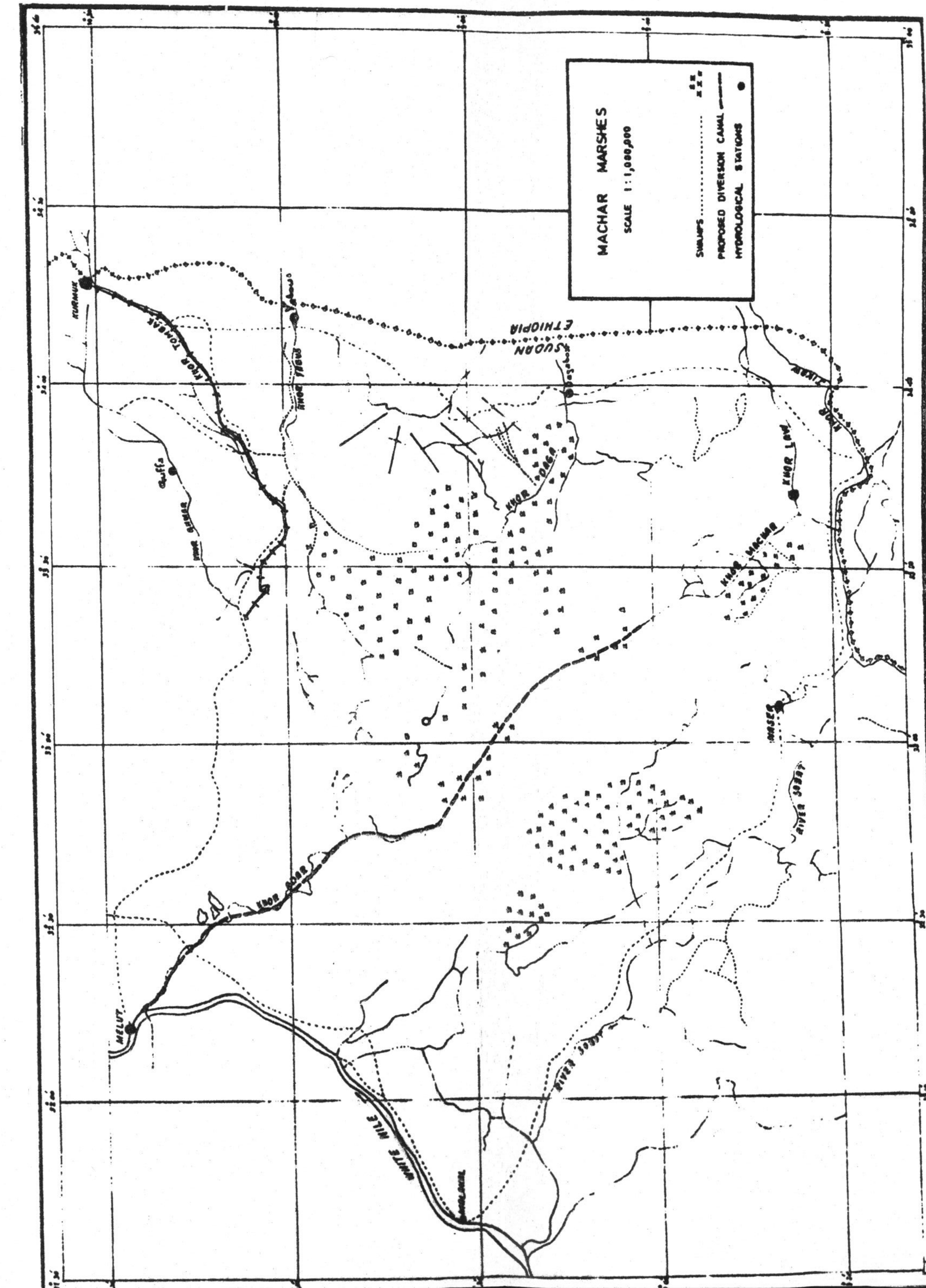
WHITE NILE
BLUE NILE
Roseires
Malakal
ETHIOPIA
Jonglei
CONGO
UGANDA
KENYA
Lake Victoria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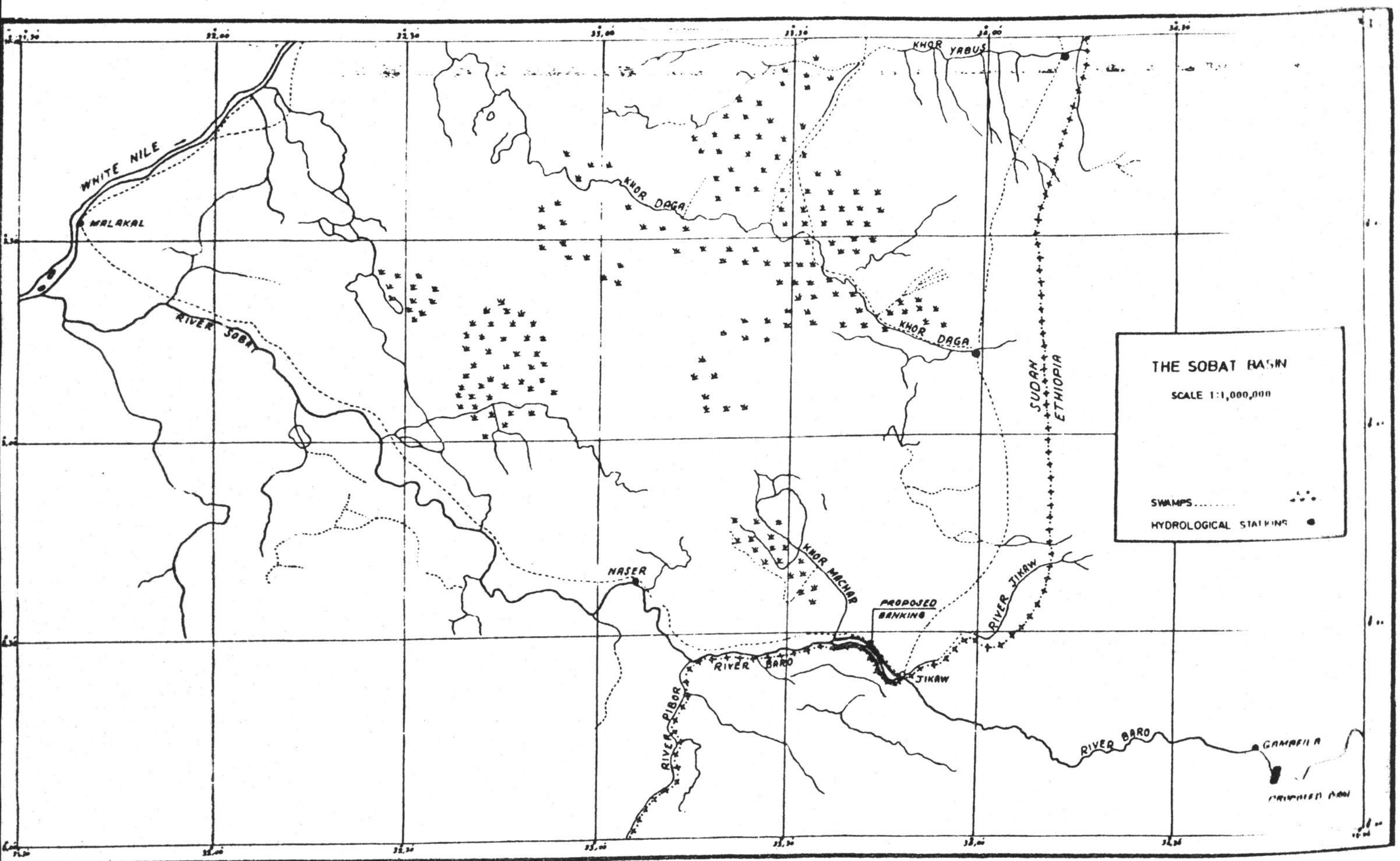
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JIKAW
RIVER BARO
RIVER PIBOR
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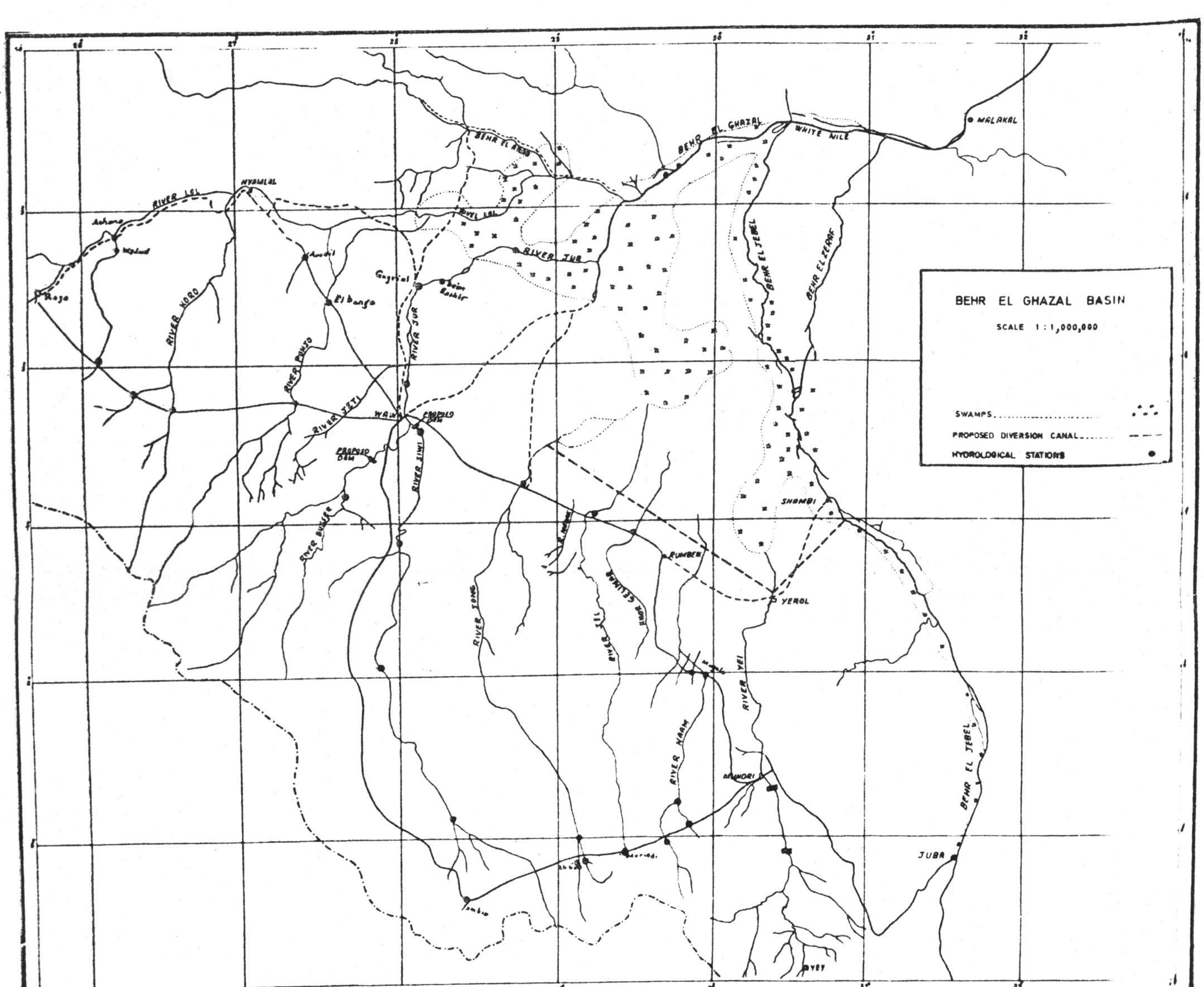
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RIVER JUR
RIVER KORO
RIVER PONGO
RIVER JETI
RIVER SIWI
RIVER BUSERI
RIVER TONJ
RIVER YEI
RIVER NAAM
WAW
SHAMBE
YEROL
RUMBEK
JUBA
Raga
El Bongo
Gogrial
Aweil
Tambura