VOLUME II

THE EQUATORIAL NILE PROJECT: ITS EFFECTS AND THE REMEDIES

CONTENTS

CHAPTER 1. THE PROJECT

PART I

THE EFFECTS ON LOCAL INTERESTS

CHAPTER 2. HYDROLOGICAL CHANGES AND EFFECTS

CHAPTER 3. EFFECTS ON PASTURE AND ANIMAL HUSBANDRY

CHAPTER 4. EFFECTS ON FISH AND FISHERIES

CHAPTER 5. OTHER EFFECTS

PART II

DIRECT REMEDIES

CHAPTER 6. PASTURE REMEDIES

CHAPTER 7. AGRICULTURAL ALTERNATIVES

CHAPTER 8. THE ENGINEERING ASPECTS OF REMEDIAL MEASURES

CHAPTER 9. SOME SELECTED REMEDIES

CHAPTER 10. APPLICATION AND COSTS OF DIRECT REMEDIES

PART III

REVISED OPERATION OF THE PROJECT

CHAPTER 11. THE REVISED OPERATION OF THE PROJECT

CHAPTER 13. APPLICATION AND COSTS OF THE REVISED OPERATION

LIST OF TABLES

CHAPTER 1. THE PROJECT

1. INTRODUCTION

As early as 1904 a map was printed, in a report by Sir William Garstin on the basin of the Upper Nile, on which was shown a line from Bor to the White Nile representing a canal to by-pass the *Sudd* region of the Bahr el Jebel. Garstin's report laid the foundations of a hydrological service which covers the Nile and all its important tributaries today, and whose records in some instances are continuous for nearly 50 years. By the 1930's sufficient knowledge of the hydrology of the swamps had been gained for three alternative projects to be proposed whose purpose was to prevent some of the enormous losses of water which occur there. These three projects are known as the Veveno-Pibor Scheme, the Jonglei Canal Scheme, and the Jebel Banking Scheme. In the first scheme water was to be carried from the Bahr el Jebel to the Veveno in a cut, and thence to the White Nile via the Pibor and the Sobat; in the second there was to be a by-pass canal starting at Jonglei; and in the third losses were to be prevented by building banks alongside the river. The three schemes were examined in detail and in 1938 the Minister of Public Works in Egypt directed that the Jonglei Canal Scheme was to be accepted in its general form as the officially approved scheme.

In 1933 the mass of valuable hydrological data accumulated was made available to all by the publication by the Egyptian Public Works Ministry of *The Nile Basin*, written by various authors, notably Hurst, Phillips, Black, and Simaika. In 1938 Butcher published his masterly analysis of the swamps in *The Sadd Hydraulics*. Since the second world war the authors of *The Nile Basin* have, in Volume VII, improved on the previous proposals by combining them with a new idea known as 'Century Storage', and have outlined the most comprehensive plan yet devised for conservation of the Nile as a whole, in which the Equatorial Nile Project is included. It is with this Project that we are concerned. Since they stressed that the projects must be considered as a whole, as the parts were clearly connected, we mention the other parts briefly before examining the Equatorial Nile Project in detail.

The authors considered the following principal projects to be both sufficient and necessary to control the Nile in the interests of irrigation in Egypt and the Sudan and to provide flood protection for Egypt. They are listed below, together with developments which have taken place since Volume VII was published (see Fig. F 1).

MAIN NILE

A new main Nile reservoir between Atbara and Wadi Halfa to be used for flood protection and for annual storage. A site for this reservoir was being surveyed at the Fourth Cataract just upstream of Merowe, but since the beginning of 1953 all attention has turned to a new project for a gigantic reservoir with a dam at Aswan. As yet there are no details of this, but the suggestion is that it will store Blue Nile flood-water, and provide century storage. An additional project under investigation on the Main Nile is a reservoir in Wadi Rayan in Egypt for flood control and storage.

BLUE NILE

A reservoir for over-year storage at Lake Tana for irrigation in Egypt and the Sudan, to assist in flood protection for both countries, and to provide a supplementary reserve. A dam site at Roseires on the Blue Nile is also being investigated for irrigation in the Sudan.

EQUATORIAL NILE (BAHR EL JEBEL AND WHITE NILE)

A very large reservoir in Lake Victoria to provide over-year storage, combined with regulation of Lake Kioga and a smaller reservoir in Lake Albert. A diversion channel in the *Sudd* region to carry the timely flow from Lake Albert with small losses, in conjunction with the Bahr el Jebel with diminished losses. Depending largely on the method of excavation of the channel, its alignment may be either 'direct' from Jonglei to the White Nile at the mouth of the Sobat, or running along the eastern edge of the swamps of the *Sudd* region north of Jonglei and paralleling the Bahr el Zeraf in its lower reaches. A possible alternative to a diversion channel is to prevent spill in the *Sudd* region by embanking the Bahr el Jebel, the White Nile and the Bahr el Zeraf.

Several projects have been suggested which were not included in the original proposals by the authors of *The Nile Basin*, Volume VII, and it is very likely that more schemes may be considered before the Equatorial Nile Project is carried out and control of the Nile is achieved.

The point we wish to emphasize is that whatever the project may be, it should be considered in relation to the whole as well as in detail by itself. In this report we confine our detailed investigations to the Equatorial Nile Project as put forward by the authors of *The Nile Basin*, Volume VII, and subsequently modified by Dr. Mohamed Amin and Mr. H. G. Bambridge in *The Modified Jonglei Canal and Over-year Storage Schemes*, submitted in October 1948. The question of alternative alignments of the Jonglei Canal may be considered in general terms in an appendix to this report at a later date; our investigations have been based on the 'Direct' Line from Jonglei to the White Nile at the mouth of the Sobat.

2. THE EQUATORIAL NILE PROJECT

We start by describing the Equatorial Nile Project as it is conceived at present, and follow the description with an account of its effects in the Jonglei Area in detail.

LAKE VICTORIA

As is well known, the Lake Victoria Dam is now under construction at the Owen Falls. It was designed primarily to generate electric power for Uganda, but has been modified to suit the Egyptian requirements to control the lake as a century storage reservoir.

The capacity needed in Lake Victoria was arrived at by studying the records of 42 years from 1905 to 1946, which included the high flood years of 1916–17. From the mass diagram of the inflow into Lake Victoria it was found that the curve departed from the mean by 87 milliards above it and 33 milliards below it, totalling 120 milliards for 42 years, equivalent to 185 milliards for 100 years, or 2·76 m. over the area of the lake of 67,000 sq. km. From a trial computation of a suggested method of regulation for the period 1905–46 on principles which will be clear later, it was found that a range of 3·00 m. was necessary, or a capacity of 201 milliards. The proposed range in Lake Victoria is therefore from 9·80 to 12·80 m. on the Entebbe gauge. The discharge out of the lake will never fall below 44 m/d, which is required for the generation of electricity, nor exceed 100 m/d which was the previous natural maximum. The object of the storage is to equalize the flow to 20 milliards per year (55 m/d), the long-term mean at the lake exit, but the flow there will vary during the year in order to build up storage in Lake Albert in the untimely season so that it is full to normal level at the beginning of the timely season, and to maintain the required timely discharge downstream of Mutir. It is also suggested that at high lake levels the discharge should be increased according to a sliding scale as follows:

Entebbe Gauge	Discharge in m/d
12.30	60
12.35	70
12.40	80
12.45	90
12.50	100

LAKE KIOGA

The times of travel of water from Lake Victoria exit to Lake Kioga and from the outlet at Atura to Lake Albert are both negligible, but the time of passage of water through the lake is indefinite. It is therefore proposed to build a regulating barrage at Lake Kioga outlet so that alterations at Owen Falls can be copied immediately at Lake Kioga outlet and the time-lag between Lake Victoria and Lake Albert eliminated completely. This means that the timely and untimely periods at Lakes Victoria and Albert will be identical. This part of the project has yet to be investigated.

LAKE ALBERT

Having computed the capacity of Lake Victoria to equalize the flow at its exit, it remained to calculate the capacity required in Lake Albert to equalize the flow at the latter's exit. This was done by the same method as for Lake Victoria, the departures from the mean of the curve of the mass diagram having a total range of 62 milliards in 42 years (1905–46) which included the high flood period 1916–18. However in those years, instead of discharging the mean, the untimely discharge could have been increased to 22 milliards, thereby effecting a reduction of 13 milliards in storage, making the total capacity required in Lake Albert 49 milliards for 42 years. The capacity required in Lake Albert can be still further reduced by operating Lake Victoria and Lake Kioga to relieve it of some storage. In view of these facts it was considered acceptable to operate Lake Albert between the levels of 10·00 and 18·50 m. on the Butiaba gauge (capacity 49 milliards), though it was postulated that the dam at Mutir should be built to allow for raising should this range prove insufficient after a reasonable trial period.

Since the effects of the Equatorial Nile Project in the Jonglei Area will depend entirely on the operation of the Lake Albert Dam (in conjunction with the torrents balancing reservoir), it is of the utmost importance to examine the principles involved and the method of operation in detail. These are embodied in the suggested working arrangements and a summary of the important points is given below, though they may well be modified in one way or another later.

(i) The extreme permissible range of levels, for the present, will be from 9·00 m. to 18·50 m. on the Butiaba gauge.

(ii) For normal regulations the level in Lake Albert will be raised to 14·00 m. on the Butiaba gauge (subject to revision after a trial period) at the beginning of the timely season. This level may be lowered during the timely season and raised gradually during the untimely season so as to regain its normal value at the beginning of the next timely season.

(iii) The storage between 14·00 m. and 18·50 m. on the Butiaba gauge is to be used only when necessary for emergency flood protection. (These three items are to date the subject of agreements at a technical level which are liable to be revised.)

(iv) The object of regulation is to control the discharge at the Lake Albert Dam so that the total discharge at Mongalla, including that from local tributaries, will be 17 milliards (90 m/d) in the timely season (December 11 to June 20 at Mongalla).

(v) Since the total discharge required at Mongalla during the untimely season is about 9·9 milliards (57 m/d) the total annual flow passing Mongalla will approximate as nearly as possible to the long-term mean natural discharge of 27 milliards (*The Nile Basin*, Vol. IV, 3rd Supplement).

(vi) The timely quota will be reduced to 9 milliards, or increased to 22 milliards (120 m/d), depending on the forecast of Main Nile storage and natural supply made on December 1st each year.

(vii) The untimely discharge may also be liable to variation, since the discharge downstream of Mutir cannot fall below the limit, say 40 m/d, necessary to maintain navigation in the Mutir–Nimule reach.

(viii) The timely season at Mutir will be taken provisionally as December 1st to June 10th, subject to revision in the light of experience.

(ix) From the time when the dams at Owen Falls and Mutir are completed the regulation at Mutir will, as far as the regulation at Owen Falls Dam permits, ' tend to a gradual reversal of the seasons ' in the swamps, in steps as indicated in Tables 186–189, pp. 407–10.

(x) The minimum permissible mean daily discharge at Mutir Dam will be such as to ensure safe navigation both between Mutir and Nimule and below Rejaf. On present data this is estimated to be 44 m/d, subject to revision in the light of experience.

(xi) When the level of Lake Albert exceeds 14·00 m. on the Butiaba gauge, the discharge at Mutir Dam will be increased as much as possible in the conditions at the time, provided that the discharge at Mongalla does not exceed the following mean rates:

Mean rate over 24 hours ...	150 m/d
,, ,, ,, 10 days ...	140 m/d
,, ,, ,, 30 days ...	130 m/d
,, ,, ,, 6 months ...	120 m/d

(xii) When the level of Lake Albert reaches its maximum of 18·50 m. on the Butiaba gauge, escapage at the above-mentioned maximum mean rates will continue to check any further rise in lake level. As soon as the available data indicate a tendency towards the conditions of a falling flood, the discharges downstream of Mutir Dam will be reduced to give the required normal quotas, allowing Lake Albert Reservoir to be emptied gradually to normal working level and thus making full use of the flood-water stored above that level.

SITE OF LAKE ALBERT DAM

It was originally suggested that the Lake Albert Dam should be built at Mutir, about 79 km. north of the lake exit, but recent work has shown that from the hydrological and engineering points of view Nimule is the most suitable site for the construction of the dam for the following reasons :

(i) The rock foundation would need little excavating, and stone necessary for building is close at hand.

(ii) There would be no need to provide special measures for navigation above Nimule.

(iii) It would be possible to make use of the torrential streams, whose waters are mainly untimely, between the lake and Nimule and to counterbalance those north of Nimule.

TORRENTS BALANCING RESERVOIR

Since no allowance has been made in the capacity of Lake Albert to absorb the natural inflow when the controlled outflow is reduced to counterbalance the torrents between Mutir and Rejaf, and since in any case with the dam at Mutir it will be extremely difficult to control the torrents, it was recommended that the valley north of Nimule should be investigated to determine the possibility of constructing a dam (or dams) between Nimule and Rejaf and to estimate its capacity for this purpose.

SUDD DIVERSION CHANNEL

We have described, as briefly as possible, the dam and regulating headworks which will control the flow of the river through the Jonglei Area, and we now proceed to the engineering works proposed in the *Sudd* region itself in order to transmit the water to the north without incurring enormous losses in the swamps. We must here distinguish between the Canal itself which will begin at Jonglei and the banked channel which will lead to it from the Bahr el Jebel barrage below the Atem Head. We refer to the former as the 'Jonglei Canal', the latter as the 'Atem Inlet Channel', and the whole system by which water is carried through from the Atem Head to the Sobat mouth as the '*Sudd* Diversion Channel'.

Although the Jonglei Canal and its regulators will be constructed in stages, we describe here the Project as it is proposed in the 55 m/d Canal stage. This is done so that the reader will have as clear a picture as possible of the main features of the scheme. The intermediate steps can then be described briefly, as well as the extension to the 80 m/d Canal stage, and proposals for flood protection.

North of Mongalla the first engineering work proposed is banking on the left of the Bahr el Jebel to prevent spill and losses above a discharge of 65 m/d at Mongalla. Unfortunately no clear plan has yet been worked out concerning this banking, and the various schemes mentioned in different parts of the Egyptian report appear to be alternatives rather than the component parts of one whole scheme. For the sake of clarity we will describe what appears to be the latest design and then tabulate the other suggestions.

It is made clear beyond any doubt that the head regulator of the *Sudd* Diversion Channel will be at the Atem Head in the 55 m/d Canal stage. At this control point there will be a regulator and lock on the Atem, and a barrage, regulator and lock on the Bahr el Jebel downstream of the Atem Head at a point between Lake Fajarial and Lake Papiu. The banking on the left of the Bahr el Jebel will be taken from Tombe to this barrage. The Atem will be remodelled and banked from its head to Jonglei to carry 80 m/d. At Jonglei there will be another canal regulator with a lock, and a barrage and regulator without a lock across the lower Atem downstream of the canal regulator. There will be no control works across the Bahr el Jebel at Jonglei latitude.

The following works are also mentioned, and we assume they were considered as alternatives or additions to the above :

(i) Banking on the left of the Bahr el Jebel north of the Bahr el Jebel barrage to Jonglei latitude, with a small regulator at the mouth of Lake Papiu.

(ii) Training works in the Aliab Valley, possibly after the 55 m/d Canal stage.

(iii) In the event of the Bahr el Jebel not being used for navigation, a bank will be required across the valley for road communication between east and west banks.

It is not stated where this road will be. If it is at the Bahr el Jebel barrage downstream of the Atem Head, it will cut across the Aliab system between Lakes Fajarial and Papiu, and a bridge will be needed. If it is intended to build the bank at Jonglei latitude, a bridge will be needed to cross the Bahr el Jebel. In any case it is not understood why the Bahr el Jebel might not be used for navigation.

THE JONGLEI CANAL

On the 'Direct' Line the Canal will start at Jonglei and run straight to Mogogh (lat. 8° 30′ N. ; long. 31° 23′ E.). From Mogogh it will bear 14 degrees east of north, straight to the White Nile at the Sobat mouth. North of Mogogh the Canal will cross the Khor Atar, and a large cross-drainage work will be necessary there or the flow in Khor Atar will be diverted into Khors Kwanjor and Fullus. There will, in fact, be two canals each carrying 27·5 m/d at their heads, and interconnected with cross-cuts. The second canal head regulator will not have a lock. At the tails of the canals there will be regulator falls and one lock. No other structures are contemplated.

The features of the design of the canals are: first that the velocity should not exceed 1·0 m. per second ; secondly that the water-level in the canals should conform as closely as possible to the natural configuration of the ground ; and thirdly that the type adopted should avoid the necessity of intermediate regulators.

The details of the canals' design are as follows :

Each Canal 27·5 m/d	Head to Km.176	Km.176 to Km.280
Water and Bed Slope ...	9 cm./km.	7 cm./km.
Bed Width	76 to 72 m.	54 to 53 m.
Depth	4 m.	5 m.
Side Slopes	2 : 1	2 : 1

Since weed growth is expected on the canals' sides, the discharge of any part of the canals where the depth is less than 3·0 m. is ignored.

Details of the structures are as follows :

BAHR EL JEBEL BARRAGE DOWNSTREAM OF THE ATEM HEAD

Maximum capacity 60 m/d—flood-escape discharge
Minimum capacity 30 m/d
Maximum upstream level R.L. 418·95
Maximum downstream level R.L. 416·80
Ground level R.L. 416·0 (approx.)
Road level R.L. 421·0
8 openings 6·0 m. wide
One lock 100 m. × 18 m.

REGULATOR AND LOCK AT THE ATEM HEAD

Capacity 55 m/d—normal timely discharge
Levels as for barrage, see above
10 openings 6·0 m. wide
Lock 100 m. × 18 m.

JONGLEI CANAL REGULATORS AND LOCK

Twin regulators capacity 27·5 m/d
Maximum upstream level R.L. 411·85
Maximum downstream level R.L. 409·25
Ground level R.L. 410·50
Road level R.L. 413·85
Each regulator 6 openings 6·0 m. wide
One lock 100 m. × 18 m.

BARRAGE ON LOWER ATEM DOWNSTREAM OF JONGLEI

Capacity 60 m/d—flood-escape discharge
Maximum upstream level R.L. 411·85
Maximum downstream level R.L. 411·60
Ground level R.L. 410·50
Road level R.L. 413·85
12 openings 6 m. wide

CANALS' TAILS REGULATOR—FALLS AND LOCK

Capacities each 27·5 m/d
Upstream level R.L. 386·14
Downstream level R.L. 381·14
Ground level R.L. 389·95
Each 6 openings × 6·0 m.
One lock 100 m. × 18 m.

OPERATION OF THE PROJECT

In the 55 m/d Canal stage the discharges at Mongalla will be regulated normally according to the table below :

Site	Discharges (in m/d)	
	Timely	Untimely
Mongalla	90	57
Atem Head Latitude	85	52
Atem Head Regulator	55	17
Bahr el Jebel Barrage	30	35
Lower Atem Barrage	—	—

The timely period at Mongalla is assumed to be from December 11th to June 20th.

The foregoing figures are the basic ones for our estimate of the effects throughout this report, but several other features of the proposals have important bearings on the effects and are described below.

PROGRESSIVE STAGES IN THE CONSTRUCTION OF THE PROJECT

It will have been noticed that in item (ix) of the principles embodied in the suggested working arrangements (p. 401 above) it is clearly stated that, from the time when the dams at Owen Falls and Mutir are completed, the regulation at Mutir will tend to cause a gradual reversal of the seasons in the swamps, and the 55 m/d Canal stage will be reached in five steps.

STAGE I: STORAGE DAMS ONLY

As soon as the storage dams are constructed it will be necessary to build up storage in Lake Victoria, and to do this the flow at Mongalla will be regulated to 65 m/d continuously throughout the year. This amounts to 23·7 milliards a year, so that on the average the equivalent of 3·3 milliards per year at Mongalla will be stored in the Great Lakes.

STAGE II: 10 M/D CANAL. MALAKAL DISCHARGE UNALTERED

The second step will be to dig a canal from Jonglei on the 'Direct' Line to the Sobat mouth to carry about 10 m/d. This canal will be 28 m. wide and 4 m. deep, both these dimensions changing where the slope changes at km. 176. The Project will then be operated to keep some water in the canal, but to maintain the normal discharge of the White Nile at Malakal unaltered. The discharges at Mongalla will be reduced to 19·5 milliards per year and over-year storage will be further increased in Lake Victoria by the equivalent of 7·5 milliards per year on the average at Mongalla. The only structures required for this stage will be a regulator and lock at Jonglei, and a fall and lock at the tail of the canal. These will be built to suit the 27·5 m/d stage.

STAGE III: 10 M/D CANAL. MALAKAL TIMELY FLOW INCREASED BY ONE MILLIARD

The third step will be a change in the operation of the canal so that the timely flow at Malakal is increased by one milliard. The Mongalla discharge rises to 22·2 milliards per year, leaving on the average the equivalent of 4·8 milliards at Mongalla to be stored in Lake Victoria.

STAGE IV: 27·5 M/D CANAL. MALAKAL TIMELY FLOW INCREASED BY THREE MILLIARDS

For the fourth step the 10 m/d canal will be widened to carry 27·5 m/d. Since the structures in Stage II will have been built to suit this, no works other than widening the canal will be called for. The timely discharge will be increased to 70 m/d at Mongalla, and the annual flow to 23·4 milliards, leaving on the average the equivalent of 3·6 milliards at Mongalla for over-year storage.

STAGE V: 55 M/D CANAL. MALAKAL TIMELY FLOW INCREASED BY SEVEN MILLIARDS

The fifth step to the 55 m/d Canal stage depends on the completion of all the large engineering works described above (pp. 402–3). It involves the following :

- (i) Banking of the left of the Bahr el Jebel from Tombe to Bahr el Jebel barrage and of the east bank from 15 km. north of Bor to the barrage.
- (ii) Atem Head regulator and lock to pass 55 m/d.
- (iii) Bahr el Jebel barrage, regulator and lock to pass 60 m/d downstream of the Atem Head.
- (iv) Remodelling and banking of the Atem to carry a maximum discharge of 80 m/d.
- (v) Second Jonglei Canal regulator, without a lock, similar to the first.
- (vi) Barrage across the lower Atem with regulator to pass 60 m/d, downstream of the Jonglei Canal regulator.
- (vii) Excavation of the second 27·5 m/d canal parallel to the first and connected to it with cross-cuts.
- (viii) Regulator fall at the tail of the second canal.

In this stage the timely discharge at Mongalla will be increased further to 90 m/d, and the annual discharge to 27 milliards, i.e. to the long-term mean.

This completes the description of the Equatorial Nile Project as far as the 55 m/d Canal stage, and of the intermediate steps from the construction of the Owen Falls and Mutir Dams to reach that stage.

For the purpose of examining the effects we have tabulated present and future discharges in all the stages in Tables 186 to 190, at Mongalla, at Jonglei both in the Canal and in the Bahr el Jebel, at the Tail of the Swamps, and at Malakal, and have represented the discharges at those points diagrammatically in Figs. F 2, F 3, and F 4.

It remains to point out that in the fifth step from the 27·5 m/d to the 55 m/d Canal stages, the head of the *Sudd* Diversion Channel moves from Jonglei to the Atem Head, and, from the point of view of the effects of the Project, so does the division between the Southern and Central Zones.

It will be seen from the above that in the 55 m/d Canal stage the increase in the timely flow, or timely benefit, at Malakal will normally be about 7 milliards, or 5·2 milliards at Aswan. The annual discharges at Mongalla and at the Tail of the Swamps will be 27 and 22 milliards respectively. The large difference of 5 milliards is 18·5% of the discharge at Mongalla, and represents the estimate of normal transmission losses in the Bahr el Jebel and in the canals between Mongalla and Malakal. It will be remembered that at present the discharge at the Tail of the Swamps amounts to 14·2 milliards, so that the present losses amount to 12·8 milliards. Under the Equatorial Nile Project 6·9 milliards will be saved in the timely season and 0·9 milliards in the untimely season, making a total of 7·8 milliards which, together with future normal transmission losses of 5 milliards, accounts in full for the present loss of 12·8 milliards.

THE TIME FACTOR

A short table of budgetary requirements in the Egyptian report indicates that it is expected that twenty-five years will elapse from the day of approval of the scheme to its completion to the 55 m/d Canal stage.

80 M/D CANAL STAGE

With over-year storage in Lakes Victoria and Albert it will be necessary later to supplement the Main Nile supplies when shortages occur, such as in 1913. To do this the timely discharge at Mongalla will be increased up to 22 milliards (120 m/d), depending on the shortage in annual storage and natural supplies as forecast on December 1st each year.

In this case the capacity of the *Sudd* Diversion Channel will be increased to 80 m/d, either by digging a third parallel canal on the ' Direct ' Line to carry 25 m/d, or by banking and re-modelling the Bahr el Jebel to carry the extra amount. This will be decided when experience has shown by how much the carrying capacity of the Bahr el Jebel can be improved by closing spills or banking in certain reaches.

It is stated that the masonry works required will be as for other canals without locks. We assume that this means that the Atem Head regulator must be enlarged to discharge the additional 25 m/d, unless it is intended in the 55 m/d Canal stage to build it to suit the 80 m/d Canal stage, in line with banking and remodelling the Atem, and not for 55 m/d as stated. Otherwise the additional discharge may be passed through the 55 m/d regulator by increasing the head of water upstream of it by 60 cm., which appears to be the more likely alternative.

If it is finally decided to dig a third parallel canal, then an additional regulator and a fall will be needed at the head and tail of it. The alternative of improving the carrying capacity of the Bahr el Jebel will not involve the construction of any more regulators because the lower Atem barrage regulator will have been built to a capacity of 60 m/d in the 55 m/d Canal stage.

When all these works are completed the distribution of the flow between the various regulators will be :

Mongalla Discharge ...	120 m/d
Atem Head Latitude ...	113 m/d (6% loss)
Atem Head Regulator ...	80 m/d
Bahr el Jebel Barrage ...	33 m/d

The discharge of 80 m/d in the Atem will be divided between the lower Atem through the barrage and the Jonglei canals through the Jonglei regulator, according to their final carrying capacities to be decided later.

FLOOD PROTECTION

It is unfortunate that the subject of flood protection is dealt with after the normal operations of the Project, because for obvious reasons it is an aspect of the scheme of first importance where the Sudan is concerned. The proposals for dealing with flood protection are stated in the suggested working arrangements for Lake Albert which are given above.

Lake Albert will be operated normally to reach a gauge-reading of 14 m. at Butiaba at the beginning of the timely season (December 1st) and lowered according to supplies required and arriving from Lake Victoria during the timely period.

Normal regulation at Mutir during the untimely period (beginning on 11th June) will be to keep the Mongalla discharge at 57 m/d, including the contributions of the torrents. Since this is the rainy season, Lake Albert level will normally rise. In the case of an extremely high flood, as in 1916–18 at Lake Albert, the level may rise above the normal level of 14 m. on the Butiaba gauge, and the intention then is to increase the discharge at Mongalla to 22 milliards, as far as conditions allow, in six months or to 44 milliards per year, until the available data indicate that the flood is falling.

The suggested limits for the Mongalla discharge are

Mean rate over 24 hours	...	150 m/d
„ „ „ 10 days	...	140 m/d
„ „ „ 30 days	...	130 m/d
„ „ „ 6 months	...	120 m/d (22 milliards)

From a study of the proposals for the 80 m/d Canal stage, it is clearly the intention to dispose of as much of this as possible in the swamps north of the Bahr el Jebel barrage as follows :

Disposal of discharge of 150 m/d in the 80 m/d Canal Stage

Mongalla Discharge	...	150 m/d
Atem Head Latitude	...	140 m/d
Atem Head Regulator	...	80 m/d
Bahr el Jebel Barrage	...	60 m/d
Jonglei Canal Regulator	...	20 m/d
Lower Atem Barrage	...	60 m/d

The discharge in the Central Zone will therefore amount to 120 m/d, 60 m/d each from the Bahr el Jebel and Lower Atem barrages.

In the 55 m/d Canal stage we can assume that the discharges will be similar, since the Atem will have a capacity of 80 m/d and the Atem regulator, it appears, will be capable of passing this quantity with a higher upstream level.

We have now described briefly, but completely, the latest Egyptian proposals for constructing and operating the Equatorial Nile Project, and can turn to the examination of its effects in more detail in the next chapter.

TABLE 186

PRESENT AND FUTURE DISCHARGES AT MONGALLA

In millions of cubic metres per day. Totals in milliards.

10-Day Period	1912–42 Normals	Storage Dams Only	10 m/d Canal Malakal No Change	10 m/d Canal Malakal Timely Benefit 1 milliard	27·5 m/d Canal Malakal Timely Benefit 3 milliards	55 m/d Canals Malakal Timely Benefit 7 milliards
January 1 ...	65·3	65·0	48·0	62·5	70·0	90·0
2 ...	63·5	65·0	48·0	62·5	70·0	90·0
3 ...	62·2	65·0	48·0	62·5	70·0	90·0
February 1 ...	60·7	65·0	48·0	62·5	70·0	90·0
2 ...	59·4	65·0	48·0	62·5	70·0	90·0
3 ...	58·8	65·0	48·0	62·5	70·0	90·0
March 1 ...	58·4	65·0	48·0	62·5	70·0	90·0
2 ...	58·1	65·0	48·0	62·5	70·0	90·0
3 ...	57·7	65·0	48·0	62·5	70·0	90·0
April 1 ...	59·4	65·0	48·0	62·5	70·0	90·0
2 ...	60·7	65·0	48·0	62·5	70·0	90·0
3 ...	65·6	65·0	48·0	62·5	70·0	90·0
May 1 ...	71·7	65·0	48·0	62·5	70·0	90·0
2 ...	76·3	65·0	48·0	62·5	70·0	90·0
3 ...	76·5	65·0	48·0	62·5	70·0	90·0
June 1 ...	73·7	65·0	48·0	62·5	70·0	90·0
2 ...	73·4	65·0	48·0	62·5	70·0	90·0
3 ...	73·5	65·0	59·0	59·0	57·0	57·0
July 1 ...	76·6	65·0	59·0	59·0	57·0	57·0
2 ...	77·8	65·0	59·0	59·0	57·0	57·0
3 ...	81·6	65·0	59·0	59·0	57·0	57·0
August 1 ...	87·3	65·0	59·0	59·0	57·0	57·0
2 ...	89·9	65·0	59·0	59·0	57·0	57·0
3 ...	90·5	65·0	59·0	59·0	57·0	57·0
September 1 ...	91·9	65·0	59·0	59·0	57·0	57·0
2 ...	90·0	65·0	59·0	59·0	57·0	57·0
3 ...	87·8	65·0	59·0	59·0	57·0	57·0
October 1 ...	87·5	65·0	59·0	59·0	57·0	57·0
2 ...	85·4	65·0	59·0	59·0	57·0	57·0
3 ...	83·3	65·0	59·0	59·0	57·0	57·0
November 1 ...	81·7	65·0	59·0	59·0	57·0	57·0
2 ...	79·6	65·0	59·0	59·0	57·0	57·0
3 ...	76·4	65·0	59·0	59·0	57·0	57·0
December 1 ...	72·8	65·0	59·0	59·0	57·0	57·0
2 ...	70·2	65·0	48·0	62·5	70·0	90·0
3 ...	68·3	65·0	48·0	62·5	70·0	90·0
TOTALS						
Dec. 11–June 20	12·6*	12·5	9·3	12·0	13·5	17·3
June 21–Dec. 10	14·4	11·3	10·2	10·2	9·9	9·9
Year	27·0	23·8	19·5	22·2	23·4	27·2

* The present timely period at Mongalla is September 21st–March 31st.

TABLE 187

FUTURE DISCHARGES IN JONGLEI CANAL AT HEAD

In millions of cubic metres per day. Totals in milliards.

10-Day Period		Storage Dams Only	10 m/d Canal Malakal No Change	10 m/d Canal Malakal Timely Benefit 1 milliard	27·5 m/d Canal Malakal Timely Benefit 3 milliards	55 m/d Canals Malakal Timely Benefit 7 milliards
January	1	0	10·0	10·0	27·5	55·0
	2	0	10·0	10·0	27·5	55·0
	3	0	10·0	10·0	27·5	55·0
February	1	0	10·0	10·0	27·5	55·0
	2	0	10·0	10·0	27·5	55·0
	3	0	10·0	10·0	27·5	55·0
March	1	0	10·0	10·0	27·5	55·0
	2	0	10·0	10·0	27·5	55·0
	3	0	10·0	10·0	27·5	55·0
April	1	0	10·0	10·0	27·5	55·0
	2	0	10·0	10·0	27·5	55·0
	3	0	10·0	10·0	27·5	55·0
May	1	0	10·0	10·0	27·5	55·0
	2	0	10·0	10·0	27·5	55·0
	3	0	10·0	10·0	27·5	55·0
June	1	0	10·0	10·0	27·5	55·0
	2	0	10·0	10·0	27·5	55·0
	3	0	{ ½ × 10·0 ½ × 5·0	½ × 10·0 ½ × 5·0	½ × 27·5 ½ × 17·0	½ × 55·0 ½ × 17·0
July	1	0	5·0	5·0	17·0	17·0
	2	0	5·0	5·0	17·0	17·0
	3	0	5·0	5·0	17·0	17·0
August	1	0	5·0	5·0	17·0	17·0
	2	0	5·0	5·0	17·0	17·0
	3	0	5·0	5·0	17·0	17·0
September	1	0	5·0	5·0	17·0	17·0
	2	0	5·0	5·0	17·0	17·0
	3	0	5·0	5·0	17·0	17·0
October	1	0	5·0	5·0	17·0	17·0
	2	0	5·0	5·0	17·0	17·0
	3	0	5·0	5·0	17·0	17·0
November	1	0	5·0	5·0	17·0	17·0
	2	0	5·0	5·0	17·0	17·0
	3	0	5·0	5·0	17·0	17·0
December	1	0	5·0	5·0	17·0	17·0
	2	0	{ ½ × 5·0 ½ × 10·0	½ × 5·0 ½ × 10·0	½ × 17·0 ½ × 27·5	½ × 17·0 ½ × 55·0
	3	0	10·0	10·0	27·5	55·0
Totals						
Dec. 16–June 25 ...		0	1·9	1·9	5·3	10·6
June 25–Dec. 15 ...		0	0·9	0·9	2·9	2·9
Year		0	2·8	2·8	8·2	13·5

TABLE 188

PRESENT AND FUTURE DISCHARGES IN BAHR EL JEBEL AT JONGLEI

In millions of cubic metres per day. Totals in milliards.

10-Day Period	1912–42 Normals	Storage Dams Only	10 m/d Canal Malakal No Change	10 m/d Canal Malakal Timely Benefit 1 milliard	27·5 m/d Canal Malakal Timely Benefit 3 milliards	55 m/d Canals Malakal Timely Benefit 7 milliards
January 1 ...	53·7	58·6	34·5	46·6	35·0	30·0
2 ...	58·2	58·6	34·5	46·6	35·0	30·0
3 ...	57·8	58·6	34·5	46·6	35·0	30·0
February 1 ...	56·0	58·6	34·5	46·6	35·0	30·0
2 ...	55·5	58·6	34·5	46·6	35·0	30·0
3 ...	54·8	58·6	34·5	46·6	35·0	30·0
March 1 ...	54·1	58·6	34·5	46·6	35·0	30·0
2 ...	53·7	58·6	34·5	46·6	35·0	30·0
3 ...	53·7	58·6	34·5	46·6	35·0	30·0
April 1 ...	53·6	58·6	34·5	46·6	35·0	30·0
2 ...	53·8	58·6	34·5	46·6	35·0	30·0
3 ...	54·5	58·6	34·5	46·6	35·0	30·0
May 1 ...	56·1	58·6	34·5	46·6	35·0	30·0
2 ...	58·1	58·6	34·5	46·6	35·0	30·0
3 ...	60·0	58·6	34·5	46·6	35·0	30·0
June 1 ...	63·9	58·6	34·5	46·6	35·0	30·0
2 ...	66·0	58·6	34·5	46·6	35·0	30·0
3 ...	67·1	58·6	{ ½ × 34·5 ½ × 49·0	½ × 46·6 ½ × 49·0	35·0	{ ½ × 30·0 ½ × 35·0
July 1 ...	68·1	58·6	49·0	49·0	35·0	35·0
2 ...	68·2	58·6	49·0	49·0	35·0	35·0
3 ...	69·4	58·6	49·0	49·0	35·0	35·0
August 1 ...	71·0	58·6	49·0	49·0	35·0	35·0*
2 ...	71·8	58·6	49·0	49·0	35·0	35·0
3 ...	74·3	58·6	49·0	49·0	35·0	35·0
September 1 ...	76·2	58·6	49·0	49·0	35·0	35·0
2 ...	76·9	58·6	49·0	49·0	35·0	35·0
3 ...	78·0	58·6	49·0	49·0	35·0	35·0
October 1 ...	77·7	58·6	49·0	49·0	35·0	35·0
2 ...	75·6	58·6	49·0	49·0	35·0	35·0
3 ...	72·4	58·6	49·0	49·0	35·0	35·0
November 1 ...	69·6	58·6	49·0	49·0	35·0	35·0
2 ...	67·4	58·6	49·0	49·0	35·0	35·0
3 ...	66·0	58·6	49·0	49·0	35·0	35·0
December 1 ...	65·1	58·6	49·0	49·0	35·0	35·0
2 ...	64·0	58·6	{ ½ × 49·0 ½ × 34·5	½ × 49·0 ½ × 46·6	35·0	{ ½ × 35·0 ½ × 30·0
3 ...	62·6	58·6	34·5	46·6	35·0	30·0
TOTALS						
Dec. 16–June 25	11·1	11·2	6·6	8·9	6·7	5·8
June 26–Dec. 15	12·3	10·2	8·5	8·5	6·1	6·1
Year	23·4	21·4	15·1	17·4	12·8	11·9

TABLE 189

PRESENT AND FUTURE DISCHARGES AT TAIL OF SWAMPS

In millions of cubic metres per day. Totals in milliards.

10-Day Period		1912–42 Normals	Storage Dams Only	10 m/d Canal Malakal No Change	10 m/d Canal Malakal Timely Benefit 1 milliard	27·5 m/d Canal Malakal Timely Benefit 3 milliards	55 m/d Canals Malakal Timely Benefit 7 milliards
January	1 ...	43·3	37·0	38·0	43·0	54·0	74·0
	2 ...	43·1	37·0	38·0	43·0	54·0	74·0
	3 ...	43·1	37·0	38·0	43·0	54·0	74·0
February	1 ...	42·0	37·0	38·0	43·0	54·0	74·0
	2 ...	41·2	37·0	38·0	43·0	54·0	74·0
	3 ...	40·9	37·0	38·0	43·0	54·0	74·0
March	1 ...	40·5	37·0	38·0	43·0	54·0	74·0
	2 ...	40·1	37·0	38·0	43·0	54·0	74·0
	3 ...	39·1	37·0	38·0	43·0	54·0	74·0
April	1 ...	38·7	37·0	38·0	43·0	54·0	74·0
	2 ...	38·1	37·0	38·0	43·0	54·0	74·0
	3 ...	37·9	37·0	38·0	43·0	54·0	74·0
May	1 ...	37·3	37·0	38·0	43·0	54·0	74·0
	2 ...	36·9	37·0	38·0	43·0	54·0	74·0
	3 ...	35·9	37·0	38·0	43·0	54·0	74·0
June	1 ...	35·4	37·0	38·0	43·0	54·0	74·0
	2 ...	35·6	37·0	38·0	43·0	54·0	74·0
	3 ...	35·6	37·0	38·0	43·0	54·0	74·0
July	1 ...	36·0	37·0	39·5	39·5	45·0	45·0
	2 ...	36·2	37·0	39·5	39·5	45·0	45·0
	3 ...	36·8	37·0	39·5	39·5	45·0	45·0
August	1 ...	37·5	37·0	39·5	39·5	45·0	45·0
	2 ...	38·0	37·0	39·5	39·5	45·0	45·0
	3 ...	38·5	37·0	39·5	39·5	45·0	45·0
September	1 ...	39·1	37·0	39·5	39·5	45·0	45·0
	2 ...	39·7	37·0	39·5	39·5	45·0	45·0
	3 ...	40·0	37·0	39·5	39·5	45·0	45·0
October	1 ...	41·2	37·0	39·5	39·5	45·0	45·0
	2 ...	40·5	37·0	39·5	39·5	45·0	45·0
	3 ...	40·2	37·0	39·5	39·5	45·0	45·0
November	1 ...	39·3	37·0	39·5	39·5	45·0	45·0
	2 ...	38·8	37·0	39·5	39·5	45·0	45·0
	3 ...	38·5	37·0	39·5	39·5	45·0	45·0
December	1 ...	38·8	37·0	39·5	39·5	45·0	45·0
	2 ...	40·7	37·0	39·5	39·5	45·0	45·0
	3 ...	42·5	37·0	38·0	43·0	54·0	74·0
TOTALS							
Dec. 21–June 30		7·6	7·1	7·3	8·3	10·4	14·2
July 1–Dec. 20		6·7	6·4	6·8	6·8	7·8	7·8
Year		14·3	13·5	14·1	15·1	18·2	22·0

TABLE 190

PRESENT AND FUTURE DISCHARGES AT MALAKAL

In milliards of cubic metres per day. Totals in milliards.

10-Day Period	1912–42 Normals	Storage Dams Only	10 m/d Canal Malakal No Change	10 m/d Canal Malakal Timely Benefit 1 milliard	27·5 m/d Canal Malakal Timely Benefit 3 milliards	55 m/d Canals Malakal Timely Benefit 7 milliards
January 1 ...	76·8	70·5	71·5	76·3	87·5	107·0
2 ...	68·7	62·6	63·6	68·6	79·6	99·6
3 ...	62·5	56·4	57·4	62·4	73·4	93·4
February 1 ...	57·2	52·2	53·2	58·2	69·2	89·2
2 ...	54·3	50·1	51·1	56·1	67·1	87·1
3 ...	52·3	48·4	49·4	54·4	65·4	85·4
March 1 ...	50·6	47·1	48·1	53·1	64·1	84·1
1 ...	49·2	46·1	47·1	52·1	63·1	83·1
3 ...	47·0	44·9	45·9	50·9	61·9	81·9
April 1 ...	45·5	43·8	44·8	49·8	60·8	80·8
2 ...	45·7	44·6	45·6	50·6	61·6	81·6
3 ...	45·8	44·9	45·9	50·9	61·9	81·9
May 1 ...	46·6	46·3	47·3	52·3	63·3	83·3
2 ...	49·9	50·0	51·0	56·0	67·0	87·0
3 ...	54·2	55·3	56·3	61·3	72·3	92·3
June 1 ...	59·7	61·3	62·3	67·3	78·3	98·3
2 ...	65·1	66·5	67·5	72·5	83·5	103·0
3 ...	70·0	71·4	72·4	77·4	88·4	108·0
July 1 ...	74·6	75·6	78·1	78·1	83·6	83·6
2 ...	78·6	79·4	81·9	81·9	87·4	87·4
3 ...	82·6	82·8	85·3	85·3	90·8	90·8
August 1 ...	86·7	86·2	88·7	88·7	94·2	94·2
2 ...	90·0	89·0	91·5	91·5	97·0	97·0
3 ...	93·3	91·8	94·3	94·3	99·8	99·8
September 1 ...	96·3	94·2	96·7	96·7	102·0	102·0
2 ...	98·9	96·2	98·7	98·7	104·0	104·0
3 ...	101·0	98·0	100·0	100·0	106·0	106·0
October 1 ...	104·0	99·8	102·0	102·0	108·0	108·0
2 ...	105·0	101·0	104·0	104·0	109·0	109·0
3 ...	106·0	103·0	105·0	105·0	111·0	111·0
November 1 ...	106·0	104·0	106·0	106·0	112·0	112·0
2 ...	105·0	103·0	106·0	106·0	111·0	111·0
3 ...	103·0	101·0	104·0	104·0	109·0	109·0
December 1 ...	100·0	98·2	101·0	101·0	106·0	106·0
2 ...	95·7	92·0	94·5	94·5	100·0	100·0
3 ...	86·7	81·2	82·2	87·2	98·2	118·0
TOTALS						
Dec. 21–June 30	11·0	10·6	10·8	11·8	13·8	17·7
July 1–Dec. 20	16·5	16·2	16·6	16·6	17·6	17·6
Year	27·5	26·8	27·4	28·4	31·4	35·3

PART I

THE EFFECTS ON LOCAL INTERESTS

INTRODUCTION

A summary account of the Equatorial Nile Project has been given in the previous chapter. In the previous volume the records of our survey of the Jonglei Area have been presented in some detail. This has been necessary as a preliminary to our investigation of the effects of the Project and later, to our suggestions for the measures which might be applied to remedy the losses which will result. The direct or primary effects will, of course, be hydrological—changes in the present seasonal fluctuations in river levels. The reader will realize that such alteration in the river régime will set up a whole chain of ecological events, resulting in changes in soil type, vegetation, and hence grazing values, on the flood-plain of the White Nile system. Changes will follow from the draining of swamps at present produced by seasonal inundations of varying depths and duration, as well as from the opposite—the permanent flooding of areas which at present dry out when the river drops. Moreover in some reaches there may be a heavy reduction in fish population, in others no reduction but an increased dispersal of the fish in deeper water, making them more difficult to catch.

There will also be effects on land in the flood-plain which, when exposed, is actually or potentially of value for the production of crops. There will be changes—not necessarily disadvantageous—in the present system of communications, and there will be other secondary effects of perhaps lesser importance which must be examined in the interests of the people who live in this area and of the Sudan as a country.

Under present conditions the economy of the inhabitants is well adapted to the characteristics of the environment, as, we venture to hope, we have already demonstrated in our previous volume. Generalizations are not everywhere valid, or are valid to a lesser degree in some areas than in others, but it seems safe to say that the large majority of the people of this area are, in one way or another, dependent on the natural fluctuations of the Nile for their livelihood, even though that dependence is largely seasonal and restricted to the dry months of the year. We must therefore examine this chain of effects which will start with hydrological alterations and end in no less radical changes in the local economy, changes which are likely to be detrimental unless steps are taken to provide sound alternatives.

2

CHAPTER 2. HYDROLOGICAL CHANGES AND EFFECTS

1. INTRODUCTION

Following the description of the Equatorial Nile Project given above we now proceed to examine its effects. For this purpose several points must be made clear.

Our analysis of the effects in detail is based on what will happen in a normal year in the 55 m/d Canal stage, on the assumption that the 'Direct' Line of the Jonglei Canal will be followed. The Jonglei Area is divided for this purpose into three hydrological Zones which have been explained in a previous chapter and are :

Southern Zone: From Nimule to the Bahr el Jebel barrage downstream of the Atem Head between Lakes Fajarial and Papiu.
It is important to note here that in the intermediate constructional stages the boundary between this and the Central Zone will be at Canal Head, i.e. at Jonglei, while in the 55 m/d stage it will be at the Bahr el Jebel barrage, i.e. at the Atem Head.

Central Zone: From the Bahr el Jebel barrage to a line drawn roughly through Yoynyang on the Bahr el Ghazal, Buffalo Cape on the Bahr el Jebel, Fangak on the Bahr el Zeraf, and Abwong on the Sobat.

Northern Zone: From the northern boundary of the Central Zone to Kosti.

We deal first with the hydrological effects of the Project on each Zone in the 55 m/d Canal stage. This is followed by general considerations of the effects of intermediate constructional stages, of the extension to the 80 m/d Canal stage, and of flood-escape discharges.

2. CHANGES AND EFFECTS UNDER NORMAL OPERATION OF THE PROJECT IN THE 55 M/D CANAL STAGE

SOUTHERN ZONE

THE MAIN RIVER

NIMULE TO JUBA

In this reach the river is swift-flowing and confined to a narrow channel, so that alterations in the discharges will have little or no effect outside the main channel of the river. The construction of a balancing reservoir (or series of reservoirs) to control the torrents will, however, radically alter conditions in the valley. Whatever may be the final result of the negotiations over the site of the Lake Albert Dam, we shall show later that a dam at Nimule is almost essential for control of the torrents ; if the Lake Albert Dam itself is not built at this site, then a low-level dam for a balancing reservoir will be necessary. There may also have to be another dam (or series of dams) between Nimule and Rejaf to assist in this control. Since this part of the Project is still under investigation, we can do no more than state that there may be changes and note that further investigations will have to be made when the design is complete.

JUBA TO THE ATEM HEAD

In Table 191 (p. 437) we have set out the principal changes in the Southern Zone. Future maximum and minimum discharges at Mongalla will be almost the same as at present, but will occur at the opposite times of the year. From the detailed surveys of the Mongalla-Gemmeiza and Aliab valleys and the cross-sections of the Bahr el Jebel in the Southern Zone (see Vol. I, pp. 1, 49) it will be noted that this reach of the river is characterized by flood-plains bordering it, below it in level, and bounded by high ground on one side and by the deltaic river bank on the other. We have also explained that these flood-plains receive water, or moisture, in five different ways, namely :

(i) From the Bahr el Jebel by spill over the crest of the river bank and in spill-channels.
(ii) From the Bahr el Jebel by backwater from the downstream end.
(iii) From local inland watercourses.
(iv) From the Bahr el Jebel through an underground water-table.
(v) From rainfall.

Owing to differences in degree in topographical and hydraulic features (i.e. water slopes and sizes of alluvial banks) between the Southern and Northern Zones, in calculating losses of flood-plain we are not able to apply the idealized profile method to the Southern Zone, as we have done in the case of the Northern Zone. The basic reason is that the idealized profile method assumes that the water-level across the valley is uniform from one side to the other and that the water surface is parallel to the low river profile. Whereas this is a valid assumption in the Northern Zone, our field investigations in the Southern Zone have shown that the flooding of the *toiches* depends predominantly on the backwater from farther downstream. It is on the basis of the surveys of the Mongalla-Gemmeiza and Aliab valleys and the backwater flooding from their downstream ends that our estimate of losses of flood-plain is based. Under the Project the Bahr el Jebel will be banked on the west from Tombe to the Bahr el Jebel barrage to reduce losses by spill. It will also be banked from 15 km. north of Bor to the barrage, on the east bank. South of Tombe the river will not be banked.

In considering the effect of changes in the river régime we have assumed that the areas normally flooded in the rainy season and uncovered in the dry season, i.e. the areas flooded by discharges between 58 and 92 m/d at Mongalla, will be lost because the *toiches* will be either banked off to prevent spill or flooded at the time they are normally needed for grazing. The figures are in Table 192 (p. 437), where it will be seen that the main river normally covers and uncovers only 774 of the 1,581 sq. km. of flood-plain.

Having considered the first two items in the list of sources of water supply, we must estimate what will be left when the available water is limited to rainfall, underground water-table, and the contribution of the local torrents. We know that rainfall alone is insufficient to produce *toich* grazing, but from the evidence collected in our surveys we know also that rainfall supplemented either by local run-off or by underground water-table is enough to produce such pasture. The Aliab Valley survey shows that the underground water-table may affect the *toiches* up to a distance of from 1 to 1·5 km. from the river. As the river will be high in the dry season, it is safe to assume that the extent of the water-table will not be reduced. The area affected by underground water seeping from the main river channels is estimated from the cross-sections to be 200 sq. km. between Juba and Bor (see Table 193, p. 437).

Area of Flood-Plain Irrigated by Local Watercourses

In the Southern Zone there are a number of local inland watercourses which join the Bahr el Jebel and its flood-plain. These include the Luri, Koda, Gwir, Tapari (or Gel), Khors Wanga and Para, and a number of smaller streams of local origin. These streams will be of immense importance in the future when, under the Equatorial Nile Project, spill from the Bahr el Jebel is eliminated. It is unfortunate that no measurements have yet been made of their discharges, and steps should be taken to erect gauges on them at the earliest opportunity. In Volume I we have estimated the run-off of the first four from rainfall and catchment areas (Table 43, p. 76). The average annual discharges of the Luri, Koda and Gwir total 321 million cubic metres. The flow of the Tapari is estimated to be 440 million cubic metres in an average year, but since it discharges into Lake Fajarial, which is 5 km. from the northern limit of the Southern Zone, it does not contribute much to this Zone. In order to estimate the areas which might be irrigated by these rivers we make some comparisons between the flood-plain of Khor Gwir in the Aliab Valley, which has been carefully surveyed, with irrigation in the Gezira and elsewhere. Climatic data for Malek and Wad Medani are given below:

CLIMATE IN THE ALIAB VALLEY

	Malek		Gezira Research Farm, Wad Medani	
	August	September	August	September
Rainfall in mm.	131	120	143	69
Relative Humidity %	87	83	77	70
Mean Daily Temperature °C....	25·8	26·8	27·8	28·9
Piche Evaporation mm./day ...	2·5	3·1	7·2	8·2

From the records of irrigation in the Gezira[1] in the 20-year period 1925–45 the average consumption of water in August and September is 500 m^3.p.f. of crop per month. The crops, when watered for 8 months from August to March, take a total of 6,100 m^3. p.f., or an average of 762 m^3. p.f. per month. In the Gash Delta the land is given one watering amounting to 5,200 m^3. p.f. which is put on in one month, the remarkable soil of the delta being able to absorb over 1 m. depth of water. The average annual rainfall there is not more than 327 mm.

In the six months from mid-April to mid-October the rainfall at Malek averages 116 mm. per month. On the basis of climate alone, we would expect less water to be needed in Khor Gwir than in the Gezira. The soils are not vastly different and major slopes are of the same order, but in the Gezira there is an accurately controlled and intricate distributing system of canals, whereas in the Aliab there are only a few small natural channels obstructed by thick growth of grass. It is obviously not possible to make an accurate forecast of the area which run-off in local watercourses will cover, but from a consideration of the above figures it seems reasonable to take a water-duty of 4,200 m^3. p.f. spread over 6 months or 700 m^3. p.f. per month.

This is equivalent to one metre depth of water applied in addition to rainfall, and a million cubic metres will cover one square kilometre.

The flow from Khor Gwir (117 million cubic metres per year—see Table 43, p. 76) will probably cover about 100 sq. km. in the Aliab Valley, which, from topographical considerations, is possible. The Luri and the Koda also average about 100 million cubic metres each, but the area they can irrigate is limited by the configuration of the land to about 10 sq. km. on the Koda and 40 sq. km. on the Luri. The Tapari (Gel) joins the Aliab *toiches* at Lake Fajarial some 5 km. from the Atem barrage, and it would probably not cover more than 20 sq. km. in the Southern Zone (but much more in the Central Zone). Finally our field observations show that the effect of the smaller streams and Khors Wanga and Para is by no means negligible and it seems reasonable to allow about 30 sq. km. from all smaller streams. The results have been summarized in Table 194 (p. 438) where it will be seen that approximately 200 sq. km. will still be irrigated naturally by local watercourses in the Southern Zone.

Conclusion

We estimate that the losses of flood-plain along the Bahr el Jebel will amount to about 774 sq. km., either because spill is prevented by banking, as in the Aliab Valley and east of the Bahr el Jebel north of Bor, or because the river seasons are reversed and the flood-plain will be inundated at the wrong time of the year. On the credit side we have calculated that some 200 sq. km. are affected by the underground water-table supplied from the main river and this condition will continue; another 200 sq. km. will continue to be irrigated naturally by local watercourses. In the Aliab Valley, since it will be banked off, both these alternatives will produce pasture in the dry season, but south of Tombe, where it is assumed that there will not be any banking, some of the alternative areas will be flooded by the high discharges in the timely season. It is difficult to estimate exactly where river spill and the alternatives will overlap, but generally speaking the area watered by local watercourses is separate from that affected by the Bahr el Jebel and that supplied by underground water is above normal high river, and on the whole we might say that both areas will produce pasture which will be accessible.

From an examination of the data on the Mongalla–Gemmeiza *toich* it will be seen that at a discharge of 90 m/d the water-level does not top the crest of the river bank, though spill and backwater channels carry water from the lowest discharges.

INLAND WATER-SYSTEMS

In the previous section we have described how local inland watercourses will affect the flood-plains of the Bahr el Jebel in the Southern Zone. The slopes of these watercourses towards the river vary from 63 cm. to several metres per kilometre at their mouths (Table 3, p. 50). There is therefore no possibility that the backwater from the river will affect them appreciably when the river is high in the dry season.

DOMESTIC WATER SUPPLIES

Changes in the river régime will not affect domestic water supplies in the Southern Zone in any way.

IRRIGATION AND DRAINAGE

The Equatorial Nile Project will have an extremely beneficial effect on potential irrigation and natural drainage of the *toiches* in the Southern Zone. In the rainy season the river will be kept low, so that levels will permit free drainage northwards of the flood-plains bordering the river from Juba to the Atem barrage. From the data collected in the Mongalla–Gemmeiza and Aliab Valley surveys (Tables 375 and 388, pp. 829, 841), it will be seen that almost the whole of both valleys can be commanded for irrigation from the Bahr el Jebel even at the lowest future discharge of 57 m/d. With a high discharge in the dry season, gravity irrigation should be possible almost anywhere on the *toiches* in the Southern Zone. Where banking is employed—as from Tombe northwards—such irrigation could be under control, but south of Tombe the flood-plains would be covered in the dry season unless all the deep spill-channels were closed.

CENTRAL ZONE

THE MAIN RIVERS

At present the flow in the swamps is measured at Jonglei latitude, where conditions are suitable. When discussing quantities of water in this section we must refer to discharges at Jonglei, though in fact the head of the *Sudd* Diversion Channel will be on the Atem some 50 km. farther south along the Bahr el Jebel.

The average annual swamp flow at Jonglei is 23·4 milliards. At Buffalo Cape and Fangak the average flow totals 14·5 milliards, which does not differ appreciably from the flow at the

Tail of the Swamps of 14·3 milliards. Assuming that normal transmission losses amount to 10 parts per 100,000 per kilometre (*The Nile Basin*, Vol. VII, p. 84) over a distance of 644 km., the distance from Jonglei to the Sobat mouth via the Bahr el Jebel and White Nile, the normal loss will be about 1·5 milliards and the flow at the Tail of the Swamps will be 21·9 milliards. The difference of 7·6 milliards represents the amount of spill into the swamps, whose total area is estimated to be 6,545 sq. km.[2] between Jonglei and Lake No, including the swamps of Bahr el Zeraf.

Under the Project the controlled flow at Jonglei will be 35 m/d in the untimely season and 30 m/d in the timely season. The flow at the Tail of the Swamps corresponding to these two discharges at Jonglei is 29·4 and 26 m/d respectively (Table 195, p. 438). Losses at 30 m/d are therefore 13·3% and, with the same percentage loss at 35 m/d, the Tail of the Swamps discharge will be 30·4 m/d. Relative to the flow in the dry season, the flow in the untimely season will spill at the rate of 1 m/d.

In addition to this slight spill from the Bahr el Jebel, there will be run-off from the Tapari (Gel), estimated at 400 million cubic metres per year. The mouth of the Tapari (Gel) is at Lake Fajarial, and as the Bahr el Jebel will be banked the Tapari will flow into Lake Papiu. Under present conditions the Aliab flow is ponded by a bluff of land downstream of Lake Papiu which forces it back into the Bahr el Jebel. It appears reasonable to assume that the Tapari run-off will enter the Bahr el Jebel in the future at the same point, and will contribute to natural spill from the Bahr el Jebel farther downstream. The only other flow known to join the Bahr el Jebel is from the Lau (or Yei) via Khor Moich into Lake Nuong. The flow of the Lau at Yirol is estimated at one milliard in an average year. It is unfortunate that there are no records of the Khor Moich, but it has been observed to flow strongly into Lake Nuong. We have pointed out that the defined channel of Khor Moich seen from the air indicates considerable slope towards Lake Nuong (Vol. I, p. 28), and the deep part of the section of the river is roughly 20 m. wide and about 3·5 m. deep at the point where the projected road trace from Gainglil to Shambe crosses it. It is therefore comparable with the Tapari (Gel) at Pap, and, though its channel is not continuous from Lake Nyubor, there is evidence that overland flooding reaches it from the Lau. It is obviously important to gauge the flow in Khor Moich to determine its contribution to the flooding of the swamps, but until this is done we can only give the best estimate possible, and we suggest that 250 million cubic metres per year is not unreasonable, or one-quarter of the flow of the Lau at Yirol.

In order to estimate the effect of the addition of the flow of Khors Tapari (Gel) and Moich to the Bahr el Jebel we have adopted the following method.

The total quantity of water supplied by these two khors is estimated to be 0·650 milliard. Fortunately, the flow of the Lau (Yei) at Yirol is gauged and we have estimated its flow in 10-day periods in Table 49 (Vol. I, p. 82) which total 1·09 milliards per year. If we assume that the contributions of the Tapari and Moich are on the same pattern, which is not unreasonable, then by simple proportion (60%) we can estimate the monthly contributions of the latter to the Bahr el Jebel discharge. The results are given in Table 196, p. 438). In the same table we give the computation for calculating the amount of spill and the area covered. We assume that the former is the difference between the actual losses in the swamp flow (Table 195, p. 438) and the losses at a discharge of 30 m/d at Jonglei, which amount to 13·3%. It will be seen that the total amounts to 0·362 milliard, which will cover 362 sq. km., and this is the total area which will be covered by spill from the Bahr el Jebel and local run-off.

In connection with the area of alluvial bank affected by underground seepage from the Bahr el Jebel in the Central Zone, we are unable to do more than say there will be some benefit from this source. The cross-section at Peake's Track (Fig. A 15) shows that the swamp formation is similar to that in the areas surveyed in more detail in the Southern Zone. Soil samples show a much higher proportion of clay in the Central Zone, and the existence of bands of silt, or sand, is indicated by the presence of those types of vegetation associated with it in the Southern Zone.

The total future area of flood-plain irrigated naturally in the Central Zone is estimated to be about 362 sq. km. Over the distance from the Atem Head to Buffalo Cape, about 530 km., the area can be regarded as having an average width of 0·68 km.

INLAND WATER-SYSTEMS

The Eastern Plain

Banking east of the Bahr el Jebel from 15 km. north of Bor, and dredging and banking of the Atem from its head to Jonglei, will eliminate all spill from the river over the Eastern Plain, and the construction of the Canal on the 'Direct' Line will cut across the drainage depression from Pengko by which rain-flooding travels north-west between Kongor and Duk Faiwil.

The area bounded by the Bahr el Jebel, Bahr el Zeraf, and the ' Direct ' Line of the Canal will not therefore be subject to overland flooding from farther south or from river spill. On the other hand on the plain east of the Canal line rain-flooding will be intensified and Khor Chieth, or the upper Atar, will carry more flow.

If a suitable cross-drainage structure is built where the Khor Chieth crosses the line of the Canal natural conditions will not be affected, but should the alternative of diverting the Khor Chieth into Khors Kwanjor and Fullus be adopted it would lead to heavier flooding to the east and less to the west of the Canal. It is obvious that gauges should be erected on the inland water-systems of the Eastern Plain, including the wide depression to the east of Pengko, so that the hydrology of the whole area can be explained and the quantities of water involved in overland flooding estimated.

Farther to the north of the Central Zone and east of the Bahr el Jebel lies Zeraf Island which is intersected by numerous watercourses. Our examination of the gauge-readings inland on some of these watercourses and at their junctions with the Bahr el Zeraf shows that run-off drains to the river during the rains and the river spills inland in the dry season.

Aligning the Canal direct from Jonglei to the mouth of the Sobat (i.e. the ' Direct ' Line) has the advantage that this natural function is not interfered with, as would be the case if the Canal were to run close to the edge of the present swamps. A lot of good grazing is produced in these watercourses by rainfall and river spill ; lower river levels in the future will hasten drainage, and river spill will be much reduced, resulting in loss of the pasture. Generally speaking we expect the same physical processes to occur in the future, but at lower levels and in different watercourses which lie in what is now permanent swamp. The amount of pasture which will be available will depend on river spill, and has been taken into account when calculating the areas which will be irrigated naturally by spill (see p. 420).

The Western Plain

We have already considered the effects of the Project on the Tapari (Gel) and Khor Moich in the section on main rivers, since their waters run into the Bahr el Jebel. What we consider now is the effect of elimination of river spill from the plain west of the Bahr el Jebel.

From the survey we have seen that this particular area receives water according to location as follows :

(i) From the Bahr el Jebel by spill over its left bank.
(ii) From the south-western torrents.
(iii) From the Bahr el Ghazal.
(iv) From rainfall.

In the *First Interim Report* it was estimated that the quantities involved were 6·2 milliards from the Bahr el Jebel and 6·4 milliards from the south-western torrents. These enormous quantities of water would lead, one would expect, to a vast permanent swamp with large areas of papyrus. Actually all that we have seen, even in a very wet year, are considerable expanses of *Hyparrhenia rufa* grass mostly under water, and, from an air reconnaissance, some areas of open water and a little papyrus.

In the survey of the Jonglei Area (Vol. I) we have given the latest estimate of the contribution of the south-western torrents measured on the line of the Tonj-Yirol road, which is 3·25 milliards, and have pointed out how only a fraction of that reaches the Western Plain.

In the *First Interim Report*[(3)] it was estimated that 4·5 milliards spill over the left bank between Jonglei and Peake's Latitude and 1·6 milliards over both banks between Peake's Latitude and Buffalo Cape. Not all of the loss can be spill, and it is clear that some account should be taken of normal losses in transmission. If, with the authors of *The Nile Basin*[(4)], we assume that normal transmission losses amount to 10 parts per 100,000 per km. we can compute them as follows:

1927–36 average annual discharge at Jonglei Latitude=23·0 milliards (*The Sadd Hydraulics*, p. 29)
Distance to Peake's Latitude=265 km.
Total normal transmission loss=0·6 milliards.

1927–36 average annual discharge at Peake's Latitude=16·1 milliards (*The Sadd Hydraulics*, p. 29).
Distance to Buffalo Cape=185 km.
Total normal transmission loss=0·3 milliards.

Hence the amount spilled towards the Western Plain[(5)] is :

From Jonglei to Peake's Latitude ... $\frac{2}{3}$ (6·9−0·6)=4·2 milliards.
From Peake's Latitude to Buffalo Cape $\frac{1}{2}$ (1·9−0·3)=0·8 milliards.

Thus in the Central Zone we come to the conclusion that on the average 5·0 milliards of river spill travel westwards between Lake Nuong and Buffalo Cape, and that most of this will be eliminated in the future. The quantity of river spill and the area of flood-plain inundated by the main river under the Equatorial Nile Project in the Central Zone have been calculated in the section on main rivers (p. 420). It is most important to assess whether the natural irrigation from the south-western torrents will be enough for the production of good grazing. If we assume that one-quarter of the average annual flow (3·25 milliards) on the Tonj-Yirol road line reaches the Western Plain, then the quantity of water reaching it will be 810 million cubic metres per year and, on the same basis as before, this should irrigate 810 sq. km. of pasture, in addition to rainfall and without taking into consideration spill from the Bahr el Ghazal. The latter is of the order of 1·7 milliards per year (Vol. I, p. 27), assuming that the river spills equally over both banks.

DOMESTIC WATER SUPPLIES

There are a number of inland water-systems which form the main sources of drinking-water supplies for people in the Central Zone. On the west bank of the Bahr el Jebel, between Lake Nuong and Lake No, spill reaches Khors Chier and Neang, which later become the Puragwier and the Bilnyang and which are seldom known to dry up even at the Ler-Wun Shwai road-crossing. Farther north Khor Waard carries spill-water inland until late in the dry season, and the same can be said of a network of channels leaving and returning to the Bahr el Jebel between Adok and Buffalo Cape. On the east bank north of Jonglei there are no similar spill channels outside the swamps until one reaches the Zeraf Cut. Northwards from there, the Zeraf Island in particular is intersected by inland watercourses which have been seen to carry water inland in the dry season, and the same applies to the east bank of the Bahr el Zeraf south of Fangak.

By and large a very important source of domestic water supplies will be lost under the Equatorial Nile Project, particularly in the Central Zone in the channels mentioned above and other small ones, and remedies for these losses must be provided.

Attention has been drawn in Volume I of this report (p. 36) to the fact that the depth to water-table below the Eastern Plain increases approximately with distance eastwards from the river, whereas from south to north the depth below ground level does not change although the ground falls over 100 feet in the area covered. This certainly suggests that the Bahr el Jebel is the main source of underground water. If this is so we can expect two effects from the Project ; first that drying-up of the swamps will reduce percolation underground and therefore lower the water-table, and secondly, by taking water across country, the Canal, on the same assumption, will raise the underground water-table in its neighbourhood. On the whole it seems likely that on the Eastern Plain the losses in the first case will be balanced by gains in the second. On the Western Plain and on the Zeraf Island there are few wells to-day. Some of them are affected by local watercourses as at Ler, and others, we assume, by the Bahr el Jebel and its swamps, such as at Fagwir on the Zeraf Island. There may also be some deterioration in underground supplies in these two areas.

IRRIGATION

There are no examples of artificial irrigation systems in the Central Zone, and therefore no effects to note. As far as natural irrigation is concerned we have mentioned in the previous volume that the largest and most important natural irrigation system is from the Bahr el Jebel into the swamps of the Central Zone.

Between the Atem Head and Buffalo Cape-Fangak there are approximately 6,554 sq. km. of permanent swamps, including those on the Bahr el Zeraf. All this land is commanded from the river by gravity flow. Under the Equatorial Nile Project most of these swamps will be dried out and the land made available for irrigation schemes or rain cultivation.

Secondly, the Jonglei Canal on the ' Direct ' Line will traverse the Eastern Plain from Jonglei to the Sobat mouth, an area which is suitable for the layout of large irrigation schemes. One of the principles in the design of the Canal is that water-levels in the Canal should conform as closely as possible to natural ground levels. Apart from the very remote risk entailed by designing the Canal so that the water-level will be above ground level, it appears that the main purpose of this stipulation is to prevent abstraction of water from the Canal by gravity flow. Therefore, in any irrigation schemes which may be necessary for remedial measures on the line of the Canal, water will have to be pumped. The effect of the alignment and present design of the Canal will be to make it possible to irrigate the country which it traverses, but only by resorting to pumping water from it. Alternatively the design of the Canal could be changed. This is a point of great importance to which we shall refer later.

DRAINAGE

In the survey of the Jonglei Area we noted that there was no natural drainage to the main river during the rains in the Flood Region and that the Eastern and Western Plains suffered from lack of drainage because of soil and topography. Under the Equatorial Nile Project there will still be no drainage directly into the main rivers, but the depressions bordering the rivers, where there are no swamps, will no longer be filled by river spill except in limited quantities, and rain-water and overland flooding will be able to collect in them and run northwards. This water will be ponded where bluffs of higher ground are adjacent to the main river channel until the level in the latter falls, as it will slightly in the timely season.

In particular the area bounded by the Jonglei Canal, the White Nile, the Bahr el Zeraf and the Bahr el Jebel will be protected from overland flooding from the south and east by the Canal itself, and since there will be only a very small quantity of river spill, conditions will be suitable for drainage.

NORTHERN ZONE

THE MAIN RIVERS

The detailed analysis of flood-plain areas given in this section was carried out in 1950. At that time we were not able to refer officially to Dr. Amin and Mr. Bambridge's proposals for discharges in the 55 m/d Canal stage of the Equatorial Nile Project, and the calculations were based on the figures given in ' General Comments on the Jonglei Team's First Interim Report of June 1946 ', by the Inspector-General of Irrigation in June 1947 (unpublished).

Discharges at the Tail of the Swamps were taken as 73 m/d and 39 m/d in the timely and untimely periods respectively. In the later document they are given as 74 m/d and 45 m/d. The differences are small, particularly in the figures for the timely season with which we are largely concerned in calculating losses of flood-plain area. For this reason, and because there may be subsequent modifications, we have not attempted to alter the original analysis.

In the Northern Zone we are concerned with the White Nile from Lake No to Kosti, the River Sobat from Abwong to its mouth, the Bahr el Zeraf north of Fangak, the Bahr el Jebel north of Buffalo Cape, and the Bahr el Ghazal between Yoynyang and Lake No. At present, during the latter part of the dry season the discharge of the River Sobat at its mouth falls to about 7 m/d (as compared with its maximum of 67 m/d in November), and, as the discharge at the Tail of the Swamps does not vary very much from its mean of 39 m/d, it is the fall of the Sobat which exposes the flood-plains where the *toich* pasture grasses are found from the southern limits of the Northern Zone to a point somewhere north of Melut. From Melut northwards the operation of the Jebel Aulia Reservoir is of increasing importance, until, as will be seen later, at Jebelein it can be considered the ruling factor.

As the Egyptian Irrigation Department in the Sudan has been measuring these rivers for many years and has taken cross-sections of the White Nile north of Malakal, at intervals of about 20 km., to Jebelein, and some south of Malakal, this analysis starts with a considerable advantage over all others in that there are more data to work on. In addition, the work of J. W. Wright on the White Nile flood-plain between Malakal and Jebel Aulia (see Vol. III, Chapter 2) has provided us with a firm foundation on which to build.

The Egyptian Irrigation Department records have been published up to 1942 in Volumes II and III of *The Nile Basin* with their supplements. In order to find out the effect of the operation of the Jebel Aulia Reservoir, we have obtained from the same source gauges and discharges for Malakal, Melut, Renk, Jebelein, Rabak, Ed Dueim, and Jebel Aulia for the period 1943 to 1949, which have not yet been published by the Physical Department of the Public Works Ministry in Cairo. We have also been supplied with prints of the 22 cross-sections of the White Nile between Malakal and Jebelein.

This then is the satisfactory array of data, and on it we attempt to calculate and plot the exposure of the flood-plain north of Malakal under the future régime, in the 55 m/d Canal stage, throughout a ' normal ' year. From these graphs it will be possible to see exactly what the losses amount to in three divisions of the river, namely from Malakal to Melut, from Melut to Renk and from Renk to Jebelein. North of Jebelein it will be seen that the effect of the future régime will be negligible in comparison with the flood-plain covered and exposed by the operation of the Jebel Aulia Reservoir.

Future Discharges

At Malakal

The future discharges from the Tail of the Swamps and the Canal are given in ' General Comments on the Jonglei Team's First Interim Report of June 1946 '. In the 55 m/d Canal stage, the combined swamps' and Canal discharge at Malakal will be 73 m/d between December 21st and June 30th, and 39 m/d for the rest of the year.

These have been added to the normal discharge of the Sobat (1912–42 from *The Nile Basin*, Vol. IV, 3rd Supp.) in order to obtain the future Malakal discharges. These are given in Table 197 (p. 439) together with the present normal discharges at Malakal.

Time-Lag

The normal time of travel of a fluctuation between Malakal and Khartoum is 20 days at all seasons (*The Nile Basin*, Vol. VII, Plate 15 and Appendix IV). As the distance is 811 km., the velocity of travel of a fluctuation is therefore 40 km. per day. Table 198 (p. 440) shows the time-lag in days from Malakal to Melut, Renk, Jebelein, and Rabak.

Transmission Losses

In *The Nile Basin*, Vol. VII, Table 14, p. 84, the losses between Malakal and Renk for the period 1928–44 are given as 74 p.p.m. per km. In future, with a higher mean annual discharge, the losses will be greater as there will be higher discharges and more of the flood-plain covered in the timely, or dry, season when evaporation is at its greatest; not, as at present, only in the untimely season when rainfall more than balances evaporation. However, in the absence of more accurate data we can reasonably assume that the losses will be 75 p.p.m. per km. Table 198 shows the losses at the places we have selected north of Malakal and the percentage of the Malakal discharge remaining.

At Melut, Renk, Jebelein, and Rabak

Future discharges at these places are given in Table 199 (p. 441) against the 10-day period for Malakal. No account has been taken of the filling and emptying of the Jebel Aulia Reservoir.

Future Gauges

The prediction of future gauges is not quite as straightforward as the prediction of future discharges. At present gauge-discharge curves can only be constructed for the river rising and falling under natural conditions. In general there are two curves, one for rising river and one for falling river, the latter showing a higher gauge-reading for any discharge than the former. As the rate of rise or fall also effects the gauge-discharge curves, and as in future there will be abrupt changes at the beginning and end of the timely period, and as the normal rate of rise or fall during the timely season will occur at levels different from the present ones, the forecast of future levels calls for a certain amount of judgment and cannot be quite exact.

Furthermore under natural conditions before the Jebel Aulia Dam was built the ponding effect of the Blue Nile was felt at Rabak and Jebelein, so that the correlation between Malakal discharges and the gauges at those places was not normal. As there will be higher discharges in future in June when the Jebel Aulia Reservoir will be empty, interpolation and extrapolation has been necessary.

At Malakal

Gauge-discharge curves for rising and falling river for Malakal have been constructed from figures for observed discharges for the period 1943 to 1949 (supplied by the Egyptian Irrigation Department and not previously published), and are reproduced in Fig. F 5.

It will be noticed that the discharges corresponding to a gauge-reading of 11·50 m. are 71 m/d when the river is falling and 80·5 m/d when it is rising. If we were to assume that 1912–42 mean gauges and discharges gave a reliable gauge-discharge curve, the discharges corresponding to the Malakal gauge of 11·50 would be 77 m/d when the river was falling and 82·6 m/d when it was rising. As there is a considerable difference we have adopted the former curves, based on the most recent discharges of the river. It is possible that there has been some change in the White Nile at Malakal since the record Sobat flood of 1946–47.

During the timely season in future the change-over from a falling river to a rising one will occur at a discharge of about 80 m/d with steady conditions for about 2 months. At present the change-over occurs when the discharge is at its lowest, about 45 m/d, when the gauge discharge relationship is found to be very variable. The forecast of future levels at Malakal has been made by plotting the points for a falling river and for a rising river according to the present gauge-discharge relationships and by drawing a smooth curve between them which leaves the higher falling river curve on March 1st and joins the lower rising river curve at the beginning of May. The results are plotted in Fig. F 11 and compared with present normal gauges, and are listed in Table 200 (p. 442).

At Melut

The gauge-discharge curves for Melut were plotted from observed discharges taken between 1947 and 1949. Nearly all the observations were taken on a falling river, and the curve for the rising river is regarded as not very reliable. These curves are shown in Fig. F 6.

The future gauges at Melut were obtained from the discharges (Table 199) and the gauge-discharge curve, using the same procedure as for Malakal, except for July and August when the Malakal mean discharge relationship with Melut mean gauges was used as giving a better indication of the naturally rising river. The results are plotted in Fig. F 11, compared with present normal gauges, and are listed in Table 200.

At Renk

The gauge-discharge curves for rising and falling river at Renk were constructed from measured discharges of the river for the period 1928 to 1932 (before Jebel Aulia Dam was built) which are published in the first supplement to *The Nile Basin*, Vol. II. The curves are shown in Fig. F 7.

As Renk is affected by the backwater of the Jebel Aulia Dam, these curves are not applicable when the dam is in operation. In order therefore to determine future gauges at Renk when the dam is in operation and the Canal giving its full discharge, two more curves have been constructed, giving the relationship between the discharges at Malakal and the gauge-reading at Renk 10 days later when the reservoir is full, from figures supplied by the Egyptian Irrigation Department for the period 1943 to 1949. The discharges at Malakal were obtained by converting the 10-day mean gauge by means of the gauge-discharge curve (Fig. F 5), and the Renk gauge taken was the 10-day mean gauge for the period 10 days later. The curves for falling and rising discharges are given in Fig. F 10.

In constructing the curve of future gauges at Renk from March to July inclusive the normal gauge-discharge relationship (Fig. F 7) was used. As Renk is some distance from Jebel Aulia, the backwater has little effect there in March and July and the reservoir will be practically empty in between. From October to the end of January the reservoir will be full, and therefore the second set of curves applies (Fig. F 10). For February, when the reservoir is partly full, it is a simple matter to join up the curves for January and March already drawn; and for August and September, when the river is rising steadily, the same thing can be done without introducing any serious error. The resulting curve is plotted in Fig. F 12 in comparison with the normal river for 1912 to 1932 and the full Jebel Aulia operation from 1943 to 1949, and the figures are given in Table 201 (p. 443).

At Jebelein

From the figures supplied by the Egyptian Irrigation Department for the period 1943 to 1949 a curve correlating the discharge at Malakal with the gauge at Jebelein 10 days later, under the condition of full reservoir, has been made (Fig. F 10) in the same way as for Renk. The curve of future levels for October to January (reservoir full) is then easily drawn.

The predominant effect of the Jebel Aulia Dam is clearly seen in Fig. F 10. Although the range of discharges on the falling river curve at Malakal is from 110 m/d to 50 m/d, the level at Jebelein falls only 30 cm. from 12·63 to 12·33 m.

For the condition of empty reservoir we have to fall back on a simple correlation between the mean discharges at Malakal and the mean gauges at Jebelein (10-day lag) for the 1912 to 1932 period. However, as the natural rising river coincided with the natural rise of the Blue Nile, and as the effect of the latter was felt at Jebelein, the correlation for rising river is not normal. The curve for the falling river is normal, and so is the beginning and lowest part of the rising curve. In order to obtain the correlation for a rising river at the higher future E.N.P. levels in May and June, when the reservoir is quite empty, we have to extend the rising curve and join it to the top of the falling curve. The result is similar to other rising river discharge curves relative to the falling ones; it is shown by a dotted line in Fig. F 8.

The future gauges for March to July at Jebelein were obtained from this curve, and the remainder in February and in August and September by connecting plotted curves in the same way as for Renk gauges.

Jebelein normal gauges for 1912–32, Jebel Aulia régime normal gauges for 1943–49, and future E.N.P. gauges are plotted in Fig. F 12 and listed in Table 201.

At Rabak (Kosti Bridge)

Future E.N.P. gauges at Rabak were obtained in exactly the same way as for Jebelein. The Malakal discharge-Rabak gauge (12½-day lag) relationship with the reservoir full is plotted in Fig. F 10, and the correlation between Malakal mean discharges and Rabak mean gauges (12½-day lag) for 1912–32 is shown in Fig. F 9. The result, together with natural river gauges for 1912–32 Jebel Aulia and E.N.P. régimes, is plotted in Fig. F 13 and listed in Table 202 (p. 444). This concludes the description of how the gauges under the future régime have been obtained at Malakal, Melut, Renk, Jebelein, and Rabak.

Flood-Plain Areas

From Malakal to Jebelein

In Appendix IV to the *Third Interim Report* of the Jonglei Investigation Team, Mr. J. W. Wright, of the Sudan Survey Department, showed that for certain purposes the White Nile and its flood-plain north of Malakal could be considered as a trough, composed of a narrow low-water channel and a flood-plain increasing in width with successive increases in water-level above low water. The important conclusion of that report, which has enabled us to continue the investigation, is quoted below :

> "In the southern reach (Malakal to Jebelein) the total areas of flood-plain submerged at most intermediate levels could be estimated within 10% by using the existing cross-sections surveyed by the Egyptian Irrigation Department. For, in spite of their apparent dissimilarity, they show sufficient uniformity in the required characteristics of the river banks and flood-plain to make it possible to use mean values with comparatively small probable errors."

The method of estimating the flood-plains' widths consists of using the normal low-water level and the width of the water surface at that level as data on the 22 cross-sections of the White Nile between Malakal and Jebelein; and further of measuring the increase in the width of the plain flooded for small increments in level above datum, here assuming the water surface across the section to be horizontal in all cases. Wright found that the river could be divided into three reaches, for each of which a mean value of the idealized profile (the term he applies to the curve obtained by plotting flood-plain widths against increases in level above datum) could be used as applying to the whole reach or any part of it. They were from Malakal to Melut, from Melut to Jebelein, and from Jebelein to Jebel Aulia.

As we are concerned with tribal areas we have sub-divided the second reach into two, from Melut to Renk and from Renk to Jebelein. Furthermore, as it seemed advisable to carry out an independent check on Wright's work in view of its importance, we obtained copies of the 22 cross-sections between Malakal and Jebelein.

These were then re-plotted at twice the vertical and horizontal scales, and flood-plain widths measured for each rise of 10 cm. above datum. The positions of the cross-sections and the reduced levels of their data are given in Table 203 (p. 445). The widths of the mean flood-plains calculated in this way, compared with Wright's results, are given in Table 204 (p. 445). Though the values for flood-plain widths are substantially the same, there are some differences for which the following reasons are given.

From Malakal to Melut there are two factors which account for the differences. First, it was found that the cross-section at Detwok had been plotted 1 m. too high. It so happened that we decided to extend this section for 30 km. inland to determine levels, and as soon as this work was begun it was obvious that a mistake had been made. After checking, this was confirmed by the Inspector of Irrigation, Upper Nile Inspectorate, Malakal.

Secondly, at the highest levels Wright has included high land lying behind the ridges which border the river, and, from his point of view, correctly. It has been mentioned that the ridges are cut in places by khors and that at high river levels flooding may occur there. But we are attempting to estimate the changes in the grazing areas, and as it must take many years for *toich* grasses to establish themselves it is thought that, owing to the infrequency with which the high levels occur (for instance in 1909, 1918, and 1946), the area behind the ridge cannot be included in the grazing area unless the very high river becomes a regular feature. (Later investigations indicate that river flooding rarely occurs inland of the Shilluk ridge.)

For the reaches between Melut and Jebelein it is thought that the difference in the intermediate values can be explained by the fact that a larger scale was used and that the sections were re-plotted. On the small scales of the original cross-sections (vertical 1/100; horizontal 1/20,000) a slight variation in drawing the horizontal lines or in plotting the datum would account for considerable difference in flood-plain widths. The flood-plain mean widths and areas for each of the three reaches are given in Table 205 (p. 446) and are plotted in Fig. F 14.

The areas are obtained by multiplying the mean widths by the lengths of the reaches concerned, which are as follows :

Malakal–Melut	...	142 km.
Melut–Renk	...	178 ,,
Renk–Jebelein	...	102 ,,

We now revert to our tables of future gauges and calculate the mean gauges for each of the three reaches as above and for each of the three conditions, namely normal river, Jebel Aulia Dam in operation, and the future régime. The results are given in Tables 206 and 207 (pp. 446–7).

From these tables it is a straightforward operation to read off the areas of flood-plain inundated throughout the year for each of the three reaches and for each of the three conditions. This has been done, and the results are given in Tables 208 and 209 (pp. 447–8) and plotted in Figs. F 15 and F 16.

As a final check let us compare our results for the flood-plain areas between Malakal and Jebelein from the highest to the lowest levels with those estimated by Wright. It will be recalled that Wright related all areas to the Malakal gauge as shown in Table 28 of the *Third Interim Report*. We have, at Malakal, the highest gauge-reading in December, 12·75 m., and the lowest in April and May, 11·58 m. According to this table, the maximum flood-plain area which is given for a level of 12·70 (reservoir full) is 971 sq. km. between Malakal and Jebelein, and the minimum for 11·60 is 243 sq. km. Summing our results in Tables 208 and 209 we have for the highest and lowest levels flood-plain areas as follows :

	At Highest Level sq. km.	At Lowest Level sq. km.
Malakal-Melut	275	87
Melut-Renk	468	146
Renk-Jebelein	275	48
TOTAL	1,018	281

This shows fairly satisfactory agreement with the previous work.

It will be noted that as the river normally falls to 10·00 or datum at Malakal, the figure 281 sq. km. represents the maximum loss of flood-plain between Malakal and Jebelein. This is 27·6% of the total flood-plain.

From Tables 208 and 209 we can also deduce that the losses of flood-plain at the time when most of it is exposed are: between Malakal and Melut 87 out of 275 sq. km. or 31·5%; betwen Melut and Renk 146 out of 468 sq. km. or 31·2%; and between Renk and Jebelein 48 out of 275 sq. km. or 17·5%.

As far as pasture is concerned other factors must be considered, such as the time of exposure of the flood-plain and the time taken for the flood-plain to dry out sufficiently to allow burning. The diagrams show this clearly.

North of Jebelein

It has already been noted that the loss of exposed flood-plain between Renk and Jebelein will be as low as 17·5%, and the effect of the Jebel Aulia régime on water-levels at Jebelein and Rabak has been clearly demonstrated in Fig. F 10.

As an example of the effect north of Jebelein, we have selected the cross-section at Rabak and calculated the flood-plain widths at different levels up to full reservoir level. The results are given in Table 210 (p. 448) and Fig. F 14.

From the table of future gauges at Rabak (Table 202, p. 444) we are able to read off directly the width of flood-plain inundated there throughout the year under the normal river, Jebel Aulia and future régimes. The results are given in Table 211 (p. 449) and Fig. F 16.

If Rabak can be considered as the centre of the Jebel Aulia Reservoir and its gauge used to show the mean gauge between Jebel Aulia and Jebelein, then from Table 211 and from Table 26(c) of the *Third Interim Report* we have the following figures:

	Maxima		Minima	
	Gauge	Flood-Plain Mean Width metres	Gauge	Flood-Plain Mean Width metres
Future Régime ...	13·99	2,800	11·00	260
Jebel Aulia Régime ...	13·99	2,800	10·24	40
Natural River ...	12·26	925	10·00	0

On this assumption, it appears that the Jebel Aulia régime has increased the maximum flood-plain width from 925 to 2,800 m. and of this only 220 m. will be lost under the higher future discharges—or less than 8%.

It is hoped that this example is sufficient to show that north of Jebelein, owing to the operation of Jebel Aulia Reservoir, the loss of flood-plain will be negligible.

Present and Future Tribal Grazing Areas Between Malakal and Jebelein

The investigation has so far been based on reaches of the river, and it is now necessary to relate these reaches to tribal areas. This has been done in Tables 212 to 214 (pp. 449–50) which call for little explanation. The following points should be noted however. The tribal river frontages have been scaled as accurately as possible from a map (scale 1/250,000), and, as our predecessors did in Part V of the *Third Interim Report*, we have had to assume that the flood-plain area is divided equally between the two banks.

As the investigation applies only to the river between Malakal and Jebelein it must be noted that the Shilluk have a further 124 km. of river frontage south of Malakal compared with 266 km. north of it, and that the Baggara river frontage north of Jebelein is not included.

Area of Flood-Plain Between Malakal and Jebelein Related to Malakal Gauge

Whereas the analysis given above gives the losses in flood-plain areas, a more approximate result can be obtained by relating the areas to the Malakal gauge. This has been done and the results plotted in Fig. F 17, which also gives the gauge correlations for this reach of the river.

It must be emphasized that the figures given here concern areas of flood-plain, and not areas of pasture. Exactly how the areas of pastures of different feeding values are affected is estimated elsewhere in this report (see p. 463 et seq.).

Backwater Effects

White Nile: Malakal to Lake No

We have calculated above in detail the changes in flooding of the White Nile plain north of Malakal. We now proceed to investigate in more detail the backwater effect in the White Nile south of Malakal.

The maxima and minima effective gauge-readings at Malakal for present and future conditions are taken from Table 200 (p. 442) and from them, by examination of corresponding water-levels at the Sobat mouth, we arrive at the following:

	Malakal		Sobat Mouth	
	Present	Future	Present	Future
Max. Gauge-Readings	12·30	12·39	12·56	12·63
Reduced Levels ...	384·41	384·50	384·99	385·08
Min. Gauge-Readings	10·04	11·58	10·07	11·80
Reduced Levels ...	382·15	383·69	382·50	384·23

The Sobat mouth is the origin of the present backwater effects, and since the Canal, on the 'Direct' Line, will join the White Nile there, it will be the origin of the backwater effects in the timely season when the Sobat is low. Between Malakal and the Sobat mouth the best assumption we can make is that the flood-plain is similar to the idealized profile for the Malakal-Melut reach. South of the Sobat mouth we are able to use a combination of cross-sections taken from the Egyptian Irrigation Department contour survey maps of the White Nile to a scale of 1/50,000 and backwater computations on the basis provided by Dr. H. E. Hurst in Chapter XI of *The Nile Basin*, Vol. V.

From Table 195 (p. 438) by interpolation we obtain the following discharges at key points on the Bahr el Jebel and White Nile systems :

Gauging Point	Discharges in m/d	
Mongalla	37·5	31·7
Jonglei Latitude	35·0	30·0
Bahr el Zeraf below Cuts	7·8	6·2
Bahr el Jebel below Peake's Track	24·5	22·1
Buffalo Cape	23·8	21·7
Tail of the Swamps	29·4	26·0

For backwater computations we need to know the water surface levels of the natural river without backwater, and the backwater curve for the river based on slopes and water depths. For normal river when the Sobat is low the average slope from Lake No to the Sobat mouth is 2·82 cm./km. (1/35,400), though in between those points there are slight variations. In February 1922, the low period in the second of two years of low flow at Mongalla, the monthly mean discharge was 31·8 m/d and little more in March and January. Approximately three months later the flow at Buffalo Cape was 22 m/d, and at the Tail of the Swamps 25·4 m/d. These figures are very close to the timely season conditions for the Bahr el Jebel and White Nile systems under the Project, but without the backwater effect, and we have adopted the levels and slopes for that period as the datum levels for the backwater computation. Between Lake No and the Sobat mouth the slope was found to be also 2·83 cm./km. For the untimely period discharges under the Project, we have adopted the same slope and a Lake No gauge-reading taken from the gauge-discharge relation for the Lake No discharge site and published on Plate 95 of *The Nile Basin*, Vol. V.

Dr. H. E. Hurst has shown that for a fairly wide range of slopes and water depths the backwater curve for the White Nile changes little[6]. For our computation we have used the formula on p. 203 of the same volume, substituting values of 1/35,700 for the slope and 3·5 m. for the depth and increasing the range at the origin to 3·0 m. The results are plotted in Figs. F 20, F 21, and F 22, and given in Tables 217 to 220 (pp. 451–2). Several trial computations were made with other water depths which confirmed that the effect on the backwater curve was insignificant.

Since the flow of the Bahr el Ghazal at Khor Doleib is a negligible quantity (0·132 milliards per year), we assume that the higher discharge measured at its exit at Lake No is really Bahr el Jebel spill returning to the river, and in these computations we have also assumed that it is safe to ignore the Bahr el Ghazal contribution.

To obtain the areas of the exposed flood-plain we have extracted cross-sections, at 10 km. intervals from the Sobat mouth, from the Egyptian Irrigation Department's contour survey maps to the scale of 1/50,000. From these cross-sections the widths of flood-plain inundated at the four different levels, maxima and minima, present and future, have been determined, and from these the areas applicable to tribal areas have been calculated. The divisions of the latter are at the Zeraf mouth and 5 km. upstream of the Khor Yirr Gwol gauge. It is interesting to note that at Lake No itself there will in fact be a gain in flood-plain area covered and uncovered under the Project, because high levels at Malakal in the untimely season occur at the same time as the higher discharge down the Bahr el Jebel (35 m/d at the barrage) and low levels at the same time as the lower Bahr el Jebel flow (30 m/d at the barrage).

The areas of flood-plain according to tribal areas are given in Table 216 (p. 451).

Bahr el Jebel: Lake No to Buffalo Cape

Butcher has shown that when the Sobat mouth gauge exceeds 10·70 under normal conditions, the river between Lake No and Buffalo Cape spills into the surrounding swamps[7]. This corresponds to a gauge-reading of 13·60 at Lake No. Our computations show that under the Project the level at Lake No will fluctuate between 13·82 and 13·24, and therefore there will be some spill due to backwater in the untimely period and none in the timely period.

The theory of backwater curves is based on the assumption that the river has firm banks, and Hurst states that where there are fringing swamps, as along the Bahr el Jebel south of Lake No, the backwater effect is quickly dissipated[8]. However, since the spill under the Project in the timely season will be eliminated, we must attempt to calculate future conditions in the Bahr el Jebel south of Lake No. This has been done in the same way as for the White Nile. Datum profiles for the river without backwater effect have been obtained, for the lower discharges under the Project, by plotting on logarithmic paper water depths against discharges when the Sobat is low for the gauging sites at Buffalo Cape and upstream of Lake No. In theory the result should be a straight line with a slope of 1·79, which in practice was drawn through the points.

The results are given in Tables 224 to 226 (pp. 454-5) and plotted in Figs. F 23 and F 24.

Bahr el Ghazal

Owing to the lack of discharge sites and gauging points along the Bahr el Ghazal, we are unable to make any computations for this river, even if it were possible in theory. Since the discharge of the Bahr el Ghazal at Khor Doleib (30 km. from the mouth) is so small, it is not thought that it will be affected upstream of that point. Downstream of Khor Doleib mouth the river will be subject to fluctuations similar to those in the lower reaches of the Bahr el Jebel.

Bahr el Zeraf

Backwater profiles for the Bahr el Zeraf have been computed in exactly the same way as for the Bahr el Jebel. The results are given in Tables 221 to 223 (pp. 453–4) and plotted in Figs. F 25 and F 26.

River Sobat

The backwater profiles for the River Sobat have been calculated and the results given in Tables 227 to 229 (pp. 456–7) and plotted in Figs. F 27 and F 28. The Sobat channel is steep-sided and well defined at low levels. By applying the new levels to the cross-sections published in the *Veveno-Pibor Scheme*[9] it can soon be seen that the backwater in the timely season will not cover any flood-plain. In the untimely season the levels will be as they are now for all practical purposes. There will therefore be no adverse effects on grazing.

INLAND WATER-SYSTEMS

We consider first the area south of Malakal where levels along the main rivers are dependent on levels at Malakal. Present normal discharges and future discharges under the Project at Malakal are shown in Fig. F 4. Since future discharges will be within the range of those which have occurred in the past, we can assume that the backwater effect from Malakal will reach as far as at present, namely to:

(i) Abwong on the Sobat, 140 km. from Malakal gauge, and 117 km. from the Sobat mouth.

(ii) South of Fangak on the Bahr el Zeraf; Fangak being 133 km. from Malakal gauge, and 66 km. from the Zeraf mouth.

(iii) Buffalo Cape on the Bahr el Jebel, 197 km. from Malakal gauge, and 51 km. from Lake No.

(iv) Yoynyang on the Bahr el Ghazal, 236 km. from Malakal gauge, and 90 km. from Lake No.

It follows that inland watercourses which join any of the four main rivers between Malakal and the places mentioned above may be affected by the Equatorial Nile Project (see Fig. D 56).

Khor Fullus

The normal discharges at Khor Fullus mouth are: maximum 0·9 m/d in October falling to 0·4 m/d at the beginning of January, 0·1 m/d in April, and, after a period of no measurable flow, negative flows in June and July when the Malakal gauge usually exceeds 11·00 m.[10]

Under the Equatorial Nile Project two effects will be felt. First, since the minimum level at Malakal will be 11·58 on the gauge, 1·58 m. higher than at present, the backwater will probably extend at the most about 22 km. farther up Khor Fullus than it does now. However, since in its lower reaches the Fullus is deep and narrow (Fig. D 29) with no flood-plain, no appreciable losses will be felt. The rate of drainage between January and April will decrease, which might possibly benefit grazing areas farther up the khor. Secondly, the level at Malakal will rise to approximately its present normal maximum by the end of June, the rise starting in the middle of May. The backwater will extend to about 33 km. from Khor Fullus mouth, but again this will probably not affect pastoral economy since the rains normally begin in May at Malakal.

Khor Atar

Normally outflow from Khor Atar ceases by the end of December[11], followed by back-flow in January when the Malakal gauge exceeds 11·00 m. Natural drainage will not be affected adversely, but with higher minimum levels backwater will extend inland farther than at present. Assuming that the ground-slope is the same as in the lower reaches of the Canal, 7 cm/km., we can compare existing and future conditions tabulated below.

In the future, theoretically, there will be a sudden rise at the end of December due to increasing the Canal discharge, but in practice this will be gradual, and in any case the time of travel up the heavily grassed Khor Atar will be considerable. Therefore we consider that the backwater flow will probably range between 18·3 and 8·3 km., drying out slowly in between. Today the range is 11·3 km., and the slight decrease in future will be more than offset by the increased duration of flooding of the grasses. On balance there will be roughly no change.

KHOR ATAR: EXTENT OF PRESENT AND FUTURE BACKWATER

10-day Period	Malakal Gauges		Length of Backwater	
	Present (in metres)	Future (in metres)	Present (in kilometres)	Future (in kilometres)
December 3	11·79	12·75	11·3	25·0
January 1	11·44	12·45	6·3	20·7
2	11·11	12·28	1·6	18·3
3	10·83	12·14		16·3
February 1	10·61	12·04		14·9
2	10·46	11·93		13·3
3	10·36	11·85		12·1
March 1	10·27	11·78		11·1
2	10·19	11·72		10·3
3	10·11	11·67		9·6
April 1	10·05	11·62		8·9
2	10·04	11·60		8·6
3	10·05	11·58		8·3
May 1	10·06	11·58		8·3
2	10·19	11·73		10·4
3	10·38	11·93		13·3
June 1	10·61	12·12		16·0
2	10·82	12·28		18·3
3	11·01	12·43		20·4

Khor Yirr Gwol (Yergol)

Normally Khor Yirr Gwol flows slowly but consistently to the Nile throughout the year[12], and there is no reason to suppose that higher minimum levels will affect this at all, since its flow at present is not affected by the height of the river at Malakal.

In estimating the effects on Khors Fullus, Atar and Yirr Gwol we have considered conditions in a normal year. It should be borne in mind that there have been many years occurring in succession in which no flow was measured in any of the three watercourses. Owing to lack of data, it is not possible to examine in detail the effects on other inland water-systems in the Northern Zone south of Malakal, but in the cases examined we may summarize the results as follows:

Khor Fullus:	Backwater extended in the lower reaches where the khor is narrow, steep-sided and well defined.
Khor Atar:	Increased back-flow from January onwards, drying out slowly to a higher minimum level in April, but on balance no change.
Khor Yirr Gwol:	Apparently unaffected by levels in the White Nile.

We know from the previous study of the main rivers that there is a loss of approximately 30% of the flood-plain. From our detailed examination of the three khors for which records are available, we conclude that they will not be affected in any appreciable way by higher minimum levels on the White Nile. These three channels are near to Malakal, where the range of level is greatest. The farther south from Malakal, the less will be the range of levels and the smaller will be any effect of the Project on the inland water-systems. This leads to the general principle that in watercourses leading to the White Nile in the Northern Zone south of Malakal, the hydrology of the watercourses themselves is of major importance to grasses and grazing areas. Because they slope down to the Nile, levels in the main river are of minor importance to them, in contrast to the river *toiches* whose flooding depends entirely on levels in the main river.

North of Malakal we consider below the effects in the larger inland watercourses joining the river, namely Khors Wol, Nyadwai, and Adar.

Khor Wol

Khor Wol is an inland water-system consisting of a well-defined, deep channel about 200 m. wide with alluvial banks and with a very ill-defined flood-plain (see Fig. D 57). When it was seen in January 1950 the water, even after the record heavy rainfall at Malakal in the previous year, was confined to the deep channel, and we can safely assume that the old flood-plain is not covered today. The future minimum level at Malakal will be 11·58 m. on the gauge, which corresponds to about 11·50 m. at Kodok opposite to the mouth of the Khor Wol, or R.L. 382·35. Khor Wol Cross-Section No. 1 is 40 km. from its mouth, and the lowest point of the bed there is R.L. 385·10. As normal high river corresponds to R.L. 383·10 the backwater does not extend as far as the first cross-section. Levels along Khor Wol are unfortunately not available so we are unable to say exactly how far the backwater extends, but from observation it appears that there is water at the Malakal–Paloich road-bridge near Akoke, about 12 km. inland, as long as the Nile is high. This dries out rapidly as soon as the Nile falls, in December or January. It is probable that the backwater under the Project will extend a few kilometres (less than 10) upstream from Khor Wol mouth, but in comparison with the total length of Khor Wol and its tributaries this amount is insignificant.

Khor Nyadwai

From the cross-section west of Detwok (Fig. A 24) it can be seen that the bed of the Khor Atara, a tributary of the Nyadwai, is at R.L. 382·0, about 1·0 m. below normal high river level. This point is about 25 km. inland measured along the course of the Nyadwai. However, we know that water is ponded there to a depth of about 1·0 m. when the level of the White Nile falls, showing that the bed farther downstream is irregular, and we are unable to say exactly how far the backwater will extend under the Project when the minimum level will be 11·50 m. at Kodok or R.L. 382·35. But, on the same grounds as for Khor Wol, we consider the amount insignificant, in relation both to the rest of the Nyadwai system and its tributaries and to the immense areas of flood-plain on the Nile.

Khor Adar

From the detailed survey of the Khor Adar we have constructed its longitudinal section (Fig. K 28). Normal high river level at the mouth of the Khor Adar is R.L. 382·03, and normal low river is R.L. 379·95, and in future under the Project it will be R.L. 381·44. When the survey was made in 1949–50 the maximum gauge at Malakal had been 12·63, while the high-water mark at the mouth of the Khor Adar was R.L. 382·30 which corresponds to a gauge-reading of 12·36 at Melut. The actual maximum gauge-reading in 1949 at Melut was 12·41 m. The backwater effect was felt as far as 50 km. from the Khor Adar mouth, but when the White Nile levels fell in March and April the water profile did not alter significantly except in the first 20 km. from the river. Although discharges are not measured at present, it should be noted that Khor Adar contains water permanently. The cross-sections (Figs. K 25 and K 26) show that the Khor Adar has the same formation as the White Nile, namely a deep channel and a wide flood-plain bounded by deltaic banks. We also know that the flood-plain is not normally covered in the reach surveyed and water is confined to the deep channel. There are two exceptions to this rule; first, when there has been abnormal flooding into the Machar Marshes as in 1946–47, and secondly, within the area affected by backwater from the river. As far as grazing is concerned it is clear that even at Cross-Section No. 1, 5 km. from the river, where the future minimum level will be 381·44, the flood-plain will be exposed when the White Nile level falls from its maximum (see Fig. K 28). We therefore conclude that the Equatorial Nile Project will have an insignificant effect on the khor-bed grazing of Khor Adar.

This last example has shown in detail how little in fact the effect will be on a channel like Khor Adar. We had reached the same conclusions tentatively when considering other major inland watercourses in the Northern Zone, based on less detail and more general inferences. That our general conclusions are confirmed in detail in one important case gives us confidence in them.

DOMESTIC WATER SUPPLIES

The Equatorial Nile Project will have no effect on hafirs or open wells in the Northern Zone.

There will be some slight benefit in inland water-systems because the backwater will extend a few kilometres inland, but as some of the channels mentioned in the previous section contain water all the year round in any case, this benefit cannot be said to amount to anything appreciable.

IRRIGATION

Natural irrigation, by which in the Northern Zone we mean the natural flooding and uncovering of the *toiches* bordering the river, is the first item to consider under this heading. This has been fully examined previously when considering the effects on the flood-plains of the main rivers. The other example of natural irrigation in the Northern Zone, the Machar Marshes, will not be affected in any way.

All our topographical information and the evidence of practical examples go to show that irrigation by pumps is possible almost anywhere[18] in the Northern Zone, east of Lake No on the White Nile, north of Fangak on the Bahr el Zeraf, and on the banks of the Sobat. The minimum level at Malakal under the Equatorial Nile Project will be 1·58 m. higher than at present. This figure decreases according to distance from Malakal up the backwaters of the four main rivers, and also decreases northwards from 1·58 m. at Malakal to 1·0 m. at Kosti. It is obvious that higher minimum levels will be of immense benefit to existing and potential pump irrigation schemes. The range of levels at Malakal will be between 12·39 and 11·58, or 0·81 m. instead of 2·30 m. as at present. (This ignores, for practical reasons, theoretical high and low levels of short duration calculated immediately following changes in Canal discharges.)

Southwards the range will diminish to almost zero on the Bahr el Jebel and Bahr el Zeraf and to natural values on the Sobat and Bahr el Ghazal, according to distance from Malakal. Northwards the range will be at Melut 0·73 m., at Renk 1·0 m., at Jebelein 1·85 m., at Kosti (Rabak) 2·98 m. On the White Nile as far north as Renk the small range of levels and higher minimum levels will be of particular importance in overcoming one of the main difficulties in connection with pump schemes, that of finding suitable pump sites, and any dredging required for these will be reduced in quantity.

DRAINAGE

The Equatorial Nile Project will have no appreciable effect on either natural drainage or artificial drainage schemes in the Northern Zone. During the rainy season the ruling river level at Malakal will be only 9 cm. higher than at present, which will have a negligible effect on drainage. Furthermore the highest river levels occur in November, three months after the height of the rainy season in August. In the dry season the only effect will be slight increases in backwater levels in natural drainage-channels and these have been considered in detail in a previous section.

Cross-sections show that artificial drainage schemes could be introduced to drain limited areas bordering the river down to normal high river levels, and this will not be affected appreciably as levels during the rains will be similar to those of the present day.

3. CHANGES AND EFFECTS IN OTHER STAGES AND OPERATIONS OF THE PROJECT

Our estimate of compensation for loss of livelihood will be based on the effects of the Project when operated normally in the 55 m/d Canal stage, which have been examined in detail above.

It is also important to consider other stages and operations in general terms, particularly the intermediate constructional stages, the extension to the 80 m/d Canal stage, and proposals for flood protection and flood-escape discharges.

INTERMEDIATE CONSTRUCTIONAL STAGES

As explained in the description of the Project (p. 404) the completion of the 55 m/d Canal stage will be achieved in five stages :

Stage I—Construction of Storage Dams Only.
Stage II—10 m/d Canal. Malakal Discharge Unaltered.
Stage III—10 m/d Canal. Benefit at Malakal 1·0 milliards.
Stage IV—27·5 m/d Canal. Benefit at Malakal 3·0 milliards.
Stage V—55 m/d Canal. Benefit at Malakal 7·0 milliards.

Before examining the effects of individual stages we make some comments which apply to all of them. From the practical point of view, i.e. considering the labour and money involved, the construction of such a large project is bound to be carried out in stages, and over a long period of time, estimated at 25 years, and it is intended to change the régime of the river in corresponding steps.

This is highly desirable, especially for the inhabitants of the Jonglei Area and for those whose duty it will be to observe the effects and to provide the remedies. Though it is the clearly expressed intention to alter the river régime gradually, we must examine the proposals to see if the intention will, in fact, be realized by them.

It is also worth noting that during the intermediate stages the discharge of the Bahr el Jebel at Mongalla will be 23·8, 19·5, 22·2, and 23·4 milliards per year. Since the long-term mean is 27 milliards and since it will take 25 years to reach the 55 m/d Canal stage, then assuming equal time for completing each stage 120 milliards will be stored by the time the construction is finished. If for some reason or other the construction programme is delayed, then water will have to be escaped into the swamps of the Central Zone or normal working levels in Lakes Victoria and Albert exceeded. In other words the Project cannot eliminate losses in the swamps completely unless and until it is taken to the 55 m/d Canal stage. This is one reason why the normal operation in the intermediate stages should be designed to reproduce the normal variation from high discharges during the rains to low discharges in the dry season. For details of discharges at all key points the reader should now refer to Tables 186 to 190 (pp. 407–11) and Figs. F 2 to F 4.

NORTHERN ZONE

Since it can most easily be disposed of we will begin with the Northern Zone, and in doing so anticipate some facts and figures the reasons for which will become clear later. From Table 190 it will be seen that the maximum and minimum discharges at Malakal in the 27·5 m/d Canal stage will be 112 m/d and 61 m/d, which correspond to Malakal gauge-readings of 12·60 and 10·85 m. (The reader will note that in the other intermediate stages there will be no appreciable effect at Malakal.)

From Fig. F 17, which gives flood-plain areas between Malakal and Jebelein, it will be seen that the areas of flood-plain corresponding to these two gauge-readings at Malakal are 1,000 sq. km. at the high gauge-reading, when Jebel Aulia Reservoir level is full, and 115 sq. km. at the low one when the reservoir is empty. The area available for grazing will therefore be 885 sq. km. instead of 913 at present (Table 212, p. 449), a loss of 3% which will not make any appreciable difference. The discharge at Malakal will fall below 75 m/d between January 20th and June 1st. As will be seen later these figures and dates coincide almost exactly with grazing requirements in the Northern Zone, so we can say with confidence that no appreciable adverse effects will be felt in the Northern Zone in any of the intermediate stages before the 55 m/d Canal stage.

CENTRAL ZONE

Stage I: Storage Dams Only

Once the storage dams are built, it is the objective to accumulate water in the Lakes Victoria and Albert reservoirs, and the flow at Mongalla will be kept steady at 65 m/d all the year round. Conditions in the Bahr el Jebel will therefore change immediately. The normal fluctuation between 78 m/d and 54 m/d at Jonglei in the rainy and dry seasons, on which the riverain grazing depends, will disappear. The boundaries of the swamps will still continue to spread owing to rainfall and to recede in the dry season owing to evaporation, but it is not expected that this will be nearly adequate for grazing needs.

In point of fact it is hard to see exactly how the Mongalla discharge will be kept absolutely constant all the year round. To do so assumes complete control of the torrents and, since neither the site of the Lake Albert Dam nor the design of the balancing reservoir have yet been decided conclusively, the assumption is debatable. The torrents normally vary between 29 m/d in August and nothing from December to March. In order to maintain the natural fluctuation for grazing on the Bahr el Jebel it would seem highly desirable not to control the torrents completely, and we recommend that the immediate adverse effect on grazing in the Central (and of course Southern) Zone in the first stage (storage dams only) should be remedied by allowing most of the torrents to flow as at present. In any case it would be a simple matter to arrange discharges at Mongalla in the rainy and dry seasons differing by 20 m/d approximately and still pass the desired total of 23·8 milliards a year. This would answer completely our present objections to the effects of a steady discharge throughout the year.

Stages II, III and IV: 10 M/D to 27·5 M/D Canals

In the second stage the Mongalla discharge will be reduced to 19·5 milliards per year, but in the Bahr el Jebel north of Jonglei the flow will vary from 49 m/d to 34·5 m/d in the rainy and dry seasons respectively. This fluctuation, in addition to rainfall and evaporation, will probably be sufficient to suit grazing.

In the third stage, the 10 m/d Canal when the benefit at Malakal will be 1·0 milliard, the variation in the Bahr el Jebel discharge at Jonglei will be merely from 49 m/d to 47 m/d, giving a total annual discharge of 22·2 milliards at Mongalla. This again is quite inadequate for grazing, but it might be rectified by increasing the flow to about 62 m/d at Jonglei for the untimely season. Unfortunately in the second stage the fluctuations will have been between 49 m/d and 34·5 m/d, and it will be undesirable to increase the extent of the swamps once they are dried out. In the fourth stage the flow at Jonglei latitude will be 35 m/d throughout the year, which is yet another change in the régime. It is obvious that four different régimes in the Central Zone in the intermediate stages will cause considerable dislocation, and that the solution lies in deciding first what the régime should be in the 55 m/d Canal stage and progressing from present to final conditions in graded steps. This will be dealt with fully when we come to our proposals for the Revised Operation of the Project (see p. 705).

Jonglei Canal

With regard to discharges in the Jonglei Canal in the intermediate stages, our only comment concerns flow in the untimely season. We have pointed out in our detailed comments on the 55 m/d Canal stage that it is unlikely that 17 m/d will give sufficient water depth for navigation in one 27·5 m/d canal if it is to be 76 m. wide and 4 m. deep with a slope of 9 cm/km. (see p. 536).

SOUTHERN ZONE

Our remarks on conditions in the Central Zone apply also to the Southern Zone in the intermediate stages, with one important difference. It will be seen from Table 186 (p. 407) that the discharge at Mongalla will be reduced to 65 m/d as soon as the storage dams are constructed, and this figure will not be exceeded at any time of the year in any stage until the 27·5 m/d Canal stage (when the timely season flow will be 70 m/d at Mongalla). In Butcher's *The Sadd Hydraulics* (Plate XIII, facing p. 104) it is clearly demonstrated that for discharges up to 65 m/d all the water passing Mongalla reaches Bor, except for about 4% or normal transmission losses. Even at 70 m/d at Mongalla the losses are only 8·5%. For all practical purposes therefore we can say that in the Southern Zone the normal process of flooding and uncovering the *toiches* will be stopped from the very first in the constructional stages, and that the slight flooding in the 27·5 m/d Canal stage will be at the wrong time of the year.

As with the Central Zone, this point will be dealt with fully when we come to remedial measures.

80 M/D CANAL STAGE

In this stage the discharge at Mongalla will be 120 m/d during the timely season (Table 230, p. 458, and Fig. F 2). From our surveys of the Aliab and Mongalla-Gemmeiza valleys we know that such a discharge will inundate both areas completely. The loss of grazing in the Southern Zone will therefore be 100%. In the Central Zone there will be no difference between the 55 m/d Canal and 80 m/d Canal stages if the extra 25 m/d is taken by a third canal. There will also be virtuallly no change in conditions if the carrying capacity of the Bahr el Jebel is increased by banking and blocking spill-channels. We have estimated that some 360 sq. km. is irrigated naturally by the Tapari (Gel) and Khor Moich, combined with some spill from the Bahr el Jebel. After banking, it is quite likely that the latter will be replaced by an extension of the underground water-table strips bordering the river.

In the Northern Zone the discharge during the timely season will not fall below 105 m/d at Malakal, which is almost the normal maximum (106 m/d) during the untimely season to-day. The *toiches* will be completely flooded for the whole of the dry season and the loss of grazing in the Northern Zone will be 100%.

FLOOD-ESCAPE DISCHARGES

During a period of high flood-escape the discharge at Mongalla may rise to 150 m/d for a short period. Over a 6-month period the maximum average discharge will be limited to 120 m/d. In Dr. Amin and Mr. Bambridge's report there is one example of how 150 m/d at Mongalla will be distributed between the Bahr el Jebel and the Canal at the Atem regulator and Jonglei Canal Head ; namely 60 m/d into the Bahr el Jebel through the barrage downstream of the Atem Head, and 60 m/d downstream of the Jonglei Canal Head through the lower Atem barrage, making a total of 120 m/d in the Bahr el Jebel latitude, which is 42 m/d greater than the present normal maximum discharge at that point. The Canal at the same time will only take 20 m/d, and losses between Mongalla and the barrage are put at 10 m/d. Such conditions would of course be quite unacceptable even for a short period, but the example does indicate that during a period of high flood-escape the intention is to use the *Sudd* region as a vast evaporating pan. Over a long period the maximum flow at Mongalla will be 120 m/d or 22 milliards in 6 months. This amount is estimated to give conditions in the Central Zone, with the Bahr el Jebel banked to the barrage downstream of the Atem Head, comparable to the worst 6-month period in 1917, when the flow at Mongalla totalled 34 milliards in the untimely season, and therefore no worse than conditions previously suffered. This argument ignores the fact that in the interval, perhaps 25 years, the *Sudd* region will have dried up completely except for rainfall, and its inhabitants may have moved to settlements near the river, where they would be overwhelmed by a sudden return to conditions similar to those in 1917 which even then were intolerable.

On the supposition that such is the intention we have constructed a table (Table 231, p. 459) showing possible discharges at key points from Mongalla to Malakal, corresponding to a flow of 120 m/d at Mongalla. In the Southern and Central Zones there would be the catastrophic inundation described above and insufficient variation to produce grazing. In the Northern Zone, on the other hand, assuming the Sobat discharge to be normal, the area of plain flooded and uncovered between discharges of 133 m/d and 73 m/d at Malakal (gauges 12·92 m. and 11·35 m.) would be 900 sq. km. or almost exactly equal to the present flood-plain area between Malakal and Jebelein.

We conclude this section with a note on the water-levels at Bor during a period of high flood-escape, and show that the Egyptian proposals do not contain any details of canalizing or of banking the Aliab to deal with these high flows.

The following figures have been extracted from Dr. Amin and Mr. Bambridge's *Modified Jonglei Canal and Over-Year Storage Schemes*, October 1948.

WATER-LEVELS

AT THE ATEM HEAD

Mongalla Discharge	Reduced Levels
150 m/d	418·85
120 m/d	418·00
90 m/d	417·00
57 m/d	415·75

No water slopes given.

BANKED AND DREDGED ATEM

Mongalla Discharge	Below Atem Head	Above Jonglei Regulator
150 or 120 m/d	416·90	411·85
90 m/d	416·40	411·25
57 m/d	415·30	410·25

Water slope 8 cm/km.

TOMBE TO JONGLEI LATITUDE (BANKING)

	Water-Level	Distance km.
Tombe	428·90	0
Bor	420·82	63
Atem Head	415·00	115
Jonglei Latitude	409·50	167

Water slopes: Tombe-Bor 14·4 cm/km.
Bor-Jonglei 10·4 cm/km.

Bank level 1·5 m. above water-level.

From the above several points are clear.

At a slope of 10·4 cm/km. between Bor and the Atem Head the difference in level is about 5·5 m. Hence the level at Bor at a Mongalla discharge of 150 m/d will be about R.L. 424·5, and 1·0 m. lower at a discharge of 120 m/d at Mongalla.

The reduced level of Bor gauge is 408·52 and the gauge reads up to 12·50 m. The gauge-reading corresponding to the top of the protective pitching at Bor at the river-front is 12·50, or R.L. 421·02. Hence the water-level under these conditions will be about 3·5 m. above the quay at Bor at the highest discharge of 150 m/d at Mongalla.

The bank design clearly applies to the previous proposal when the only regulator was at Jonglei with a water-level of 409·50 at maximum normal discharge, and not to the most recent proposal with the barrage downstream of the Atem Head and a banked and dredged Atem channel. There are no details given in the Egyptian proposals showing how these high flows will be dealt with.

As this is quite unacceptable we must insist on adequate channel carrying capacity from Tombe to the Atem Head to pass the maximum flood-escape discharge.

TABLE 191

EFFECTS OF THE EQUATORIAL NILE PROJECT NORMAL OPERATION IN THE 55 M/D CANAL STAGE

In millions of cubic metres per day

Place	Present Conditions		Future Conditions	
	Max. Untimely Flow m/d	Min. Timely Flow m/d	Untimely Flow m/d	Timely Flow m/d
		Southern Zone		
Bahr el Jebel at Mongalla	92 Sept.	58 March	57 July–Nov.	90 Dec.–June
		Central Zone		
Bahr el Jebel at Jonglei ...	78 Sept.	54 March–April	35 July–Nov.	30 Dec.–June
Canal at Jonglei... ...	—	—	17 July–Nov.	55 Dec.–June
		Northern Zone		
			Effective Maximum	Effective Minimum
White Nile at Malakal ...	106 Oct.–Nov.	46 April	112 Nov.(1)	81 April(2)

(1) Theoretically also 118 m/d at the end of December when the Canal discharge is increased to 55 m/d at the beginning of the timely season.
(2) Theoretically also 78 m/d at the beginning of July when the Canal discharge is reduced to 17 m/d at the beginning of the untimely season.

TABLE 192

SOUTHERN ZONE LOSSES IN FLOOD-PLAIN AREA

In square kilometres

Place	Total Areas of Flood-Plain				Flood-Plain Losses			
	Right	Left	Total	Cumul. Total	Right	Left	Total	Cumul. Total
Juba								
	?	?	175	175	?	?	71	71
Mongalla								
	120	35	155	330	49	14	63	134
Terakeka								
	75	115	190	520	30	47	77	211
Gemmeiza								
	40	90	130	650	16	37	53	264
Tombe								
Tombe								
	65	160	225	225	38	55	93	93
Malek								
	15	130	145	370	9	77	86	179
Bor								
	249	312	561	931	147	184	331	510
Atem Head (5 km. above Lake Papiu)								
Totals				1,581				774

1. From Juba to Tombe the areas flooded have been assumed to bear the same relation to the total flood-plain areas as the area flooded on the Mongalla–Gemmeiza *toich* bears to the area surveyed, i.e. 65: 160 sq. km.
2. From Tombe to the barrage at the Atem Head the areas flooded and exposed have been calculated on the following assumptions:
   (i) The area affected by spill from the Bahr el Jebel is 864·5 sq. km., i.e. 931 sq. km. less the area irrigated by Khor Gwir, 66·5 sq. km., which lies south of Malek.
   (ii) The area flooded and exposed in the north-east portion of the Aliab Valley, i.e. 92/156 sq. km., is typical of the flooding from the Bahr el Jebel over the whole of the reach.

TABLE 193

SOUTHERN ZONE WIDTHS AND AREAS OF ALLUVIAL BANKS OF THE BAHR EL JEBEL AND ITS SIDE-CHANNELS BETWEEN JUBA AND BOR

In kilometres and square kilometres

Section	Applicable To			Width of Alluvial Bank				Total km.	Total Area sq. km.
				Main Channel		Side-Channels			
	from	to	km.	left	right	left	right		
A	0	7·3	7·3	0·180	0·200	{0·220 0·160}	0·240	1·000	7·30
B	7·3	17·4	10·1	0·300	0·230			0·530	5·35
C	17·4	27·3	9·9		0·200	0·400	0·420	1·020	10·10
D	27·3	37·3	10·0	0·200	0·560			0·760	7·60
E	37·3	48·4	11·1	0·400				0·400	4·44
F	48·4	59·6	11·2	0·050	0·170	0·060	0·220	0·500	5·60
G	59·6	71·0	11·4	0·140	0·400			0·540	6·16
H	71·0	82·2	11·2	0·560	0·500			1·060	11·87
I	82·2	92·2	10·0	0·480	0·400	0·250	0·360	1·490	14·90
J	92·2	101·0	8·8	0·600		0·280	0·360	1·240	10·91
K	101·0	109·8	8·8	0·760	0·280	0·060	0·660	1·760	15·49
L	109·8	119·8	10·0	0·680	1·300	{0·080 0·520}	{0·700 0·320}	3·600	36·00
M	119·8	129·5	9·7	0·400	0·200	0·330	0·640	1·570	15·23
N	129·5	138·8	9·3	1·540	0·120			1·660	15·44
O	138·8	149·5	10·7	1·400				1·400	14·98
P	149·5	160·0	10·5	1·800	0·020			1·820	19·11
Totals			160·0						200·48

TABLE 194

SOUTHERN ZONE
AREAS OF FLOOD-PLAIN IRRIGATED NATURALLY
BY LOCAL WATERCOURSES

Watercourse	Estimated Average Annual Flow milliards	Estimated Area Irrigated square kilometres
Khor Gwir	0·117	100
Luri	0·126	40
Koda	0·078	10
Tapari (Gel)	0·440	20
Other Small Streams		30
Total		200

TABLE 195

DISCHARGE RELATIONS AT KEY POINTS ON THE BAHR EL JEBEL
In millions of cubic metres per day

Mongalla	Jonglei Latitude	Peake's Latitude	Tail of the Swamps
120	102·5	51·9	51·0
110	94·5	50·6	49·0
100	86·5	49·6	47·0
90	78·6	48·5	44·5
80	70·6	46·7	42·0
70	62·6	44·2	40·0
65	58·6	42·9	39·0
60	54·6	41·6	37·5
55	50·6	40·3	36·0
50	46·6	39·0	34·5
45	42·2	37·6	33·0
40	37·5	34·0	31·0
35	32·9	30·8	28·0
30	28·5	27·0	25·0

NOTES: Columns 1, 2, and 3 from *The Sadd Hydraulics*, p. 39.
Column 4 scaled from Plate 18, p. 86, *The Nile Basin*, Vol. VII.
The figures in column 4 ignore the effect of the Bahr el Ghazal, whose flow at Khor Doleib reaches 1·0 m/d in April only in a normal year and totals 0·132 milliards per year on the average.

TABLE 196

ESTIMATE OF FUTURE SPILL IN THE CENTRAL ZONE

10-Day Period		Jebel Flow at Jonglei m/d	Tapari and Moich m/d	Total in Central Zone m/d	Tail of Swamps Flow m/d	Tail of Swamps Flow with Losses 13·3% m/d	Spill m/d
June	1 ...	30	2	32	27	28	1
	2 ...	30	2	32	27	28	1
	3 ...	35	2	37	31	32	1
July	1 ...	35	3	38	31	33	2
	2 ...	35	3	38	31	33	2
	3 ...	35	3	38	31	33	2
August	1 ...	35	5	40	32·5	35	2·5
	2 ...	35	5	40	32·5	35	2·5
	3 ...	35	5	40	32·5	35	2·5
September	1 ...	35	5	40	32·5	35	2·5
	2 ...	35	5	40	32·5	35	2·5
	3 ...	35	5	40	32·5	35	2·5
October	1 ...	35	5	40	32·5	35	2·5
	2 ...	35	5	40	32·5	35	2·5
	3 ...	35	5	40	32·5	35	2·5
November	1 ...	35	2	37	31	32	1
	2 ...	35	2	37	31	32	1
	3 ...	35	2	37	31	32	1
December	1 ...	35	0	35	29	30	1
	2 ...	30	0	30	26	26	0
	3 ...	30	0	30	26	26	0
						Total Spill	0·362 milliards

TABLE 197

PRESENT AND FUTURE DISCHARGES OF THE WHITE NILE AT MALAKAL

In millions of cubic metres per day. Totals in milliards.

10-Day Period	1912–42 Normal Discharge Malakal	1912–42 Normal Discharge Sobat	Future Canal and Swamps 55 m/d Stage	Future Normal Discharge Malakal
December 3	86·7	44·2	73·0	117·0
January 1	76·8	33·5	73·0	106·0
2	68·7	25·6	73·0	98·6
3	62·5	19·4	73·0	92·4
February 1	57·2	15·2	73·0	88·2
2	54·3	13·1	73·0	86·1
3	52·3	11·4	73·0	84·4
March 1	50·6	10·1	73·0	83·1
2	49·2	9·1	73·0	82·1
3	47·0	7·9	73·0	80·9
April 1	45·5	6·8	73·0	79·8
2	45·7	7·6	73·0	80·6
3	45·8	7·9	73·0	80·9
May 1	46·6	9·3	73·0	82·3
2	49·9	13·0	73·0	86·0
3	54·2	18·3	73·0	91·3
June 1	59·7	24·3	73·0	97·3
2	65·1	29·5	73·0	102·0
3	70·0	34·4	73·0	107·0
July 1	74·6	38·6	39·0	77·6
2	78·6	42·4	39·0	81·4
3	82·6	45·8	39·0	84·8
August 1	86·7	49·2	39·0	88·2
2	90·0	52·0	39·0	91·0
3	93·3	54·8	39·0	93·8
September 1	96·3	57·2	39·0	96·2
2	98·9	59·2	39·0	98·2
3	101·0	61·0	39·0	100·0
October 1	104·0	62·8	39·0	102·0
2	105·0	64·5	39·0	103·0
3	106·0	65·8	39·0	105·0
November 1	106·0	66·7	39·0	106·0
2	105·0	66·2	39·0	105·0
3	103·0	64·5	39·0	103·0
December 1	100·0	61·2	39·0	100·0
2	95·7	55·0	39·0	94·0
TOTALS				
Dec. 21–June 30	11·0	3·5	14·0	17·5
July 1–Dec. 20	16·6	9·8	6·8	16·6
Year	27·6	13·3	20·8	34·1

TABLE 198

TIME-LAG AND TRANSMISSION LOSSES
MALAKAL–KOSTI (RABAK)

TIME-LAG

Place	Distance from Malakal kilometres	Time-Lag days
Malakal	0	0
Melut	142	3½
Renk	320	8
Jebelein	422	10½
Rabak	496	12½

TRANSMISSION LOSSES

Place	Distance from Malakal kilometres	Losses %	Remaining Discharge %
Malakal	0	0	100
Melut	142	1·06	98·94
Renk...	320	2·40	97·60
Jebelein	422	3·16	96·84
Rabak	496	3·72	96·28

NOTE: Wright computes the average loss between Malakal–Renk at 3·26%, but the observed loss averages only 0·73%. The exact figure for losses is obscured by natural inflows which are not normally measured.

TABLE 199

DISCHARGES NORTH OF MALAKAL UNDER THE FUTURE E.N.P. REGIME

In millions of cubic metres per day

MALAKAL	DISCHARGES M/D				
10-Day Period	Malakal	Melut	Renk	Jebelein	Rabak
Lag Days	0	3½	8	10½	12½
January 1	106·0	105·0	104·0	103·0	102·0
2	98·6	97·5	96·2	95·4	94·9
3	92·4	91·4	90·2	89·5	88·9
February 1	88·2	87·2	86·0	85·2	84·8
2	86·1	85·1	84·0	83·2	82·8
3	84·4	83·4	82·3	81·5	81·1
March 1	83·1	82·1	81·0	80·3	79·9
2	82·1	81·2	80·0	79·4	79·0
3	80·9	80·0	78·9	78·1	77·7
April 1	79·8	77·9	77·8	77·2	76·8
2	80·6	79·7	78·6	77·9	77·5
3	80·9	80·0	78·9	78·1	77·7
May 1	82·3	81·4	80·2	79·5	79·5
2	86·0	85·0	83·8	83·1	82·7
3	91·3	90·3	89·0	88·2	87·8
June 1	97·3	96·2	94·7	94·0	93·5
2	102·0	101·0	100·0	99·0	98·5
3	107·0	106·0	105·0	104·0	103·0
July 1	77·6	76·7	75·6	75·0	74·6
2	81·4	80·5	79·4	78·6	78·2
3	84·8	83·8	82·5	82·0	81·6
August 1	88·2	87·2	86·0	85·2	84·8
2	91·0	90·0	89·0	87·9	87·5
3	93·8	92·7	91·5	90·7	90·2
September 1	96·2	95·1	93·6	93·0	92·5
2	98·2	97·0	95·7	94·9	94·4
3	100·0	98·9	97·6	96·8	96·3
October 1	102·0	101·0	99·2	98·2	97·7
2	103·0	102·0	101·0	99·9	99·4
3	105·0	103·0	102·0	101·0	101·0
November 1	106·0	104·0	103·0	102·0	101·0
2	105·0	104·0	103·0	102·0	101·0
3	103·0	102·0	101·0	99·8	99·3
December 1	100·0	99·0	98·0	96·1	95·6
2	94·0	93·0	91·7	90·8	90·3
3	117·0	116·0	114·0	113·0	112·8

TABLE 200

PRESENT AND FUTURE GAUGES AT MALAKAL AND MELUT

In metres

10-Day Period		Malakal		Melut	
		Present Normal (*)	Future E.N.P.	Present Normal (*)	Future E.N.P.
January	1	11·44	12·45	11·51	12·37
	2	11·11	12·28	11·17	12·25
	3	10·83	12·14	10·86	12·16
February	1	10·61	12·04	10·63	12·07
	2	10·46	11·93	10·46	11·99
	3	10·36	11·85	10·34	11·92
March	1	10·27	11·78	10·25	11·84
	2	10·19	11·72	10·17	11·77
	3	10·11	11·67	10·10	11·71
April	1	10·05	11·62	10·03	11·66
	2	10·04	11·60	10·01	11·61
	3	10·05	11·58	10·02	11·57
May	1	10·06	11·58	10·02	11·54
	2	10·19	11·73	10·10	11·53
	3	10·38	11·93	10·25	11·64
June	1	10·61	12·12	10·45	11·83
	2	10·82	12·28	10·64	11·98
	3	11·01	12·43	10·82	12·14
July	1	11·18	11·73	11·00	11·98
	2	11·33	11·54	11·15	11·42
	3	11·48	11·68	11·30	11·50
August	1	11·64	11·81	11·46	11·64
	2	11·76	11·92	11·59	11·76
	3	11·88	12·02	11·71	11·86
September	1	11·98	12·09	11·82	11·94
	2	12·06	12·16	11·91	12·00
	3	12·13	12·21	11·98	12·05
October	1	12·20	12·27	12·03	12·10
	2	12·25	12·31	12·09	12·15
	3	12·28	12·34	12·12	12·19
November	1	12·30	12·37	12·14	12·23
	2	12·29	12·39	12·14	12·26
	3	12·25	12·37	12·12	12·25
December	1	12·17	12·32	12·06	12·17
	2	12·03	12·18	11·96	12·07
	3	11·79	12·75	11·79	12·40

(*) Normals 1912–42.

TABLE 201

GAUGES FOR NATURAL RIVER, JEBEL AULIA, AND E.N.P. REGIMES AT RENK AND JEBELEIN

In metres

10-Day Period	Renk			Jebelein		
	Normal Natural(1)	Jebel(2) Aulia	E.N.P.	Normal Natural(3)	Jebel Aulia(2)	E.N.P.
January 1 ...	11·31	12·03	12·29	11·03	12·60	12·70
2 ...	11·06	11·97	12·15	10·81	12·58	12·65
3 ...	10·80	11·87	11·97	10·53	12·55	12·57
February 1 ...	10·62	11·71	11·76	10·31	12·49	12·46
2 ...	10·49	11·49	11·58	10·16	12·32	12·34
3 ...	10·40	11·30	11·43	10·06	12·15	12·19
March 1 ...	10·33	11·07	11·33	9·99	12·06	12·00
2 ...	10·26	10·84	11·27	9·96	11·61	11·76
3 ...	10·21	10·58	11·22	9·93	11·22	11·50
April 1 ...	10·16	10·34	11·18	9·90	10·85	11·27
2 ...	10·14	10·27	11·15	9·90	10·57	11·10
3 ...	10·13	10·18	11·13	9·94	10·33	10·97
May 1 ...	10·12	10·11	11·11	9·96	10·19	10·86
2 ...	10·16	10·08	11·12	10·00	10·10	10·78
3 ...	10·24	10·21	11·25	10·08	10·15	10·86
June 1 ...	10·37	10·37	11·41	10·17	10·25	10·96
2 ...	10·50	10·56	11·56	10·30	10·38	11·08
3 ...	10·64	10·68	11·71	10·42	10·50	11·22
July 1 ...	10·76	10·81	11·79	10·53	10·60	11·35
2 ...	10·90	10·94	11·12	10·65	10·73	10·84
3 ...	11·02	11·06	11·08	10·78	10·91	10·89
August 1 ...	11·16	11·21	11·18	10·94	11·20	11·19
2 ...	11·28	11·39	11·32	11·14	11·54	11·49
3 ...	11·40	11·53	11·48	11·29	11·76	11·76
September 1 ...	11·49	11·64	11·60	11·39	11·91	12·00
2 ...	11·57	11·79	11·72	11·43	12·14	12·21
3 ...	11·63	11·94	11·82	11·41	12·24	12·34
October 1 ...	11·67	12·04	11·89	11·39	12·45	12·42
2 ...	11·70	12·11	11·95	11·37	12·50	12·48
3 ...	11·73	12·15	12·00	11·36	12·55	12·52
November 1 ...	11·75	12·18	12·04	11·34	12·58	12·56
2 ...	11·76	12·20	12·07	11·34	12·61	12·59
3 ...	11·74	12·21	12·10	11·34	12·60	12·61
December 1 ...	11·71	12·19	12·11	11·32	12·59	12·61
2 ...	11·65	12·18	12·08	11·29	12·60	12·60
3 ...	11·54	12·16	12·04	11·22	12·61	12·58

(1) Normals 1912–32.
(2) Normals 1943–49.
(3) Normals 1914–32.

TABLE 202

GAUGES FOR NATURAL RIVER, JEBEL AULIA, AND E.N.P. REGIMES AT RABAK

In metres

10-Day Period		Rabak (Kosti Bridge)		E.N.P.
		Normal Natural (1)	Jebel Aulia (2)	
January	1	11·31	13·97	13·99
	2	11·11	13·96	13·99
	3	10·85	13·95	13·97
February	1	10·61	13·91	13·92
	2	10·44	13·76	13·84
	3	10·26	13·58	13·70
March	1	10·21	13·36	13·50
	2	10·13	13·04	13·23
	3	10·07	12·61	12·87
April	1	10·02	12·12	12·45
	2	9·99	11·57	11·96
	3	10·01	10·95	11·52
May	1	10·00	10·65	11·14
	2	10·02	10·29	11·00
	3	10·08	10·24	11·03
June	1	10·17	10·29	11·15
	2	10·31	10·41	11·28
	3	10·47	10·56	11·46
July	1	10·63	10·71	11·73
	2	10·81	10·97	11·08
	3	11·05	11·52	11·52
August	1	11·45	12·23	12·24
	2	11·86	12·77	12·77
	3	12·10	13·04	13·04
September	1	12·24	13·20	13·20
	2	12·26	13·50	13·50
	3	12·20	13·73	13·73
October	1	12·10	13·82	13·83
	2	11·98	13·86	13·90
	3	11·85	13·90	13·95
November	1	11·75	13·91	13·97
	2	11·69	13·92	13·98
	3	11·66	13·91	13·98
December	1	11·62	13·91	13·98
	2	11·58	13·93	13·98
	3	11·50	13·96	13·97

(1) Normals 1912–32.
(2) Normals 1943–49.

TABLE 203

DATA FOR 22 CROSS-SECTIONS OF THE WHITE NILE, MALAKAL TO JEBELEIN

MALAKAL—MELUT

Cross-Section No.	Distance from Malakal kilometres	R.L. of Datum
0	0	382·10
1	20	381·80
2	40	381·40
3	60	381·10
4	81	380·70
5	101	380·40
6	122	380·10
7	142	379·80

MELUT—RENK

Cross-Section No.	Distance from Malakal kilometres	R.L. of Datum
8	161	379·50
9	180	379·20
10	200	378·90
11	221	378·60
12	240	378·30
13	261	378·00
14	284	377·60
15	300	377·30
16	324	377·00

RENK—JEBELEIN

Cross-Section No.	Distance from Malakal kilometres	R.L. of Datum
17	346	376·70
18	365	376·40
19	384	376·00
20	404	375·70
21	419	375·40

TABLE 204

FLOOD-PLAIN WIDTHS. COMPARISON OF RESULTS.

All figures in metres

Height above Datum	Malakal—Melut		Melut—Renk		Renk—Jebelein	
	J. W. Wright	J.I.T.	J. W. Wright	J.I.T.	J. W. Wright	J.I.T.
0·2	20	43	50	69	36	62
0·4	100	128	197	223	116	178
0·6	140	175	289	325	274	312
0·8	200	239	371	427	340	427
1·0	260	304	488	580	400	510
1·2	330	379	640	732	526	618
1·4	410	468	795	916	670	757
1·6	630	725	1,045	1,146	760	962
1·8	900	1,002	1,305	1,496	1,140	1,360
2·0	1,250	1,292	1,750	2,104	1,324	1,788
2·2	1,450	1,588	2,180	2,458	1,900	2,197
2·4	1,750	1,816	2,580	2,716	2,380	2,554
2·6	2,000	1,956	2,980	2,914	2,640	2,815
2·8	2,250	2,069	3,070	3,074	2,920	3,039
3·0	2,550	2,133	3,320	3,326	3,060	3,174
Width of River at Datum	400	414	566	586	596	647

TABLE 205

FLOOD-PLAIN MEAN WIDTHS AND AREAS
MALAKAL–JEBELEIN

In kilometres and square kilometres

Height above Datum	Malakal–Melut (Length = 142 kilometres)		Melut–Renk (Length = 178 kilometres)		Renk–Jebelein (Length = 102 kilometres)	
	Width	Area	Width	Area	Width	Area
0·1	0·024	3·4	0·037	6·6	0·024	2·4
0·2	0·043	6·1	0·069	12·3	0·082	6·3
0·3	0·078	11·1	0·140	24·9	0·115	11·7
0·4	0·128	18·2	0·223	39·7	0·178	18·2
0·5	0·151	21·4	0·267	47·5	0·255	26·0
0·6	0·175	24·9	0·325	58·0	0·312	31·8
0·7	0·210	29·8	0·376	67·0	0·386	39·4
0·8	0·239	34·0	0·427	76·0	0·427	43·6
0·9	0·273	38·8	0·500	89·0	0·466	47·5
1·0	0·304	43·2	0·580	103	0·510	52·0
1·1	0·340	48·3	0·654	116	0·561	57·3
1·2	0·379	53·8	0·732	130	0·618	63·1
1·3	0·426	60·5	0·823	147	0·682	69·6
1·4	0·468	66·5	0·916	163	0·757	77·2
1·5	0·532	75·5	1·056	188	0·845	86·2
1·6	0·725	103	1·146	204	0·962	98·2
1·7	0·869	123	1·296	231	1·105	113
1·8	1·002	142	1·496	266	1·360	139
1·9	1·150	163	1·781	318	1·591	162
2·0	1·292	183	2·104	375	1·788	182
2·1	1·431	205	2·314	412	1·966	200
2·2	1·588	225	2·458	438	2·197	224
2·3	1·699	242	2·592	462	2·416	248
2·4	1·816	258	2·716	483	2·554	260
2·5	1·889	268	2·827	504	2·707	276
2·6	1·956	278	2·914	518	2·815	287
2·7	2·008	285	3·006	536	2·975	303
2·8	2·069	294	3·074	548	3·039	310
2·9	2·105	299	3·179	566	3·106	317
3·0	2·133	303	3·326	592	3·174	324

TABLE 206

AVERAGE GAUGES FOR NATURAL RIVER, JEBEL AULIA, AND E.N.P. REGIMES
MALAKAL-MELUT AND MELUT-RENK

In metres

Date	Malakal–Melut		Melut–Renk		
	Normal	E.N.P.	Normal	Jebel Aulia	E.N.P.
Jan. 1 ...	11·47	12·41	11·41	11·77	12·33
2 ...	11·14	12·26	11·11	11·57	12·20
3 ...	10·84	12·15	10·83	11·36	12·08
Feb. 1 ...	10·62	12·05	10·62	11·17	11·91
2 ...	10·46	11·96	10·47	10·97	11·78
3 ...	10·35	11·88	10·37	10·82	11·67
Mar. 1 ...	10·26	11·81	10·29	10·66	11·58
2 ...	10·18	11·74	10·21	10·50	11·52
3 ...	10·10	11·69	10·15	10·34	11·46
Apr. 1 ...	10·04	11·64	10·09	10·18	11·42
2 ...	10·02	11·60	10·07	10·14	11·38
3 ...	10·03	11·57	10·07	10·10	11·35
May 1 ...	10·04	11·56	10·07	10·06	11·32
2 ...	10·14	11·63	10·13	10·09	11·32
3 ...	10·31	11·78	10·24	10·23	11·44
June 1 ...	10·53	11·97	10·41	10·41	11·62
2 ...	10·73	12·13	10·57	10·60	11·77
3 ...	10·91	12·23	10·73	10·75	11·92
July 1 ...	11·09	11·85	10·88	10·90	11·88
2 ...	11·24	11·48	11·02	11·04	11·27
3 ...	11·39	11·59	11·16	11·18	11·29
Aug. 1 ...	11·55	11·72	11·31	11·33	11·41
2 ...	11·67	11·84	11·43	11·49	11·54
3 ...	11·79	11·94	11·58	11·62	11·67
Sept. 1 ...	11·90	12·01	11·65	11·73	11·77
2 ...	11·98	12·08	11·74	11·85	11·86
3 ...	12·05	12·13	11·80	11·96	11·93
Oct. 1 ...	12·11	12·18	11·85	12·03	11·99
2 ...	12·17	12·23	11·89	12·10	12·05
3 ...	12·20	12·26	11·92	12·13	12·09
Nov. 1 ...	12·22	12·30	11·94	12·16	12·13
2 ...	12·21	12·32	11·95	12·17	12·16
3 ...	12·18	12·31	11·92	12·16	12·17
Dec. 1 ..	12·11	12·24	11·88	12·12	12·14
2 ...	11·99	12·12	11·80	12·07	12·07
3 ...	11·79	12·57	11·60	11·97	12·22

These figures are obtained by averaging the gauges at the ends of the reaches in Tables 200 and 201.

TABLE 207

AVERAGE GAUGES FOR NATURAL RIVER, JEBEL AULIA, AND E.N.P. REGIMES
RENK–JEBELEIN
In metres

Date		Normal River	Jebel Aulia	E.N.P.
Jan.	1	11·17	12·31	12·49
	2	10·93	12·27	12·40
	3	10·66	12·21	12·27
Feb.	1	10·46	12·10	12·11
	2	10·32	11·90	11·96
	3	10·23	11·72	11·81
Mar.	1	10·16	11·56	11·66
	2	10·11	11·22	11·51
	3	10·07	10·90	11·36
Apr.	1	10·03	10·59	11·22
	2	10·02	10·42	11·12
	3	10·03	10·25	11·05
May	1	10·04	10·15	10·98
	2	10·08	10·09	10·95
	3	10·16	10·18	10·95
June	1	10·27	10·31	11·18
	2	10·40	10·47	11·29
	3	10·53	10·59	11·46
July	1	10·64	10·70	11·57
	2	10·77	10·83	10·98
	3	10·90	10·98	10·98
Aug.	1	11·05	11·20	11·18
	2	11·21	11·46	11·40
	3	11·37	11·64	11·62
Sept.	1	11·44	11·77	11·80
	2	11·50	11·96	11·96
	3	11·52	12·14	12·08
Oct.	1	11·53	12·24	12·15
	2	11·53	12·30	12·21
	3	11·54	12·35	12·26
Nov.	1	11·54	12·38	12·30
	2	11·55	12·40	12·33
	3	11·54	12·40	12·30
Dec.	1	11·51	12·39	12·36
	2	11·47	12·39	12·34
	3	11·38	12·38	12·31

These figures are obtained by averaging the gauges at the ends of the reaches in Tables 200 and 201.

TABLE 208

FLOOD-PLAIN AREAS INUNDATED BY NATURAL RIVER, JEBEL AULIA, AND E.N.P. REGIMES
MALAKAL–MELUT AND MELUT–RENK
In square kilometres

Date		Malakal–Melut		Melut–Renk		
		Normal	E.N.P.	Normal	Jebel Aulia	E.N.P.
Jan.	1	72	259	165	255	468
	2	51	236	118	200	438
	3	36	215	80	156	405
Feb.	1	26	196	59	127	329
	2	20	174	45	99	258
	3	15	158	36	79	222
Mar.	1	9	144	28	63	201
	2	6	130	14	47	191
	3	3	121	9	32	181
Apr.	1	1	112	5	11	167
	2	0	103	4	8	159
	3	1	92	4	6	155
May	1	1	88	4	4	150
	2	4	110	8	6	150
	3	11	138	17	16	174
June	1	22	176	40	40	209
	2	31	210	54	58	255
	3	39	230	69	71	335
July	1	48	152	86	89	301
	2	57	73	105	108	142
	3	66	101	125	127	145
Aug.	1	85	126	148	152	165
	2	118	150	170	187	195
	3	140	170	201	210	222
Sept.	1	152	184	216	240	255
	2	178	200	245	285	290
	3	193	210	266	357	343
Oct.	1	206	220	285	387	371
	2	218	230	310	412	395
	3	224	235	335	420	410
Nov.	... ...	227	242	348	428	420
	2	226	245	353	430	428
	3	220	244	335	428	430
Dec	1	206	232	302	417	423
	2	181	208	266	401	402
	3	140	275	205	362	443

TABLE 209

FLOOD-PLAIN AREAS INUNDATED BY NATURAL RIVER, JEBEL AULIA, AND E.N.P. REGIMES
RENK–JEBELEIN
In square kilometres

Date		Normal River	Jebel Aulia	E.N.P.
January	1	61	249	275
	2	49	242	260
	3	36	230	243
February	1	23	200	202
	2	12	162	174
	3	8	117	141
March	1	5	93	106
	2	3	64	87
	3	2	48	74
April	1	1	31	64
	2	0	20	58
	3	1	8	55
May	1	1	5	51
	2	2	2	50
	3	5	6	50
June	1	9	11	62
	2	18	20	69
	3	28	31	82
July	1	35	40	94
	2	42	44	51
	3	48	51	51
August	1	55	63	62
	2	64	82	77
	3	75	103	100
September	1	81	128	139
	2	86	174	174
	3	88	208	196
October	1	89	236	210
	2	89	248	230
	3	90	254	240
November	1	90	258	248
	2	91	260	251
	3	90	260	248
December	1	87	259	255
	2	83	259	253
	3	76	258	249

TABLE 210

FLOOD-PLAIN WIDTHS
RABAK

Rise above Datum in metres	Width Inundated in kilometres
0·00	0·000
0·10	0·010
0·20	0·015
0·30	0·020
0·40	0·030
0·50	0·040
0·60	0·045
0·70	0·050
0·80	0·060
0·90	0·065
1·00	0·075
1·10	0·085
1·20	0·115
1·30	0·135
1·40	0·155
1·50	0·180
1·60	0·195
1·70	0·220
1·80	0·250
1·90	0·270
2·00	0·290
2·10	0·365
2·20	0·505
2·30	0·560
2·40	0·675
2·50	0·800
2·60	0·940
2·70	1·080
2·80	1·240
2·90	1·400
3·00	1·560
3·10	1·740
3·20	1·925
3·30	2·110
3·40	2·480
3·50	2·780
3·60	2·965
3·70	3·130
3·80	3·265
3·90	3·835
4·00	3·495

TABLE 211

FLOOD-PLAIN WIDTHS INUNDATED BY NATURAL RIVER, JEBEL AULIA, AND E.N.P. REGIMES
RABAK
In kilometres

10-Day Period		Natural River	Jebel Aulia	E.N.P.
January	1	0·135	3·460	3·490
	2	0·090	3·450	3·490
	3	0·060	3·440	3·450
February	1	0·042	3·390	3·400
	2	0·030	3·200	3·300
	3	0·020	2·930	3·120
March	1	0·020	2·270	2·780
	2	0·015	1·630	1·975
	3	0·020	0·955	1·350
April	1	0·000	0·400	0·730
	2	0·000	0·195	0·285
	3	0·000	0·065	0·185
May	1	0·000	0·045	0·095
	2	0·000	0·025	0·065
	3	0·010	0·020	0·070
June	1	0·015	0·025	0·100
	2	0·025	0·030	0·130
	3	0·035	0·040	0·150
July	1	0·045	0·055	0·230
	2	0·055	0·065	0·080
	3	0·075	0·185	0·185
August	1	0·170	0·530	0·530
	2	0·260	1·195	1·200
	3	0·365	1·635	1·630
September	1	0·530	1·920	1·925
	2	0·540	2·780	2·780
	3	0·505	3·160	3·160
October	1	0·365	3·280	3·290
	2	0·290	3·330	3·380
	3	0·260	3·380	3·440
November	1	0·240	3·390	3·460
	2	0·220	3·400	3·475
	3	0·215	3·390	3·475
December	1	0·210	3·390	3·475
	2	0·200	3·420	3·475
	3	0·180	3·450	3·460

TABLE 212

PRESENT AND FUTURE TRIBAL GRAZING AREAS
MALAKAL–JEBELEIN

Tribe	River Frontage from Malakal in kilometres			Flood-Plain Areas in square kilometres		
	From	To	Distance	Present	E.N.P.	Percentage Lost
Shilluk (East Bank)	0	66	66	56	37	34%
Shilluk (West Bank)	0	142	142	114	76	33%
Shilluk (West Bank)	142	200	58	69	42	39%
Total Shilluk			266	239	155	35%
Dunjol Dinka	66	96	30	24	16	33%
Paloich Dinka	96	142	46	36	25	32%
Paloich Dinka	142	230	88	105	64	39%
Abialang Dinka	230	320	90	110	75	32%
Abialang Dinka	320	380	60	65	42	36%
Total Dinka			314	340	222	35%
Baggara (East Bank)	380	422	42	59	51	14%
Baggara (West Bank)	200	320	120	146	100	31%
Baggara (West Bank)	320	422	102	129	102	21%
Total Baggara			264	334	253	24%
Total Malakal-Jebelein			844	913	630	31%

TABLE 213

PRESENT MEAN FLOOD-PLAIN WIDTHS IN TRIBAL AREAS
MALAKAL–JEBELEIN

Tribe	Nearest Applicable Gauge	Gauges		Flood-Plain Widths (½ Means) metres		
		Max.	Min.	Max.	Min.	Diff.
Shilluk (East Bank)	Malakal	12·30	10·04	850	5	845
Shilluk (West Bank)	Mean of Malakal-Melut	12·22	10·02	800	0	800
Shilluk (West Bank)	Melut	12·14	10·01	1,190	0	1,190
Dunjol Dinka ...	Mean of Malakal-Melut	12·22	10·02	800	0	800
Paloich Dinka ...	Melut	12·14	10·01	785	0	785
Paloich Dinka ...	Melut	12·14	10·01	1,190	0	1,190
Abialang Dinka ...	Renk	12·21	10·08	1,240	15	1,225
Abialang Dinka ...	Renk	12·21	10·08	1,100	10	1,090
Baggara (East Bank)	Jebelein	12·61	10·10	1,415	15	1,400
Baggara (West Bank)	Mean of Renk and Melut–Renk	12·19	10·07	1,225	10	1,215
Baggara (West Bank)	Mean of Renk-Jebelein	12·40	10·09	1,277	12	1,265

TABLE 214

FUTURE MEAN FLOOD-PLAIN WIDTHS IN TRIBAL AREAS
MALAKAL–JEBELEIN

Tribe	Nearest Applicable Gauge	Gauges		Flood-Plain Widths (½ Means) metres		
		Max.	Min.	Max.	Min.	Diff.
Shilluk (East Bank)	Malakal	12·39	11·58	900	340	560
Shilluk (West Bank)	Mean of Malakal-Melut	12·32	11·56	860	325	535
Shilluk (West Bank)	Melut	12·26	11·53	1,270	540	730
Dunjol Dinka ...	Mean of Malakal–Melut	12·32	11·56	860	325	535
Paloich Dinka ...	Melut	12·26	11·53	825	290	535
Paloich Dinka ...	Melut	12·26	11·53	1,270	540	730
Abialang Dinka ...	Renk	12·11	11·11	1,160	330	830
Abialang Dinka ...	Renk	12·11	11·11	980	280	700
Baggara (East Bank)	Jebelein	12·61	10·78	1,415	210	1,205
Baggara (West Bank)	Renk	12·11	11·11	1,160	330	830
Baggara (West Bank)	Mean of Renk-Jebelein...	12·36	10·95	1,250	245	1,005

TABLE 215

PRESENT AND FUTURE TRIBAL FLOOD-PLAIN AREAS
LAKE NO–MALAKAL

Tribe and Bank	River Frontage from Lake No in km.			Flood-Plain Areas in sq. km.		
	From	To	Distance	Present	E.N.P.	Percentage lost
Dinka (¹)	0	30	30	105	105	—
Nuer(²)	0	78	78	210	185	12%
Shilluk(³)	30	146	116	193	138	28%
Shilluk(⁴)	78	146	68	88	59	33%
Total				596	487	18%

(1) Dinka (left bank) from Lake No to Shilluk boundary: 30 km.
(2) Nuer (right bank) from Lake No to Zeraf mouth: 78 km.
(3) Shilluk (left bank) from boundary to Malakal: 116 km.
(4) Shilluk (right bank) from Zeraf mouth to Malakal: 68 km.

TABLE 216

WHITE NILE
MALAKAL—LAKE NO
FLOOD-PLAIN WIDTHS AND AREAS

Cross-Section from Sobat Mouth in km.	Width of Exposed Flood-Plain in Kilometres			
	Normal	E.N.P.	Gain	Loss
0	2·8	1·7	—	1·1
10	3·1	1·6	—	1·5
20	3·4	2·7	—	0·7
30	2·8	1·7	—	1·1
40	2·9	2·2	—	0·7
50	3·2	1·3	—	1·9
60	2·1	1·4	—	0·7
70	3·1	2·1	—	1·0
80	5·4	4·4	—	1·0
90	8·3	7·2	—	1·1
100	5·5	5·0	—	·05
110	8·4	6·9	—	1·5
120	7·2	9·1	1·9	—

Reach	Length in km.	Average Width (in km.)			Area (in sq. km.)		
		Normal	E.N.P.	Loss	Normal	E.N.P.	Loss
Lake No to Shilluk Boundary ...	30	7·0	7·0	0	210	210	—
Shilluk Boundary to Zeraf Mouth	48	4·4	3·3	1·1	210	160	50
Zeraf Mouth to Sobat Mouth ...	45	3·0	2·0	1·0	135	90	45
Sobat Mouth to Malakal	23	1·8	1·2	0·6	41	27	14
Totals	146				596	487	109

TABLE 217

WHITE NILE
SUMMARY OF BACKWATER PROFILES

Place and Kilometrage	Present Normals		Future E.N.P.	
	Normal High	Normal Low	Maximum Untimely	Minimum Timely
	Reduced Levels			
Sobat Mouth 0	384·99	382·50	385·08	384·23
10...	5·05	2·78	5·13	4·29
Fanyikang 19	5·11	3·04	5·17	4·35
20...	5·11	3·06	5·18	4·35
30...	5·19	3·35	5·24	4·42
40...	5·27	3·63	5·30	4·50
Zeraf Mouth 45 ...	5·32	3·78	5·34	4·56
50...	5·36	3·91	5·37	4·60
Tonga 59	5·47	4·18	5·45	4·70
60...	5·48	4·20	5·45	4·70
70...	5·59	4·48	5·55	4·82
80...	5·71	4·76	5·65	4·95
Khor Yirr Gwol 88 ...	5·84	5·00	5·76	5·07
90...	5·86	5·05	5·77	5·08
100...	6·02	5·33	5·90	5·25
110...	6·19	5·61	6·03	5·43
120...	6·39	5·90	6·20	5·61
Lake No 122	386·42	385·95	386·23	385·65

GAUGE-READINGS
In metres

	Normal		Maximum Untimely	Minimum Timely
	High	Low		
Sobat Mouth	12·56	10·07	12·65	11·80
Zeraf Mouth	12·76	11·27	12·83	12·05
Tonga	12·89	11·67	12·94	12·19
Khor Yirr Gwol ...	14·17	13·43	14·19	13·50
Lake No	14·03	13·54	13·82	13·24

TABLE 218
WHITE NILE
NORMAL BACKWATER PROFILES

Place and Kilometrage	Reduced Level of Low River	Gauge Readings	Backwater		Theoretical Gauge Readings m.	Actual Normal High River m.
			Height above Datum m.	R.L.		
Sobat Mouth 0	382·50	10·07	2·49	384·99	12·56	12·56
10	2·78	—	2·27	5·05	—	—
Fanyikang 19	3·04	10·96	2·07	5·11	13·03	12·97
20	3·06	—	2·05	5·11	—	—
30	3·35	—	1·84	5·19	—	—
40	3·63	—	1·64	5·27	—	—
Zeraf Mouth 45	3·78	11·27	1·54	5·32	12·81	12·76
50	3·91	—	1·45	5·36	—	—
Tonga 59	4·18	11·67	1·29	5·47	12·96	12·89
60	4·20	—	1·28	5·48	—	—
70	4·48	—	1·11	5·59	—	—
80	4·76	—	0·95	5·71	—	—
Khor Yirr Gwol 88	5·00	13·43	0·84	5·84	14·27	14·17
90	5·05	—	0·81	5·86	—	—
100	5·33	—	0·69	6·02	—	—
110	5·61	—	0·58	6·19	—	—
120	5·90	—	0·49	6·39	—	—
Lake No 122	385·95	13·54	0·47	386·42	14·01	14·03

When Sobat Mouth gauge is 10·70 = R.L. 383·13 Lake No gauge-reading will be 13·59 = R.L. 386·00.

TABLE 219
WHITE NILE
BACKWATER PROFILE UNDER THE E.N.P.—TIMELY PERIOD

Place and Kilometrage	Reduced Level of Datum River	Backwater		Theoretical Gauge Readings m.
		Height above Datum m.	R.L.	
Sobat Mouth 0	381·72	2·51	384·23	11·80
10	2·00	2·29	4·29	—
Fanyikang 19	2·26	2·09	4·35	12·27
20	2·28	2·07	4·35	—
30	2·56	1·86	4·42	—
40	2·85	1·65	4·50	—
Zeraf Mouth 45	3·00	1·56	4·56	12·05
50	3·13	1·47	4·60	—
Tonga 59	3·40	1·30	4·70	12·19
60	3·41	1·29	4·70	—
70	3·70	1·12	4·82	—
80	3·98	0·97	4·95	—
Khor Yirr Gwol 88	4·22	0·85	5·07	13·50
90	4·26	0·82	5·08	—
100	4·55	0·70	5·25	—
110	4·83	0·60	5·43	—
120	5·11	0·50	5·61	—
Lake No 122	385·17	0·48	385·65	13·24

TABLE 220
WHITE NILE
BACKWATER PROFILE UNDER THE E.N.P.—UNTIMELY PERIOD

Place and Kilometrage	Reduced Levels of Datum Profile	Backwater Curve		Theoretical Gauge Readings m.
		Height above Datum m.	R.L.	
Sobat Mouth 0	382·10	2·98	385·08	12·65
10	2·38	2·75	5·13	—
Fanyikang 19	2·64	2·53	5·17	13·09
20	2·66	2·52	5·18	—
30	2·95	2·29	5·24	—
40	3·23	2·07	5·30	—
Zeraf Mouth 45	3·38	1·96	5·34	12·83
50	3·51	1·86	5·37	—
Tonga 59	3·78	1·67	5·45	12·94
60	3·80	1·65	5·45	—
70	4·08	1·47	5·55	—
80	4·36	1·29	5·65	—
Khor Yirr Gwol 88	4·60	1·16	5·76	14·19
90	4·65	1·12	5·77	—
100	4·93	0·97	5·90	—
110	5·21	0·82	6·03	—
120	5·50	0·70	6·20	
Lake No 122	385·55	0·68	386·23	13·82

TABLE 221

BAHR EL ZERAF

SUMMARY OF BACKWATER PROFILES

Place and Kilometrage	Present Normals		Future E.N.P.	
	Normal High	Normal Low	Maximum Untimely	Minimum Timely
Zeraf Mouth 0	385·32	383·78	385·34	384·56
20	5·85	4·54	5·45	4·71
40	6·48	5·31	5·66	5·01
R.P. 10 52	6·90	5·77	5·87	5·25
60	7·18	6·07	6·02	5·43
Fangak 66	7·41	6·30	6·14	5·58
80	7·88	6·84	6·49	5·96
Longtam 88	8·16	7·24	6·70	6·19
100	8·59	7·60	7·04	6·56
R.P. 19 105	8·78	7·78	7·20	6·72
120	9·35	8·36	7·69	7·24
140	390·12	9·13	8·38	7·95
R.P. 29 155	390·71	389·70	388·92	388·51

GAUGE-READINGS

In metres

Station	Normal High	Normal Low	Maximum Untimely	Minimum Timely
Zeraf Mouth 0	12·76	11·30	12·83	12·05
R.P. 10	14·75	13·57	13·72	13·10
Fangak	12·01	10·94	10·71	10·15
R.P. 19	16·47	15·46	14·90	14·42
R.P. 29	18·46	17·41	16·64	16·23

TABLE 222

BAHR EL ZERAF

NORMAL BACKWATER PROFILES

Place and Kilometrage	Reduced Levels of Low River	Reduced Levels of High River without Backwater	Backwater		Gauge-Readings	
			Height above Datum m.	R.L.	Theoretical m.	Actual m.
Zeraf Mouth 0 ...	383·78	384·10	1·22	385·32	12·81	12·76
20	4·54	5·01	0·84	5·85		
40	5·31	5·92	0·56	6·48		
R.P. 10 52 ...	5·77	6·47	0·43	6·90	14·75	14·75
60	6·07	6·83	0·35	7·18		
Fangak 66 ...	6·30	7·10	0·31	7·41	11·98	12·01
80	6·84	7·66	0·22	7·88		
Longtam 88 ...	7·24	7·98	0·18	8·16		
100	7·60	8·46	0·13	8·59		
R.P. 19 105 ...	7·78	8·66	0·12	8·78	16·46	16·47
120	8·36	9·26	0·09	9·35		
140	9·13	390·06	0·06	390·12		
R.P. 29 155 ...	389·70	390·66	0·05	390·71	18·43	18·46

Water Slopes: Low River 3·75 cm/km.
High River km. 0–km. 66 4·53 cm/km.
km. 66–km. 155 4·0 cm/km.

Water Depth: Low River 3·90 m.
High River 5·25 m.

Bed Slope: 4·55 cm/km.

Low River Gauges:

	Theoretical	Actual
Zeraf Mouth	11·27	11·30
R.P. 10	13·62	13·57
Fangak	10·87	10·94
R.P. 19	15·48	15·46
R.P. 29	17·42	17·41

TABLE 223

BAHR EL ZERAF
BACKWATER PROFILES UNDER THE E.N.P.

Place and Kilometrage	Untimely Maximum			Timely Minimum		
	R.L. Water Surface Datum	Backwater		R.L. Water Surface Datum	Backwater	
		Above Datum m.	R.L.		Above Datum m.	R.L.
Zeraf Mouth 0 ...	383·14	2·20	385·34	382·64	1·92	384·56
20	3·88	1·57	5·45	3·40	1·31	4·71
40	4·62	1·04	5·66	4·15	0·86	5·01
R.P. 10 52 ...	5·07	0·80	5·87	4·60	0·65	5·25
60	5·36	9·66	6·02	4·90	0·53	5·43
Fangak 66 ...	5·58	0·56	6·14	5·13	0·45	5·58
80	6·10	0·39	6·49	5·66	0·30	5·96
Longtam 88 ...	6·40	0·30	6·70	5·96	0·23	6·19
100	6·84	0·20	7·04	6·41	0·15	6·56
R.P. 19 105 ...	7·03	0·17	7·20	6·59	0·13	6·72
120	7·58	0·11	7·69	7·16	0·08	7·24
140	8·32	0·06	8·38	7·91	0·04	7·95
R.P. 29 155 ...	388·88	0·04	388·92	388·48	0·03	388·51

Water Slopes:	Untimely	3·7 cm/km.
	Timely	3·77 cm/km.
Water Depth:	Both	3·90 m.
Bed Slope:	,,	4·55 cm/km.

Gauge-Readings:

	Untimely	Timely
Zeraf Mouth	12·83	12·05
R.P. 10	13·72	13·10
Fangak	10·71	10·15
R.P. 19	14·90	14·42
R.P. 29	16·64	16·23

TABLE 224

BAHR EL JEBEL
SUMMARY OF BACKWATER PROFILES

Place and Kilometrage	Present Normals		Future E.N.P.	
	Normal High	Normal Low	Maximum Untimely	Minimum Timely
	Reduced Levels			
Lake No 0	386·42	385·95	386·23	385·65
10	6·69	6·28	6·44	5·91
20	6·97	6·60	6·65	6·17
30	7·24	6·93	6·88	6·44
40	7·53	7·26	7·11	6·71
50	7·82	7·59	7·36	6·99
Buffalo Cape 51·3 ...	7·85	7·63	7·39	7·03
60	8·09	7·88	7·62	7·27
70	8·35	8·15	7·87	7·55
90	8·93	8·74	8·40	8·11
100	389·22	389·03	368·68	388·40

GAUGE-READINGS
In metres

Place	Normals		Maximum Untimely	Minimum Timely
	High	Low		
Lake No	14·03	13·54	13·82	13·24
Buffalo Cape	11·27	11·05	10·81	10·45

TABLE 225

BAHR EL JEBEL
NORMAL BACKWATER PROFILES

Place and Kilometrage	Reduced Levels of Datum	Backwater Curve		Gauge-Readings	
		Height Above Datum m.	R.L.	Theoretical m.	Actual m.
		High River			
Lake No 0	386·20	0·22	386·42	14·01	14·03
10	6·51	0·18	6·69		
20	6·82	0·15	6·97		
30	7·12	0·12	7·24		
40	7·43	0·10	7·53		
50	7·74	0·08	7·82		
Buffalo Cape 51·3	7·78	0·07	7·85	11·27	11·27
60	8·03	0·06	8·09		
70	8·30	0·05	8·35		
80	8·61	0·05	8·66		
90	8·89	0·04	8·93		
100	389·18	0·04	389·22		
		Low River			
Lake No 0	385·95	Nil			13·54
10	6·28				
20	6·60				
30	6·93				
40	7·26				
50	7·59				
Buffalo Cape 51·3	7·63	Nil			11·05
60	7·88				
70	8·15				
80	8·46				
90	8·74				
100	389·03				

TABLE 226

BAHR EL JEBEL
BACKWATER PROFILES UNDER THE E.N.P.

Place and Kilometrage	Reduced Levels of Datum	Backwater Curve		Gauge-Readings
		Height above Datum m.	R.L.	Theoretical m.
		Untimely Period		
Lake No 0	385·76	0·47	386·23	13·82
10	6·05	0·39	6·44	
20	6·33	0·32	6·65	
30	6·62	0·26	6·88	
40	6·90	0·21	7·11	
50	7·19	0·17	7·36	
Buffalo Cape 51·3	7·23	0·16	7·39	10·81
60	7·48	0·14	7·62	
70	7·76	0·11	7·87	
80	8·05	0·09	8·14	
90	8·33	0·07	8·40	
100	388·62	0·06	388·68	
		Timely Period		
Lake No 0	385·51	0·14	385·65	13·24
10	5·80	0·11	5·91	
20	6·08	0·09	6·17	
30	6·37	0·07	6·44	
40	6·65	0·06	6·71	
50	6·94	0·05	6·99	
Buffalo Cape 51·3	6·98	0·05	7·03	10·45
60	7·23	0·04	7·27	
70	7·51	0·04	7·55	
80	7·80	0·04	7·84	
90	8·08	0·03	8·11	
100	388·37	0·03	388·40	

TABLE 227

RIVER SOBAT
SUMMARY OF BACKWATER PROFILES

Place and Kilometrage	Present Normals		Future E.N.P.	
	Normal High	Normal Low	Maximum Untimely	Minimum Timely
	Reduced Levels			
Sobat Mouth 0	384·99	382·50	385·08	384·23
Hillet Doleib 9	5·20	2·52	5·29	4·23
50	6·25	2·85	6·30	4·46
100	7·90	3·66	7·93	4·85
Abwong 117	8·52	4·06	8·55	5·10
150	9·85	5·01	9·87	5·72
200	392·00	6·92	392·01	7·17
Nyanding 239	3·77	8·57	3·77	8·66
250	394·32	389·03	394·32	389·10

GAUGE-READINGS
In metres

Place	Normals		Maximum Untimely	Minimum Timely
	High	Low		
Sobat Mouth	12·56	10·07	12·65	11·80
Hillet Doleib	13·68	11·04	13·77	12·73
Abwong	14·74	10·25	14·77	11·49
Nyanding	13·00	7·81	13·00	7·94

TABLE 228

RIVER SOBAT
NORMAL BACKWATER PROFILES

HIGH RIVER
Depth 9·0 metres. Slope 5·00 centimetres per kilometre.

Place and Kilometrage	Reduced Levels of Datum Profile	Backwater		Theoretical Gauge Reading m.	Actual Normals
		Height above Datum m.	Reduced Level		
Sobat Mouth 0	381·60	3·39	384·99	12·56	12·56
Hillet Doleib 9	2·05	3·15	5·20	13·71	13·68
50	4·10	2·15	6·25		
100	6·60	1·30	7·90		
Abwong 117...	7·45	1·07	8·52	14·91	14·74
150	9·10	0·75	9·85		
200	391·60	0·40	392·00		
Nyanding Mouth 239	3·52	0·25	3·77	13·05	13·00
250	4·10	0·22	4·32		

LOW RIVER
Depth 4·5 metres. Slope 4·41 centimetres per kilometre.

Place and Kilometrage	Reduced Levels of Datum Profiles	Backwater		Theoretical Gauge Reading m.	Actual Normals
		Height above Datum m.	Reduced Level		
Sobat Mouth 0	377·98	4·52	382·50	10·07	10·07
Hillet Doleib 9	378·37	4·15	2·52	11·03	11·04
50	380·18	2·67	2·85		
100	382·39	1·27	3·66		
Abwong 117	383·16	0·90	4·06	10·45	10·25
150	384·59	0·42	5·01		
200	386·80	0·12	6·92		
Nyanding Mouth 239	388·53	0·04	8·57	7·85	7·81
250	389·00	0·03	9·03		

TABLE 229

RIVER SOBAT
BACKWATER PROFILES UNDER THE E.N.P.

UNTIMELY PERIOD

Depth 9·0 metres. Slope 5·00 centimetres per kilometre.

Place and Kilometrage	Reduced Levels of Datum Profile	Backwater		Theoretical Gauge-Reading metres
		Height above Datum metres	Reduced Level	
Sobat Mouth 0	381·60	3·48	385·08	12·65
Hillet Doleib 9	2·05	3·24	5·29	13·77
50	4·10	2·20	6·30	
100	6·60	1·33	7·93	
Abwong 117	7·45	1·10	8·55	14·77
150	9·10	0·77	9·87	
200	391·60	0·41	392·01	
Nyanding Mouth 239	3·52	0·25	3·77	13·00
250	4·10	0·22	4·32	

TIMELY PERIOD

Depth 4·5 metres. Slope 4·41 centimetres per kilometre.

Place and Kilometrage	Reduced Levels of Datum Profile	Backwater		Theoretical Gauge-Reading metres
		Height above Datum metres	Reduced Level	
Sobat Mouth 0	377·98	6·25	384·23	11·80
Hillet Doleib 9	378·37	5·86	4·23	12·73
50	380·18	4·28	4·46	
100	382·39	2·46	4·85	
Abwong 117	383·16	1·94	5·10	11·49
150	384·59	1·13	5·72	
200	386·80	0·37	7·17	
Nyanding Mouth 239	388·53	0·13	8·66	7·94
250	389·00	0·10	9·10	

TABLE 230

EQUATORIAL NILE PROJECT
DISCHARGES IN THE 80 M/D CANAL STAGE

In millions of cubic metres per day. Totals in milliards.

10-Day Period at Mongalla		Mongalla Discharge	Atem Head Latitude		10-Day Period at Malakal		Tail of the Swamps		Malakal Discharge
			Jebel	Canal			Jebel	Canal	
January	1	120	33	80	January	2 ...	28	70	123·0
	2	120	33	80		3 ...	28	70	117·0
	3	120	33	80	February	1 ...	28	70	113·0
February	1	120	33	80		2 ...	28	70	111·0
	2	120	33	80		3 ...	28	70	109·0
	3	120	33	80	March	1 ...	28	70	108·0
March	1	120	33	80		2 ...	28	70	107·0
	2	120	33	80		3 ...	28	70	106·0
	3	120	33	80	April	1 ...	28	70	105·0
April	1	120	33	80		2 ...	28	70	106·0
	2	120	33	80		3 ...	28	70	106·0
	3	120	33	80	May	1 ...	28	70	107·0
May	1	120	33	80		2 ...	28	70	111·0
	2	120	33	80		3 ...	28	70	116·0
	3	120	33	80	June	1 ...	28	70	122·0
June	1	120	33	80		2 ...	28	70	127·0
	2	120	33	80		3 ...	28	70	132·0
	3	57	35	17	July	1 ...	30	15	83·6
July	1	57	35	17		2 ...	30	15	87·4
	2	57	35	17		3 ...	30	15	90·8
	3	57	35	17	August	1 ...	30	15	94·2
August	1	57	35	17		2 ...	30	15	97·0
	2	57	35	17		3 ...	30	15	99·8
	3	57	35	17	September	1 ...	30	15	102·0
September	1	57	35	17		2 ...	30	15	104·0
	2	57	35	17		3 ...	30	15	106·0
	3	57	35	17	October	1 ...	30	15	108·0
October	1	57	35	17		2 ...	30	15	109·0
	2	57	35	17		3 ...	30	15	111·0
	3	57	35	17	November	1 ...	30	15	112·0
November	1	57	35	17		2 ...	30	15	111·0
	2	57	35	17		3 ...	30	15	109·0
	3	57	35	17	December	1 ...	30	15	106·0
December	1	57	35	17		2 ...	30	15	100·0
	2	120	33	17		3 ...	28	70	142·0
	3	120	33	17	January	1 ...	28	70	131·0
Totals									
Dec. 11 to June 20		23·0	6·3	15·4	Dec. 21 to June 30 ...		5·4	13·4	22·3
June 21 to Dec. 10		9·9	6·1	2·9	July 1 to Dec. 20 ...		5·2	2·6	17·6
Year		32·9	12·4	18·3	Year		10·6	16·0	39·9

TABLE 231

EQUATORIAL NILE PROJECT
DISCHARGES DURING A PERIOD OF FLOOD-ESCAPE.

In millions of cubic metres per day. Totals in milliards.

10-Day Period at Mongalla		Mongalla Dis-charges	Atem Head*		10-Day Period at Malakal		Tail of the Swamps			Malakal Dis-charges
			Jebel	Canal			Jebel	Canal	Total	
January	1	120	93	20	January	2	49	17·5	66·5	92·1
	2	120	93	20		3	49	17·5	66·5	85·9
	3	120	93	20	February	1	49	17·5	66·5	81·7
February	1	120	93	20		2	49	17·5	66·5	79·6
	2	120	93	20		3	49	17·5	66·5	77·9
	3	120	93	20	March	1	49	17·5	66·5	76·6
March	1	120	93	20		2	49	17·5	66·5	75·6
	2	120	93	20		3	49	17·5	66·5	74·4
	3	120	93	20	April	1	49	17·5	66·5	73·3
April	1	120	93	20		2	49	17·5	66·5	74·1
	2	120	93	20		3	49	17·5	66·5	74·4
	3	120	93	20	May	1	49	17·5	66·5	75·8
May	1	120	93	20		2	49	17·5	66·5	79·5
	2	120	93	20		3	49	17·5	66·5	84·8
	3	120	93	20	June	1	49	17·5	66·5	90·8
June	1	120	93	20		2	49	17·5	66·5	96·0
	2	120	93	20		3	49	17·5	66·5	100·9
	3	120	93	20	July	1	49	17·5	66·5	105·1
July	1	120	93	20		2	49	17·5	66·5	108·9
	2	120	93	20		3	49	17·5	66·5	112·3
	3	120	93	20	August	1	49	17·5	66·5	115·7
August	1	120	93	20		2	49	17·5	66·5	118·5
	2	120	93	20		3	49	17·5	66·5	121·3
	3	120	93	20	September	1	49	17·5	66·5	123·7
September	1	120	93	20		2	49	17·5	66·5	125·7
	2	120	93	20		3	49	17·5	66·5	127·5
	3	120	93	20	October	1	49	17·5	66·5	129·3
October	1	120	93	20		2	49	17·5	66·5	131·0
	2	120	93	20		3	49	17·5	66·5	132·3
	3	120	93	20	November	1	49	17·5	66·5	133·2
November	1	120	93	20		2	49	17·5	66·5	132·7
	2	120	93	20		3	49	17·5	66·5	131·0
	3	120	93	20	December	1	49	17·5	66·5	127·7
December	1	120	93	20		2	49	17·5	66·5	121·5
	2	120	93	20		3	49	17·5	66·5	110·7
	3	120	93	20	January	1	49	17·5	66·5	100·0
TOTALS										
Dec. 11 to June 20		23·2	17·9	3·8	Dec. 21 to June 30 ...		9·4	3·4	12·8	16·2
June 21 to Dec. 10		20·8	16·1	3·5	July 1 to Dec. 20 ...		8·5	3·0	11·5	21·3
Year		44·0	34·0	7·3	Year		17·9	6·4	24·3	37·5

*Distribution inferred from example given for Mongalla discharge of 150 m/d.

NOTES AND REFERENCES

(1) Tothill, J. D. (Ed.), *Agriculture in the Sudan*, O.U.P., 1948, p. 608.

(2) Butcher, A. D., *The Sadd Hydraulics*, Cairo, 1938, p. 47.

(3) Jonglei Investigation Team, *First Interim Report*, 1946, p. 44.

(4) Hurst, H. E., *The Nile Basin*, Cairo, Vol. VII, p. 84.

(5) Assuming proportions as in the *First Interim Report*.

(6) Hurst, op. cit., Vol. V, p. 207.

(7) Butcher, op. cit., p. 55.

(8) Hurst, op. cit., Vol. V, p. 215.

(9) Public Works Ministry, Cairo, 1938.

(10) Hurst, op. cit., Vols. III and IV, Third Supplement.

(11) ibid.

(12) ibid.

(13) Sections taken by Sir Alexander Gibb & Partners at a later date modify this generalization considerably, but the irrigable areas are still considerable.

CHAPTER 3. EFFECTS ON PASTURE AND ANIMAL HUSBANDRY

1. INTRODUCTION

In the previous chapter we have described the effects of the Equatorial Nile Project on the hydrology of the Jonglei Area. It will be realized that alterations in hydrological conditions will cause changes in the ecological characteristics of the flood-plains and this in turn will affect their economic utilization by the local inhabitants. In this report we are chiefly concerned with these effects on the economy of this area. Before turning to their economic significance, it is necessary to review briefly the effects of the change in the river régime on the ecological character of the flood-plains. We have shown in the previous volume how the present *toich* and *sudd* ecosystems (i.e. soils and vegetation) owe their characteristics predominantly to the hydrological factor. Once the principles of their present interrelation with the river régime are appreciated and the significance of the hydrological changes is understood, the reader should have no difficulty in following the arguments set out below, though at first glance they may appear involved.

We have pointed out that while the moisture conditions in the inland areas are controlled by rainfall alone, on the riverain flood-plains they depend mainly on the seasonal fluctuations of water-levels in the adjoining rivers and watercourses. The areas which are only sporadically flooded, but where the water-table rises annually with the rising river or khor to within a few centimetres from the surface, have been shown to carry vegetation dominated by *Phragmites communis*. These areas may be regarded as transitional between the *toich* and the intermediate land, but as they are characterized by a moisture content sufficient to promote vigorous growth of plants throughout the year they should be regarded as *toich*. It is clear that while on the lighter soils, with less impeded lateral water movements, such areas of *Phragmites* can extend for some distance inland from the main channels, on the heavy soils the conditions giving rise to *Phragmites toiches* will be present only in the immediate vicinity of the rivers.

The areas which are seasonally inundated by river spill carry vegetation dominated by *Echinochloa* spp. and *Oryza* spp. etc., i.e. predominantly *toich* grassland. The distribution of these species is determined as shown in Volume I. On the basis of our present knowledge we consider depth and duration of flooding, especially the latter, to be the most important factors. The duration of flooding is the only factor from which we have been able to estimate ecological changes in quantitative terms from actual ground surveys and the analysis of predicted hydrological changes, and it has therefore been taken as the basis of our assessment.

Moreover we have already pointed out that from the pedological point of view the period of water-saturation (i.e. the period of anaerobic and reducing conditions) is the most important factor, to which the soils of the *toich* land owe their distinguishing characteristics. The depth of seasonal flooding is less important in this connection (see Vol. I, pp. 100–3). The chief property of *toich* soils on which other properties depend is the comparatively high organic matter content. The evidence gathered during our investigation, though scientifically not conclusive, indicates that the organic matter content is roughly proportional to the duration of flooding. This is not surprising if it is appreciated that it is the slowing down of decomposition in anaerobic conditions which prevents the nearly complete destruction of organic matter characteristic of inland soils. Water-saturation either from flooding or from a rising water-table (as in the case of *Phragmites toiches*) has essentially a similar effect.

Certain parts of the flood-plain are inundated to depths varying from practically nothing to nearly 3 m. In such conditions hydrarch plant succession leads to the development of a peat layer characteristic of *sudd* soils. The majority of *sudd* areas represent the transition stage between the floating and the swamp stages of the hydrosere. Papyrus is generally a dominating, or at least the most obvious, plant species on this type of land. The *sudd* ecosystem requires for its existence nearly permanent flooding. The limitation of the annual fluctuation of levels within the range of one metre (so that the roots of the floating vegetation mat anchoring it to the mineral soil are not torn annually) is probably also essential. The lack of *sudd* downstream of the Zeraf mouth is probably explained at least in part by the fact that the river fluctuation at present exceeds this maximum range.

The changes in hydrological conditions described in the previous chapter can be classified as follows and their ecological significance should be obvious from the preceding paragraphs.

TABLE 232

PRINCIPAL CHANGES IN HYDROLOGICAL CONDITIONS AND THEIR EFFECTS ON THE *TOICH* AND *SUDD* ECOSYSTEMS

Change in Hydrological Conditions	Effect on Vegetation	Effect on Soil
A. *Toich Ecosystem*		
1. Higher water-table	Probably no change	No change unless period of saturation increased
2. Increased period of seasonal flooding	Change in following direction: *E. pyramidalis*→*E. stagnina*→*Vossia cuspidata*	Increase in organic matter and intensification of characteristics distinguishing *toich* soils
3. Permanent flooding	Replacement of *toich* grasses by *sudd* vegetation	Formation of organic horizon. Development of *sudd* soils
4. Permanent deep flooding ...	Disappearance of vegetation, later possible formation of *sudd*	Probable formation of *sudd* soils in later stages
5. Lower water-table	Change from *Phragmites-Echinochloa toich* towards intermediate grassland type	Loss of characteristics distinguishing *toich* soils. Replacement of *toich* by intermediate or high land soils
6. Decreased duration of seasonal flooding	Changes in following direction: *V. cuspidata*→*E. pyramidalis*	Oxidation of organic matter, and partial loss of characteristics distinguishing *toich* soils
7. Permanent termination of seasonal flooding	Change from *toich* grassland to intermediate type grassland	Nearly total oxidation of organic matter. Loss of characteristics distinguishing *toich* soils. Development of intermediate or high land soils
B. *Sudd* Ecosystem		
1. Increased depth of flooding ...	Up to certain limit no change ...	Up to certain limit increase in depth of organic matter
2. Decreased depth of flooding ...	Probably no change within certain limits	Decrease in depth of organic matter
3. Replacement of permanent by seasonal flooding	Change from *sudd* to *toich* vegetation	Loss of organic horizon. Change from *sudd* to *toich* soils
4. Complete cessation of river spill	Change from *sudd* to intermediate land vegetation	Loss of organic horizon. Change to intermediate or high land soils

N.B.—If non-flooded high land areas or sporadically rain-flooded intermediate land areas are in future seasonally inundated by river spill they will turn into *toich*; if they are permanently inundated they will turn into *sudd*.

The reader will realize that though changes in hydrological conditions can be brought about very rapidly by human effort, ecological changes will be much slower, the period taken by them depending on the extent of the change from the present to the future hydrological conditions. We have no data to assess the rapidity of the changes and therefore the ecological discussion of the intermediate constructional stages of the Project is highly speculative.

We wish to emphasize again that the changes in the hydrological conditions will affect the ecosystem as a whole, i.e. both vegetation and soils. From the point of view of the economic effects the changes in the vegetation are, of course, more important. As far as the quantitative considerations are concerned we have concentrated in this chapter on describing the changes in vegetation of the flood-plains and their effects on animal husbandry. It will, however, be realized that the quantitative aspects (i.e. areas affected) of changes in soils can be easily deduced from the tables describing present and future distribution of vegetation species, remembering that *toich* vegetation is, and will be, associated with *toich* soils, and *sudd* vegetation is, and will be, associated with *sudd* soils.

The significance of the effect of these changes upon the agricultural utilization of the soils is discussed in a later chapter. The division of the land into ecological regions in Volume I was necessary for a proper geographical appreciation of the area, but the control of the Nile and the effects of such control raise a new set of conditions in three different reaches of the Nile, which reaches do not correspond exactly to the ecological regions. We now refer to the three Zones—

Southern, Central and Northern—which are based entirely on hydrological effects on the main Nile system, and where the term ' Zone ' is used it has always this application. Geographically the southern and northern limits of the three Zones at the main rivers are :

Southern Zone:	South—Nimule, on the Uganda frontier
	North—Bahr el Jebel barrage (Atem Head)
Central Zone:	South—Bahr el Jebel barrage (Atem Head)
	North—(*a*) Buffalo Cape (km. 50) on the Bahr el Jebel
	(*b*) Fangak on the Bahr el Zeraf
	(*c*) Yoynyang " " Bahr el Ghazal
	(*d*) Abwong " " River Sobat
Northern Zone:	South—(*a*), (*b*), (*c*), (*d*), as above
	North—Jebel Aulia Dam

It will be seen from the above that the Southern Zone includes the Ironstone Region and the extreme southern part of the Flood Region. The whole of the Central Zone comes within the Flood Region; the Northern Zone includes the northern part of the Flood Region and all the Semi-Arid Region.

2. THE SOUTHERN ZONE

It has been shown in the previous chapter that the seasons of high and low river will be reversed in the 55 m/d Canal stage of the Project. The intention is to avoid excessive water losses through spill, even at normal high levels, by banking the main channel (left bank) from Tombe to the Atem Head and from just north of Bor (right bank) to the Canal Head. South of these places the nature of the river bank is such that spill losses will be small, but should experience show that losses by spill through the larger breaks in the bank are appreciable, these larger openings could be closed without great difficulty. No definite proposals have yet been put forward for banking or blocking channels in this manner between Juba and Tombe, and for the purpose of our investigation we must assume that no attempt will be made to do so, though the possibility is borne in mind and mentioned in the text which follows.

The system of natural irrigation of pasture land by the normal seasonal fluctuation of the main river levels has been described in Volume I, as has the indispensable nature of this pasture for local livestock during the dry season. With the prevention of river spill this natural irrigation will cease and the existing natural pastures will be replaced by vegetation dependent almost entirely on local rainfall, local run-off, the effluent of a few small streams from inland and an underground water-table created by seepage from the main river channel. The effects of these new conditions on the distribution of grass species throughout the Southern Zone are discussed in detail in the following section, and the importance of the change in vegetation with regard to dry season grazing is made clear below. The effect of the Project on high and intermediate land and khor-bed swamp pasture is negligible, but the effect on main riverain swamp pasture will be far-reaching.

EFFECTS ON PASTURE TYPES

RIVERAIN SWAMP GRASSLAND

In our survey (Vol. I, Ecology) we have shown that the distribution of vegetation along the flood-plain in the southern reaches is determined, as along other reaches, primarily by factors created by the normal river régime. Under the Project there will be radical changes in the régime which will disturb or modify these governing factors. Therefore before we proceed to make quantitative estimates of the effect of these changes on pasture, we should attempt a qualitative study of the main factors. These factors are dealt with in the same way as in our previous volume (see p. 152–4).

Depth and Duration of Flooding

The reader is referred to Table 123 (Vol. I, p. 185) where figures for depth and duration for various species under natural river conditions are given.

As already mentioned, there are a number of stages in the construction of the Equatorial Nile Project, each stage having a slightly different effect. We are, however, primarily concerned with the 55 m/d Canal stage, though in the Southern Zone the effects will be felt immediately at the first stage, i.e. storage dams only, and it is necessary briefly to review these earlier stages if we are to have a complete picture of events at the 55 m/d stage.

Storage Dams Only (Stage I)

During this stage the river will remain permanently within its banks and there will be no spill. The flood-plain will not be inundated ; therefore depth and duration of flooding by river spill will cease to be factors determining the distribution of vegetation species.

Intervening Stages

There will be no spill in the first and second 10 m/d Canal stages (Stages II and III) and only slight spill at the 27·5 m/d stage (Stage IV). Conditions will therefore be similar to the storage dams stage.

55 m/d Canal Stage (Stage V)

At this stage the Bahr el Jebel will be banked between Tombe and the barrage on the left bank, and between a point north of Bor and the Atem Head on the right bank. South of Tombe we assume that the river will not be banked. Thus north of Tombe there will be no inundation of the flood-plain from the river, and depth and duration of flooding by spill will no longer be operative as important factors governing the distribution of vegetation species. In other words conditions will be the same as in the preliminary stages of the Project, but for different reasons. South of Tombe the river will spill through channels—i.e. similar to normal conditions, except that :

(i) There will be no spill over the crest of the bank.
(ii) The duration of flooding at all depths will be fairly uniform over the area inundated and exposed, since the river level will rise and fall steeply at regular times—December and June.
(iii) The depth of flooding will be uniformly greater over the area flooded and exposed, because the minimum river level will be higher.
(iv) Flooding will be between December and June instead of the normal period May to December, i.e. a reversal of the present seasonal régime.

If, however, it is decided to bank off spill-channels, conditions will be similar to those operating north of Tombe, and depth and duration due to spill will again cease to be factors governing the distribution of vegetation.

Current Velocity

The expected average velocities for a section of the river in this reach under the Project compared with normal velocities are summarized below. However, in the survey we have shown that current velocity is only an important factor governing species growing directly by the river and along the channels of major watercourses, and that velocities on the flood-plain are negligible and have little or no effect on the distribution of species. These observations will still apply under future conditions, and in any case, with no inundation of the flood-plain in the greater part of the Zone, current velocity will not be a relevant factor. The present and future maximum and minimum velocities for a section of the river at Mongalla are:

Present Maximum	...	1·1 m/sec.
,, Minimum	...	0·9 m/sec.
Future Maximum	...	1·1 m/sec.
,, Minimum	...	0·9 m/sec.

Climate: Rainfall

Actual rainfall will not change, but it will become more effective in that it will no longer be in phase with river flooding. In the first place, with the banking of spill-channels, there will be no flooding ; in the second place, without the banking of spill-channels south of Tombe, flooding will be between December and June, i.e. after one rains period is over and before the next begins.

Changes in Soils

South of Tombe (in the 55 m/d Canal stage) flooding from the river, which now coincides with the rains season, will in future coincide with the rainless months. As far as soils are concerned the changes likely to take place can be briefly summarized as follows :

(i) A slight decrease in the flood-plain area is expected so that an area of *toich* soils, no longer saturated in future, will become intermediate or high land soils.
(ii) The area of *toich* soils which at present supports *Phragmites communis* will remain practically unchanged. These soils are flooded by river spill comparatively infrequently, i.e. in years of exceptionally high river levels. They owe their saturation and hence characteristics to the seasonal rise in the water-table which coincides with the rains season. Under future conditions this rise will continue to take place, but during the rainless months. The degree and period of saturation cannot be exactly predicted and therefore the changes mentioned here are largely a matter of speculation. From the point of view of vegetation, however, it should be noted that the moisture supply throughout the year will certainly be improved.
(iii) The soils now seasonally inundated by river spill, i.e. soils of the *toich* supporting mainly *Echinochloa* spp. and *Oryza* spp., will in future be inundated during the dry season and the period of saturation will be increased, with a resultant increase in organic matter content and related physical and chemical changes.
(iv) There will be some increase in conditions favouring papyrus and other forms of vegetation characteristic of the *Sudd* and a consequent increase in *sudd* soils.

This applies in the area south of Tombe provided that no banking or blocking of channels is carried out to prevent spill. North of Tombe where river spill will be prevented by banking there will be improved aeration and hence oxidation of the organic matter in those soils which now owe their distinguishing characteristics to inundation from the main river. Inundation from khors and local run-off as well as seepage will maintain seasonal saturation conditions in some parts of the area. Thus, while *sudd* soils will in time disappear almost completely, quite a large area (about 600 sq. km.) of *toich* soils will remain.

Rate of Rise in Flood-Waters

This, in relation to rainfall, has previously been given as a factor governing the development and distribution of plant species. North of Tombe it will cease to be a factor altogether, since there will be no flooding. South of Tombe, if there is no banking of spill-channels, it will remain a factor of considerable importance. In this reach some areas, such as parts of the flood-plain between Mongalla and Gemmeiza, are not flooded by river spill at present except at high discharge, and this will remain so under the Project although the seasons will be reversed. Therefore the vegetation in these areas will not be affected by rate of rise. Other areas in this reach, however, do receive flooding by spill or backwater effect, and this will also be the case under the Project, except that flooding will occur between December and June rather than between June and December as at present. Further, whereas now there is a gradual rise, in future the river will rise from its new minimum (which is roughly equivalent to normal minimum) to its maximum (roughly equivalent to normal maximum) within a period of 10 to 20 days, i.e. a rise of a maximum of 1 m. in 10 days instead of several months. It has been shown that if such a quick rise took place under present conditions it would have a drastic effect on vegetation. However under the Project the rise will take place after the area has received the full benefit of the rains, during which the vegetation will have had time to reach full development, but whether or not the plants can adapt themselves afterwards—at the mature stage—to flood conditions lasting six to seven months is questionable. Fortunately the sudden rise of 1 m. will only affect those sites that will carry vegetation predominantly of the floating species, for it is expected that at those sites still subject to inundations from the river there will be a spread of the floating types, *Echinochloa stagnina* and *Vossia cuspidata*, and at the lowest end of the scale *Cyperus papyrus*.

Grazing and Burning

As factors, these will only continue if the new vegetation which develops under the new conditions can be utilized for pasture.

Summary of Changes in Environmental Factors

Changes in environmental factors after the 55 m/d Canal stage is reached can be summarized as follows:

South of Tombe:

(*a*) With Banking:

(i) No river spill; depth and duration of flooding no longer operative.
(ii) Current velocity; operative only at the main river.
(iii) Rainfall; unchanged, but more effective since it will be the main source of soil moisture.
(iv) Soils; loss of organic matter from surface layers.
(v) Rate of rise in flood waters; not operative.
(vi) Seepage; higher water-table owing to high water-level in the river during dry season.
(vii) Run-off; as at present.

(*b*) Without Banking:

(i) Spill during dry season giving six months' flooding; a reversal of the seasonal fluctuation in river levels.
(ii) Depth more uniform and more even.
(iii) Current velocity; roughly as at present.
(iv) Rainfall; unchanged, but more effective, as above.
(v) Soils; probable increase in organic matter content of surface layers.
(vi) Rate of rise of flood-waters; will continue to be a factor of considerable importance.
(vii) Seepage; water-table as at present, only reversed in seasons.
(viii) Run-off; as at present.

North of Tombe (River banked):

(i) No river spill; depth and duration of flooding no longer operative.
(ii) Current velocity; operative only at the main river.
(iii) Rainfall; more effective and will become the main source of soil moisture.
(iv) Soils; destruction of organic layer in *sudd* soils and loss of organic matter from surface soil layer in *toich* soils.
(v) Rate of rise in flood-waters; not operative.
(vi) Seepage; higher water-table owing to more permanently high water-level in river during the dry season.
(vii) Run-off; as at present.

Changes in Vegetation

With so many modifications in the factors which at present govern the distribution of plant species along the river, it is clear that definite changes in vegetation may be expected.

We are primarily concerned with the effect in the 55 m/d Canal stage, but it is worth stressing here that changes will be different in the successive preliminary stages of the Project, and different in the two main reaches of this Zone (i.e. north of Tombe and south of Tombe) because of variations in topography and according to whether banking is carried out or not. North of Tombe there will only be one major change in vegetation due to the deprivation of the flood-plain of seasonal spill; in the initial stages because discharges will be kept low throughout the year, in later stages because the main channel of the river will be banked. South of Tombe the changes predicted are more complex. In the initial stages there will be no spill and the water-table will be lower than usual, resulting in changes in vegetation due to a reduction in moisture from both sources. In the later stages a further change may be expected because spill will take place in some parts and the water-table will be raised, but in the timely season, not in the untimely season as at present. There will therefore be a 'double change', the extent of which will depend on how far the vegetation will have had time to alter or adapt itself to the different ecological conditions in the interim. The time factor is important. This assumes that banking to prevent spill will not be carried out—otherwise the effects would be the same as in the northern reach of the Zone. In this Zone the difficulties of predicting the changes in vegetation and their ultimate distribution after the 55 m/d Canal stage is in operation are therefore obvious. However, taking into consideration the present distribution of species in relation to the factors described in the previous volume (pp. 152 et seq.) and those which will be in operation in future, we have attempted to estimate the changes, which are dealt with quantitatively below.

Quantitative Considerations

The reader should here refer to Volume III, Special Investigations, in which two stretches of the flood-plain in the Southern Zone have been described in detail, the Aliab Valley and the Mongalla-Gemmeiza *toich*.

The Aliab Valley, north of Tombe, lies in the stretch which in future will be completely banked off and protected from river spill, and where only one major change in vegetation, taking place over a long period, is expected. The Mongalla-Gemmeiza *toich* is situated south of Tombe where a 'double change' in vegetation seems likely. Our survey and estimate of changes in vegetation in both these areas is taken to be typical of the two river stretches in which they are found, i.e. north of Tombe to Atem Head and south of Tombe to Juba.

The Mongalla-Gemmeiza *toich*

A map illustrating the present distribution of species along the flood-plain between Mongalla and Gemmeiza is given in Volume IV (Fig. H 13). Further Fig. H 23 shows the distribution of grass species by area in relation to the duration of flooding and other factors. Where an area is occupied by a mixture of species, estimates of their proportions have been made, based on field notes and observations, from which we have produced Table 392 (Vol. III, p. 843), giving the areas and percentage of the total area occupied by each species individually.

Taking into consideration the factors on which this distribution is based (i.e. river flooding, depth and duration of flooding, seepage, water-table, rainfall and run-off, soils, etc.), and the changes which will occur in these factors under the Project, shown in Fig. H 25 (Mongalla-Gemmeiza), we have determined a new distribution of vegetation by area for the Mongalla-Gemmeiza *toich* at the 55 m/d stage. As at present, there will be a large area where species are mixed, and to estimate the proportions of each species in those mixed areas we have referred to data recorded in the survey to find areas where similar ecological conditions prevail and have taken the estimated proportions worked out for those areas. An estimate of the area occupied by different species under future conditions has been reached, by interpolation and—admittedly—somewhat arbitrary methods. This is recorded in Table 395 (p. 846).

The Flood-Plain South of Tombe

In order to estimate the distribution of species in the whole flood-plain between Juba and Tombe we have applied the results of our estimates in the limited area described above.

present distribution

The total estimated area of flood-plain between Juba and Tombe is 650 sq. km. (see Table 192, p. 437). To obtain the present distribution of species we have divided up the area according to the percentage distribution of species as determined in the Mongalla-Gemmeiza reach (see Table 395). The results are given in Table 233, p. 471.

From the point of view of dry season grazing, the two areas of importance are :

132·4 sq. km. of *Echinochloa stagnina*
341·8 sq. km. of *Echinochloa pyramidalis*

of which 90% and 95% respectively are accessible in the dry season, i.e. 119·2 sq. km. and 324·7 sq. km. The remaining areas—i.e. of *Vossia cuspidata*, papyrus, *Phragmites*, etc. and open water—are of little or no importance as pasture.

FUTURE DISTRIBUTION

To obtain the future distribution of species we have had to take into consideration the areas of flood-plain that will in future continue to be irrigated naturally by the Rivers Koda and Luri and other small streams, estimated to be 80·0 sq. km. (see p. 471). At present it is assumed that these rivers have little effect in governing the distribution of plant species on the flood-plain because of the effect of the normal river régime. We have therefore subtracted this figure of 80 sq. km. from 650 sq. km., which gives us a figure of 570 sq. km. over which we assume changes in vegetation will be similar to those occurring along the Mongalla-Gemmeiza *toich*.

The future percentage distribution of vegetation and open water in that area of the Mongalla-Gemmeiza flood-plain surveyed in detail is given in Table 394 (p. 845) and in column 2 of Table 395. We have applied these percentages to the 570 sq. km. referred to above and record the future distribution of species in Table 234 (a), p. 471.

It is assumed that the remaining 80 sq. km. of the flood-plain affected by these rivers will be inundated to a depth of 1 m., sufficient to produce *Echinochloa pyramidalis* (see Table 234 (b)).

In Table 234 (c) the total estimated future distribution of species over the whole of the flood-plain between Juba and Tombe under the Equatorial Nile Project is given.

In order to estimate the value of the new species distribution in terms of accessible dry season pasture we must again refer to the effects on the distribution of species in the surveyed area of the Mongalla-Gemmeiza stretch of the flood-plain, described in Volume III. It will be noted from Table 394 that under the Project 22·5 sq. km. out of the total area of 33·2 sq. km. of *Echinochloa stagnina* will be flooded in the dry season (i.e. inaccessible). Similarly 5·6 sq. km. out of the total area of 34·8 sq. km. of *Echinochloa pyramidalis* will be also inaccessible. Furthermore all the *Vossia cuspidata* and *Cyperus papyrus* will be flooded in the dry season, while the areas of *Phragmites communis* and *Hyparrhenia rufa* will be completely exposed.

In order to assess the areas of species that will be accessible over the whole reach under the Project, we have assumed that the accessible areas of each species will occur in the same proportions as those already determined for the area surveyed in the Mongalla-Gemmeiza reach, except in those areas affected by the Rivers Koda and Luri, which will be fully exposed.

When considering the future distribution of the accessible species in terms of grazing value (see p. 473), only those areas occupied by *Echinochloa stagnina*, *Echinochloa pyramidalis* and intermediate land species will be considered. The total future accessible areas of these species are estimated to be :

Echinochloa stagnina	37·8 sq. km.
Echinochloa pyramidalis	183·3 ,, ,,
Intermediate land species (*Hyparrhenia rufa*) ...	47·9 ,, ,,

THE ALIAB VALLEY

A map showing the distribution of species in the Aliab Valley, together with a graph showing the distribution by area in relation to depth and duration of flooding, etc. of species east and north of the River Aliab, are given in Figs. H 3 and H 22. These show areas occupied by major vegetative associations (i.e. papyrus dominated, *E. pyramidalis* dominated, etc.) and, as in the case of the Mongalla-Gemmeiza reach, we have determined the areas occupied by each species individually (see Table 381, p. 834).

Taking into consideration the factors which have produced the above distribution under present conditions and the changes which will take place in the future, we have determined the new distribution of species by area when the 55 m/d Canal stage is in operation—see Fig. H 24 and Table 386 (p. 838).

THE FLOOD-PLAIN: TOMBE TO ATEM HEAD

PRESENT DISTRIBUTION

The total estimated area of the flood-plain between Tombe and Atem Head is 931 sq. km. (Table 192, p. 437). To estimate the present distribution of species over this stretch we have used the data from the Aliab Valley, as we used the Mongalla-Gemmeiza data for the flood-plain between Juba and Tombe. There are only two rivers which open on to the flood-plain over this stretch—the Khor Gwir and the Tapari. The Khor Gwir affects 66·5 sq. km. of flood-plain, but the Tapari is not at present a major factor in determining vegetation because it discharges into an area already subject to inundation from the main river. For the remainder of the flood-plain not affected by Khor Gwir, we have used the proportions obtained from the north-eastern part of the Aliab Valley as given in Table 381. Table 235 (p. 472) gives the present distribution of species over the area affected by the Bahr el Jebel (a), and Khors Gwir and Tapari (b) and (c); (d) gives the total distribution of species by area for the whole flood-plain between Tombe and Atem Head.

In determining the above distribution in terms of valuable animal grazing, we only consider *Echinochloa stagnina*, *Echinochloa pyramidalis* and *Oryza barthii*, since *Phragmites communis* has no value as grazing and *Cyperus papyrus* and *Vossia cuspidata* are anyway inaccessible owing to flooding. Of the areas occupied by *Echinochloa stagnina* and *Echinochloa pyramidalis*, we estimate that 90% and 95% respectively are accessible :

Echinochloa stagnina ...	158·6 sq. km.
Echinochloa pyramidalis ...	421·7 ,, ,,
Oryza barthii	8·0 ,, ,,

FUTURE DISTRIBUTION

To obtain the future distribution of species over this stretch we have had to consider the area of flood-plain affected by Khors Gwir and Tapari. It is estimated that in future Khor Gwir will effectively irrigate naturally 100 sq. km. and that the Tapari will irrigate 20 sq. km. The remainder of the area (811 sq. km.) will receive only rainfall and moisture from underground water-tables.

To the area of flood-plain, excluding the area affected by Khors Gwir and Tapari, we have applied the estimated future distribution of species for the north-eastern part of the Aliab Valley (as given in Table 386), with results recorded in Table 236 (a), p. 472. We apply the present distribution in the Khor Gwir basin to the areas which will be irrigated by Khors Gwir and Tapari. The distribution of species over both these areas under the Project is given in Table 236, (b) and (c). In Table 236 (d) the future total distribution of species by area over the flood-plain between Tombe and the Atem Head is given. The whole of this area will be accessible in the dry season, so from the point of view of grazing value the following areas are of importance:

Echinochloa stagnina	59·0 sq. km.
Echinochloa pyramidalis	328·6 ,, ,,
Oryza barthii	14·4 ,, ,,
Intermediate land species (*Hyparrhenia rufa*) ...	306·6 ,, ,,

TOTAL AREA: JUBA TO ATEM HEAD

Table 237 (p. 473) gives the estimated present and future distribution of plant species over the whole flood-plain in the Southern Zone, i.e. from Juba to Atem Head. This refers, however, to total distribution and not specifically to areas which are and will be accessible and therefore of value as pasture. Below we sum up the total areas accessible in the dry season :

	Present sq. km.	Future sq. km.
Echinochloa stagnina	277·8	96·8
Echinochloa pyramidalis	746·4	511·9
Oryza barthii	8·0	14·4
	1,032·2	623·1
Intermediate land species (*Hyparrhenia rufa*)	Nil	354·5
	1,032·2	977·6

The relationship of the above distribution to present and possible future stock numbers is given later (see p. 473 et seq.).

INLAND KHOR-BED PASTURE

There are a number of inland waterways in the Southern Zone which produce some khor-bed pasture in the dry season. We have already considered the Khors Luri, Koda, Gwir, and Tapari in relation to the areas of riverain flood-plain where their waters contribute to the development of swamp pastures. This will remain unchanged in the future and in fact their contribution will be of much greater importance.

We have not yet considered what pastures these khors produce inland in their beds, and what effect the Project will have upon them. The present hydrological régime of all these rivers is independent of the Nile and therefore the Project will not have any appreciable effect on the pasture they normally produce. At present the Khors Luri and Koda produce a negligible amount of khor-bed pasture, except at their mouths. The River Luri has a sandy bed completely bare of vegetation, high banks and a flood-plain of cotton soil dominated mostly by *Hyparrhenia rufa*. The Koda is similar, having a flood-plain dominated by *Hyparrhenia* sp. and *Hygrophila* sp. In the dry season little pasture is produced by either, so their present utility is negligible. This will remain unchanged in the future.

The course of the Khor Gwir lies entirely within a clay flood-plain between its source and where it enters the Bahr el Jebel in the Aliab Valley—a distance of 140 km. The grass in its bed (*Hyparrhenia* sp. and *Echinochloa pyramidalis*) will remain unchanged.

The pasture in the bed of the Tapari will also remain unchanged, as also will the grass along its flood-plain (mostly *Hyparrhenia* sp., while *Echinochloa pyramidalis* is probably the predominant grass in its bed). Its tributary, the Tali, which is 200 m. wide by 0·80 m. deep, carries some *Echinochloa pyramidalis* in its bed.

Grasses produced by other inland waterways which have flood-plains, such as the Kinyeti and the Koss, will also remain unchanged.

INTERMEDIATE AND HIGH LAND PASTURE

These will not be affected directly by changes in the normal river régime, although they will be affected indirectly because of the greater dependence upon them when riverain pastures have been reduced.

TABLE 233
PRESENT DISTRIBUTION OF SPECIES
JUBA–TOMBE

Open Water ...	9·3 sq. km.
Cyperus papyrus ...	19·4 ,, ,,
Vossia cuspidata ...	15·6 ,, ,,
Echinochloa stagnina ...	132·4 ,, ,,
Echinochloa pyramidalis ...	341·8 ,, ,,
Phragmites communis ...	131·5 ,, ,,
TOTAL ...	650·0 ,, ,,

TABLE 234
FUTURE DISTRIBUTION OF SPECIES
JUBA–TOMBE

(*a*) Excluding flood-plain areas affected by Rivers Koda, Luri, and other small streams.

Open Water ...	25·7 sq. km.
Cyperus papyrus ...	51·9 ,, ,,
Vossia cuspidata ...	62·7 ,, ,,
Echinochloa stagnina ...	117·4 ,, ,,
Echinochloa pyramidalis ...	123·0 ,, ,,
Phragmites communis ...	141·4 ,, ,,
Intermediate spp. (*Hyparrhenia*) ...	47·9 ,, ,,
TOTAL ...	570·0 ,, ,,

(*b*) Areas of flood-plain affected by Rivers Koda, Luri, and other small streams.

Echinochloa pyramidalis ...	80·0 sq. km.

(*c*) Total Distribution.

Open Water ...	25·7 sq. km.
Cyperus papyrus ...	51·9 ,, ,,
Vossia cuspidata ...	62·7 ,, ,,
Echinochloa stagnina ...	117·4 ,, ,,
Echinochloa pyramidalis ...	203·0 ,, ,,
Phragmites communis ...	141·4 ,, ,,
Intermediate spp. (*Hyparrhenia*) ...	47·9 ,, ,,
TOTAL ...	650·0 ,, ,,

TABLE 235

PRESENT DISTRIBUTION OF SPECIES
TOMBE-ATEM HEAD

(*a*) Excluding flood-plain areas affected by Khors Gwir and Tapari (Gel).	
Open Water ...	108·1 sq. km.
Cyperus papyrus	62·3 „ „
Vossia cuspidata	111·5 „ „
Echinochloa stagnina	165·1 „ „
Echinochloa pyramidalis	396·8 „ „
Phragmites communis	20·7 „ „
TOTAL	864·5 „ „
(*b*) Area affected by Khor Gwir.	
Echinochloa stagnina	11·1 sq. km.
Echinochloa pyramidalis	47·1 „ „
Oryza barthii	8·0 „ „
Phragmites communis	0·3 „ „
TOTAL	66·5 „ „
(*c*) Area affected by Tapari. Nil.	
(*d*) Total Distribution.	
Open Water ...	108·1 sq. km.
Cyperus papyrus	62·3 „ „
Vossia cuspidata	111·5 „ „
Echinochloa stagnina	176·2 „ „
Echinochloa pyramidalis	443·9 „ „
Oryza barthii	8·0 „ „
Phragmites communis	21·0 „ „
TOTAL	931·0 „ „

TABLE 236

FUTURE DISTRIBUTION OF SPECIES
TOMBE-ATEM HEAD

(*a*) Excluding flood-plain areas affected by Khors Gwir and Tapari (Gel).	
Echinochloa stagnina	39·0 sq. km.
Echinochloa pyramidalis	243·6 „ „
Phragmites communis	221·8 „ „
Intermediate spp. (*Hyparrhenia*)	306·6 „ „
TOTAL	811·0 „ „
(*b*) Area affected by Khor Gwir.	
Echinochloa stagnina	16·7 sq. km.
Echinochloa pyramidalis	70·8 „ „
Oryza barthii	12·0 „ „
Phragmites communis	0·5 „ „
TOTAL	100·0 „ „
(*c*) Area affected by Tapari (Gel).	
Echinochloa stagnina	3·3 sq. km.
Echinochloa pyramidalis	14·2 „ „
Oryza barthii	2·4 „ „
Phragmites communis	0·1 „ „
TOTAL	20·0 „ „
(*d*) Total Distribution.	
Echinochloa stagnina	59·0 sq. km.
Echinochloa pyramidalis	328·6 „ „
Oryza barthii...	14·4 „ „
Phragmites communis	222·4 „ „
Intermediate spp. (*Hyparrhenia*) ...	306·6 „ „
TOTAL	931·0 „ „

TABLE 237

PRESENT AND FUTURE DISTRIBUTION OF SPECIES
SOUTHERN ZONE: JUBA–ATEM HEAD

Species	Present Distribution in sq. km.	Future Distribution (E.N.P.) in sq. km.
Open Water	117·4	25·7
Cyperus papyrus	81·7	51·9
Vossia cuspidata	127·1	62·7
Echinochloa stagnina	308·6	176·4
Echinochloa pyramidalis ...	785·7	531·6
Oryza barthii	8·0	14·4
Phragmites communis	152·5	363·8
Intermediate spp. (*Hyparrhenia*)	—	354·5
TOTAL AREA	1,581·0	1,581·0

EFFECTS ON GRAZING AND ANIMAL MANAGEMENT

In the preceding section the distribution of grass species over the flood-plain of the Bahr el Jebel is summarized in Table 237, where the total estimated area of each species at the present time and under the Project is given. As far as dry season grazing is concerned, open water, *Cyperus papyrus* and *Phragmites communis* are valueless, as is the type of *Vossia cuspidata* present in the Southern Zone. Thus the present and future areas of useful riverain pasture are 1,032·2 sq. km. and 977·6 sq. km. respectively.

From grazing experiments carried out at Malakal we have calculated the stock-carrying capacity of the two main swamp pasture types at different times during the dry season (Table 259, p. 504). But whereas the river flood-plain at Malakal is exposed at the end of January or in February, in the Southern Zone it is gradually exposed in December ; further, there are rain showers throughout the dry season in the Southern Zone, but at Malakal there are at least two dry months, January and February. This does not affect appreciably the stock-carrying capacity of deep-flooded pasture, but it does increase that of shallow-flooded pasture in the Southern Zone. We consider that 1 sq. km. of shallow-flooded pasture in the Southern Zone has a carrying capacity of 130 Animal Unit Months during the period January–February, as compared with 100 for the whole or part of the four-month period December–March in the Northern Zone.

In the future, owing to a great reduction in river spill, only 623·1 sq. km. of the flood-plain will produce accessible dry season swamp pasture and 354·5 sq. km. will carry intermediate grass types such as *Hyparrhenia* and *Setaria* species. These have been shown to have little nutritive value when mature and their usefulness in the dry season depends on the quantity of regrowth they produce after the coarse rains growth has been burnt. Since the flood-plain is likely to be better drained than the Eastern Plain (Vol. I, p. 286), the dry season regrowth will be less than the average for the latter ; i.e. it will carry less than 20 Animal Units to the square kilometre throughout the dry season. For this reason we have given the intermediate grassland area of the future flood-plain a value of 17 as its carrying capacity in Animal Units per square kilometre during the dry season.

Since the main river is to be banked north of Tombe, and since the peoples north and south of Tombe are administratively and ethnographically distinct, we must refer to the two reaches separately.

JUBA TO TOMBE

In Table 239 (p. 475) the areas of shallow-flooded and deep-flooded pasture, present and future (Juba to Tombe), are given in columns 4 and 7 ; their stock-carrying capacities in Animal Units per square kilometre per month are given in columns 5 and 8 ; their total stock-carrying capacities are shown in columns 6 and 9 ; and the last column shows the total stock-carrying capacity of the reach. The future carrying capacity is seen to be only 134 TAUM as against a potential 299 TAUM at present. In Table 241 (p. 476), column 1 shows the number of Animal Units actually using this riverain pasture at the present time ; column 2 is the potential carrying capacity (from Table 239); the present surplus is in column 3. Column 4 shows the future potential carrying capacity (from Table 239). The difference between columns 1 and 4 gives the actual loss (col. 5) using present livestock numbers: the difference between columns 2 and 4 gives the loss of potential grazing. There is no actual loss over the season as a whole, but there is a shortage in February of grazing for 4,600 Animal Units. This is reduced to 3,000 Animal Units because of the surplus in January. Since the total livestock population does not depend on riverain pasture for its entire grazing requirements, this deficit need not be considered, provided the loss of potential grazing is remembered.

TOMBE TO ATEM HEAD

North of Tombe to the Atem Head, five kilometres south of Lake Papiu, the stock-carrying capacity of the flood-plain is treated in the same way, using Tables 240 and 241 below. In Table 241 we see that the actual loss of grazing will amount to 128 TAUM and that a maximum of 46,948 Animal Units require alternative pasture in February.

For the sake of completeness, carrying capacities present and future and losses actual and potential are tabulated for the Southern Zone in Table 242, p. 476 ; but it should be remembered that the two reaches must be treated separately.

The importance of this loss of dry season pasture must be made clear. We have shown in Volumn I that riverain swamp pasture is essential in the dry season not only for the well-being, but for the very survival, of livestock in this Zone. Inland water supplies are few and of very small capacity; inland grasses are, on the whole, of little or no nutritive value in the dry season. Only where *Hyparrhenia rufa* is subjected to heavy flooding over a prolonged period and where enough moisture is retained in the soil is there sufficient regrowth to provide useful dry season grazing inland. Even this pasture varies in quality and area from year to year, depending on rainfall and overland flooding (creeping flow) and this cannot be relied upon.

One would expect that the prevention of river spill over the river flood-plain would automatically make accessible an increased area of rains season pasture. Only where villages are within easy reach of the river flood-plain will this addition to rains season grazing be of any real value. The underfoot conditions on the flood-plain during the rainy season will be similar to those inland, with standing water in the depressions and mud in most other places. Only the edges of the flood-plain could be grazed at the height of the rains. In any event there is now a great surplus of grass in the rainy season which cannot be grazed because of flood conditions, so that any additional rains season grass is merely an addition to surplus.

Thus in the rainy season grazing conditions will remain more or less unaltered and in the dry season a maximum of 46,948 Animal Units will be without food. None of the 128 TAUM actual deficit at the river can be replaced by natural pasture under present conditions. The method of its replacement will be discussed later under the heading of Direct Remedies.

(Note. It is worth recording that in the part of the Aliab Valley actually surveyed deep-flooded pasture occupies 47·1 sq. km. and shallow-flooded pasture occupies 143·0 sq. km. Their combined stock-carrying capacity at the height of the dry season is calculated to be 34,184 Animal Units. The actual number of livestock using this area at the time of the survey has been recorded (see Vol. III, p. 835) the total being 38,930 Animal Units. Assuming that all the livestock recorded obtained all their forage on the riverain pasture throughout the dry season (which is unlikely), our calculation shows a 12 % difference ; this is sufficiently accurate to justify our method.)

TABLE 238

NUMBERS OF LIVESTOCK USING RIVERAIN PASTURE

SOUTHERN ZONE

Tribe	Total Population by Tribes			Number Using River Swamp Pasture	
	Cattle	Sheep & Goats	A.U.	Fraction	A.U.
Bari West Bank	7,500	20,700	10,100	—	10,100
Bari East Bank	4,500	13,800	6,200	—	6,200
Mandari West Bank ...	10,000	11,100	11,400	—	11,400
Mandari Tali	4,000	4,200	4,500	—	2,300
Mandari East Bank ...	4,600	4,700	5,200	—	5,200
Bor Gok	44,000	10,000	45,300	—	45,300
Bor Athoich	38,000	10,000	39,200	$\simeq(\frac{1}{5})$	7,900
Aliab	60,000	15,000	61,900	$\simeq(\frac{4}{5})$	50,000
	172,600	89,500	183,800	—	138,400

TABLE 239

PRESENT AND FUTURE STOCK-CARRYING CAPACITIES OF RIVERAIN PASTURE

JUBA–TOMBE

PRESENT

Month	Intermediate			Shallow-Flooded			Deep-Flooded			Total A.U. per reach
	Area in sq. km.	A.U. per sq. km.	A.U. per Area	Area in sq. km.	A.U. per sq. km.	A.U. per Area	Area in sq. km.	A.U. per sq. km.	A.U. per Area	
January ...	—	—	—	324·7	50	16,235	119·2	400	47,680	63,915
February...	—	—	—	324·7	80	25,976	119·2	400	47,680	73,656
March ...	—	—	—	324·7	160	51,952	119·2	240	28,608	80,560
April ...	—	—	—	324·7	160	51,952	119·2	240	28,608	80,560
Total ...	—	—	—	—	—	146,115	—	—	152,576	298,691

FUTURE

Month	Intermediate			Shallow-Flooded			Deep-Flooded			Total A.U. per reach
	Area in sq. km.	A.U. per sq. km.	A.U. per Area	Area in sq. km.	A.U. per sq. km.	A.U. per Area	Area in sq. km.	A.U. per sq. km.	A.U. per Area	
January ...	47·9	17	814	183·3	50	9,165	37·8	400	15,120	25,099
February...	47·9	17	814	183·3	80	14,664	37·8	400	15,120	30,598
March ...	47·9	17	814	183·3	160	29,328	37·8	240	9,072	39,214
April ...	47·9	17	814	183·3	160	29,328	37·8	240	9,072	39,214
Total ...	—	—	3,256	—	—	82,485	—	—	48,384	134,125

TABLE 240

PRESENT AND FUTURE STOCK-CARRYING CAPACITIES OF RIVERAIN PASTURE

TOMBE–ATEM HEAD

PRESENT

Month	Intermediate			Shallow-Flooded			Deep-Flooded			Total A.U. per reach
	Area in sq. km.	A.U. per sq. km.	A.U. per Area	Area in sq. km.	A.U. per sq. km.	A.U. per Area	Area in sq. km.	A.U. per sq. km.	A.U. per Area	
January ...	—	—	—	429·7	50	21,485	158·6	400	63,440	84,925
February...	—	—	—	429·7	80	34,376	158·6	400	63,440	97,816
March ...	—	—	—	429·7	160	68,752	158·6	240	38,064	106,816
April ...	—	—	—	429·7	160	68,752	158·6	240	38,064	106,816
Total ...	—	—	—	—	—	193,365	—	—	203,008	396,373

FUTURE

Month	Intermediate			Shallow-Flooded			Deep-Flooded			Total A.U. per reach
	Area in sq. km.	A.U. per sq. km.	A.U. per Area	Area in sq. km.	A.U. per sq. km.	A.U. per Area	Area in sq. km.	A.U. per sq. km.	A.U. per Area	
January ...	306·6	17	5,212	343·0	50	17,150	59·0	400	23,600	45,962
February...	306·6	17	5,212	343·0	80	27,440	59·0	400	23,600	56,252
March ...	306·6	17	5,212	343·0	160	54,880	59·0	240	14,160	74,252
April ...	306·6	17	5,212	343·0	160	54,880	59·0	240	14,160	74,252
Total ...	—	—	20,848	—	—	154,350	—	—	75,520	250,718

TABLE 241

DECREASE IN STOCK-CARRYING CAPACITY OF RIVERAIN PASTURE
JUBA–TOMBE AND TOMBE–ATEM HEAD

JUBA–TOMBE

	Present			E.N.P.		
	Actual	Potential	Surplus	Potential	Actual Loss or Gain(1)	Potential Loss(2)
January	23,500	63,915	40,415	25,099	+ 1,599	38,816
February	35,200	73,656	38,456	30,598	− 4,602	43,058
March	35,200	80,560	45,360	39,214	+ 4,014	41,346
April	35,200	80,560	45,360	39,214	+ 4,014	41,346
Total	129,100	298,691	169,591	134,125	+ 5,025	164,566

TOMBE–ATEM HEAD

	Present			E.N.P.		
	Actual	Potential	Surplus	Potential	Actual Loss(1)	Potential Loss(2)
January	68,800	84,925	16,125	45,962	22,838	38,963
February	103,200	97,816	− 5,384	56,252	46,948	41,564
March	103,200	106,816	3,616	74,252	28,948	32,564
April	103,200	106,816	3,616	74,252	28,948	32,564
Total	378,400	396,373	17,973	250,718	127,682	145,655

NOTE: All figures represent Animal Units.
(1) Difference between col. 1 and col. 4.
(2) Difference between col. 2 and col. 4.

TABLE 242

DECREASE IN STOCK-CARRYING CAPACITY OF RIVERAIN PASTURE
SOUTHERN ZONE

	Present			E.N.P.		
	Actual	Potential	Surplus	Potential	Actual Loss(1)	Potential Loss(2)
January	92,300	148,840	56,540	71,061	21,239	77,779
February	138,400	171,472	33,072	86,850	51,550*	84,622
March	138,400	187,376	48,976	113,466	24,934	73,910
April	138,400	187,376	48,976	113,466	24,934	73,910
Total	507,500	695,064	187,564	384,843	122,657	310,221

NOTE: All figures represent Animal Units.
* See p. 474, line 11.
(1) Difference between col. 1 and col. 4.
(2) Difference between col. 2 and col. 4.

OTHER EFFECTS

INSECTS

The drying-out of the swamp in the Aliab Valley—north of Tombe—should lead to a very great reduction in the mosquito population in the dry season, but it is unlikely to affect the numbers of biting-flies. In the Northern Zone the river flood-plain dries out completely in the dry season at the present time, but the fly menace is none the less acute.

South of Tombe there will be some spill or backwater into channels or depressions during the dry season, and so the ill-effects of mosquitoes will increase, and at a season when people and livestock move close to these areas of spill. It is unlikely that there will be any appreciable effect on the biting-fly population, since the dry season vegetation of the flood-plain will be similar in quality, though not quantity, to that which is present now.

COMMUNICATIONS

The normal movement of cattle to dry season camps takes place in January and the return journey in April. In the Southern Zone many thousands of cattle are made to swim across the Bahr el Jebel, either to islands between the east and west channels—south of Tombe—or from the east bank to the Aliab Valley—north of Tombe. In January and April the normal discharge at Mongalla is between 59 and 65 m/d, whereas the future discharge will be 90 m/d. This last figure corresponds to the present normal maximum discharge and to swim herds of cattle across the river under such conditions would be to incur considerable risks. An additional hazard will be the banking on the left bank from Tombe to Atem Head. Either facilities for crossing the river must be made available, or pasture must be provided on the 'home' side of the river. This must be kept in mind, particularly when considering the Aliab Valley as an area for the production of pasture by artificial means—gravity irrigation. The number of cattle involved in the swimming of main channels to dry season camps is about 40,000 head.

CONCLUSIONS

(i) High land and intermediate land pastures will not be affected.

(ii) Inland khor-bed pastures will only be affected for a very short distance from their junction with the main river. The effect will be negligible.

(iii) Much of the flood-plain of the Bahr el Jebel will dry out, but the actual area of useful pasture (dry season) will be smaller than at present, and its stock-carrying capacity will be very considerably reduced.

(iv) The decrease in dry season grazing value will be that required to support a maximum of 46,948 A.U. over the four-month dry season, January to April.

(v) It will be extremely difficult to swim cattle across the main Bahr el Jebel channels in future dry seasons because the river will be at its highest level and because the left bank from Tombe to Atem Head will be raised.

3. THE CENTRAL ZONE

In the Central Zone, the Canal is to carry the main volume of water, and the Bahr el Jebel will be kept as far as possible below spill level. Spill will be reduced to a minimum, but unless the mouths of the main affluent or effluent channels are banked off there will be slight spill at such places as Khors Waard, Joknyang, Jurwel, Famyr.

The conclusion is that almost all swamp in the Central Zone will disappear, as such, except where perpetuated by the effluent of some large tributary with a different catchment. Only the Gel (Tapari), Moich, and perhaps the Jurwel, have sufficient discharge to reproduce even localized swamp conditions; but in conjunction with the effects of seepage, rain precipitation and local run-off their discharge should be sufficient to produce swamp grasses requiring low water-duty over a limited area.

That part of the swamp which will receive moisture mainly from precipitation and local run-off will clearly be subject to shallower depths and shorter periods of flooding. For this reason papyrus and swamp grasses are likely to be replaced by grasses which are usually found on intermediate land—grasses of much lower dry season value. On the other hand the soils in this area may prove more suitable for cultivation, provided oxidation is retarded by the proper application of water at the outset of the Project. Since the process of drying-out will be gradual and from the periphery, the intermediate fodder grasses from outside should have time to establish themselves as the edge of the swamp retreats.

Because the actual swamp in the Central Zone is almost unsurveyed it is not possible to estimate with any accuracy how much is exposed during the dry season at the present time. The actual loss of pasture, accessible or not, cannot be determined and our only clue is from the number of livestock which use this dry season pasture at the present time. In the Southern and Northern Zones the Nile is the one reliable source of drinking-water and dry season grazing, but in the Central Zone there are alternatives. Some of the livestock of the east bank may move to the upper Khor Atar or upper Fullus water-systems, those of the west bank to the Moich, Bilnyang or Padwar, depending on availability of drinking-water and quality and quantity of pasture. These alternatives are therefore of variable value and in any case it is doubtful whether they could support all the herds even in optimum conditions. The main advantage provided by the Nile is that it produces water and pasture every year, independent of rains, flooding, drainage and the other factors which make inland grazing unreliable. It is an insurance against pasture famine, and the loss of such an advantage is of much greater importance than the loss of a mere area of grazing.

Many waterways having direct communications with the Bahr el Jebel and the Bahr el Zeraf have a two-way flow, i.e. they carry water from the main river inland when the main river level is high, and discharge into the main river when its level is low enough (see Vol. I, p. 22 et seq.). It so happens that the season of high river levels coincides with the rainy season and that of low river levels coincides with the dry season. The effect of this rainy season ponding in these watercourses is to inundate their flood-plains to a considerable depth and also to encourage flooding of the surrounding land by the prevention of drainage. These conditions of flooding favour the growth of grass types which produce green regrowth in the dry season. When the Project is completed the levels in the Bahr el Jebel and Bahr el Zeraf will be considerably below the natural minimum, so that there will be little or no backwater effect in, or spill into, those watercourses which connect with them. Not only will the countryside in general be less subject to flooding, but also the khor beds, being subject to a much lesser degree of flooding—depth and duration—may cease to produce reliable swamp pasture; and their usefulness, like that of the surrounding intermediate land, will be entirely dependent on rainfall and local run-off.

Other channels which must be mentioned are those which take off from the main channels of the river and discharge into them again at some distance downstream. Such channels are common on the west bank of the Bahr el Jebel and in the southern part of the Zeraf Island. The water-levels in these channels fluctuate with the levels in the main rivers, providing conditions suitable for swamp grasses and thus producing naturally irrigated pasture. It is on these channels, rather than on the main river channels which are often inaccessible because of a fringing barrier of permanent swamp, that dry season cattle-camps are set up in the areas mentioned. In future these channels will not be flooded from the river and will receive only rain precipitation and local run-off. Such conditions will again favour intermediate type grasses rather than the natural swamp grasses and will reduce the dry season grazing to a mere fraction of its present value.

To present the effects of the Project in the Central Zone in terms of square kilometres of pasture reduced in value by lack of natural irrigation is not possible without a detailed survey of the swamp. It is possible to state, within limits, the area of pasture likely to be flooded by inland watercourses. With regard to future river spill it is only possible to say that limited spill will occur, probably sufficient to irrigate 362 sq. km. of flood-plain to a depth of one metre over the season mid-June to mid-December. It has been further estimated that in the Western Plain an area of 810 sq. km. will be irrigated annually by the Rivers Lau, Na'am, Gel and Tonj.

The effects in terms of Thousand Animal Unit Months grazing have been calculated and recorded later (see p. 488). Present requirements are known, but future grazing areas and their stock-carrying capacities have been obtained by applying local knowledge and what data are available; and with some confidence, because in the Southern Zone a similar system produced close agreement with results obtained from more detailed sample surveys.

EFFECTS ON PASTURE TYPES

RIVERAIN SWAMP GRASSLAND AND PERMANENT PAPYRUS SWAMP

We have seen in the previous volume (p. 150) how the natural river régime produces certain ecological conditions under which riverain swamp pasture, and particularly papyrus swamp, has developed along its flood-plain. The normal river régime will be altered under the Project, resulting in drastic modifications in some of the factors determining these conditions. There will therefore be changes in vegetation, which will readjust itself to quite different environmental conditions. Below we deal briefly with the changes which will disturb the present equilibrium in the Central Zone.

Depth and Duration of Flooding (By River Spill)

At present the river spills along its whole length in the Central Zone when at maximum level, and in some areas spill is permanent throughout the season. Depth and duration of flooding are the major operative factors in determining which species grow along the flood-plain. In future, with controlled flows in the Bahr el Jebel of 35 m/d in the untimely season (June to December) and 30 m/d in the timely season, there will be no river spill over the crest of the bank but there will be slight spill along spill-channels in the 35 m/d period (6 months). The present area affected by river spill is estimated to be 6,554 sq. km. between the Atem barrage and Buffalo Cape-Fangak. The future area affected by spill is estimated to be 362 sq. km. (assuming the amount of spill covers the area to an average of 1 m. in depth). As a result river spill, and hence depth and duration, will no longer be main factors in determining the distribution of plant species except in a comparatively limited area, and even there the duration of flooding will not exceed six months in the year.

Current Velocity

Current velocity will continue to be important along the main waterways of the Bahr el Jebel and Bahr el Zeraf. In addition, the current velocity in the Jonglei Canal must be taken into account.

Actual calculation of average velocities is difficult, but the following figures have been worked out for the Bahr el Jebel above the Zeraf Cuts :

Present Maximum	1·00 m/sec.
Future (E.N.P.) Maximum ...	0·90 m/sec.
Present Minimum	0·95 m/sec.
Future Minimum	0·90 m/sec.

There will therefore be very little change in river velocities along the Bahr el Jebel.

Current velocity will be of some significance in the spread of certain types of grasses along the edges of the Canal and is worth mentioning here in connection with navigation in the future, a subject which is dealt with from all aspects later (see p. 536).

Changes in Soils

In the Central Zone the greater part of the present riverain flood-plain will no longer be seasonally inundated. The water-saturation conditions which give rise to the *toich* soils will no longer exist. Hence these soils will ultimately change into either intermediate or high land soils, according to the character of the site on which they occur and their parent material, factors which mainly determine the soil moisture régime.

Only a very small proportion of the *sudd* soils will remain, as the future minimum river level will be nearly a metre below the present average minimum. Permanent flooding will therefore be confined to the deepest depressions behind the alluvial banks. The modification of the hydrological conditions which give rise to these soils means an increase in aeration, decomposition of the organic matter, and in time the complete disappearance of the organic top horizon characteristic. They will therefore become *toich*, intermediate or high land soils according to the particular hydrological conditions prevailing in each area of the flood-plain.

Climate: Rainfall

With a much smaller area of flood-plain affected by river spill, rainfall will become a more important factor.

Rate of Rise in Flood-Waters

With only limited spilling the area of flood-plain affected will be small, so the area in which this factor will continue to be operative is very limited. Furthermore flooding will not take place until the end of June, by which time sufficient rain has fallen in a normal year for plants to be well grown and they are therefore unlikely to be drowned.

Grazing and Burning

Whether or not these two factors will still be of significance largely depends on the future usefulness of the area as pasture.

Changes in Vegetation

The one major hydrological change, the reduction of river spill, will result in a change of vegetation in one direction, unlike the effects in the southern reach of the Southern Zone where a double change will occur before the vegetation settles into a new equilibrium with the environment.

Quite a large area of the flood-plain in the Central Zone is dominated by papyrus, and we have described the ecological conditions under which this flourishes, i.e. almost permanent flood conditions (300 days on an average) with depths varying from 80 cm. to 350 cm. or more. These are the two major factors governing the distribution of papyrus. In future there will only be flooding in limited areas, i.e. along the spill-channels such as the Joknyang, Waard, Moich, Jurwel and Famyr, and even in these channels flooding will be for six months in the year only. Seepage and the presence of a water-table are not sufficient for the development of papyrus, even where seepage is permanent and the water-table is high. Conditions will therefore be no longer suitable for the development of papyrus in the Central Zone and in areas where it is found at present it will be replaced by other forms of vegetation.

Excluding the areas still affected by river spill, we may picture conditions along the rest of the flood-plain as follows : a flat plain with a predominantly clay soil, from which organic matter has been lost, receiving its water supply only by rainfall which, because of the impermeability of the clay soil, will stand in sheets on the surface at the height of the rainy season. Such conditions are already prevalent in the Central Zone at the moment, for example on the Eastern Plain where the total amount of rainfall is almost equal to that which falls over the papyrus swamp. The vegetation of the Eastern Plain is open grassland of the intermediate *Hyparrhenia rufa* type. We may therefore assume that the major part of the papyrus swamp will change to grassland of this type. At present within the papyrus swamp there are isolated islets of *Phragmites communis*, which also occurs in places along the river banks, i.e. at the more elevated sites but where its roots can still reach the water-table. Since conditions will no longer be suitable for papyrus, even where there is seepage, it is expected that *Phragmites* will spread downwards from the elevated sites and farther along and back from the river bank.

At present the remainder of the flood-plain not dominated by papyrus carries riverain swamp grassland, predominantly of the *Echinochloa pyramidalis* type, except in deeper khors where *Vossia cuspidata* and *Echinochloa stagnina* are dominant. The necessary ecological conditions for the development of these species have been discussed in the previous volume (see p. 165). In future, conditions over the area they occupy will be similar to those future conditions already given for papyrus swamp, except that these conditions will come about more rapidly. These areas also will therefore carry open grassland of the intermediate *Hyparrhenia rufa* type, the *Hyparrhenia rufa* which will establish itself in the depressions now occupied by *Echinochloa stagnina* producing a greater amount of regrowth when burnt than the *Hyparrhenia* establishing itself on sites now occupied by *Echinochloa pyramidalis*.

In the future then we expect the major part of the flood-plains of the Bahr el Jebel and the Bahr el Zeraf in the Central Zone to become predominantly open grassland of the *Hyparrhenia rufa* type, with a band of *Echinochloa pyramidalis* behind the banks of the rivers and the banks themselves supporting *Phragmites communis*. The intermediate grasses will first establish themselves over the area now occupied by riverain swamp pasture, working inwards from the periphery of the flood-plain and eventually penetrating into the decreasing papyrus swamp.

For six months of the year the river will spill through unbanked spill channels, and possibly over its banks at some sites. These spill-channels will in future probably carry *Echinochloa pyramidalis* and, possibly, limited amounts of *Echinochloa stagnina* where the water is held back in depressions when the river drops in the dry season (in the 30 m/d period).

Quantitative Considerations

Because of the lack of detailed information about the swamps of the Central Zone we do not know what areas are at present exposed when the river drops, neither do we know what is the total distribution of species throughout the Zone. We are therefore unable to compare future areas with present areas of vegetation distribution.

The area which will in future be affected by river spill (including the discharges of the Khors Gel and Moich) is estimated to be 362 sq. km. out of a present total of 6,554 sq. km., the remaining area of 6,192 sq. km. receiving local rainfall and run-off water only. As already mentioned, we consider that this latter area will become dominated by intermediate grassland (mainly *Hyparrhenia rufa*).

Future river spill under the Project will inundate and expose 362 sq. km. and will produce pasture of the riverain swamp type, but it is difficult to estimate with certainty in what proportions the different swamp species will occur. We have, however, been able to make an estimate by applying the Aliab Valley data, obtained from that portion of the area surveyed which lies to the north-east of the River Aliab. In other words, we assume that conditions in these 362 sq. km. in the future will be similar to present conditions in the north-eastern part of the Aliab Valley. This is not unreasonable, as the following explanation will show.

An examination of the cross-section at Peake's Track (Fig. A 15) shows that the water-level as surveyed corresponds to a discharge of about 50 m/d at Jonglei. At 30 m/d (the future timely discharge) the water-level in the Bahr el Jebel will be 88 cm. lower[1]. Since this section is taken near Peake's Channel, we would expect the site to be at the northern end of a valley similar to the Aliab but at present permanently flooded. Under the Project the lowest level will be well below the crest of the alluvial bank, and it is reasonable to suppose that conditions similar to those in the Aliab Valley at present will be reproduced in the future over the area affected by river spill within the Central Zone. There is one major qualification to this direct comparison which must be mentioned ; at Tombe slopes are on the average 10 cm/km., whereas in the Central Zone they are of the order of 5 cm/km. (see Table 1, Vol. I,

p. 49). Otherwise conditions are not dissimilar, and until sample areas in the Central Zone can be surveyed with the same attention to detail as in the Aliab Valley the assumption must be allowed to stand.

The percentage proportions of species distribution over the area surveyed to the north-east of the River Aliab are:

Open Water...	12·5 per cent.
Cyperus papyrus	7·2 „ „
Vossia cuspidata	12·9 „ „
Echinochloa stagnina ...	19·1 „ „
Echinochloa pyramidalis ...	45·9 „ „
Phragmites communis ...	2·4 „ „
	100·0 „ „

Applying these percentages to the future area affected by river spill in the Central Zone, we arrive at the following areas of species and open water in square kilometres:

Open Water...	45·2 sq. km.
Cyperus papyrus	26·1 „ „
Vossia cuspidata	46·7 „ „
Echinochloa stagnina ...	69·1 „ „
Echinochloa pyramidalis ...	166·2 „ „
Phragmites communis ...	8·7 „ „
	362·0 „ „

We have therefore over the whole riverain flood-plain of the Central Zone the above future estimated distribution of species and open water, plus 6,192 sq. km. intermediate land *Hyparrhenia rufa* type pasture.

INLAND KHOR-BED PASTURE

The Central Zone, falling within the Flood Region, abounds in many inland waterways and khors, most of which have pasture of the *Echinochloa* type and sometimes *Vossia cuspidata* in their beds. Many will be affected by the Equatorial Nile Project.

Khor-bed pasture, since it has in general a similar composition to that of riverain swamp grassland, has great value as dry season grazing if water is available. The factors governing its development are similar to those influencing riverain swamp grassland, i.e. the necessary depth and duration of flooding produced either directly by river spill into the khor or by a combination of river spill, rainfall, and run-off.

Khor-bed pasture found in inland waterways which have catchment areas far distant from, and independent of, the Bahr el Jebel will not be affected. Further, pasture found along Khor Moich is produced mainly by water derived from the River Lau, and this will remain largely unchanged. (The area of the Nile flood-plain affected by Khor Moich has already been considered.)

On the other hand there are many watercourses directly connected with the main channels of the river and deriving a large portion of their flood-water from them. These occur on both sides of the Bahr el Jebel and Bahr el Zeraf. On the East bank of the Zeraf, for example, the Khor Jurwel and others in that vicinity receive flood-water both from the main river and from the hinterland to the east. Grasses of the khor-bed type will undoubtedly be reduced in area, though there may be sufficient water from the eastern catchment to produce some quantity of *Echinochloa pyramidalis* within the beds.

Zeraf Island is a network of inland waterways all of which carry khor-bed pasture. Many of these are connected either to the Bahr el Jebel or the Bahr el Zeraf. In the rains season the levels in the khors inland are higher than the levels of the main rivers with which they connect; in the dry season the levels of inland khors and main rivers coincide. This shows that these khors act as drainage-channels during the rainy season but that backwater from the river maintains the level inland during the dry season (see Vol. I, p. 22). In future the lower river levels in the Bahr el Jebel and Bahr el Zeraf will facilitate better drainage, and river spill will be much reduced; depth and duration of flooding in the khors will therefore be correspondingly decreased and a change in composition of vegetation is certain to occur. Such khors as the Liet and Nyakang will most probably in future only carry intermediate grassland of the *Hyparrhenia rufa* type, less valuable than khor-bed pasture but from which good regrowth should be obtained after burning.

West of the Bahr el Jebel there is a vast network of inland waterways, some of which are independent of river spill and others deriving most of their water by spill from the Bahr el Jebel.

The khor-bed pasture along the Waard–Gul–Padwar–Tiak khor system is the result of spill from the Bahr el Jebel through Khor Waard, of rainfall, and of run-off from the surrounding ridges. In addition backwater from the Bahr el Ghazal via Khors Doleib, Dhudhur and Tiak prevents drainage during the rains season. Water is therefore held within the khor system long enough to produce khor-bed pasture of *Vossia cuspidata* and *Echinochloa stagnina*. In future there will be only a limited amount of flooding in this system by backwater passing a comparatively short way up Khor Waard (15 km. approximately) when the Bahr el Jebel is high (35 m/d). This latter area has already been included in the area of riverain flood-plain affected by river spill. The rest of the system, except that within the backwater effect of the Bahr el Ghazal, will therefore in future receive water by rainfall and run-off only. The rainfall and run-off ought to be sufficient to produce *Echinochloa pyramidalis* in the deeper beds of the channels and *Hyparrhenia rufa* along either side. Further there will still be backwater up the Doleib–Dhudhur–Tiak khor system from the Bahr el Ghazal via Khor Aradeiba (since this system is connected with the main rivers in the Northern Zone where the hydrological effects are different), and rain-water and run-off will not drain away freely. This northern part of the system—say approximately north and west of the km. 60–Panyang Road—will probably produce a greater amount of *Echinochloa pyramidalis* in its beds. The papyrus and *Vossia cuspidata* along the Khor Aradeiba will remain unchanged.

Two other channels which at present produce khor-bed pasture in their beds (mostly *Vossia cuspidata*) are the Joknyang and the Twek. Like the pasture in the khor beds above, it is produced by a combination of river spill, rainfall and run-off. In future there will be little or no spill, except for a small area affected by backwater from the Bahr el Jebel. This has been included in the area of flood-plain affected by river spill. The rest of the areas of these two khors will therefore only receive rainfall and run-off, which will probably be sufficient to produce intermediate *Hyparrhenia rufa* type pasture only.

There are only two other main inland waterways with subsidiary channels which produce khor-bed grazing and which receive river spill. These are the Bilnyang and Puragwier, which are known as the Neang and Chier where they take off from the Bahr el Jebel south of Adok. Along the middle of these khors is found *Vossia cuspidata*, and over their flood-plain *Echinochloa pyramidalis* and *Hyparrhenia rufa*. In future, spill from the Bahr el Jebel will travel a very limited distance up this network (an area already included within the area of flood-plain affected by spill), and the remainder, the major proportion, will receive rainfall and run-off only, sufficient probably to produce a limited amount of *Echinochloa pyramidalis* in the deepest depressions along the khor bed with *Hyparrhenia rufa* outside.

Farther south, Khors Luri, Na'am, Gel and Tonj derive their water from a distant catchment and do not receive river spill. Their khor-bed pasture will therefore not be affected.

INTERMEDIATE LAND PASTURE

Eastern Plain

This lies north of the Bor-Pibor Road and east of the Bahr el Jebel and Bahr el Zeraf. The area in the vicinity of Jonglei receives river spill from the Atem in addition to rainfall, while the north-eastern corner is flooded by spill from the Pibor. In future there will be no spill from the Atem.

The remainder of the plain receives its water by rainfall directly, and by flooding from the south via the depression east of Pengko. A combination of both heavy rainfall over the plain and heavy rainfall over the southern catchment produces creeping flow, i.e. water advancing over a flat plain without any defined channels. The direction of flow between Kongor and Duk Faiwil is from south-east to north-west. North of Duk Faiwil it is collected into Khor Chieth, which runs along the east side of the Duk Ridge and eventually becomes the Atar. In general heavy and prolonged flooding at present produces this vast area of intermediate *Hyparrhenia rufa* grassland. Northwards the Khors Atar, Fullus and Geni provide better drainage, with the result that flooding is less extensive and *Hyparrhenia* is largely replaced by *Setaria incrassata*.

The Jonglei Canal will cut across this vast plain, thus preventing the general flow of the rain flood-water coming from the south and passing north-westwards between Kongor and Duk Faiwil. For this reason the area to the west of the Canal between Atem Head and the Chieth road-bridge will be subject to rainfall only (there being no river spill from the Atem Head). On the other hand flooding east of the Canal will be slightly intensified and the Khor Chieth will carry more flow. Therefore west of the Canal it is probable that *Hyparrhenia rufa* may be replaced by the *Setaria incrassata* type intermediate grassland, or, if *Hyparrhenia rufa* remains, the amount of regrowth after burning will be much less than at present. East of the Canal there will probably be no change, except that the regrowth from *Hyparrhenia rufa* over the plain may be improved.

North of the line where the Canal crosses the Khor Chieth there will be no effect or change in composition if a suitable cross-drainage structure is built. However, if the Khor Chieth is diverted into the Khors Kwanjor and Fullus there will be heavier flooding to the east, with improved regrowth from the *Hyparrhenia rufa*, and less flooding to the west of the Canal, resulting in poor regrowth or a change to the *Setaria incrassata* type of grassland.

With less severe flooding west of the Canal there will probably be an increase of the area covered by the *Acacia seyal* and *Balanites aegyptiaca* forests.

Zeraf Island (South of Buffalo Cape–Fangak Line)

At present in this area the intermediate pasture is predominantly of the *Hyparrhenia rufa* type and occurs mainly behind the riverain swamp grasslands and along khor flood-plains. In future, with lower river and inland water-levels, drainage will be better and flooding will be reduced. We may expect that the *Hyparrhenia rufa* type will change to *Setaria incrassata*, or continue as *Hyparrhenia rufa* but with poor regrowth after burning. Further there are areas of *Setaria incrassata* lying behind the *Hyparrhenia rufa* and riverain pastures ; these will probably remain unchanged. With improved drainage and less severe surface flooding the areas covered by acacia forests should increase.

Western Plain

This lies west of the Bahr el Jebel and was referred to in our previous reports as the Eastern Ghazal Swamps. It is intersected by numerous watercourses, such as the Bilnyang and Pura-gwier which carry spill from the Bahr el Jebel. It also receives a large volume of water from the Rivers Tonj, Gel and Na'am and a further quantity by spill from the Bahr el Ghazal. The pasture in the beds of these khors has already been considered, but outside these khors there are vast areas which are dominated by intermediate *Hyparrhenia rufa* type pasture, which provides good regrowth grazing when burnt.

In future this area will receive no flood-water by spill from the Bahr el Jebel but will continue to receive its normal supply from the Gel, Na'am and Tonj. In general there is at present much more flooding here than is desirable (see Vol. I, p. 27), and it appears reasonable to assume that the cutting-off of river spill will not have an adverse effect, although there might be a slight decrease in the area which will produce useful regrowth pasture.

There are other areas of intermediate *Hyparrhenia rufa* type grassland lying mainly behind the riverain swamp pasture of the Bahr el Jebel and between inland waterways; for example between Khor Tiak and the Joknyang, and again between the Joknyang and the riverain swamp grasslands of the Bahr el Jebel. These areas rely both on river spill and rainfall, which combine to give prolonged flooding and grasses predominantly of the *Hyparrhenia rufa* type. In future, with no river spill, they will receive rainfall only. This will still be sufficient to cause surface flooding because of the impermeability of the heavy clay soils, but probably only enough for the development of the *Setaria incrassata* type grassland, rather than *Hyparrhenia rufa*.

HIGH LAND PASTURE

This will not be affected, but with improved drainage on Zeraf Island and in the area west of the Bahr el Jebel high land pasture grasses will probably extend over slightly larger areas than at present.

EFFECTS ON GRAZING AND ANIMAL MANAGEMENT

One of the objects of the Project is to prevent loss of water by reducing to a minimum spill from the main river. The result will be the drying-out not only of the *Sudd*, the area of permanent papyrus swamp which is of no grazing value, but also of the swamp pastures on which the local livestock at present depend during the dry season. The dried-out bed of the swamp is expected to become a grass plain intersected by numerous depressions running generally from south to north. As described in the previous section there will always be a small amount of spill, sufficient to affect 362 sq. km. of land and to produce the grasses listed on page 481. From this table we see that deep-flooded pasture (*E. stagnina*) will occupy 69·1 sq. km. and shallow-flooded pasture (*E. pyramidalis*) 166·2 sq. km. Deep-flooded pasture will have a carrying capacity of 400 Animal Units to the square kilometre in January and February, and 240 A.U. per sq. km. in March and April, as in the Southern Zone. Shallow-flooded pasture is expected to be similar to that now found in the Northern Zone and, since the swamp pasture will only be required from January onwards, we consider that the shallow-flooded pasture will carry 50 Animal Units per month in January and February and 160 per month thereafter. When studying the effects of the Project we must consider the minimum figure, i.e. the carrying capacity in January and February.

That part of the dried-out swamp which is not subject to river spill will receive moistur only from rain precipitation and run-off, and we consider that this will encourage the estab lishment of the intermediate type of grassland which will produce regrowth after the coarse rains growth has been burnt off, e.g. *Hyparrhenia rufa*. On the Eastern Plain, where there is very little drainage, the dry season regrowth supports an average of 20 Animal Units per square kilometre (the best will carry 30), but considering the undulating nature of the swamp bed we do not think that the regrowth will be so robust and have assumed that this type of pasture will have a carrying capacity of 17 A.U. per sq. km.

The Central Zone is too large a unit for a detailed description of the effects, and so we have divided it into four tribal groups. From Butcher's analysis of the *Sudd*[2] we have calculated the area of reclaimed swamp in each tribal sector to be as follows:

	Square kilometres	% of Zone Total
1. Bahr el Jebel right bank from the Barrage to Zeraf Cut I and Bahr el Zeraf right bank from Zeraf Cut I to Fangak	2,717	41·5
2. Zeraf Island (Central Zone)	2,040	31·1
3. Bahr el Jebel left bank from the Barrage to Shambe	247	3·8
4. Bahr el Jebel left bank from Shambe to Buffalo Cape	1,550	23·6
	6,554	100·0

In estimating the future carrying capacity of reclaimed swamp in each sector we assume that the areas affected by spill in the four sectors are in the same proportions as the sector areas to the total area of the swamp. Further, of the area affected by spill in each sector, 19·1% will carry *Echinochloa stagnina* (deep-flooded pasture) and 45·9% will carry *E. pyramidalis* (shallow-flooded pasture) (see p. 481).

BOR ATHOICH, TWI, NYAREWENG AND GHOL DINKA; GAWEIR AND THIANG (MAINLAND) NUER

From Table 244 (p. 488) the number of Animal Units using main river grazing in this sector is 179,200. It is not suggested that all of them come down to the river itself, but they depend for their dry season grazing on the receding of the flood-waters derived from the main river. There are many depressions and channels far from the main river channel which receive river spill. This flows northwards following the general land-slope and, by maintaining soil moisture, encourages the continued growth of pasture grasses throughout the dry season. When river spill is prevented (except into major channels) these distant depressions, as well as swamp areas adjacent to the main channel, will receive only rain precipitation and local run-off, and this is not likely to produce other than intermediate type grasses. Even the run-off from the east will be prevented from reaching the river flood-plain by the banks of the Canal.

The area of swamp in this sector is 2,717 sq. km. or 41·5% of the whole. The area subject to spill will be 41·5% of 362 sq. km. or 150 sq. km.

Thus, apart from open water, papyrus, and *Phragmites communis* which are of no value, the area of pasture grasses will be:

	Square kilometres	Minimum carrying capacity in Animal Units
Echinochloa stagnina	28·7	11,480
Echinochloa pyramidalis ...	68·8	3,440
Intermediate grass species ...	2,567·0	43,639
TOTALS	2,664·5	58,559

The number of Animal Units at present dependent on swamp pasture in this sector is 179,200; alternative pasture must be found for 120,641 A.U. for the 4-month dry season.

Inland one of the main effects of the Project will be the provision of a reliable water supply (the Canal) in an area where only a few shallow wells exist at present. Along the line of the Canal the plain immediately to the west will not produce reliable dry season regrowth grazing because it will be subject to rain precipitation only. To the east of the Canal the degree of rains season flooding will increase because the Canal will hinder drainage, e.g. via the upper Khor Atar. Living conditions in the rainy season may therefore deteriorate, but dry season regrowth in the adjacent plains and khors should be improved. Cattle, watering at the Canal, could graze up to 15 km. east of the Canal between Atem Head and Chieth Bridge—over the Khor Atar—a distance of about 225 km. and an area of 3,375 sq. km. North of Chieth Bridge the plains do not produce reliable dry season grazing and flood-water from the south-east will be carried westwards under the Canal or will be diverted into Khors Kwanjor and Fullus to the east. Of this 3,375 sq. km., about 40% is forest or inhabited land unsuitable for grazing. The remainder, 2,025 sq. km., at a stocking rate of 20 A.U. per sq. km., will support 40,500 A.U. In listing the Animal Units using river pasture (Table 244) we have allowed for 5,000 A.U. watering from wells in this area; additional watering facilities would thus allow a further 35,500 A.U. to graze here.

Of the 120,641 Animal Units displaced from river pasture, 35,500 can be grazed on inland intermediate type regrowth, leaving 85,141 A.U. still to be accommodated. This is the very minimum, since more than 79,000 A.U. of those provided for will graze intermediate type regrowth, which is dependent on rainfall plus overland flooding (creeping flow).

SOUTHERN ZERAF ISLAND NUER

The area of swamp in this sector is 2,040 sq. km. or 31·1% of the whole. The area subject to spill in the future will be 31·1% of 362 or 113 sq. km.

After deducting areas of no value for grazing (open water, papyrus, etc.), the area of pasture grass will thus be :

	Square kilometres	Minimum carrying capacity in Animal Units
Echinochloa stagnina	21·6	8,640
Echinochloa pyramidalis ...	51·9	2,595
Intermediate grass species ...	1,927·0	32,759
TOTALS	2,000·5	43,994

The number of Animal Units dependent on swamp pasture in this sector is 57,000 (Table 244) so that alternative pasture will have to be found for 13,006 A.U. for the 4-month dry season. A certain amount of intermediate type dry season regrowth may be produced in the larger inland khors (which have wide, flat beds), but this will have little effect on the total stock-carrying capacity of the area.

CHICH, ALIAB, AND OTHER LAKES DISTRICT DINKA

Seasonal movements of livestock in this sector are complicated by the fact that there are both main river and inland khor-bed swamp pastures. Tribal sections with permanent villages adjacent to the river swamp are Gok, Lang and Ador (sections of the Chich), and their cattle make most use of riverain pasture. The Akeir section of the Aliab live and graze their animals around Lake Papiu. But, owing to the scarcity of inland pasture, the Dinka of Lakes District are great wanderers, and groups of Atwot and Luaich come from around Yirol to the swamp pasture to the north of Lake Fajarial. Other sections of Chich may come over from Khor Lau to the Kenisa swamp pasture. In such circumstances it is difficult to give a definite figure for livestock using river pasture in this sector, but we estimate the figure at 61,900 Animal Units. Considering that the corresponding geographical section east of the Bahr el Jebel is occupied by 80% of the Bor Athoich and about 75% of the Twi Dinka (approx. 88,000 A.U.), we believe the above estimate to be reasonable.

The area of swamp in this sector is 247 sq. km. or 3·8% of the total for the Zone. The area which will be subject to spill is therefore 3·8% of 362 or 14 sq. km. Thus, after deducting areas of no value for grazing, the area of pasture grasses will be :

	Square kilometres	Minimum carrying capacity in Animal Units
Echinochloa stagnina	2·7	1,080
Echinochloa pyramidalis ...	6·4	320
Intermediate grass types ...	233·0	3,961
TOTALS	242·1	5,361

This suggests a loss of dry season grazing for 56,539 Animal Units, since there is no surplus of dry season grazing inland. Lake Papiu is within this sector and it will receive the waters of the Tapari (Gel) via Lake Fajarial and connecting depressions. This is likely to produce 30 sq. km. of mixed deep-flooded and shallow-flooded pasture, in the ratio of 6 : 4, having a stock-carrying capacity of 7,800 Animal Units. This reduces the number of livestock deprived of dry season pasture in this sector to 48,739 Animal Units. But at the present time the livestock in this sector depend less on actual main river swamp than on the swamp pasture in inlets and depressions holding rain run-off, which is ponded by river spill. Spill itself probably only occurs in the larger inlets. This ponding effect will not be completely eliminated, but it will be very considerably reduced and the swamp grasses will probably be replaced by intermediate type grasses having good dry season regrowth. Let us assume (a) that approximately half the livestock population, 31,000, depends on these inlets and depressions and (b) that the grasses in the depressions are deep-flooded 20% and shallow-flooded 80%, having stock-carrying capacities of 400 and 50 per sq. km. respectively. From these figures we calculate the present grazing area to be 258 sq. km., using the equation

$$31{,}000 = Y \times \left(\frac{400 \times 20}{100} + \frac{50 \times 80}{100}\right)$$
$$\therefore \quad Y = 258$$

With a future cover of intermediate grasses having a dry season stock-carrying capacity of 30 A.U. per sq. km., the carrying capacity of the depressions will be 7,740 Animal Units. Livestock will require to water at the main river, but this should be within reasonable walking distance.

Thus the net loss of dry season pasture within this sector will be that required by 40,999 Animal Units for the four months January to April.

NUONG, DOK, AAK, JAGEY, AND JIKAING NUER

The dry season movements of livestock in this sector are probably more diverse than in any other, partly because the main river swamp is largely permanent swamp, and partly because inland alternative dry season pasture is extensive but is situated far from the permanent villages. The total livestock population is 125,300 Animal Units, of which 76,000 are reckoned to use main river swamp pasture; the remainder move inland to pastures, mainly intermediate type regrowth, along Khors Moich, Neang, Bilnyang, and Padwar and the Waard-Tiak system.

The area of main river swamp in this sector is 1,550 sq. km. or 23·6% of the whole. The area subject to spill in the future is therefore taken to be 23·6% of 362 or 85 sq. km. Thus, after deducting areas of no grazing value, the area of pasture grasses will be :

	Square kilometres	Minimum carrying capacity in Animal Units
Echinochloa stagnina	16·2	6,480
Echinochloa pyramidalis ...	39·0	1,950
Intermediate grass species ...	1,465·0	24,905
TOTALS	1,520·2	33,335

This means that 42,665 Animal Units will be deprived of dry season swamp pasture.

Of the inland khor systems, the Waard-Gul-Tiak system is likely to be affected, the grasses in the khor beds changing from the shallow-flooded swamp type to the intermediate type. In addition, since rains season and early dry season spill will be eliminated, there will be a slight deterioration in water supplies near khor-bed grazing, especially in the Waard-Padwar section. It is reasonable to say that the 5% of the animal stock (2,450 AU.) of the Dok and Aak Nuer and the 15% (5,670 A.U.) of the Jagey which normally graze this watercourse will require to be accommodated elsewhere.

In the previous section (p. 483) the effect of the Project on the Western Plain is described as negligible. The slight reduction in area of useful pasture will be offset by easier accessibility due to slightly decreased flooding. The carrying capacity will remain as at present; the figure of 41,180 is obtained by subtracting from the total livestock figure (125,300) the numbers using riverain pasture (76,000) and khor-bed pasture (8,120).

Thus the total number of livestock which will be deprived of dry season pasture is 50,785 Animal Units.

OTHER EFFECTS

COMMUNICATIONS

From the Atem Head to the Canal tail the dredged channel, with raised right bank, and the Canal itself will be obstructions preventing the free movement of livestock from one side to the other, since there is no proposed crossing except at the Canal head and tail. It is estimated that 112,600 Animal Units cross this line (the ' Direct ' Line) in their seasonal movement to and from dry season grazing areas, as follows:

Bor Athoich	10%	3,100	Animal Units
Twi	90%	69,100	,, ,,
Nyareweng...	85%	21,800	,, ,,
Ghol	85%	14,800	,, ,,
Gaweir and Thiang	10%	3,800	,, ,,
		112,600	,, ,,

In future there will be a great reduction in the stock-carrying capacity of riverain pasture and an increase in that of intermediate pasture east of the Canal. This will not apply to the Bor Athoich area where there will be no improvement of intermediate pasture, but there will be an increase in carrying capacity of 35,500 Animal Units (see p. 485) in the country north of the Canal head. The livestock population living east of the Atem–Canal line and the number which can be accommodated are listed in Table 243 below, as is the number of livestock which will have to cross the Canal either to riverain grazing or to alternative pasturage if this is produced west of the Canal. The additional grazing for 35,500 Animal Units has been divided amongst the tribes, excepting Athoich, in the same proportions as their livestock populations bear to the total livestock population.

TABLE 243

NUMBER OF LIVESTOCK REQUIRING TO CROSS THE ATEM-CANAL IN FUTURE

Tribe	Livestock Population	Livestock Living East of Atem-Canal		Grazing Available East of Atem-Canal	Number requiring to cross Atem-Canal
		%	Number		
Bor Athoich	31,300	100%	31,300	5,100	26,200
Twi	76,800	90%	69,100	18,200	50,900
Nyareweng	25,600	85%	21,800	5,900	15,900
Ghol	17,400	85%	14,800	3,400	11,400
Gaweir and Thiang ...	38,500	25%	9,600	8,000	1,600
	189,600		146,600	40,600	106,000

CONCLUSIONS

Throughout the whole of the Central Zone there will be a decrease in available dry season grazing affecting 189,931 Animal Units. This estimate takes into consideration vast areas of intermediate type pastures whose dry season value is dependent on rainfall and which, we have estimated, will support 189,684 Animal Units during the four-month dry season, January to April inclusive. The reliability of this pasture must receive prolonged investigation before full confidence can be placed in it as an alternative to swamp pasture naturally irrigated as at present.

The position regarding future areas of natural pasture and their stock-carrying capacities is summarized below:

Location	Animal Units per season	Total
A. E.N.P. FLOOD-PLAIN		
1. East Bank; Barrage to Fangak	58,559	
2. Zeraf Island	43,994	
3. West Bank; Barrage to Shambe	5,361	
4. West Bank; Shambe to Buffalo Cape	33,335	141,249
B. PASTURE OTHER THAN ON RIVER FLOOD-PLAIN		
5. Along line of the Canal	35,500	
6. The Western Plain	41,180	
7. Lake Papiu	7,800	
8. Lakes District intermediate grasses	7,740	92,220
Total carrying capacity of natural pasture		233,469
Number of Animal Units to be accommodated		423,400
Number deprived of dry season pasture		189,931

TABLE 244

NUMBERS OF LIVESTOCK USING RIVERAIN PASTURE

CENTRAL ZONE

Tribe	Total Population of Tribe			A.U. affected by E.N.P.
	Cattle	Sheep	Animal Units	
Bor Athoich	38,000	10,000	39,300	31,300*
Twi	76,000	6,000	76,800	75,800
Nyareweng	25,300	2,000	25,600	24,500
Ghol	17,200	1,400	17,400	14,300
Gaweir (mainland)	36,700	6,000	37,500	32,300
Thiang (mainland)	1,000	300	1,000	1,000
Totals	194,200	25,700	197,600	179,200
Gaweir (Island)	12,300	2,000	12,500	12,500
Thiang (Island)	14,000	3,000	14,400	14,400
Lak	47,000	8,700	48,100	30,100*
Totals	73,300	13,700	75,000	57,000
Chich	50,000	35,000	54,400	38,000
Aliab	60,000	15,000	61,900	11,900*
Lakes District Others	225,000	45,000	230,700	12,000
Totals	335,000	95,000	347,000	61,900
Nuong	25,000	10,400	26,300	26,300
Dok and Aak	47,000	16,000	49,000	49,000
Jagey	37,200	5,000	37,800	37,800
Jikaing	34,800	14,000	36,500	12,200*
Totals	144,000	45,400	149,600	125,300
Grand Total	746,500	179,800	769,200	423,400

* Number of A.U. within the Central Zone.

TABLE 245

PRESENT AND FUTURE STOCK-CARRYING CAPACITIES OF

RIVERAIN PASTURE IN TRIBAL UNITS

CENTRAL ZONE

Tribal Unit	Thousand A.U. per Season		
	Present	Future E.N.P.	Loss
1. Bor Athoich (⅘), Twi, Nyareweng and Ghol Dinka; Gaweir and Thiang (Mainland) Nuer	179·2	94·1	85·1
2. Zeraf Island Nuer (south of Fangak and Buffalo Cape) ...	57·0	44·0	13·0
3. Chich, Aliab (⅕) and other Lakes District Dinka	61·9	20·9	41·0
4. Nuong, Dok, Aak, Jagey and ⅓ Jikaing Nuer	125·3	74·5	50·8
Total	423·4	233·5	189·9

4. THE NORTHERN ZONE

In general terms the ultimate effect of the Project in the Northern Zone will be to raise both the minimum and maximum river levels. In the southern half of the Zone (within the Flood Region) present fluctuations are caused mainly by the Sobat discharge, and Nile levels will continue to be affected by the Sobat flood in the untimely season in the future. Between July and December the river will behave more or less as it does now; between January and June there will be a slight delay in the drop in river levels and the lowest point, as now, will be at the beginning of April; but the discharge will be considerably greater than at present (80·8 m/d instead of 45·5 m/d at Malakal).

In the southern half (Flood Region) of the Northern Zone the effect of the Jebel Aulia Dam will not be felt, and not only low depressions in the flood-plain but considerable areas more elevated will be permanently flooded. It has been shown in the previous volume that the low-lying areas of the flood-plain produce what we have called deep-flooded pasture and the more elevated areas produce shallow-flooded pasture. From experimental data collected, we deduce that deep-flooded pasture provides about three times more grazing than an equivalent area of shallow-flooded pasture. Our deductions cannot be entirely conclusive without long-term experiment, but they give a good indication of the order of the difference between the two types of pasture. It is significant that, with the natural river régime, south of Melut deep-flooded pasture is available from the beginning of January whereas shallow-flooded pasture is of little value until March or even April. (For stock-carrying capacities see Table 259, p. 504.)

From the boundary of the Central Zone northwards the reduction in area of flood-plain exposed will be due to permanent flooding of the low-lying parts. Since this area produces almost all of the present deep-flooded pasture the Project will remove a vital part of the grazing available, particularly at the beginning of the year.

North of Melut (in the Semi-Arid Region) the fluctuation in river levels is governed now, and will continue to be governed, by the operation of the Jebel Aulia Dam. In the two reaches Melut to Renk and Renk to Jebelein the loss of exposed flood-plain pasture will be 33·7% and 18% respectively; but north of Jebelein the change will be so slight (8%) that only the mud flats at the lowest levels of the flood-plain will be affected and the area of riverain pasture will remain as at present.

Throughout the Northern Zone any loss in area of flood-plain is due to the raising of the minimum river level. This means that low depressions, channels and lagoons, whose drying-out exposes deep-flooded pasture under natural conditions, will in future contain water permanently. This will encourage a type of vegetation accustomed to prolonged or permanent flooding, e.g. papyrus or *Vossia cuspidata*, which is useless as livestock fodder. Within the Semi-Arid Region, since only the minimum level will be affected, there will not be any change in the type of pasture over the remainder of the flood-plain, except that seepage instead of penetrating from the main channel alone will be operative from all low channels having permanent water. These permanent channels will also have their disadvantages. They will provide even better conditions for breeding flies than exist at the present and will form natural obstacles to livestock. As far as sheep and goats are concerned—and there are at present 273,000 of them in the Semi-Arid Region of the Northern Zone alone—a depth of 25 cm. of water on top of mud will prevent their moving freely to pastures on the other side of such a depression.

In addition to an alteration in the area of the river flood-plain exposed in the dry season, and in the period and depths of flooding, the altered régime will affect such inland waterways as have a direct connection with the main river. A high level in the main river has some ponding effect in its tributaries for a short distance from their mouths. During the rainy season the main river level will be only slightly higher than natural mean maximum, but at the beginning of the dry season, when the main river level normally drops, the future level will rise (in theory) to its highest level (in December) and thereafter will fall, though only as far as the level of the natural river at the end of July, i.e. just under half way between the natural mean maximum and natural mean minimum. The effect of this increased ponding of inland waterways will be two-fold; it will prolong the period during which surface water will be available for people and livestock; and by increasing the period and, near the mouths, depth of flooding it should improve the productivity of khor-bed swamp pasture.

The influence of depth and duration of flooding on different pasture types is described in Volume I, Chapter 2. In the following sections the effects of the alteration in the river régime on riverain pasture are discussed. The relevant data are tabulated at the end of each section.

EFFECTS ON PASTURE TYPES

RIVERAIN SWAMP GRASSLAND

Depth and Duration of Flooding

With a rise in both the minimum and maximum river levels under the Equatorial Nile Project, depths of flooding along the flood-plain will be changed; there will be increased depths of flooding in some areas and new areas will be flooded for depths varying from a few centimetres to over 150 cm. Duration of flooding will also change, some of the old areas becoming permanently flooded and new areas being flooded for periods varying from a few days to 365 days. Since we have shown that there exists a relationship between species distribution along the flood-plain and depth and duration of flooding, it is expected that the distribution of grass species will follow the altered hydrological régime accordingly.

Current Velocity

It has been shown that current velocity is a limiting factor in the distribution of some grass species, especially those growing along the main river and backwater khors. Below we give the present and estimated future maximum and minimum river velocities for a section of the river at Malakal:

Present	Maximum	...	0·56 m/sec.
,,	Minimum	...	0·38 m/sec.
Future	Maximum	...	0·57 m/sec.
,,	Minimum	...	0·51 m/sec.

There is therefore no appreciable change in maximum river velocities (which occur during November in both cases), although the future minimum will be much higher. River current velocity will therefore continue to be a limiting factor and, because it will be more consistent, will probably be slightly more effective.

Climate: Rainfall

The Equatorial Nile Project will have no effect on climate in the Northern Zone and rainfall will be unchanged.

We have already mentioned the importance of the present phase relationship between rainfall and the initial stages of flooding over the flood-plain, and have shown that at present sufficient rainfall generally falls over the plain before flooding from the river commences, thus enabling the plants to start growth before they are subject to flood conditions. This phase relationship will remain relatively unchanged under the Equatorial Nile Project.

Changes in Soils

The hydrological conditions in the several reaches between Buffalo Cape and Kosti will vary according to their positions in relation to the Canal mouth and the Sobat (i.e. backwater) and to the Jebel Aulia Reservoir. Generalizations are not therefore possible and we must refer to the area reach by reach.

Between Buffalo Cape and Lake No it seems likely that the future minimum level in the Bahr el Jebel will be below the surface of the mineral layers of the *sudd* soils, with perhaps a few exceptions where the organic horizon is at present especially deep. Consequently the peat layer which has developed under conditions of permanent inundation, the chief characteristic of these soils, will be exposed to oxidation and in time will disappear or, in the exceptional cases mentioned above, will be reduced in depth. As the future maximum will—as far as can be predicted—be below spill level except in the area immediately south of Lake No, the area of *toich* soils will be considerably reduced.

Farther north between Lake No and the Shilluk boundary on the left bank, the soils are at present of the transitional type between *toich* and intermediate. As will be shown later, if the cross-section at Lake No (Fig. A 21) is accepted as representative of this reach, these soils are flooded only when the river is exceptionally high. Under future conditions the maximum river levels will be below the present maximum, so that no flooding by spill will take place. On the other hand the future minimum levels will be higher than they are now, so that the water-table in the immediate vicinity of the river will remain near the surface and affect soil characteristics.

On the right bank, the corner of the Zeraf Island (for some way downstream of Lake No) is at present covered with *sudd* soils and *Cyperus papyrus*. As at Lake No the future minimum level will be only 30 cm. below the present minimum, and as approximately 25 km. downstream of this point the present and future minima coincide, it is obvious that there will be little decrease in the area of *sudd* soils. *Toich* soils will remain unaltered as far as 25 to 30 km. downstream of Lake No. Over the remaining part of the right bank as far as the Zeraf mouth there are at present no *sudd* soils. Here, while the maximum will remain unchanged, the minimum will be higher (78 cm. higher at the Zeraf mouth). Consequently the area of the *toich* soils will be reduced and *sudd* soils may increase, as hydrological conditions will be more favourable for the formation of the latter.

In the rest of the Northern Zone the maximum river levels (under the 55 m/d Canal stage) will be only slightly higher than they are now. On the other hand minimum river levels will be as much as 1·5 m. higher than at present. Areas permanently flooded are now few, but may be expected to increase in future. Moreover the range in river levels, which is at present one of the main factors limiting peat accumulation as a result of hydrosere, will be considerably reduced. The formation of *sudd* soils in the lagoons and depressions, where there will be stagnant water practically throughout the year, may therefore occur. On the other hand there will be a reduction in *toich* soils, because the area flooded and exposed according to the seasonal fluctuations of the river will decrease. Although under future conditions *toich* soils may be expected to develop in areas where there are now intermediate or even high land soils not flooded at present, an even larger proportion of these areas may acquire an organic horizon characteristic of *sudd* soils.

Grazing and Burning

Provided the future distribution of species enables the inhabitants to utilize the area as at present, these factors will continue to operate.

Quantitative Considerations

The effect of the Project in the Northern Zone will be a general raising of both the minimum and maximum river levels, with the result that large areas of flood-plain now annually exposed at low river will in future be permanently flooded. In addition, the higher minimum level under the Project will result in the inundation of areas of flood-plain not flooded under normal river conditions.

We have shown that the normal gradual flooding and exposing of the flood-plain results in the production of grasses with varying degrees of palatability and feeding value over different areas, i.e. shallow-flooded and deep-flooded types (see Vol. I, p. 272).

The three main questions are therefore as follows :

(i) Will the areas of flood-plain permanently flooded under the new régime continue to produce useful pasture grasses, or will other kinds of vegetation arise ?

(ii) Will land now producing shallow-flooded type pasture, i.e. *Oryza* spp. and *Echinochloa pyramidalis*, produce deep-flooded types, i.e. *Echinochloa stagnina*, under the new régime ?

(iii) Will the land at present above the high flood mark but which will in future be seasonally inundated by high river levels produce a more useful type of pasture ?

Below we attempt to answer these questions, but only for that part of the Northern Zone between Malakal and Jebelein, for it is only over this reach that flood-plain widths and areas have been calculated in detail. North of Jebelein it has been shown that the changes in river levels will be so slight that the effects of the Project in that area may be dismissed as negligible. Southwards, between Malakal and the boundaries of the Central Zone, not all areas of flood-plain have been calculated, and information about present grass distribution is of a much more general nature, based on information from a few cross-sections (see Vol. I, pp. 159–60).

The White Nile: Malakal-Jebelein Reach

In our analysis of grass distribution along the flood-plain between Malakal and Jebelein (Vol. I, p. 155), we have shown that the distribution is governed by certain environmental factors; the chief measurable ones being the depth and duration of flooding, as determined by flood-plain level above river gauge datum. From figures obtained for these factors, together with estimates of the proportions of grasses along the flood-plain and the assumption that the distribution of depths is a normal one, we have obtained for four sites (Malakal, Melut, Renk and Jebelein), and later for the reaches Malakal–Melut, Melut–Renk and Renk–Jebelein, estimates of the grass distribution over areas that become flooded between successive rises of 0·25 m. in the average gauge levels for each reach.

From the work based on idealized cross-sections (pp. 426–8), the actual flood-plain areas between average gauge intervals for each reach are known, and it has been possible to work out the actual areas of each species on those parts flooded between average gauge level intervals for each reach (see Tables 110, 111, 112, Vol. I, pp. 180–1).

It has been assumed that the distribution of species over each of the three reaches is determined by the duration of flooding since, with a predominantly clay soil, it is supposed that there is little seepage and the effectiveness of a water-table is limited. Duration of flooding has been shown to be related to depth of flooding and the level of flood-plain above river gauge datum (Vol. I, p. 156). This being the case, we have assumed that areas of flood-plain which under the new régime will receive periods of flooding similar to those of areas which at present have the grass distribution given in Tables 107, 108, 109 (Vol. I, p. 179) will also have a similar distribution of grasses.

Table 254 (p. 498) gives flood duration figures in 10-day periods for both the average 1946–51 river and the future normal (55 m/d Canal stage) for flood-plain levels above river gauge datum in the reaches Malakal–Melut, Melut–Renk and Renk–Jebelein.

Tables 246, 247, 248 (pp. 496–7) show the percentage distribution of grass species related to the future normal river gauge levels which give the equivalent flood duration periods for the average 1946–51 river.

From the idealized profiles (see pp. 426–7), the area of flood-plain between the new gauge intervals is known. By using the proportions for the same gauge intervals as shown in Tables 246, 247, 248, an estimate of the distribution of each species and the area it will cover under the future hydrological conditions for each reach is obtained.

From Tables 206 and 207 (pp. 446–7), the future maximum and minimum gauge levels for the three reaches are given as:

Reach	Maximum	Minimum
Malakal–Melut	12·41	11·56
Melut–Renk	12·33	11·27
Renk–Jebelein	12·49	10·95

In Table 249 (p.497) it will be noted that for the Malakal–Melut reach the distribution of grass species is given at 0·25 intervals between 11·50 and 13·00 gauge level readings. In fact at the higher limit riverain swamp grasses (*Echinochloa pyramidalis*) begin to fade out beyond 12·50, which is near to the future maximum gauge level of 12·41. Furthermore, since any grass below the level of 11·56 will not be exposed, and therefore not accessible for grazing, it has been accepted that for practical purposes the value of the flood-plain between Malakal and Melut as pasture should be only that portion of it which is inundated between average gauge levels for the reach of 11·60 minimum and 12·31 maximum[3].

Similar conditions exist in the other two reaches, and it has been decided that in these cases only the flood-plain inundated between gauge levels 11·36 and 12·20 for Melut–Renk reach and 10·96 and 12·39 for Renk–Jebelein reach should be considered as valuable pasture.

Table 252 (p. 498) shows the proportion of the flood-plain of the three reaches which will in future be available riverain swamp grassland, and the proportions by area of the grass constituents. Table 253 shows how the new flood-plain compares in terms of pasture with that produced by normal river régime, and where losses will occur.

We have so far only considered changes which will take place in the portion of the flood-plain annually flooded and exposed under the Project. Below this area there will be some of the original flood-plain, mostly depressions, watercourses and lagoons, which will be subject to permanent flooding. Many of these areas at present carry, deep-flooded pasture types and it will be interesting to see what proportion of the area permanently flooded will still carry deep-flooded types and whether the remaining area will also carry vegetation.

In Table 107 (Vol. I, p. 179), which gives the percentage distribution of grasses for average gauge intervals for the Malakal–Melut reach, it will be noted that *Vossia cuspidata* extends down to areas flooded at gauge levels of 8·75 (permanently flooded) and then stops. *Echinochloa stagnina* extends only as far as the gauge level 9·50. The actual flood-plain, however, is taken as the area flooded between gauge levels 10·00 and 12·50. Anything below 10·00 may be regarded as being inaccessible (i.e. permanently flooded). In future the flood-plain will be that area inundated between gauge levels 11·50 and 12·50, anything below 11·50 being permanently flooded—in fact 75·5 sq. km. of the original flood-plain. If distribution of species, as determined by depth and duration, remains the same as at present, we may expect a proportion of this to be covered by deep-flooded type grasses—equivalent to those now covering areas inaccessible under normal river. In fact of the 75·5 sq. km. we expect 66·9 sq. km. to be covered with vegetation which will never be exposed, and which will have minimum flood depths varying from a centimetre to 150 cm. In future the range of depths over the new flood-plain between minimum and maximum will be about 100 to 125 cm. Therefore the depths at the lowest levels (i.e. old flood-plain areas) will vary from 100–125 cm. to 250–300 cm. The depth of water over the remaining 8·6 sq. km. will be between a minimum of 150 cm. and a maximum of over 300 cm. It is likely therefore that this area will remain permanent open water. 66·9 sq. km. of old flood-plain will still carry vegetation, of which a considerable proportion will be in old depressions and khors. The largest proportion of the vegetation over these areas will be *Vossia cuspidata* and there will also be some *Echinochloa stagnina*. There is a possibility, however, that if papyrus is still brought downstream by the river, and these sites are still accessible from the river, papyrus will become established in limited areas where the range of levels is not too great, as at present in the Flood Region.

Similar conditions will exist in the Melut–Renk and Renk–Jebelein reaches, where 138 sq. km. and 41·5 sq. km. respectively of original flood-plain will be permanently flooded. Of the 138 sq. km. in the Melut–Renk reach it is estimated that 100 sq. km. will remain dominated by *Vossia cuspidata* and 13·39 sq. km. by *Echinochloa stagnina*, and that the remainder will be open water. There is again the possibility of papyrus becoming established in some of the khors. In the Renk–Jebelein reach it is estimated that about 27·5 of the 41·5 sq. km. will be

grassed, mostly by *Vossia cuspidata*, with again the possibility of papyrus developing in some khors. The possibilities of utilizing grasses from the permanently flooded areas must not be overlooked, for they may help to offset the losses in accessible pasture under the Equatorial Nile Project.

The White Nile: Malakal to Lake No

The reader is referred to Table 215 (p. 450), which gives the present and future tribal flood-plain areas. The effects on pasture are considered according to these areas.

Dinka: Lake No to Shilluk boundary (left bank)

The distance of river frontage is given as 30 km. and the present and future flood-plain as 105 sq. km., and there will therefore be no loss in area. The reader is now referred to the northern portion of the cross-section of the White Nile at Lake No, Fig. A 21, and to the account of this section given in the text (Vol. I, p. 160). The northern portion of this section is dominated mainly by *Echinochloa pyramidalis* and intermediate *Hyparrhenia rufa* type grassland. Further, it will be noticed from the section that the river level at the time of the investigation was close to the normal maximum (the present normal maximum water-level at Lake No is 386·42 m.), and that the northern portion of the section had water only in the bottom of a few local depressions, bearing no relationship to the water-level in the river. It may be assumed that the northern portion of the section does not receive river spill directly, and very little, if any, via Khor Alou and other depressions. The area therefore receives its moisture by direct rain precipitation, local run-off, and possibly from an underground water-table for a short distance from the river.

The future maximum water-level at Lake No will be 386·23 m., i.e. 19 cm. lower than normal maximum. The future minimum water-level will also be lower, 385·65 m. as compared with a normal minimum of 385·95 m. The area will therefore continue to be free from direct river spill, and in general such ecological conditions as are produced by the river will remain relatively unchanged, except that probably a lower minimum (30 cm. lower) will mean a lower water-table in the area running directly alongside the river. Since we have no information about the extent and importance of the water-table in this area, we must ignore it and conclude that conditions along the northern part of the section will remain unchanged and that vegetation will remain the same.

If we take this section as typical of the flood-plain north of the White Nile between Lake No and the Shilluk boundary, an area of 105 sq. km., we may conclude that there will be no loss in flood-plain area or change in grass composition.

Nuer: Lake No to Zeraf mouth (right bank)

The distance of river frontage is given as 78 km. and the total flood-plain area as 210 sq. km. In future the area will be reduced to 185 sq. km. ; a loss of 12% of present flood-plain area.

The reader is again referred to Fig. A 21 ; this time to the southern portion of the cross-section, which is dominated by *Cyperus papyrus*. Unlike the water-level along the northern portion of the section, that along the southern portion has a direct relationship to the water-level at the river. With a normal maximum water-level of 386·42 and a minimum of 385·95 (for four ten-day periods only) it is obvious that the section is almost permanently flooded. Future levels under the Project will also continue to provide almost permanent flood conditions along the section, and it is considered that the future fluctuation will not cause any major change.

It has been shown that actual losses in flood-plain area along this reach will not occur over the first 30 km. downstream of Lake No (p. 451) ; therefore, if we again consider that the section (southern part) is typical of the flood-plain of this reach, there will be no reduction in the area or change in composition.

Losses and changes will, however, take place over the remainder of the area along the 48 km. of river-front. Over this reach papyrus is absent and the flood-plain is mostly *Echinochloa pyramidalis*, with *Vossia cuspidata* and *Echinochloa stagnina* in depressions, and *Hyparrhenia rufa* type intermediate grassland lying behind the riverain swamp grassland. In future minimum water-levels will be approximately 50 cm. higher than normal minimum—the levels increasing steadily as one proceeds downstream from Lake No, until at Zeraf mouth the difference between normal minimum and future E.N.P. minimum will be 78 cm. Future maximum levels will differ only very slightly from normal maximum, e.g. Zeraf mouth present normal 385·32 and future 385·34. The actual flood time curve will remain practically the same shape, but will extend over a higher range of levels. Thus the higher minimum will result in 12% of the area of flood-plain becoming permanently flooded, mainly in depressions and watercourses which already carry *Echinochloa stagnina* and *Vossia cuspidata*. It is expected

From the idealized profiles (see pp. 426–7), the area of flood-plain between the new gauge intervals is known. By using the proportions for the same gauge intervals as shown in Tables 246, 247, 248, an estimate of the distribution of each species and the area it will cover under the future hydrological conditions for each reach is obtained.

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The reader is referred to Table 215 (p. 450), which gives the present and future tribal flood-plain areas. The effects on pasture are considered according to these areas.

Dinka: Lake No to Shilluk boundary (left bank)

The distance of river frontage is given as 30 km. and the present and future flood-plain as 105 sq. km., and there will therefore be no loss in area. The reader is now referred to the northern portion of the cross-section of the White Nile at Lake No, Fig. A 21, and to the account of this section given in the text (Vol. I, p. 160). The northern portion of this section is dominated mainly by *Echinochloa pyramidalis* and intermediate *Hyparrhenia rufa* type grassland. Further, it will be noticed from the section that the river level at the time of the investigation was close to the normal maximum (the present normal maximum water-level at Lake No is 386·42 m.), and that the northern portion of the section had water only in the bottom of a few local depressions, bearing no relationship to the water-level in the river. It may be assumed that the northern portion of the section does not receive river spill directly, and very little, if any, via Khor Alou and other depressions. The area therefore receives its moisture by direct rain precipitation, local run-off, and possibly from an underground water-table for a short distance from the river.

The future maximum water-level at Lake No will be 386·23 m., i.e. 19 cm. lower than normal maximum. The future minimum water-level will also be lower, 385·65 m. as compared with a normal minimum of 385·95 m. The area will therefore continue to be free from direct river spill, and in general such ecological conditions as are produced by the river will remain relatively unchanged, except that probably a lower minimum (30 cm. lower) will mean a lower water-table in the area running directly alongside the river. Since we have no information about the extent and importance of the water-table in this area, we must ignore it and conclude that conditions along the northern part of the section will remain unchanged and that vegetation will remain the same.

If we take this section as typical of the flood-plain north of the White Nile between Lake No and the Shilluk boundary, an area of 105 sq. km., we may conclude that there will be no loss in flood-plain area or change in grass composition.

Nuer: Lake No to Zeraf mouth (right bank)

The distance of river frontage is given as 78 km. and the total flood-plain area as 210 sq. km. In future the area will be reduced to 185 sq. km. ; a loss of 12% of present flood-plain area.

The reader is again referred to Fig. A 21 ; this time to the southern portion of the cross-section, which is dominated by *Cyperus papyrus*. Unlike the water-level along the northern portion of the section, that along the southern portion has a direct relationship to the water-level at the river. With a normal maximum water-level of 386·42 and a minimum of 385·95 (for four ten-day periods only) it is obvious that the section is almost permanently flooded. Future levels under the Project will also continue to provide almost permanent flood conditions along the section, and it is considered that the future fluctuation will not cause any major change.

It has been shown that actual losses in flood-plain area along this reach will not occur over the first 30 km. downstream of Lake No (p. 451) ; therefore, if we again consider that the section (southern part) is typical of the flood-plain of this reach, there will be no reduction in the area or change in composition.

Losses and changes will, however, take place over the remainder of the area along the 48 km. of river-front. Over this reach papyrus is absent and the flood-plain is mostly *Echinochloa pyramidalis*, with *Vossia cuspidata* and *Echinochloa stagnina* in depressions, and *Hyparrhenia rufa* type intermediate grassland lying behind the riverain swamp grassland. In future minimum water-levels will be approximately 50 cm. higher than normal minimum—the levels increasing steadily as one proceeds downstream from Lake No, until at Zeraf mouth the difference between normal minimum and future E.N.P. minimum will be 78 cm. Future maximum levels will differ only very slightly from normal maximum, e.g. Zeraf mouth present normal 385·32 and future 385·34. The actual flood time curve will remain practically the same shape, but will extend over a higher range of levels. Thus the higher minimum will result in 12% of the area of flood-plain becoming permanently flooded, mainly in depressions and watercourses which already carry *Echinochloa stagnina* and *Vossia cuspidata*. It is expected

either that these areas will continue to be covered with these grasses, although they will not be accessible because of flooding, or that the grasses will be replaced by papyrus. The remaining area of flood-plain—*Echinochloa pyramidalis*, *Oryza* spp. and *Hyparrhenia rufa* intermediate type—will remain unchanged, because although the future lower exposed area will receive slightly increased duration of flooding, actual depths will be reduced and there will be no depth limitation imposed on either *Echinochloa pyramidalis* or *Oryza barthii*.

SHILLUK: SHILLUK BOUNDARY TO SOBAT MOUTH (LEFT BANK)

The present and future flood-plain areas over this reach have been calculated to be 175 and 125 sq. km. respectively ; a loss in flood-plain area of 28·6%.

The future maximum level over this reach will vary only slightly from the present normal maximum, but the future minimum will be considerably higher, varying between a few centimetres at the Shilluk boundary to 170 cm. near the Sobat mouth. At Zeraf mouth and Tonga the minimum levels will be higher by 78 and 52 cm. respectively. The flood-plain over this reach of river is now predominantly *Echinochloa pyramidalis* and *Oryza barthii*, but there is a considerable amount of *Echinochloa stagnina* along the many khors that take off from and re-enter the White Nile farther downstream, and in other depressions on the flood-plain.

The higher minimum under the Equatorial Nile Project will have the same effect here as it has along the south bank between Lake No and Zeraf mouth, the 28·6% loss of flood-plain pasture being in those depressions and backwater khors which will in future be permanently flooded. In other words, the area occupied by the valuable deep-flooded types of pasture grass will be lost.

The future maximum level will remain relatively unchanged, so that there will be no gain in flood-plain at the higher level as there is north of Malakal. In addition, depth of flooding over the plain will be considerably reduced, especially as one approaches the Sobat mouth—i.e. the normal and future maximum depths at the Shilluk boundary are 74 and 69 cm. respectively, but as one reaches the Sobat mouth normal maximum depth is 2·49 m. and future maximum depth will be 85 cm. If we consider the depths of flooding at which species grow it would appear therefore that *Echinochloa pyramidalis* and *Oryza barthii* will maintain their position over the area, although over limited areas of flood-plain at the lower levels duration of flooding will be suitable for the development of *Echinochloa stagnina*. Since these sites are already occupied by *Echinochloa pyramidalis* and *Oryza barthii*, which in future will not be limited in their distribution over the flood-plain by depth of flooding, it is expected that these grasses will continue to hold their ground.

It is not unreasonable to assume that the 28·6% or 50 sq. km. lost or inaccessible owing to permanent flooding will be all the deep-flooded pasture at present found in this reach, plus some of the shallow-flooded types. The remaining area therefore (12·5 sq. km.) will be shallow-flooded *Echinochloa pyramidalis* and *Oryza barthii*. The area, 50 sq. km., now carrying the deep-flooded type pasture will probably continue to carry *Echinochloa stagnina* and *Vossia cuspidata*, but with an increased area of open water and possibly *Cyperus papyrus*. It will, however, be useless for grazing because it will be permanently flooded.

SHILLUK: ZERAF MOUTH TO SOBAT MOUTH (RIGHT BANK)

The distance of river frontage is approximately 45 km., and the area of flood-plain is estimated to be 70 sq. km. Future flood-plain area is estimated at 46 sq. km., a loss therefore of 24 sq. km.

The present and future maximum and minimum gauge levels over this reach, as measured for Zeraf mouth and Sobat mouth, are given below :

	PRESENT		FUTURE	
	Maximum	Minimum	Maximum	Minimum
Zeraf Mouth ...	12·76	11·27	12·38	12·05
Sobat Mouth ...	12·56	10·07	12·65	11·80

The flood-plain over this reach is predominantly covered by *Echinochloa pyramidalis* with *Oryza* sp. and *Echinochloa stagnina* at the lower levels. The future higher minimum will flood permanently the lower sites, i.e. the sites of *Echinochloa stagnina*, and it is not unreasonable to assume that the total flood-plain area lost (24 sq. km.) will include all that is at present occupied by *Echinochloa stagnina*, plus some areas of *Echinochloa pyramidalis*.

The future slightly higher maximum levels will result in the inundation of a new area of flood-plain which will probably become dominated by *Echinochloa pyramidalis*. In addition, other areas of flood-plain now dominated by *Echinochloa pyramidalis* will have an increased flood duration. The maximum depth of flooding, however, will not exceed approximately 85 cm. at any site along the new flood-plain, so that depth of flooding will not become a limiting factor in the distribution of *Echinochloa pyramidalis* and *Oryza barthii*, and it is expected that in future they will remain dominant over the areas they now occupy, but with possibly a small intrusion by *Echinochloa stagnina*.

The area of flood-plain permanently flooded in the future will probably continue to carry *Echinochloa stagnina* and *Vossia cuspidata*, but with increased areas of open water. The possibility of papyrus establishing itself at such sites must not be overlooked.

SHILLUK: SOBAT MOUTH TO MALAKAL

The present and future flood-plain areas for this reach are 36 and 26 sq. km. respectively, a loss of 10 sq. km. The present and future gauge levels at the Sobat mouth and Malakal are as follows:

	Present		Future	
	Maximum	Minimum	Maximum	Minimum
Sobat Mouth ...	12·56	10·07	12·65	11·80
Malakal	12·30	10·00	12·39	11·68
Average	12·43	10·03	12·52	11·74

The higher minimum will result in the lower levels of flood-plain becoming permanently flooded—i.e. the sites of *Vossia cuspidata* and *Echinochloa stagnina*, plus areas of *Echinochloa pyramidalis* and *Oryza barthii*. The higher maximum will give a slight gain in flood-plain area at the upper end which will probably become dominated by *Echinochloa pyramidalis*. Conditions in fact will be similar to those of the other reaches just considered, and it is therefore not unreasonable to assume that the 26 sq. km. of accessible flood-plain will be dominated by *Echinochloa pyramidalis* and *Oryza barthii* with a limited amount of *Echinochloa stagnina* at the lower levels. The inaccessible area, i.e. 10 sq. km., might become dominated by papyrus.

RIVER SOBAT

As pointed out in Chapter 2 of this volume, the higher backwater in the timely season will not result in flooding of the flood-plain and the levels in the untimely season will be as they are now. Therefore in general there will be no alteration in conditions along the flood-plain, so that we do not expect any change in pasture or loss in flood-plain area.

BAHR EL GHAZAL

Only the lower reaches of the Bahr el Ghazal will be affected by the Project. Since our information indicates that the effects will probably be similar to those in the Bahr el Jebel at Lake No it is unlikely that there will be any change in the composition of the pasture on the flood-plain of the Bahr el Ghazal.

BAHR EL ZERAF (SOUTH OF FANGAK)

The only effect along this reach is that there will be less backwater flow up the mouths of Khor Longtam and Khor Ban, which will probably result in a decrease in deep-flooded type pasture at their mouths. The rest of the flood-plain, which is in any case very limited, will not be affected.

INLAND KHOR-BED PASTURE

SOUTH OF MALAKAL

Watercourses joining the main river in this reach are only affected by levels in the latter for a limited distance, rarely for more than a few kilometres. Above that, khor-bed pasture is determined by the hydrology of the khors themselves and is dependent on local rainfall and run-off. It follows that the pasture will not be greatly affected by changes in the régime of the Nile.

KHOR FULLUS

The backwater effect will extend only along the lower reaches where the khor is narrow and steep-sided, so that there will be no change in hydrological conditions on its flood-plain which is mainly found along the upper reaches. Grass composition along the flood-plain will therefore, remain unchanged.

Khor Atar

With a higher maximum at Malakal, backwater will extend farther inland than at present from January onwards, resulting in more prolonged inundation over the reach where backwater extends. Near the mouth flooding will be permanent and pasture lost, but this will be offset by the increased area seasonally exposed upstream. Other than this there will be no change over the rest of the flat channel bed.

Khor Yirr Gwol

This khor is unaffected by levels in the White Nile, so there will be no change in the composition of pasture along its bed or flood-plain.

North of Malakal

Khor Adar

There will be no radical change in the hydrological conditions along the flood-plain of the Khor Adar so that no major change in pasture composition is expected (see p. 430).

Khors Wol and Nyadwai

Backwater will extend less than 10 km. up the Khor Wol and the Khor Nyadwai, which have catchment systems independent of the Nile. Except therefore for a possible slight increase in deep-flooded type grasses along the first few kilometres there will be no further change in composition.

INTERMEDIATE AND HIGH LAND PASTURE

No change in the grass associations is expected. The slightly higher maximum level, which will be more constant, will hinder drainage, but its only effect is expected to be a slight improvement in the regrowth provided by intermediate grasses in close proximity to inland khors.

TABLE 246

FUTURE PERCENTAGE DISTRIBUTION OF SPECIES
MALAKAL–MELUT

Mean gauge interval	*Vossia cuspidata*	*Echinochloa stagnina*	*Oryza barthii*	*Echinochloa pyramidalis*
11·50–11·60	56	44	—	—
11·60–11·75	49	51	—	—
11·75–11·80	31	46	18	5
11·80–11·85	10	20	35	35
11·85–11·95	2	3	39	56
11·95–12·00	—	—	32	68
12·00–12·05	—	—	23	77
12·05–12·10	—	—	16	84
12·10–12·25	—	—	10	90
12·25–12·50	—	—	5	45
12·50–12·75	—	—	—	50
12·75–13·00	—	—	—	—

Note: Gauge intervals refer to E.N.P. régime equivalents of average 1946–51 gauge intervals.

TABLE 247

FUTURE PERCENTAGE DISTRIBUTION OF SPECIES
MELUT–RENK

Mean gauge interval	*Vossia cuspidata*	*Echinochloa stagnina*	*Oryza barthii*	*Echinochloa pyramidalis*
11·20–11·30	48	52	—	—
11·30–11·40	37	61	2	—
11·40–11·50	24	57	11	8
11·50–11·60	7	28	24	41
11·60–11·70	1	4	26	69
11·70–11·80	—	—	19	81
11·80–12·00	—	—	12	88
12·00–12·25	—	—	7	93
12·25–12·35	—	—	4	96
12·35–12·50	—	—	—	50
12·50–12·75	—	—	—	—
12·75–13·00	—	—	—	—

Note: Gauge intervals refer to E.N.P. régime equivalents of average 1946–51 gauge intervals.

TABLE 248

FUTURE PERCENTAGE DISTRIBUTION OF SPECIES

RENK–JEBELEIN

Mean gauge interval	*Vossia cuspidata*	*Echinochloa stagnina*	*Oryza barthii*	*Echinochloa pyramidalis*
10·70–10·85	43	7	—	—
10·85–11·05	43	55	2	—
11·05–11·20	30	57	10	3
11·20–11·30	13	53	22	12
11·30–11·45	7	46	23	24
11·45–11·60	6	44	16	34
11·60–11·80	6	40	11	43
11·80–12·10	2	18	5	75
12·10–12·40	—	—	3	97
12·40–12·60	—	—	—	100
12·60–12·80	—	—	—	50
12·80–13·00	—	—	—	50

NOTE: Gauge intervals refer to E.N.P. régime equivalents of average 1946–51 gauge intervals.

TABLE 249

FUTURE DISTRIBUTION OF SPECIES

MALAKAL–MELUT

(In sq. km.)

Average gauge interval	*Vossia cuspidata*		*Echinochloa stagnina*		*Oryza barthii*		*Echinochloa pyramidalis*		AREA OF FLOOD-PLAIN	
	Increment	Total	Increment	Total	Increment	Total	Increment	Total	Increment	Total
11·50–11·60	15·1	15·1	11·9	11·9	—	—	—	—	27·0	27·0
11·60–11·75	14·7	29·8	15·3	27·2	—	—	—	—	30·0	57·0
11·75–11·80	2·8	32·6	4·1	31·3	1·6	1·6	0·5	0·5	9·0	66·0
11·80–11·85	1·0	33·6	2·1	33·4	3·7	5·3	3·7	4·2	10·5	76·5
11·85–11·93	0·3	33·9	0·5	33·9	6·4	11·7	9·3	13·5	16·5	93·0
11·93–12·00	—	—	—	—	4·5	16·2	9·5	23·0	14·0	107·0
12·00–12·05	—	—	—	—	2·5	18·7	8·5	31·5	11·0	118·0
12·05–12·10	—	—	—	—	1·8	20·5	9·2	40·7	11·0	129·0
12·10–12·25	—	—	—	—	2·8	23·3	25·2	65·9	28·0	157·0
12·25–12·50	—	—	—	—	1·8	25·1	15·7	81·6	35·0	192·0
12·50–12·75	—	—	—	—	—	—	11·0	92·6	22·0	214·0
12·75–13·00	—	—	—	—	—	—	—	—	13·0	227·0

TABLE 250

FUTURE DISTRIBUTION OF SPECIES

MELUT–RENK

(In sq. km.)

Average gauge interval	*Vossia cuspidata*		*Echinochloa stagnina*		*Oryza barthii*		*Echinochloa pyramidalis*		AREA OF FLOOD-PLAIN	
	Increment	Total	Increment	Total	Increment	Total	Increment	Total	Increment	Total
11·20–11·30	8·2	8·2	8·8	8·8	—	—	—	—	17·0	17·0
11·30–11·40	5·9	14·1	9·8	18·6	0·3	0·3	—	—	16·0	33·0
11·40–11·50	6·0	20·1	14·3	32·9	2·7	3·0	2·0	2·0	25·0	58·0
11·50–11·60	1·1	21·2	4·5	37·4	3·8	6·8	6·6	8·6	16·0	74·0
11·60–11·70	0·3	21·5	1·1	38·5	7·0	13·8	18·6	27·2	27·0	101·0
11·70–11·80	—	—	—	—	6·7	20·5	28·3	55·5	35·0	136·0
11·80–12·00	—	—	—	—	13·1	33·6	95·9	151·4	109·0	245·0
12·00–12·25	—	—	—	—	5·3	38·9	69·7	221·1	75·0	320·0
12·25–12·35	—	—	—	—	0·9	39·8	21·1	242·2	22·0	342·0
12·35–12·50	—	—	—	—	—	—	16·0	258·2	32·0	374·0
12·50–12·75	—	—	—	—	—	—	—	—	38·0	412·0
12·75–13·00	—	—	—	—	—	—	—	—	50·0	462·0

TABLE 251

FUTURE DISTRIBUTION OF SPECIES
RENK–JEBELEIN
(In sq. km.)

Average gauge interval	*Vossia cuspidata*		*Echinochloa stagnina*		*Oryza barthii*		*Echinochloa pyramidalis*		AREA OF FLOOD-PLAIN	
	Increment	Total	Increment	Total	Increment	Total	Increment	Total	Increment	Total
10·70–10·85	3·9	3·9	0·6	0·6	—	—	—	—	9·0	9·0
10·85–11·05	7·3	11·2	9·4	10·0	0·3	—	—	—	17·0	26·0
11·05–11·20	4·7	15·9	8·8	18·8	1·5	1·8	0·5	0·5	15·5	41·5
11·20–11·30	1·4	17·3	5·5	24·3	2·3	4·1	1·3	1·8	10·5	52·0
11·30–11·45	1·0	18·3	6·6	30·9	3·3	7·4	3·4	5·2	14·3	66·3
11·45–11·60	1·2	19·5	8·8	39·7	3·2	10·6	6·7	11·9	19·9	86·2
11·60–11·80	2·4	21·9	15·9	55·6	4·4	15·0	17·1	29·0	39·8	126·0
11·80–12·10	1·1	23·0	10·0	65·6	2·8	17·8	42·1	71·1	56·0	182·0
12·10–12·40	—	—	—	—	1·6	19·4	52·4	123·5	54·0	236·0
12·40–12·60	—	—	—	—	—	—	40·0	163·5	40·0	276·0
12·60–12·80	—	—	—	—	—	—	15·5	179·0	31·0	307·0
12·80–13·00	—	—	—	—	—	—	8·5	187·5	17·0	324·0

TABLE 252

FUTURE DISTRIBUTION OF ACCESSIBLE SPECIES
MALAKAL–JEBELEIN
(Interpolated from Tables 249, 250, and 251)

Grass Species	MALAKAL–MELUT gauge-readings 11·60–12·31	MELUT–RENK gauge-readings 11·36–12·20	RENK–JEBELEIN gauge-readings 10·96–12·39
Vossia cuspidata	18·8 sq. km.	9·9 sq. km.	14·3 sq. km.
Echinochloa stagnina	22·0 „ „	24·1 „ „	58·8 „ „
Oryza barthii	24·5 „ „	37·8 „ „	19·2 „ „
Echinochloa pyramidalis	76·7 „ „	207·2 „ „	116·7 „ „
Areas of riverain swamp pasture	142·0 „ „	279·0 „ „	209·0 „ „

TABLE 253

RIVERAIN PASTURE LOSSES
MALAKAL–JEBELEIN
(In sq. km.)

	MALAKAL–MELUT		MELUT–RENK		RENK–JEBELEIN		MALAKAL–JEBELEIN		Losses over whole reach
	Present	E.N.P.	Present	E.N.P.	Present	E.N.P.	Present	E.N.P.	
Vossia cuspidata ...	15·2	18·8	24·2	9·9	21·2	14·3	60·6	43·0	17·6
Echinochloa stagnina ...	17·3	22·0	47·0	24·1	65·6	58·8	129·9	104·9	25·0
Oryza barthii	42·5	24·5	47·5	37·8	19·4	19·2	109·4	81·5	27·9
Echinochloa pyramidalis	148·0	76·7	302·3	207·2	146·3	116·7	596·6	400·6	196·0
Open Water	—	—	—	—	2·5	—	2·5	—	2·5
Areas of riverain swamp pasture	223·0	142·0	421·0	279·0	255·0	209·0	899·0	630·0	269·0

TABLE 254

PRESENT AND FUTURE GAUGE DURATION
MALAKAL–JEBELEIN

Gauge reading	MALAKAL–MELUT		MELUT–RENK		RENK–JEBELEIN	
	1946–51	E.N.P. normal	1946–51	E.N.P. normal	1946–51	E.N.P. normal
10·00	35	36	35	36	36	36
10·25	31	36	32	36	34	36
10·50	26	36	28	36	30	36
10·75	24	36	25	36	27	36
11·00	22	36	23	36	24	31
11·25	20	36	20	36	22	25
11·50	18	35	18	26	20	21
11·75	16	26	15	20	18	18
12·00	14	18	13	11	15	14
12·25	10	8	6	1	9	10
12·50	4	1	2	—	6	—
12·75	1	—	—	—	1	—
13·00	—	—	—	—	—	—

EFFECTS ON GRAZING AND ANIMAL MANAGEMENT

The data in the previous section are presented reach by reach according to the variations in the hydrology of the Nile: but since our ultimate concern is with the people along the river, the effects on pasture and animal management are presented in units of single tribes or groups of tribes having common grazing grounds.

WESTERN JIKAING NUER; RUWENG (KWIL), RUT, THOI, AND NGOK DINKA

It has been shown in the previous section that the future river régime will not alter significantly the distribution and availability of dry season pasture along the Bahr el Jebel from Buffalo Cape to Lake No, along the Bahr el Ghazal, along the left bank of the White Nile from Lake No to Tonga, and along the Sobat. Thus the Western Jikaing Nuer, Kwil Dinka and Ngok Dinka will not be affected. The Rut and Thoi Dinka spend the dry season on the Khor Atar and on the network of depressions near the lower Zeraf and they will not be affected significantly.

RUWENG (PAWENG) AND LUAICH DINKA

Of the Ruweng Dinka (living along the lower Atar) half the livestock population (or 6,200 Animal Units) use the White Nile riverain pasture within Shilluk country. It will be seen that the Shilluk themselves make use of all available pasture in the area until the end of March and that there will be adequate pasture from April onwards—under the Project—for both Shilluk and Ruweng (see Tables 255 and 267). There will be a reduction in the riverain pasture in June, but by that time inland pasture is available so that no loss need be recorded.

The remaining Ruweng spend the dry season on the lower Atar and much of the present pasture will be covered by water in the future. However, we have seen that the range of backwater effect of the Canal will be from 18·3 to 8·3 km. from the mouth instead of from 11·3 km. to nil as at present (see p. 430). The carrying capacity of the future pasture will be little different from that of the present.

The Luaich Dinka living along the Khor Fullus for the most part make use of the intermediate regrowth pasture within walking reach of the khor. Only the pasture in the khor bed will be lost—as a result of the backwater from the Canal—and since this can support approximately 1,000 Animal Units throughout the dry season, provision must be made for that number elsewhere.

LAK NUER

The Lak Nuer, at the northern end of Zeraf Island, will be directly affected by the Project and the effects have been calculated on the areas of river flood-plain which are, and will be, exposed in the dry season and the grass distribution of these areas. The present grass distribution is taken to be 10% deep-flooded and 90% shallow-flooded pasture. Deep-flooded pasture has a stock-carrying capacity of 400 A.U. per sq. km. per month for the first two months after exposure and thereafter 240 A.U. per sq. km. Shallow-flooded pasture will carry only 25 A.U. per sq. km. per month from exposure (and burning) until the early rains (April). From April onwards it supports 160 A.U. per sq. km. per month (see Table 259, p. 504).

The area of flood-plain inundated and exposed by normal and future river levels is given in Chapter I (p. 449). In the previous section the effects of the altered régime have been shown to be primarily on deep-flooded pasture, most of which will be permanently flooded and therefore lost as grazing. A small area of shallow-flooded pasture will be lost in addition. The areas of flood-plain inundated and exposed during each month cannot be calculated in detail south of Malakal, but since they are directly related to the Malakal gauge the month to month ratios in the Malakal–Melut reach are sufficiently similar to be applicable here. The difference between present and future carrying capacities is shown in Table 266 (p. 507). If only present numbers of livestock are considered, the loss of grazing amounts to 12 TAUM or a maximum of 3,780 Animal Units a month; this is the number for which alternative accommodation must be found.

SHILLUK

As already mentioned, flood-plain areas south of Malakal cannot be calculated in detail. The effects of the Project on Shilluk riverain pastures are therefore as shown in Table 267 (south of Malakal) and Table 268 (north of Malakal). The total flood-plain at the present time provides 264 TAUM grazing for a maximum of 63,000 Animal Units a month at the height of the dry season. The total future carrying capacity will be 159 TAUM or a maximum of 48,000 Animal Units a month at the height of the dry season. This last figure slightly minimizes the loss because there is a surplus of pasture south of Malakal which reduces the loss north of Malakal. Considering only the present numbers of livestock, the total effect is the loss of 105 TAUM grazing; the maximum loss of 28,100 Animal Units is made up of a loss of 11,070 south of Malakal in March (see Table 267) and a monthly loss of 17,000 north of Malakal (see Table 268).

DUNJOL AND PALOICH DINKA

These people graze their livestock on the river flood-plain between Kodok and Gelhak (Jebel Ahmed Agha) on the right bank. The area of flood-plain exposed at present is 164 sq. km. (Table 264) of which 60 are south of Melut and 104 north of Melut. The potential stock-carrying capacity of the total area of exposed plain is 110 TAUM, but at the present time it only provides for 91 TAUM (Table 268). Under the Project the flood-plain area will be reduced from 164 to 107 sq. km., and there will be a loss of potential carrying capacity of 49 TAUM, though with actual livestock population at present the loss would be only 30 TAUM (Table 268). This latter is sufficient to support an average of 6,000 Animal Units over the five-month period February to June inclusive. Any increase there may be in the khor-bed pasture of the Wol and Adar will be too small to offset this loss in any way.

ABIALANG DINKA (AND TA'AISHA)

From Gelhak (Jebel Ahmed Agha) to Geigar the river-front belongs to the Abialang Dinka, but the livestock population only uses about one-third of the grazing provided by the river flood-plain (46 out of 122 TAUM). The country inland is more suitable for the cultivation of grain, sesame and groundnuts than that of the Nilotics of the Flood Region and crop production plays a larger part in the local economy. Livestock management is, however, traditional and the profits from cultivations are generally used to enlarge the cattle population.

Under the Project the flood-plain area will be reduced from 181 to 132 sq. km., causing a loss of potential grazing of 36 TAUM, though the current livestock population would still leave 40 TAUM grazing untouched (Table 268). The excess of river swamp pasture is not allowed to go to waste entirely, since approximately 25,000 sheep (3,125 Animal Units) belonging to Baggara from the east bank are permitted to cross the northern border annually to utilize the riverain pasture from March onwards when the river drops. Thus 12·5 TAUM of the excess is utilized by animal stock from farther north.

In Table 268, column 5 combines the areas and the carrying capacities of the flood-plains belonging to Abialang Dinka and Baggara Arabs of the east bank. The picture presented gives the impression that the effects on the northern section are not as great as they are; and in any event the grazing of Arab sheep within Dinka territory is permitted only as far as Renk (not to Gelhak) and may be denied to the Baggara if the pasture land is required by the Dinka in the process of their development. In this section it is sufficient to say that the effect of the Project will be to remove 49 sq. km. of flood-plain having a potential carrying capacity of 36 TAUM. As far as the livestock of the Dinka and local Ta'aisha are concerned there will still be an excess of pasture (40 TAUM) which will only be fully utilized if the animal population increases by 8,000 Animal Units. If the present arrangement of allowing 25,000 sheep from the Baggara to graze in Dinka territory continues there will still be an excess of 27·5 TAUM of pasture, so that only the loss of potential (36 TAUM) need be recorded here.

EAST BANK BAGGARA

The river flood-plain of this section lies between Geigar and Jebelein. The area flooded and exposed annually is 52 sq. km., having a potential stock-carrying capacity estimated at 36 TAUM (Table 265). The total number of livestock in this area is 16,600 Animal Units (Table 255), but not all of these are dependent on the above flood-plain for the whole of the season January to June. From March onwards 25,000 sheep (3,125 Animal Units) are allowed to graze along the river in Dinka country between Geigar and Renk, thus accounting for 12·5 TAUM. Between January and March the maximum area of flood-plain at present exposed is 39 sq. km. (20·4% of [24 + 167]) and the total estimated stock-carrying capacity over these three months is 3·9 TAUM (20·4% of [0·65 + 3·27 + 15·11]), Tables 262 and 265. If we assume that the entire livestock population, 16,000 Animal Units, depends on river flood-plain pasture from April to June—as seems to be the case—the amount of pasture consumed within the section area in these three months would be 40·5 TAUM (13·5 × 3). To this must be added the 3·9 TAUM supplied by the flood-plain between January and March, bringing the total present estimated stock-carrying capacity to 44·4 TAUM for the period January to June. This is 8·4 TAUM more than the carrying capacity as estimated from data relating to vegetation only, the reason being perhaps that the flood-plain is overgrazed. In estimating the effects of the Project we have calculated from data relating to vegetation that the future stock-carrying capacity of the flood-plain between January and June will be 32 TAUM. The loss under the Project is therefore 12·4 TAUM or pasture for 2,500 Animal Units per month for the five-month period February to June inclusive.

When the 32 TAUM is compared with the present estimated stock-carrying capacity of the flood-plain, i.e. 36 TAUM, the loss appears to be only 4 TAUM or an average of 800 Animal Units over the five-month period.

Despite this the previous figure, 2,500 Animal Units, is adopted because the number of Animal Units recorded is known to be almost entirely dependent on riverain pasture during the low river season, and particularly in April, May and June.

WEST BANK BAGGARA

These people, Ahamda, Seleim and others, make use of riverain pasture from Torakit (Gelhak) to opposite Jebelein on the west bank. Each tribe does not inhabit the hinterland directly adjacent to the flood-plain which it uses, so the section must be treated as one unit. The area of the flood-plain exposed annually at present is 270 sq. km., having a stock-carrying capacity of 182 TAUM (Table 265).

The livestock population using this river pasture is estimated to be 62,200 Animal Units and some of these come down to the river to water in January. The Jebel Aulia Dam does not open until some time about the beginning of March; until the end of March only a limited area of riverain pasture is exposed, sufficient to support approximately 25·3 TAUM (Tables 265, 261 and 262), but this is to ignore the fact that cattle graze on the flood-plain before it is exposed—consuming probably a further 8 TAUM. We therefore consider that the river flood-plain supplies 33·3 TAUM grazing before the end of March.

There remain three months during which all the livestock under consideration, 62,200 Animal Units, depend on riverain pasture, i.e. consume 186·6 TAUM pasture. Thus over the whole dry season 219·9 TAUM grazing is consumed. This is 37·9 TAUM more than the theoretical figure, but the latter is probably correct since we know that the riverain pasture, like much of the inland pasture, is overgrazed.

Under the Project the area of the flood-plain exposed will be reduced from 270 sq. km. to 199 sq. km. and the carrying capacity from 182 to 132 TAUM. This theoretical loss of 50 TAUM grazing, 10,000 Animal Units for five months, is complete and must be made good.

OTHER EFFECTS

Two effects of veterinary interest must be recorded, though we have no detailed information in support. The prolonged retention of water in the deepest depressions of the flood-plains and the consequent lengthening of the period when damp, decaying vegetable matter provides good breeding conditions for flies will cause an increase in the fly population, particularly of *Tabanus* and *Stomoxys*. Apart from their ability to transmit disease, e.g. trypanosomiasis, these flies cause such pain and annoyance to livestock, particularly cattle, that the animals are greatly disturbed while grazing. Their food intake is reduced and a great deal of energy is spent in self-protection by kicking, stamping, biting, tail-swishing and even stampeding to avoid severe attack.

The second effect is that on the incidence of human bilharzia and animal fascioliasis. Various species of snail, namely *Bulinus* sp., *Biomphalaria* sp. and *Lymnaea* sp., live in the slow-moving waters of the Nile and are the intermediate hosts of human and animal parasites. The complete seasonal drying-out of the river flood-plain is unfavourable for the infection of the snail by the primary host and for the viability of the infective-stage larva after it has left the snail. At the present time, there being practically no depressions in the flood-plain with permanent water, humans and animals are infected by bathing in or drinking infected water from the edge of the main river; and animals pick up infection from the leaves of grass growing in slow-moving or stagnant water in pools or at the river's edge where the infective larvae are resting after leaving the snail host. Since one of the effects of the Project will be to raise the minimum river level, low depressions will be permanently flooded and the conditions for the development and transmission of *Schistosomae* (bilharzia) and *Fasciolae* (liver-fluke) will be ideal. The increase in the incidence of liver-fluke in the Kosti area since the Jebel Aulia régime came into operation is no doubt due to the fact that livestock, particularly cattle, must now wade in water to graze the tips of swamp grass in the early dry season, whereas previously the river level dropped earlier—3 months earlier—and the pasture was fairly dry before it was grazed. The proposed régime will increase the need for this practice throughout the whole Northern Zone.

Some idea of the incidence to be expected can be obtained from the numbers of livestock treated for liver-fluke by the Veterinary Service in Kosti District over the past four years. The drug in general use is Hexachlorethane, and, since it is only issued on payment, only a fraction of the infected animals has been treated at present. The efficacy of the drug has, however, become known, and the demand for the drug has risen from 1,800 doses in 1950 to 35,500 doses in the first four months of 1953.

CONCLUSIONS

In each tribal area of the Northern Zone the effects of the Equatorial Nile Project have been assessed, first in relation to the alteration in type of vegetation on the river flood-plain secondly in terms of altered stock-carrying capacity of the future exposed flood-plain, and thirdly in respect of losses, or gains, and their translation into terms of livestock. In the whole of the Northern Zone the total loss of potential pasture is estimated at 348 Thousand Animal Unit Months or that required for 70,200 Animal Units over the dry season period of five months (Table 269, p. 508). If present livestock numbers only are considered, the potential increase ignored and losses in one district offset against gains in another, the net loss is estimated at 174 TAUM or that required for 43,400 Animal Units for the five-month season. None of these losses can be replaced by natural inland pastures. The problem of providing alternative pastures by other means is discussed in the next part of this volume.

TABLE 255

NUMBERS OF LIVESTOCK USING RIVERAIN PASTURE
NORTHERN ZONE

	Cattle	Sheep	Animal Units
Lak Nuer (≃ 37%)	17,600	3,300	18,000
Ruweng (Kwil)	11,000	16,000	13,000
Ruweng (Paweng)	12,200	1,500	12,400
Thoi	3,800	500	3,900
Rut	2,300	1,000	2,400
Luaich	5,100	1,000	5,200
Western Jikaing (≃ 66%)	23,200	9,300	24,300
Total	75,200	32,600	79,200
Shilluk (South of Malakal) 39%	11,700	78,000	21,500
Shilluk (North of Malakal) 61%	18,300	122,000	33,500
Total	30,000	200,000	55,000
Dunjol	6,000	10,000	7,200
Paloich	8,500	20,000	11,000
Total	14,500	30,000	18,200
Abialang	3,500	11,000	4,900
Ta'aisha	—	6,000	700
Gelhak to Renk: Total (East Bank)	3,500	17,000	5,600
Abialang	1,500	4,000	2,000
Ta'aisha and Malakia	1,000	4,000	1,500
Muharib (East Bank Baggara)	11,000	45,000	16,600
Renk to Jebelein : Total (East Bank)	13,500	53,000	20,100
Seleim	16,000	34,000	20,200
Ahamda	8,000	32,000	12,000
Gelhak to Renk: Total (West Bank)	24,000	66,000	32,200
Seleim	8,000	8,000	9,000
Ahamda	13,000	20,000	15,500
Gima, etc.	4,500	8,000	5,500
Renk to Jebelein Total (West Bank)	25,500	36,000	30,000
Grand Total	186,200	434,600	240,300

TABLE 256

PRESENT AND FUTURE AREAS OF WHITE NILE FLOOD-PLAIN INUNDATED AND EXPOSED
MALAKAL–JEBELEIN

Month	Area Inundated		Area Exposed	
	Present sq. km.	E.N.P. sq. km.	Present sq. km.	E.N.P. sq. km.
Malakal to Melut ... Present area inundated 224 sq. km. E.N.P. area inundated 244 sq. km.				
December	176	238	48	6
January	53	236	171	8
February	20	176	204	68
March	6	132	218	112
April	1	102	223	142
May	5	112	219	132
June	31	205	193	39
Melut to Renk ... Present area inundated 429 sq. km. E.N.P. area inundated 437 sq. km.				
January	204	437	225	0
February	102	270	327	167
March	48	191	381	246
April	8	160	421	277
May	8	158	421	279
June	54	266	375	171
Renk to Jebelein ... Present area inundated 259 sq. km. E.N.P. area inundated 259 sq. km.				
January	240	259	19	0
February	160	172	99	87
March	68	89	191	170
April	20	59	239	200
May	4	50	255	209
June	21	71	238	188

1. Areas taken from Chapter 2, Tables 208 and 209, using monthly averages.
2. Maximum areas exposed are underlined.
3. Cols. 3 and 4 are obtained by subtracting cols. 1 and 2 from the maximum area inundated, now and under E.N.P. respectively.

TABLE 257

DISTRIBUTION OF PASTURE GRASSES ON THE FLOOD-PLAIN
MALAKAL–JEBELEIN

(In sq. km.)

Grass species	Shallow-flooded		Deep-flooded		Total	
	Normal	E.N.P.	Normal	E.N.P.	Normal	E.N.P.
Malakal to Melut						
Vossia cuspidata	7·60	9·40	7·60	9·40	15·20	18·80
Echinochloa stagnina	—	—	17·30	22·00	17·30	22·00
Oryza barthii	21·25	12·25	21·25	12·25	42·50	24·50
Echinochloa pyramidalis	148·00	76·70	—	—	148·00	76·70
Totals	176·85	98·35	46·15	43·65	223·00	142·00
Melut to Renk						
Vossia cuspidata	12·10	4·95	12·10	4·95	24·20	9·90
Echinochloa stagnina	—	—	47·00	24·10	47·00	24·10
Oryza barthii	23·75	18·90	23·75	18·90	47·50	37·80
Echinochloa pyramidalis	302·30	207·20	—	—	302·30	207·20
Totals	338·15	231·05	82·85	47·95	421·00	279·00
Renk to Jebelein						
Vossia cuspidata	10·60	7·15	10·60	7·15	21·20	14·30
Echinochloa stagnina	—	—	65·60	58·80	65·60	58·80
Oryza barthii	9·70	9·60	9·70	9·60	19·40	19·20
Echinochloa pyramidalis	146·30	116·70	—	—	146·30	116·70
Open Water	—	—	—	—	2·50	—
Totals	166·60	133·45	85·90	75·55	255·00	209·00

Cols. 1, 3 and 5 from Table 113 (Vol. I, p. 182)
Cols. 2, 4 and 6 from Table 252 (p. 498)

TABLE 258

DISTRIBUTION OF DEEP-FLOODED AND SHALLOW-FLOODED PASTURE ON THE FLOOD-PLAIN
MALAKAL–JEBELEIN

Month	Deep-flooded		Shallow-flooded	
	Present sq. km.	E.N.P. sq. km.	Present sq. km.	E.N.P. sq. km.
Malakal to Melut				
December	—	—	48	6
January	—	—	171	8
February	27	—	177	68
March	41	14	177	98
April	46	44	177	98
May	42	34	177	98
June	16	—	177	39
Melut to Renk				
January	—	—	225	—
February	—	—	327	167
March	43	15	338	231
April	83	46	338	231
May	83	48	338	231
June	37	—	338	171
Renk to Jebelein				
January	—	—	19	—
February	—	—	99	87
March	24	37	167	133
April	72	67	167	133
May	88	76	167	133
June	71	55	167	133

TABLE 259

STOCK-CARRYING CAPACITY OF DEEP-FLOODED AND SHALLOW-FLOODED PASTURE
NORTHERN ZONE

Month	Deep-flooded		Shallow-flooded	
	Animal Units		Animal Units	
	per feddan	per sq. km.	per feddan	per sq. km.
December	—	—	0·40	25
January	—	—	0·40	25
February	1·67	400	0·40	25
March	1·67	400	0·40	25
April	1·00	240	0·67	160
May	1·00	240	0·67	160
June	1·00	240	0·67	160

See Vol. III, p. 1042.

TABLE 260

PRESENT AND FUTURE STOCK-CARRYING CAPACITIES OF RIVERAIN PASTURE
MALAKAL–MELUT

	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
			NORMAL RIVER					
Area flood-plain exposed[1]	48	171	204	218	223	219	193	
Area deep-flooded pasture[2]	—	—	27	41	46	42	16	
Area mature grass[3]	—	—	27	41	19	1	—	
Stocking rate per sq. km.[4]	—	—	400	400	400	400	—	
Carrying Capacity in TAUM	—	—	10·80	16·40	7·60	0·40	—	35·20
Area of regrowth[5]	—	—	—	—	27	41	16	
Stocking rate per sq. km.	—	—	—	—	240	240	240	
Carrying Capacity in TAUM	—	—	—	—	6·48	9·84	3·84	20·16
Area shallow-flooded pasture[2]	48	171	177	177	177	177	177	
Stocking rate per sq. km.[4]	25	25	25	25	160	160	160	
Carrying Capacity in sq. km.	1·20	4·27	4·42	4·42	28·32	28·32	28·32	99·27
Total Carrying Capacity in TAUM ...	1·20	4·27	15·22	20·82	42·40	38·56	32·16	154·63
			EQUATORIAL NILE PROJECT					
Area flood-plain exposed[1]	6	8	68	112	142	132	39	
Area deep-flooded pasture[2]	—	—	—	14	44	34	—	
Area mature grass[3]	—	—	—	14	44	30	—	
Stocking rate per sq. km.[4]	—	—	—	400	400	400	—	
Carrying Capacity in TAUM	—	—	—	5·60	17·60	12·00	—	35·20
Area of regrowth[5]	—	—	—	—	—	4	—	
Stocking rate per sq. km.	—	—	—	—	—	240	—	
Carrying Capacity in TAUM	—	—	—	—	—	0·96	—	0·96
Area shallow-flooded pasture[2]	6	8	68	98	98	98	39	
Stocking rate per sq. km.[4]	25	25	25	25	160	160	160	
Carrying Capacity in TAUM	0·15	0·20	1·70	2·45	15·68	15·68	6·24	42·10
Total Carrying Capacity in TAUM ...	0·15	0·20	1·70	8·05	33·28	28·64	6·24	78·26

(1) From Table 256. (2) From Table 258. (4) From Table 259. (5) is (2) minus (3).
NOTE: All areas expressed in sq. km.

TABLE 261

PRESENT AND FUTURE STOCK-CARRYING CAPACITIES OF RIVERAIN PASTURE
MELUT–RENK

	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
			NORMAL RIVER					
Area flood-plain exposed[1]	—	225	327	381	421	421	375	
Area deep-flooded pasture[2]	—	—	—	43	83	83	37	
Area mature grass[3]	—	—	—	43	83	40	—	
Stocking rate per sq. km.[4]	—	—	—	400	400	400	—	
Carrying Capacity in TAUM	—	—	—	17·20	33·20	16·00	—	66·40
Area of regrowth[5]	—	—	—	—	—	43	37	
Stocking rate per sq. km.[4]	—	—	—	—	—	240	240	
Carrying Capacity in TAUM	—	—	—	—	—	10·32	8·88	19·20
Area shallow-flooded pasture	—	225	327	338	338	338	338	
Stocking rate per sq. km.[4]	—	34	33	33	160	160	160	
Carrying Capacity in sq. km.	—	7·65	10·79	11·15	54·08	54·08	54·08	191·83
Total Carrying Capacity in TAUM ...	—	7·65	10·79	28·35	87·28	80·40	62·98	277·43
			EQUATORIAL NILE PROJECT					
Area flood-plain exposed[1]	—	—	167	246	277	279	171	
Area deep-flooded pasture[2]	—	—	—	15	46	48	—	
Area mature grass[3]	—	—	—	15	46	33	—	
Stocking rate per sq. km.[4]	—	—	—	400	400	400	—	
Carrying Capacity in TAUM	—	—	—	6·00	18·40	13·20	—	37·60
Area of regrowth[5]	—	—	—	—	—	15	—	
Stocking rate per sq. km.[4]	—	—	—	—	—	240	—	
Carrying Capacity in TAUM	—	—	—	—	—	3·60	—	3·60
Area shallow-flooded pasture[2]	—	—	167	231	231	231	171	
Stocking rate per sq. km.[4]	—	—	50	50	160	160	160	
Carrying Capacity in TAUM	—	—	8·35	11·55	36·96	36·96	27·36	121·18
Total Carrying Capacity in TAUM ...	—	—	8·35	17·55	55·36	53·76	27·36	162·38

(1) From Table 256. (2) From Table 258. (4) From Table 259. (5) is (2) minus (3).
NOTE: All areas expressed in sq. km.

TABLE 262

PRESENT AND FUTURE STOCK-CARRYING CAPACITIES OF RIVERAIN PASTURE
RENK–JEBELEIN

	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
NORMAL RIVER								
Area flood-plain exposed(1)	—	19	99	191	239	255	238	—
Area deep-flooded pasture(2)	—	—	—	24	72	88	71	—
Area mature grass(2)	—	—	—	24	72	64	—	—
Stocking rate per sq. km.(4)	—	—	—	400	400	400	—	—
Carrying Capacity in TAUM	—	—	—	9·60	28·80	25·60	—	64·00
Area of regrowth(2)	—	—	—	—	—	24	71	—
Stocking rate per sq. km.(4)	—	—	—	—	—	240	240	—
Carrying Capacity in TAUM	—	—	—	—	—	5·76	17·04	22·80
Area shallow-flooded pasture(5)	—	19	99	167	167	167	167	—
Stocking rate per sq. km.(4)	—	34	33	33	160	160	160	—
Carrying Capacity in TAUM	—	0·65	3·27	5·51	26·72	26·72	26·72	89·59
Total Carrying Capacity in TAUM ...	—	0·65	3·27	15·11	55·52	58·08	43·76	176·39
EQUATORIAL NILE PROJECT								
Area flood-plain exposed(1)	—	—	87	170	200	209	188	—
Area deep-flooded pasture(2)	—	—	—	37	67	76	55	—
Area mature grass(2)	—	—	—	37	67	39	—	—
Stocking rate per sq. km.(4)	—	—	—	400	400	400	—	—
Carrying Capacity in TAUM	—	—	—	14·80	26·80	15·60	—	57·20
Area of regrowth(2)	—	—	—	—	—	37	55	—
Stocking rate per sq. km.(4)	—	—	—	—	—	240	240	—
Carrying Capacity in TAUM	—	—	—	—	—	8·88	13·20	22·08
Area shallow-flooded pasture(5)	—	—	87	133	133	133	133	—
Stocking rate per sq. km.(4)	—	—	50	50	160	160	160	—
Carrying Capacity in TAUM	—	—	4·35	6·65	21·28	21·28	21·28	74·84
Total Carrying Capacity in TAUM ...	—	—	4·35	21·45	48·08	45·76	34·48	154·12

(1) From Table 256. (2) From Table 258. (4) From Table 259. (5) is (1) minus (2).
NOTE: All areas expressed in sq. km.

TABLE 263

PRESENT AND FUTURE AREAS OF EXPOSED FLOOD-PLAIN AND THEIR STOCK-CARRYING CAPACITIES
MALAKAL–JEBELEIN

	PRESENT		E.N.P.		LOSS		% LOSS	
	sq. km.	TAUM	sq. km.	TAUM	sq. km.	TAUM	sq. km.	TAUM
Malakal to Melut ...	223	155	142	78	81	77	36·3	49·7
Melut to Renk ...	421	277	279	162	142	115	33·7	41·5
Renk to Jebelein ...	255	176	209	154	46	22	18·0	14·9
Jebelein to Kosti ...	—	—	—	—	—	—	8·0%	Nil*

* Though the area of flood-plain exposed under E.N.P. will be 8% less than under present Jebel Aulia régime, only the low mud-flats will be affected since the depths of water are beyond the range of pasture grasses (see p. 489).

TABLE 264

PRESENT AND FUTURE AREAS OF RIVERAIN PASTURE IN TRIBAL UNITS
MALAKAL–JEBELEIN

Tribal Unit	RIVER FRONTAGE IN KILOMETRES FROM MALAKAL			EXPOSED FLOOD-PLAIN IN SQUARE KILOMETRES		
	From	To	Distance	Present	E.N.P.	% Lost
Shilluk (East Bank)	0	66	66	52	33	—
Shilluk (West Bank)	0	142	142	111	71	—
Shilluk (West Bank)	142	200	58	69	45	—
		SHILLUK TOTAL		232	149	36
Dunjol Dinka ...	66	96	30	24	15	—
Paloich Dinka ...	96	142	46	36	23	—
Paloich Dinka ...	142	230	88	104	69	—
Abialang	230	320	90	106	71	—
Abialang	320	380	60	75	61	—
		DINKA TOTAL		345	239	31
Baggara (East Bank)	380	422	42	52	43	—
Baggara (West Bank)	200	320	120	142	94	—
Baggara (West Bank)	320	422	102	128	105	—
		BAGGARA TOTAL		322	242	25
		Total between MALAKAL and JEBELEIN ...		899	630	30

0 = Malakal 142 = Melut
320 = Renk (approximately) 422 = Jebelein

Areas along each reach have been divided between tribes in proportion to their river frontages.

TABLE 265

PRESENT AND FUTURE AREAS OF FLOOD-PLAIN AND THEIR STOCK-CARRYING CAPACITIES IN TRIBAL UNITS
MALAKAL–JEBELEIN

	1	2	3	4	5	6	7
	NORMAL RIVER AND JEBEL AULIA REGIME						
MALAKAL TO MELUT							
Area plain exposed	163·0	60·0	—	—	—	—	223
% of area of reach	73·1	26·9	—	—	—	—	100
Carrying Capacity in TAUM	113	42	—	—	—	—	155
MELUT TO RENK							
Area plain exposed	69·0	104·0	106·0	—	106·0	142·0	421
% of area of reach	16·4	24·7	25·2	—	25·2	33·7	100
Carrying Capacity in TAUM...	45	68	70	—	70	94	277
RENK TO JEBELEIN							
Area plain exposed	—	—	75·0	52·0	127·0	128·0	255
% of area of reach	—	—	29·4	20·4	49·8	50·2	100
Carrying Capacity in TAUM...	—	—	52	36	88	88	176
Total Carrying Capacity in TAUM	158	110	122	36	158	182	608
	EQUATORIAL NILE PROJECT						
MALAKAL TO MELUT							
Area plain exposed	104·0	38·0	—	—	—	—	142
% of area of reach	73·2	26·8	—	—	—	—	100
Carrying Capacity in TAUM...	57	21	—	—	—	—	78
MELUT TO RENK							
Area plain exposed	45·0	69·0	71·0	—	71·0	94·0	279
% of area of reach	16·1	24·7	25·4	—	25·4	33·8	100
Carrying Capacity in TAUM...	26	40	41	—	41	55	162
RENK TO JEBELEIN							
Area plain exposed	—	—	61·0	43·0	104·0	105·0	209
% of area of reach	—	—	29·2	20·6	49·8	50·2	100
Carrying Capacity in TAUM...	—	—	45	32	77	77	154
Total Carrying Capacity in TAUM	83	61	86	32	118	132	394

1. Shilluk (north of Malakal).
2. Dunjol and Paloich Dinka.
3. Abialang Dinka and Ta'aisha.
4. Baggara (East Bank) north to Jebelein.
5. 3 plus 4.
6. Baggara (West Bank) north to Jebelein.
7. Totals (excluding col. 5).

NOTE: All areas expressed in sq. km.

TABLE 266

PRESENT AND FUTURE AREAS AND STOCK-CARRYING CAPACITIES OF RIVERAIN PASTURE
LAKE NO TO ZERAF MOUTH—RIGHT BANK

	Dec.	Jan.	Feb.	Mar.	April	May	June	Total
	NORMAL RIVER (Area 210 sq. km.)							
Area flood-plain exposed ...	45·1	161·7	192·1	205·2	210·0	205·8	181·6	—
Area deep-flooded pasture ...	—	—	3·1	16·2	21·0	16·8	—	—
Area mature grass	—	—	3·1	16·2	17·9	0·6	—	—
Stocking rate per sq. km. ...	—	—	400	400	400	400	—	—
Carrying Capacity in TAUM ...	—	—	1·24	6·48	7·16	0·24	—	15·12
Area of regrowth	—	—	—	—	3·1	16·2	—	—
Stocking rate per sq. km. ...	—	—	—	—	240	240	—	—
Carrying Capacity in TAUM ...	—	—	—	—	0·74	3·88	—	4·62
Area shallow-flooded pasture ...	45·1	161·7	189·0	189·0	189·0	189·0	181·6	—
Stocking rate per sq. km. ...	25	25	25	25	160	160	160	—
Carrying Capacity in sq. km. ...	1·13	4·04	4·73	4·73	30·24	30·24	29·06	104·17
Total Carrying Capacity in TAUM	1·13	4·04	5·97	11·21	38·14	34·36	29·06	123·91
	EQUATORIAL NILE PROJECT (Area 185 sq. km.)							
Area flood-plain exposed ...	7·8	10·4	88·6	146·0	185·0	172·0	50·9	—
Area deep-flooded pasture ...	—	—	—	—	—	—	—	—
Area shallow-flooded pasture ...	7·8	10·4	88·6	146·0	185·0	172·0	50·9	—
Stocking rate per sq. km. ...	25	25	25	25	160	160	160	—
Carrying Capacity in TAUM ...	0·20	0·26	2·21	3·65	29·60	27·52	8·14	71·58
Present utilization in TAUM ...	1·13	4·04	5·97	7·20	7·20	7·20	7·20	39·94
Loss of potential pasture in TAUM	0·93	3·78	3·76	7·56	8·54	6·84	20·92	52·33
Loss of pasture used at present	0·93	3·78	3·76	3·55	nil	nil	nil	12·02

NOTE: All areas expressed in sq. km.

TABLE 267

PRESENT AND FUTURE AREAS AND STOCK-CARRYING CAPACITIES OF RIVERAIN PASTURE
SHILLUK SOUTH OF MALAKAL

	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
Normal River (Area 281 sq. km.)								
Area flood-plain exposed ...	60·4	215·5	257·1	274·5	281·0	275·3	243·0	—
Area deep-flooded pasture ...	—	—	4·2	21·6	28·1	22·4	—	—
Area mature grass	—	—	4·2	21·6	23·9	0·8	—	—
Stocking rate per sq. km. ...	—	—	400	400	400	400	—	—
Carrying Capacity in TAUM ...	—	—	1·68	8·64	9·56	0·32	—	20·20
Area of regrowth	—	—	—	—	4·2	21·6	—	—
Stocking rate per sq. km. ...	—	—	—	—	240	240	—	—
Carrying Capacity in TAUM ...	—	—	—	—	1·01	5·18	—	6·19
Area shallow-flooded pasture ...	60·4	215·5	252·9	252·9	252·9	252·9	243·0	—
Stocking rate per sq. km. ...	25	25	25	25	160	160	160	—
Carrying Capacity in TAUM ...	1·51	5·39	6·32	6·32	40·46	40·46	38·88	139·34
Total Carrying Capacity in TAUM	1·51	5·39	8·00	14·96	51·03	45·96	38·88	165·73
Equatorial Nile Project (Area 197 sq. km.)								
Area flood-plain exposed ...	8·2	11·0	94·4	155·4	197·0	183·2	54·2	—
Area deep-flooded pasture ...	—	—	—	—	—	—	—	—
Area shallow-flooded pasture ...	8·2	11·0	94·4	155·4	197·0	183·2	54·2	—
Stocking rate per sq. km. ...	25	25	25	25	160	160	160	—
Carrying Capacity in TAUM ...	0·21	0·28	2·36	3·89	31·52	29·31	8·67	76·24
Present utilization in TAUM ...	1.51	5·39	8·00	14·96	27·70(1)	27·70(1)	10·80(2)	96·06
Loss of potential pasture in TAUM	1·30	5·11	5·64	11·07	19·51	16·65	30·21	89·49
Loss of pasture used at present	1·30	5·11	5·64	11·07	nil	nil	2·13	25·25

(1) includes 6,200 Animal Units of Ruweng (Paweng) Dinka.
(2) only half local Shilluk.
NOTE: All areas expressed in sq. km.

TABLE 268

PRESENT AND FUTURE AREAS AND STOCK-CARRYING CAPACITIES OF RIVERAIN PASTURE
IN TRIBAL UNITS
MALAKAL TO JEBELEIN

	1	2	3	4	5	6	7
Normal River							
(*a*) Area of flood-plain exposed (sq. km.)	232	164	181	52	233	270	899
(*b*) Carrying Capacity in TAUM ...	158	110	122	36	158	182	608
(*c*) Livestock Population in Thousand Animal Units	33·5	18·2	9·1	16·6	25·8	62·2	139·6
(*d*) No. of months pasture is required ...	5	5	5	3+‡	5	3+‡	—
(*e*) Present Utilization in TAUM ...	168	91	46	44	90	220	569
E.N.P.							
(*f*) Area of flood-plain exposed (sq. km.)	149	107	132	43	175	199	630
(*g*) Carrying Capacity in TAUM ...	83	61	86	32	118	132	394
Losses in TAUM							
(*h*) Potential (*b* less *g*)	75	49	36	4	40	50	214
(*i*) Actual (*e* less *g*)	85	30	+40	12	+28	88	175
Losses in Animal Units per Season							
(*j*) Potential (*h*÷5)	15,000	9,800	7,200	800	8,000	10,000	42,800
(*k*) Actual (*i*÷5)	17,000	6,000	+8,000	2,500	+5,500	10,000†	27,500

1. Shilluk (north of Malakal).
2. Dunjol and Paloich Dinka.
3. Abialang Dinka and Ta'aisha.
4. Baggara (East Bank) north to Jebelein.
5. 3 plus 4; 4 is allowed to graze some of the excess in 3; see p. 500.
6. Baggara (West Bank) north to Jebelein.
7. Totals (excluding col. 5).

† Potential loss; see p. 501.
‡ see p. 501.

TABLE 269

DECREASE IN STOCK-CARRYING CAPACITY OF RIVERAIN PASTURE
NORTHERN ZONE

Tribal Unit	Thousand Animal Unit Months		Animal Units per Season	
	Actual	Potential	Actual	Potential
Lak Nuer	12	40	3,800	8,500
Luaich Dinka	5	5	1,000	1,000
Shilluk	105	164	28,100	32,900
Dunjol and Paloich Dinka ...	30	49	6,000	9,800
Abialang and Ta'aisha	+40*	36	+8,000*	7,200
Baggara (E. Bank)...	12	4	2,500	800
Baggara (W. Bank)	50†	50	10,000†	10,000
Gross Loss	214	348	51,400	70,200
Net Loss	174	348	43,400	70,200

* This figure represents surplus over present requirements, not an actual increase.
† Potential loss; see p. 501.
Net loss assumes that all surplus pasture in Abialang Dinka country is made available to Baggara from Kosti. If the present arrangement (see p. 500) is continued the net loss will be 202 TAUM or 48,300 Animal Units per season.

NOTES AND REFERENCES

(1) Butcher, A. D., *The Sadd Hydraulics*, Cairo, 1938.

(2) ibid., p. 47.

(3) Based on future minimum and maximum mean monthly gauges.

CHAPTER 4. EFFECTS ON FISH AND FISHERIES

1. INTRODUCTION

A summary, and admittedly very superficial, account of the fisheries resources of the Jonglei Area has been given in Volume I. The main known facts have been stated, and here, as an introduction to this chapter on the effects of the Equatorial Nile Project on fisheries, we can do no better than quote from a short report by Dr. E. B. Worthington written after a visit to the Jonglei Area in 1949. He says: " It is commonly held in the Sudan that the fish resources of the *Sudd* region and the associated swamps are very large and for the most part unused; and that a big expansion of the fishing industry is possible and desirable. That the resources under the natural hydrological régime are large is beyond question, and also that the existing industry is in need of organization by establishing markets and arranging distribution; but how far the natural régime, or the altered conditions, after the Jonglei Canal is made, will allow a big expansion of annual crops is open to question.

There is very little information on which to assess the position, but it appears that it can be summarized as follows:—The areas of permanent water, consisting of the river itself and the numerous khors and channels, serve as a reservoir of fish stocks, which spread over vast areas of shallow water during seasonal inundations. Many of the species of fish breed in the inundated land, and the young generation take full advantage of the high productivity and large food supplies which are there available. Then, as the floods recede, the multitude of fish which have grown in a great area of highly productive water become concentrated in the channels and khors, that is, in a smaller area of lower productivity. The system as a whole may be compared to a gigantic fish farm. The inundated swamps are comparable to ' growing ponds ' which are filled and stocked each year. After the growing period, these ponds are drained and the crop is taken as the fish become concentrated. The permanent water of the rivers and khors is comparable to ' stock ponds ' which supply the young fish for annually stocking the ' growing ponds '. It follows that if intensive fishing were to be organized in the relatively small areas of permanent water, there might be insufficient fish left to ensure an annual stocking of the swamps.

It is for this reason, though perhaps unduly simplified in the above paragraph, that, in my view, it is important to establish a fishery research unit in the Southern Sudan side by side with a fishery development unit. Until we have a much better knowledge of the fish themselves and some idea of the productive capacity of both permanent and temporary waters, it would be inadvisable to concentrate all the available fishery effort on ' development ', leaving ' research ' to look after itself.

Added to this, changes under the Jonglei Project, though difficult to assess, may have a big effect on the natural régime sketched above, and, if only in order to obtain a basis for assessing compensation, it is important to conduct some fishery research in the Southern Sudan in the early future.[1]"

Investigation and research in connection with the immediate development of fisheries resources and with the problems of the Equatorial Nile Project are identical. Unfortunately, for the reasons already stated (see Vol. I, p. 381), no systematic approach has been possible and, apart from further data of a detailed nature from isolated areas, there has not been much advance in the investigation of the Project's effects in this connection.

The problems are further stated in the Jonglei Investigation Team's *Interim Reports* and in our *Progress Report for 1948–49*, and more recently in an article (already mentioned in Vol. I), ' The Problems of Fisheries in the Area affected by the Equatorial Nile Project ' (ed. H. Sandon, *S.N. & R.*, Vol. XXXII, 1951).

In Volume I something of the part which fishing activities play in the subsistence economy of the people under present conditions has been described. We have stressed that fish are of paramount importance in the present economy of the inhabitants of the Jonglei Area, both as a subsidiary item of diet and as an essential standby during the lean time of the year when grain is running short before the harvest, or throughout the year when crops have partially or entirely failed owing to bad climatic conditions in the preceding year. Some tribes, or certain elements within some tribes, rely on fish to a greater extent than others, ranging from those whose fishing activities are seasonal and supplementary to normal diet, to those who rely almost entirely on fish like the Monythany elements of the Dinka, or, to a lesser extent, some of the Shilluk. This distinction is of some practical importance, for it may be feasible to call upon these latter people to develop their fisheries on a commercial scale for the benefit of those whose normal fishing techniques may be rendered ineffective by altered hydrological conditions or whose fisheries resources may be much reduced for similar reasons.

Generally speaking only those areas are fully exploited which are easily accessible, either permanently or seasonally, and where fish are readily obtainable by the use of such rudimentary methods as the spear, harpoon, and trap; in other words shallow waters or waters which drop in level during the dry season causing a concentration of fish. As yet, as we have seen, fishing remains an unspecialized and often collective activity, and there is little commercial exploitation except in the northern reaches of the Northern Zone or in the vicinity of the larger towns. The development of commercial fisheries has, however, received a considerable stimulus in recent years, is clearly gathering momentum, and is of obvious economic importance in the Sudan as a whole. The effects of the Project on present commercial development and on future potentialities must also be considered.

The problems are complex, but the three major questions to be answered are:

(i) Will the fish population in any given area, or throughout the area, be substantially reduced as a result of different hydrological, and hence different ecological, conditions?

(ii) Will indigenous methods of fishing be ineffective under the new river régime, making it more difficult to catch the fish?

(iii) Will the present and future development of fisheries resources on a commercial scale be adversely affected?

General answers to these questions have already been attempted in previous reports of the Jonglei Investigation Team. We must now attempt more detailed answers despite the paucity of data on which to base our conclusions.

2. THE EFFECTS OF THE EQUATORIAL NILE PROJECT (55 M/D CANAL STAGE)

SOUTHERN ZONE

The hydrological effects in the Southern Zone under each stage of the Project from the point when the dams are completed without the Canal up to the 80 m/d Canal stage have been estimated in Chapter 1 of this volume (see p. 417). Briefly, in the first stage the discharge (at Mongalla) will remain constant at 65 m/d, with the result that the flood-plain will not be inundated to any great extent and only the deeper depressions will hold water (Stage I). In the first 10 m/d Canal stage (Stage II) the discharge will drop to 48 m/d in the timely season and rise to 59 m/d in the untimely season. At neither time of the year will the flood-plain be inundated and the area of open water and marshland in the depressions remaining in the previous stage will be reduced still further. In the second 10 m/d Canal stage (Stage III), both in the timely and untimely seasons, there will be a slight improvement on the previous stage, but still a reversal in seasonal fluctuations and still little inundation of the flood-plain. In the 27·5 m/d Canal stage (Stage IV) the untimely discharge will be reduced to 57 m/d and the timely discharge increased to 70 m/d. This will be a further step towards a reversal of the seasons, with little or no flooding in the untimely (i.e. normal rains) season and a slightly increased flooding in the timely (i.e. normal dry) season. In the 55 m/d Canal stage (Stage V) the untimely discharge will remain 57 m/d, but the timely discharge will be increased to 90 m/d and will be sufficient to flood the *toiches*, a complete reversal of the seasons.

If this alteration to the present natural river régime is allowed to stand without further works, the only effect will be to deprive the fish of their normal breeding grounds during the rains, but to provide them with a similar, though more constant, area of inundated marshland and swamp during the dry season. The effects on their breeding habits cannot be calculated without further research, and it is not possible to predict whether such a change will have detrimental effects or not. It must be remembered also that in the stages leading up the 55 m/d stage the fish will be permanently deprived of a very considerable proportion of these breeding and growing grounds at all seasons of the year for many years during the construction period. A reduction in the fish population must therefore be expected for some years, even if the fish are ultimately able to adapt themselves to a reversal of the seasons.

THE EFFECTS IN DIFFERENT REACHES

These effects will be modified, however, by further works and it is now necessary to consider the Southern Zone reach by reach.

REACH NO. 1: NIMULE TO JUBA (BAHR EL JEBEL: 156 KILOMETRES)

The main characteristics of this reach have been described in the previous volume. The river is fast-running and the flood-plain is very limited in area. The exploitation of fisheries resources under present conditions is not great and certainly not a major item in the livelihood of the local inhabitants, and, although there is no reliable information available, it seems improbable that those resources are of great importance. There are a few fishing-camps set up during the dry season, especially by the Madi below the Fola Rapids and near the Assua mouth. It appears that fishing is only really productive when the discharges are low in the dry season. Under the future régime, as we have seen, the discharges will be high in the timely season and low in the untimely season and, since these correspond approximately with the dry and rains seasons respectively, there may be disadvantages, especially because fishing activities will clash with the processes of crop production at that time of the year.

There is also the problem of fish migrations, about which as yet we know very little. The dam, if sited at Nimule, will certainly interfere with migrations upstream into the Albert Nile, which appear to take place under present circumstances and may be an important feature of the breeding habits of the fishes. Stipulations for the provision of fish-ladders or passes will have to be made. This also applies to any balancing reservoirs (see p. 401) which may be necessary between Nimule and Rejaf, and is a subject we shall refer to again when we come to consider remedial measures.

REACH NO. 2: JUBA TO TOMBE (BAHR EL JEBEL: 122 KILOMETRES)

The flood-plain in this reach is more restricted than in reaches in the *Sudd* area farther north and much of it is not inundated except in years of high untimely discharges. There are, nevertheless, many lagoons and channels which are perennially flooded but drop sufficiently to enable the inhabitants of the area to spear fish and which also provide suitable stretches of open water for the more modern techniques adopted in recent years. The total area estimated to be seasonally inundated in an average year is 309 sq. km. These fisheries are a source of considerable commercial development in the provision both of fresh fish for the Juba market (population 18,500), and of sun-dried salted fish for the Belgian Congo or the Zande and other areas where there are deficiences in animal protein.

In the initial stages of the Project those areas seasonally inundated by river spill over the crest of the river banks, through spill-channels, and by backwater from the downstream end of the lagoons, will scarcely be flooded at all, or at any rate will be substantially reduced. Later, under the 55 m/d stage, there will be a complete reversal of the seasons so that they will be under water in the timely or dry season. The effects on the fish population cannot be predicted, but it is clear that the pools and lagoons will be less suitable for fishing, especially for more rudimentary techniques, during the dry season, since the waters will be deeper and the fish less concentrated. The fact that they will be more easily fishable and more readily accessible in the rains season is no real compensation, because at that time of the year the inhabitants are inland and entirely preoccupied with agricultural activities; also the curing of fish is more difficult when the relative humidity is high. Fisheries under present conditions are important just because the period of easiest and most profitable fishing coincides with the time of the year when the people are on the *toiches* with their herds and have more time to spare.

It seems possible that an attempt will be made to bank off the main channels through which the spill-water flows and, since the banks are generally high and well-defined along the main channel of the river, this should not be difficult. The object will be to prevent losses in transmission during the timely season, but it will have the effect of reducing the fisheries to a minimum. No detailed proposals for banking have, however, been made and for the purpose of this investigation we assume that banking between Juba and Tombe will not be carried out. Should any system of banking be introduced, the amount of the losses in the Southern Zone would be substantially increased.

REACH NO. 3: TOMBE TO ATEM HEAD (BAHR EL JEBEL: TOMBE TO R.P. 114: 102 KILOMETRES)

In this reach the effects, during all preliminary stages of construction and in the 55 m/d Canal stage, will be similar to those in Reach No. 2. The surrounding swamps, both on the right bank (mainly below Bor) and on the left bank (the northern part of the Aliab Valley), invariably begin to flood when the discharge at Mongalla exceeds 65 m/d (see p. 238). The fisheries potential is therefore greater, quite apart from the present exploitation by the large number of Aliab and Bor Dinka who enter the *toiches* between January and April almost every year. The interests of the Monythany Dinka who depend almost entirely on fish as a source of livelihood will also be adversely affected. This applies if the natural effect of reversing seasonal river levels is allowed to stand.

Naturally, losses in transmission in this area will be heavy during the timely season, and again, though no detailed plans have yet been made, it is proposed to prevent much or all spilling by banking. This includes the banking of the main channel of the Bahr el Jebel on the west side from Tombe to the regulator opposite the Atem Head (the boundary between the Southern and Central Zones), with the result that the whole of the northern part of the Aliab Valley will be insulated and no longer seasonally flooded. Likewise, on the eastern side of the river, the Atem will be banked from Bor to the regulator. Upstream of Bor, apart from a few inland lagoons, the banks are naturally high and the flood-plain is not extensive. Thus again, as in the Juba-Tombe reach, the effects will be detrimental whether banking is applied or not, and losses may be expected.

In present circumstances it is estimated that 787 sq. km. of marshland and swamp are seasonally inundated on the average in this reach of the Southern Zone. The remainder is irrigated to some extent by flushes from inland watercourses such as the Khor Gwir and Tapari (Gel) in the untimely season. How valuable the natural irrigation from these watercourses will be in the production of fish is not easily determined and in any case they are outside the area affected by the Project.

Assuming that all, or nearly all, river spill is to be prevented by banking, an area of 658 sq. km. will not be flooded at any time of the year and, as far as fisheries are concerned, will be a total loss. Whatever the value of the remaining area (flooded from inland), its productivity will be limited, since there will be no direct access to perennial waters in the Nile unless special provision is made.

SPECIAL CONSIDERATIONS IN THE SOUTHERN ZONE

The very abrupt change in timely and untimely discharges under all stages of the Project is a matter of considerable importance if the natural channels of the river are not banked. As we have already seen, if these channels are banked to prevent losses of water there will be a total reduction of spill and a corresponding reduction in the fisheries. If they are not banked, then there will (in the 55 m/d Canal stage) be a complete reversal of the seasons, the flood-plain being inundated from December to June and drained and exposed from June to December. Under these circumstances the steep fall in discharges from 90 m/d to 57 m/d in June, which will take place in a very short period, and the corresponding rise from 57 m/d to 90 m/d in December may have a profound effect on the fish population and on fishing activities. It will naturally take time for the marshes and pools to drain, but the process will be markedly more rapid than at present. It may be so rapid that a very large proportion of the fish, unable to return to the perennial channels quickly enough, will be trapped or will die. Doubtless the local population could make use of this phenomenon, but the inroads made both by heavy fishing and by deaths from natural causes might be more than the fish population could withstand. On the other hand the sudden rise in December need have no detrimental effects.

CENTRAL ZONE

The general effects in the Central Zone will be similar to those in Reach No. 3 of the Southern Zone, but for different reasons. In the Southern Zone untimely and timely discharges will be reversed, causing a complete reversal of the present seasonal fluctuations of the river; below Tombe spill will be prevented at all times of the year by the provision of banks. In the Central Zone discharges will, in the 55 m/d Canal stage, be reduced to a maximum untimely discharge at Jonglei of 35 m/d and a minimum timely discharge of 30 m/d, as compared with 78 m/d and 54 m/d, the present normal discharges. This reduction will take place in slow stages, from the point when the storage dams are completed up to the 55 m/d Canal stage, with the result that the *Sudd* and the extensive swamps through which the river flows will be gradually dried out and subject to local rainfall only. As a result, the bulk of the very large area of swamp and open water which at present provides vast breeding and growing grounds for the fish will eventually be lost.

The total area is estimated to be 6,554 sq. km., and for the reasons given in Chapter 2 (p. 420) it is expected that 6,192 sq. km. will be dried out and subject to rainfall and rain-flooding only, leaving only 362 sq. km. subject to river spill.

THE EFFECTS IN DIFFERENT REACHES

REACH NO. 4: ATEM HEAD TO SHAMBE LAKE (BAHR EL JEBEL: 162 KILOMETRES FROM R.P. 114)

The vast number of side-channels with extensive swamps in between and the very numerous lakes, lagoons, and papyrus-bound pools make this area a great source of food not only for the

Bor, Twi, and Chich Dinka who move there every year, but also for the Monythany Dinka whose whole livelihood is based on fishing. The area is not fully exploited, and its potentialities are enormous. The effects will therefore be two-fold. The area of annually inundated marsh-land and open water will be very substantially reduced and, though sufficient may be left to meet at least part of the needs of the Monythany Dinka and others who depend on fish from this area in the dry season only, there may be little left for commercial enterprise. One of the most promising areas for future fisheries development may be most drastically reduced.

Reach No. 5: Shambe Lake to Buffalo Cape (Bahr el Jebel: 370 Kilometres)

This reach of the river is, comparatively speaking, little exploited except at its edges near the higher ground, but the inhabitants, Nuong, Dok and Jagey Nuer on the western side, and Nyareweng and Ghol Dinka on the eastern side, certainly obtain considerable quantities of fish from it. Assuming that a very irregular strip is still left to be seasonally inundated from the main channel, many of the lagoons which border it will remain productive in fish and these will be sufficient to meet at least part of the needs of these people. Most of the lagoons contain large numbers of fish, mainly *Tilapia*, *Citharinus citharus* and *Heterotis*, all of which are of high economic value and are very suitable for commercial fisheries, since they are easily sun-dried and salted. Even if those lagoons nearest the river are still at least partly flooded, the bulk of the swamps which provide the breeding and growing grounds for the fish will dry out, and it is from these areas that the lagoons themselves are annually stocked. The potentialities, which are exceptionally large in this part of the *Sudd* area, will be greatly reduced.

In addition inland watercourses, such as the Bilnyang and the main inland water-system of Western Nuer District which begins in the Waard and Neang near Adok, at present provide most valuable fishing for the Nuer tribes of that area. Spill from the Bahr el Jebel into these watercourses will be reduced to a minimum, with a consequent loss in fish. This will also apply to similar watercourses on the right bank of the Bahr el Jebel between the Zeraf Cuts and Buffalo Cape, though the effects (on the Gaweir, Thiang and some of the Lak Nuer of the area) will not be so great.

Reach No. 6: Zeraf Cuts to Fangak (Bahr el Zeraf: 227 Kilometres)

It is the upper waters of this reach, between the Zeraf Cuts and approximately the Khor Famyr, that are potentially the most productive, although under present conditions much of the available waters is rarely exploited. The Gaweir Nuer, whose permanent habitations are on both sides of the river, though the majority live many miles inland to the east, rely mainly on the upper reaches of the main khors, such as the Gurr, Jurwel, and the Wang Gai. These are more easily accessible and lie close to the dry season grazing grounds; the waters drop to a lower level and there are probably greater concentrations of fish. All these khors are, at their lower ends, fed largely by spill from the Zeraf and under the Project will not be seasonally inundated to the same extent. At the same time some spilling will still take place, and the lagoons nearer the river may ultimately be more accessible and easier to fish. This being so, there may be sufficient to meet normal needs, though here again the whereabouts of the people and their herds is an important consideration. Under present circumstances *toich* lands which provide pasture during the dry season are also valuable as fishing grounds, and if the cattle must be moved elsewhere, only those people with time to spare away from the herds will be able to make use of those fisheries which still remain. The present seasonal subsistence economy, based as it is on animal husbandry, crop husbandry and fisheries, is bound to be adversely affected, even though some proportion of the population might devote itself to supplying the rest on a trade basis.

Below the Khor Famyr down to km. 88 the extent of the flood-plain is less and suitable lagoons or channels for fishing are fewer, but the same considerations apply. Below km. 88 as far as Fangak the banks are high and the flood-plain is restricted to a narrow fringe only a few yards wide, although the mouths of the larger khors, Gniaz Gniaz, Nyazlyel, etc., are extensive and important sources of fish.

Apart from the larger khors in the upper reaches, already mentioned, there are others which are of permanent importance and whose fisheries resources are considerable. Of these the main inland water-system, which begins between the Wang Gai and Nyakong and flows parallel to the river at the side of the main Zeraf ridge and eventually joins the White Nile as the Khor Mainya near Wath Kech, is the most important. Much of its water is derived from the Zeraf, either at its head or from side-channels such as the Nyazlyel, which joins the system at Longtam. All these are very productive in fish, which migrate to and from the main river as the khors rise and fall. The levels in these khors are partly dependent on those of the Zeraf, though the run-off from the surrounding ground is an important item. When seasonal fluctuations in the Zeraf are reduced to a minimum it may be assumed that much or all of the fisheries resources in these inland water-systems will be lost; the estuaries and lagoons nearer the river in this reach are too few to provide substantial alternatives.

Finally it should be noted that the backwater effect may be felt as far upstream as km. 100 and, although the boundary between the Northern and Southern Zone is given as Fangak, this part of the reach may be regarded as transitional. Future maximum and minimum levels will still be much lower than present normals, but the difference will be less abrupt than above this point.

NORTHERN ZONE

In the Northern Zone up to the 27·5 m/d Canal stage there will be little or no effect on the existing river régime and normal seasonal fluctuations in level will continue. Under the 55 m/d Canal stage a great deal of the flood-plain will remain submerged throughout the year. The effects will vary from the southern boundaries of the Zone, where the backwater of the Sobat in the untimely season and the Canal in the timely season begins to peter out, to the northern reaches where the effects of the Jebel Aulia Reservoir will modify those of the Project. Each reach must therefore be treated separately. As a generalization, however, the area of permanent swamp along the flood-plain will be increased, and it may be assumed that the breeding areas of the fish will be larger than ever before. The disadvantages are that waters will remain deep all through the year and local methods of fishing for subsistence purposes may be far less effective. Even such modern netting techniques as are at present employed may be less productive for the same reason. As evidence of this it will be noted that catches generally increase as river levels drop. This is evident from observations made throughout the Jonglei Area and is borne out when the total catches recorded in Table 270 are correlated with the levels of that year.

TABLE 270

MONTHLY CATCHES: BADALANG AND JEBELEIN FISHERIES CAMPS COMBINED

1952		Actual Levels 1952		1952	Normal Averages	
Month	Total Catch	Renk	Jebelein	Average	Jebel Aulia	E.N.P.
January	1,718	11·64	12·40	12·02	12·26	12·39
February	5,971	11·09	11·86	11·47	11·91	11·96
March	48,657	10·36	10·79	10·58	11·23	11·51
April	48,792	10·08	10·06	10·07	10·42	11·13
May	51,814	10·11	10·08	10·09	10·13	10·96
June	*	10·43	10·33	10·38	10·46	11·31

* Figures for Jebelein are not available. Those for Badalang (latitude 12° 02′) show a marked drop from 39,690 in May to 12,047 in June.

Without statistics of the number of net-hauls in relation to catches these figures give no more than indications because other factors are involved, but, since it is known that the number of boats operating was fairly constant, they serve to show a definite correlation between fisheries productivity and river levels. This correlation can be demonstrated in other reaches. Although the detailed records (see Table 185, p. 395) show a marked increase and decline in catches of different fish species according to the month, indicating local migrations, they also indicate an increase in total catches as the levels drop, not only because the fish are more easily netted, but also because they are concentrated in the more restricted waters. It may be assumed that the increase in minimum levels will cause greater difficulties in catching fish and thus affect not only fisheries productivity among the local inhabitants but also commercial fisheries. Alterations in river levels under the Equatorial Nile Project are demonstrated in the table below.

TABLE 271

PRESENT NORMAL MAXIMUM AND MINIMUM LEVELS AND PREDICTED E.N.P. LEVELS (NORTHERN ZONE)

	Normal Maximum	Normal Minimum	E.N.P. Maximum	E.N.P. Minimum	Reach Number	
Buffalo Cape ...	11·27 (Oct. 3)	11·05 (May 1)	10·81 (Nov. 2)	10·45 (May 1)	5/7	Bahr el Jebel
Lake No ...	14·03 (Nov. 1)	13·54 (Apr. 2)	13·82 (Nov. 2)	13·24 (May 1)	7/8	Bahr el Ghazal
Yoynyang ...	14·06 (Nov./Dec.)	13·62 (June)	No change	No change	8	Bahr el Ghazal
Tonga	12·89 (Nov. 1)	11·63 (May 1)	12·94 (Nov. 2)	12·19 (May 1)	9/10	White Nile
Zeraf Mouth ...	12·76 (Nov. 1)	11·30 (Apr. 3)	12·83 (Nov. 2)	12·05 (May 1)	10/11	White Nile
Fangak	12·01 (Nov. 1)	10·94 (May 2)	10·71 (Nov. 2)	10·15 (May 1)	11/6	Bahr el Zeraf
Sobat Mouth ...	12·56 (Nov. 1)	10·07 (Apr. 1)	12·65 (Nov. 2)	11·80 (May 1)	11/12	River Sobat
Abwong ...	14·74 (Nov. 2)	10·25 (Apr. 1)	14·77 (Nov. 2)	11·49 (May 1)	12	River Sobat
Nyanding Mouth	13·00 (Nov. 1)	7·81 (Mar. 3)	13·00 (Nov. 2)	7·94 (May 1)	12	River Sobat
Malakal ...	12·30 (Nov. 1)	10·04 (Apr. 2)	12·39 (Nov. 2)	11·58 (May 1)	11/13	White Nile
Melut	12·14 (Nov. 1/2)	10·01 (Apr. 2)	12·26 (Nov. 2)	11·53 (May 2)	13	White Nile
Renk	12·21 (Nov. 2)	10·08 (May 2)	12·11 (Dec. 1)	11·11 (May 1)	14	White Nile
Jebelein	12·61 (Dec. 3)	10·10 (May 2)	12·61 (Nov./Dec.)	10·78 (May 2)	14/15	White Nile
Rabak (Kosti) ...	13·97 (Jan. 1)	10·24 (May 3)	13·99 (Jan. 2)	11·00 (May 2)	15	White Nile

(10-day periods in brackets)

THE EFFECTS IN DIFFERENT REACHES

REACH NO. 7: BUFFALO CAPE TO LAKE NO (BAHR EL JEBEL: 51 KILOMETRES)

As already mentioned (see Vol. I, p. 389) this reach of the river is not at present exploited and potentialities are not great. It is expected that backwater effects will be felt as far upstream as Buffalo Cape, but the reach is transitional between the Northern and Southern Zones. The exact effects on future levels of the backwater are difficult to assess owing to the deltaic nature of the banks and the resultant spill.

The effects will therefore be small. The area involved is 340 sq. km. with a higher percentage of permanent swamp (papyrus) than the lower reaches in this Zone.

REACH NO. 8: YOYNYANG TO LAKE NO (BAHR EL GHAZAL: 90 KILOMETRES)

The point upstream which will be reached by backwater effects cannot be determined owing to the nature of the river banks. It may be assumed, however, that a considerable proportion of the present swamps will still be uncovered in the untimely season and inundated in the timely season. There may be some reduction in seasonal breeding areas, but in general the effects on fish will not be great.

REACHES NOS. 9 AND 10: LAKE NO TO MALAKAL (WHITE NILE: 146 KILOMETRES)

In these reaches of the river there is at present a total estimated area of flood-plain of 596 sq. km., and it is predicted that of this area 109 sq. km. will remain permanently inundated in the future. The reductions in areas uncovered, however, are variable, getting less farther upstream.

	Flood Plain Areas sq. km.	Reduction
Lake No–Shilluk Boundary (left bank)...	105	Nil
Lake No–Zeraf Mouth (right bank) ...	210	12%
Shilluk Boundary–Malakal (left bank)...	193	28%
Zeraf Mouth–Malakal (right bank) ...	88	33%

As elsewhere in the Northern Zone, this will result in an extension in permanent swamp and there will be no reduction in the fish population, but the relative decrease in range of levels will mean greater difficulties in catching fish owing to deeper waters and greater dispersal than at present.

REACH No. 11: FANGAK TO ZERAF MOUTH (BAHR EL ZERAF: 66 KILOMETRES)

The backwater effects of the Project will be felt as far upstream as Fangak and possibly as far as km. 100 which falls within Reach No. 6. Levels will, however, be generally lower than at present, both in the timely and untimely seasons, as far as km. 50; below that they will be higher. Throughout the reach there is little present or potential exploitation of fisheries and the reach may be disregarded for the purpose of assessing effects.

REACH No. 12: NYANDING-ABWONG TO SOBAT MOUTH (SOBAT: 117 KILOMETRES)

Untimely levels in the Sobat will remain much as they are now. Higher minimum levels may be expected in the timely season owing to backwater from the Canal. Typical figures are:

Place	(REDUCED LEVELS) Present Normals		(REDUCED LEVELS) Future E.N.P.		Difference
	Maximum	Minimum	Maximum (untimely)	Minimum (timely)	
Sobat Mouth	384·99	382·50	385·08	384·23	1·73
Abwong	388·52	384·06	388·55	385·10	1·04
Khor Nyanding ...	393·77	388·57	393·77	388·66	0·09
Km. 250	394·32	389·03	394·32	389·10	0·07

No alteration may therefore be expected in the untimely season. Deeper levels throughout the timely season—which coincides with the dry season—may cause variations in the present trend of fish migrations, but without necessarily any adverse effects. Deeper levels at that time of the year, however, may make it more difficult for the inhabitants to catch the fish as far upstream as Loing at the Ngok Dinka–Eastern Nuer boundary. Any commercial fisheries established in this reach may also be affected, but the difference in levels, at any rate above Nagdiar, will not be sufficient to cause grave reductions in yields if deeper nets are used. Commercial fisheries are at present sometimes hampered by too shallow waters towards the end of February, so there may be some advantages.

REACHES NOS. 13 AND 14: MALAKAL TO JEBELEIN (WHITE NILE: 426 KILOMETRES)

These two reaches are together the longest in the Northern Zone and, from the point of view of the effects of the Project, the most significant. Shilluk fisheries are an important item in their subsistence economy, and many Northern Dinka rely on fish to supplement their diet during the dry season when their cattle-camps are on the river-front. Moreover the development of commercial fisheries has already begun on a considerable scale, especially in the vicinity of Malakal and between Kaka and Kosti.

The difference in the river régime will also be the most noticeable. It is estimated that under present conditions in a normal year 913 sq. km. of the flood-plain is subject to inundation from the river in the untimely season and dries out when the river drops in the timely season. Under the 55 m/d stage, of these 913 sq. km., 283 sq. km. will never be uncovered (31%; see p. 449). The only effect, as far as fisheries are concerned, will be a reduction in actual concentration of the fish with the resultant difficulties already mentioned. There may even be some reduction in breeding areas, since papyrus may be established in the deeper water. Under present conditions, apart from floating islands of papyrus which are carried down from the *Sudd* and become temporarily attached to the banks for a season or two, papyrus does not flourish in this reach of the river. This is probably at least partly due to the very considerable range of levels in this reach (compare Lake No normals, 14·03–13·54, with those at Malakal and Renk, 12·30–10·04 and 12·21–10·10).

It must be remembered, however, that 69% of the flood-plain will still be subject to the natural seasonal process of flooding and drying out and, though there may be some loss of potential and greater difficulties in catching the fish, the supply of fish should certainly be sufficient to meet normal needs.

Reach No. 15: Jebelein to Kosti (White Nile: 75 Kilometres)

This short reach is important largely as a source of commercial fisheries. The reduction in the area of flood-plain seasonally uncovered will be approximately 8%, and under these circumstances the effects of the Project are likely to be beneficial rather than adverse.

SPECIAL CONSIDERATIONS IN THE NORTHERN ZONE

Peak Discharges under the E.N.P.

It will be noted in the tables (197 and 199, pp. 439, 441) that there will be a somewhat abrupt drop in river levels in July below the Canal mouth as the discharge will be reduced to the proposed untimely figure. These tables also indicate a very sudden and steep rise in December when the discharge is increased to the full timely figure. These figures are largely theoretical and in practice the increases and decreases must be gradual in the interests of the Project itself. Special stipulations must be made to reduce the abruptness of the change or altogether special effects upon fisheries in this part of the Northern Zone are to be expected. A sudden drop in levels in July might easily disturb the normal migrations and breeding habits of the fish. A sudden rise in December, though not necessarily detrimental to the fish themselves, might seriously dislocate fishing operations, already made difficult at that time of the year owing to deep water and the wide distribution of the fish population.

Alteration in Periods of maxima and minima

The slight alteration in the dates of predicted maxima and minima, and the normals, will be noted from an examination of Table 200 (p. 442). Throughout, the maxima and minima are reached slightly later in the year. For example under present circumstances the normal minimum at Malakal is reached in the second 10-day period in April. Under the Project it will be in the first 10-day period in May; at Renk the normal maximum is reached in the third 10-day period in November, in the future it will be in the third 10-day period in December. The average alteration in the period is about ten days; the maximum, which occurs between a point north of Malakal and Renk, is about one month. This advance in seasonal fluctuations may not seriously disturb fishing operations, but it is definitely not an advantage where commercial fisheries are concerned because the minimum is reached after the first rains have fallen and the humidity has begun to rise. The preparation and storage of sun-dried salted fish will be made more difficult in these circumstances. In other words, the season when low levels and the best fishing conditions prevail in the dry weather will be reduced in period. As far as subsistence fisheries are concerned this seasonal change may be no disadvantage; although fishing activities may, during this extended period, clash with the first processes of crop husbandry so that fewer people will be available to tend the cultivations if fish are to be caught, the best opportunity to catch fish will occur during the lean time of the year (see Vol. I, p. 245), with beneficial results for the inhabitants of the area. This applies in particular to the Shilluk, whose cultivations and permanent villages are within short walking distance of the river-front, but not to the Dinka, whose villages are built well inland and more widely distributed in relation to water supplies (hafirs) provided by the government in recent years. We do not wish to exaggerate the importance of considerations of this sort, but they must not be forgotten in the general assessment of the effects of the Project.

3. THE EFFECTS OF FLOOD-ESCAPE DISCHARGES

Details of the effects in all three Zones under the 55 m/d Canal stage have already been given. Future discharges and levels will not vary from year to year except when it is necessary to get rid of extra flood-water which can no longer be stored in the reservoirs. In these latter circumstances the discharge at Mongalla might rise to 150 m/d for short periods, while over a 6-month period it will be restricted to 120 m/d. (Maximum discharge at Mongalla under normal 55 m/d Canal stage conditions is 90 m/d.)

The details, such as are possible to find without specific proposals, are described in a previous chapter (p. 435). The effects will be obvious. In the Central and Southern Zones (if the Southern Zone is not banked) there will be vast inundations of areas previously reclaimed. As far as fisheries are concerned it would be difficult to predict the results with any accuracy. The huge area of swamp thus re-created for the period of flood-escape (up to 4½ years) would certainly not reduce the fish population and indeed would lead to temporary increases, but the problem of catching the fish would be more difficult and commercial fisheries already established would be faced with many problems. In the Northern Zone, however, there would be a temporary increase in the area permanently under water (see Tables 197 and 231). Doubtless there would be very serious dislocations of established fishing industries, but the general effect need not be detrimental.

4. THE 80 M/D CANAL STAGE

The Jonglei Investigation Team is concerned only with the 55 m/d Canal stage in detail, but the ultimate 80 m/d Canal stage must be considered in general terms (see p. 435).

Briefly, the discharges at Mongalla will be increased to 120 m/d and 57 m/d in the timely and untimely seasons respectively. The canals will carry 80 m/d in the timely season, while the natural channels below the Canal Head will carry 33 m/d and 35 m/d respectively—as under the 55 m/d stage. Discharges at Malakal will fluctuate between 112 m/d and 90 m/d.

There will therefore be no alteration in the effects in the Central Zone, but elsewhere the effects will be magnified in proportion to the increases.

SOUTHERN ZONE

In normal circumstances a discharge of 120 m/d at Mongalla would result in a total inundation of the flood-plain during the timely season; a discharge of 57 m/d would result in a more or less total exposure of the flood-plain during the rains. The reversal of the seasons would be complete, with the detrimental effects on local interests increased accordingly. If, however, the Project includes the prevention of spill by banking and blocking spill-channels, the effects will be in direct proportion to the scale and efficiency of these works.

CENTRAL ZONE

If the extra discharge of 25 m/d is taken by a third canal, the discharges in the natural channels will remain unaltered. The effects will remain the same as in the 55 m/d Canal stage. If the third canal is not built, banking and the blocking of spill-channels would allow the extra 25 m/d to be transmitted without losses in the Bahr el Jebel and there would be no alterations in the effects already predicted in 55 m/d Canal stage. It may be assumed that one or other of these methods will be employed, for otherwise most of the extra 25 m/d would be lost by spilling and evaporation.

NORTHERN ZONE

Under the 80 m/d Canal stage the maximum and minimum discharges will be 112 m/d and 105 m/d respectively. Maxima and minima (142 and 83·6 m/d), given in Table 230, p. 458, for the third 10-day period in June and the second 10-day period in December need not be regarded as significant, since they are short-term, tied to Canal discharges only, and largely theoretical. The present normal maximum at Malakal is 106 m/d, and the future minimum discharge will equal this. As a result the whole of the flood-plain will be permanently inundated in the untimely season, and the areas of inundation will be slightly increased in the timely season.

It may be assumed that the fish population will not be reduced under these circumstances, indeed it may increase, but the difficulties of catching the fish, widely dispersed and in deeper waters, will be considerable. Modern fisheries techniques might be devised to meet these difficulties. Rudimentary techniques, especially collective spearing in the shallow pools and lagoons, will no longer be effective.

5. QUANTITATIVE ESTIMATES

It has been possible in the preceding sections of this report to give some idea of the effects of the Equatorial Nile Project on the fishery resources of the Jonglei Area, but only in very general terms. A reduction in those resources may be expected in the Southern Zone and a very substantial reduction in the Central Zone: in the Northern Zone a reduction is unlikely, indeed an increase may occur, but future conditions may be such that it will be more difficult to catch the fish, especially when the present simple techniques are employed.

It is much more difficult to interpret these rather vague predictions in terms of quantity; the information available is certainly inadequate to do so with any degree of accuracy. What follows is based on such scanty data as are available and is therefore subject to revision. Our conclusions are, however, presented in a form which, we hope, will at least provide the formulae upon which more precise calculations may be made in the future.

PRESENT CONSUMPTION AND SUBSISTENCE REQUIREMENTS

Since no comprehensive survey of the fisheries in the Jonglei Area, including records of catches made by the local population, has been possible, an estimate of the actual quantity of fish caught and consumed for subsistence purposes cannot be attempted here. Sample figures would be necessary from widely distributed points on the river system, and we have already made it clear that amounts consumed vary very considerably from area to area and from season to season. Elsewhere we have given a daily consumption rate of 33 gm. per head per day as being a reasonable minimum when local resources are taken into account. This amounts to 16 kg. of fresh unboned fish or 12 kg. of boned fish per head per year, a figure which is obviously far in excess of the actual consumption in some areas, especially in the northern reaches, but is less than the average in others. As an average over the whole area it seems to us reasonable and, if this amount is not caught, it certainly could be without difficulty or any serious depletion of stock.

TABLE 272

ESTIMATED LOCAL CONSUMPTION OF FISH IN THE JONGLEI AREA

Zone	Population with direct access to Nile waters in the Jonglei Area (Juba–Jebelein)	Consumption metric tons per annum
Southern	101,630	1,626
Central	267,618	4,282
Northern	231,620	3,706
TOTAL	600,868	9,614

These estimates are concerned purely with the present and future subsistence of the people and do not take into consideration the development of commercial fisheries or the potential of the area, a subject which is considered later.

PRODUCTIVE AREAS IN THE FLOOD-PLAIN

We have already explained in the previous volume and in the introductory sections of this chapter how the flood-plain of the Nile system, with its numerous side-channels and depressions, serves as a breeding and growing area for the fish. Not all the flood-plain is, however, inundated every year, and parts of it are inundated for longer periods and to a greater depth than others. Some idea of the areas where the depth and duration of flooding are sufficient to support fish in satisfactory conditions can be obtained from the information already recorded in connection with vegetation (see Chapter 3).

Open water in lakes and depressions, both seasonal and perennial, obviously produces fish. Statistical information from almost all reaches, notably in the Aliab Valley and the upper Zeraf, is sufficient to confirm this. It is, however, doubtful whether pools which are completely surrounded by papyrus, with no direct ingress from or exit to the perennial channels of the river, are productive. The oxygen content is probably low (though this is an assumption which has not been proved) and in many cases the water dries out almost completely in the dry season without there being any easy escape for the fish to the perennial channels. Such waters may support *Protopterus* and *Anabas* (which have been observed in these conditions), but it seems doubtful that other more valuable species could survive. This matter requires further investigation, which would be worth while not only as confirmation of our own assumptions or otherwise but also in connection with more immediate fisheries development, since papyrus-locked pools are fairly numerous and, if they are not productive, they could be made so by cutting suitable channels from the main river.

Areas of papyrus are almost certainly unproductive, though doubtless they play their part as an ecological factor; insects and other forms of life breed there and are valuable as food for the fish elsewhere. The ecological characteristics of *Cyperus papyrus* have been described in detail (see p. 151). The roots extend freely into water and can penetrate the muddy substratum only when the river is low, and, though root development is comparatively poor, the whole mass rises and falls according to the level of the water and covers the surface almost completely. Although it is possible that some species of fish penetrate the root mass below in order to escape to other waters, it is doubtful whether they can survive there for long.

Papyrus, though it does not flourish in areas where the range of levels is great (i.e. approximately above Tombe and below the Zeraf mouth), requires almost permanent flooding and is found at the lowest levels in the flood-plain. Within the swamp at the other extreme is

Phragmites communis, a plant which is established well above the level of other swamp vegetation and is often found only on patches of lighter soil which are rarely inundated, but in which the water-table is high owing to seepage (see p. 151). Areas of *Phragmites* are also considered unproductive in fish. Above this level is what we have defined as 'intermediate' land, producing *Hyparrhenia* and *Setaria;* these grasses are sometimes found within the limits of the flood-plain where inundation is not deep and not of long duration, but they are generally outside the area with which we are concerned.

In the flood-plain it is those areas too low to encourage intermediate grasses and *Phragmites* and too high to support papyrus which produce conditions more suited to the breeding and growth of fish. Grasses found in these conditions are mainly *Vossia cuspidata, Echinochloa stagnina, Oryza* spp. in some localities, and *Echinochloa pyramidalis*, the frequency and distribution of each species being largely, though not entirely, determined by the depth and duration of flooding. *Vossia cuspidata*, usually found on the fringes of open water and capable of withstanding much higher current velocities than the others, requires depths varying between 450 and 170 cm. and duration of flooding between 365 and 180 days in the year. *Echinochloa stagnina* requires depths between 340 and 170 cm. and can withstand a maximum duration of 365 days in the year, but needs a minimum of 180. Such conditions are ideal for the fish in almost all respects, though *Echinochloa stagnina* has roots and rhizomes which are tangled and to some extent hamper movement. *Echinochloa pyramidalis*, on the other hand, requires depths which may be as much as 340 cm. and as little as 10 cm., with a duration of flooding which may vary between 200 and 23 days.[2] Roots are more widely spaced and the grass covers a smaller proportion of the water surface than *E. stagnina*. Some areas of *E. pyramidalis* are undoubtedly less favourable to fish than others, especially as fry and ova are particularly susceptible to the attacks of predators in shallow water. Temperature is another factor which must be taken into consideration.

The figures given below are taken from the Aliab Valley survey as an example only, and it should be noted that there is considerable variation throughout the Jonglei Area owing to differences in other factors—evaporation, temperature, rainfall, atmospheric humidity, slope, current velocity, and range of levels, including the relative rapidity of the rise and fall in water level. It is doubtful whether figures such as these can be applied precisely even within a single Zone, and generalizations undoubtedly lead to a fair degree of error. Sample surveys showing the correlation between ground levels, degree and depth of flooding, and the distribution of grasses are sufficient to indicate relative proportions. Special considerations which apply are taken into account in connection with each Zone.

SOUTHERN ZONE

From Juba to Tombe 309 sq. km. of the total flood-plain are seasonally inundated by spill water from the Nile in an average year. This area is very largely made up of lagoons of open water and stretches of *Vossia cuspidata*, *Echinochloa stagnina*, *Oryza*, and *Echinochloa pyramidalis;* only a small proportion is covered with papyrus. *Phragmites*, which is common in this reach, is generally above the level of the area where fish can thrive. On this basis we estimate that 90% of the area is productive in fish, giving a total productive area of 278 sq. km. This figure is exclusive of that part of the flood-plain which is fed by run-off and rainfall (see p. 417).

From Tombe to Atem Head, the total area seasonally inundated is estimated to be 787 sq. km.—again a figure which excludes those areas fed by rainfall or seepage. Actual figures taken from the Aliab Valley survey are as follows and are worth quoting as an example:

Open water	12·5%	Productive
Vossia cuspidata	12·9%	
Echinochloa stagnina ...	19·1%	
Echinochloa pyramidalis ...	45·9%	
Cyperus papyrus	7·2%	Unproductive
Phragmites communis ...	2·4%	

These apply only to the southern portion of the valley. North of our survey lines and up to the boundaries of the Zone there is probably more open water and a greater percentage of papyrus, *Vossia* and *Echinochloa stagnina*. Open water surrounded completely by papyrus is comparatively rare. Having taken these figures into consideration, we consider that 90% of the area is productive in fish, making a total area of 708 sq. km.

CENTRAL ZONE

In the Central Zone the present area of swamp is estimated to be 6,554 sq. km. Figures given above from the Aliab Valley provide some indication of the proportions of vegetative types, and one or two sample surveys within this Zone confirm this. At the same time such proportions, when applied to so vast an area, give scope for very considerable error.

Papyrus is almost certainly more widely distributed, though there is very much less than is generally supposed. Papyrus-locked pools are more common. Allowing for this, and for small and scattered islands of higher ground which are to be seen throughout the area, we have taken the following percentages as the basis for our calculations:

Open water	70% Productive
Vossia cuspidata	
Echinochloa stagnina ...	
Echinochloa pyramidalis ...	
Cyperus papyrus	30% Unproductive
Phragmites communis ...	
Papyrus-locked pools ...	
Higher ground	

The productive areas can therefore be taken to be not less than 70% of the whole, which gives a total of 4,588 sq. km.

NORTHERN ZONE

The total area of the flood-plain between Buffalo Cape and Jebelein (Bahr el Jebel and White Nile) is estimated to be 1,849 sq. km. in a normal year. When the gauge levels exceed the normal further areas are covered, part of which produce grasses (mainly *Echinochloa pyramidalis*), which is demonstrated in Tables 110 to 112 (see pp. 180-1). Grasses below that level are *Vossia cuspidata*, *Echinochloa stagnina*, *Oryza barthii* and *Echinochloa pyramidalis*, all of them requiring a depth and duration of flooding capable of supporting fish. Upstream of Lake No as far as the boundary between the two Zones—here taken as Buffalo Cape—the area (340 sq. km. of the total for the Zone) is similar to the Central Zone and probably only 70% is productive in fish. Bearing this and other considerations in mind, we estimate that 90% of the whole area is productive, giving a total of 1,664 sq. km.

NATURAL YIELDS

No reliable figures for natural yield are available and a full programme of research would be required to obtain even approximate figures. World figures for roughly similar swamp conditions in tropical climates vary enormously and figures for artificial fish ponds, varying between approximately 500 kg. and 2,000 kg. per acre, are scarcely applicable. Records from the Delta Lakes of Egypt at the other end of the Nile system—Menzaleh, Brullos, Idku, Mariut, Qarun[3], etc.—indicate yields (1936–41) varying between 29 and 56 kg.p.f., with an average of 39·02. It therefore seems not unreasonable to take the figure 20 kg.p.f. as a basis for our calculations, even though conditions in Egypt and the Jonglei Area are by no means identical.

FINAL ESTIMATE

Taking this figure (20 kg.p.f.) and assuming that 90% of the swamps in the Southern Zone, 70% of those in the Central Zone, and 90% of those in the Northern Zone are productive in fish, our results are recorded in Table 273. A more accurate estimate will be necessary in the future, but we consider that these figures are on the conservative side. It should also be noted that these figures refer to the area actually affected by the Project and not to subsidiary swamps or tributary rivers.

LOSS OF FUTURE POTENTIAL

In addition to fish required by the population for purely subsistence purposes, loss of future potential is very considerable, for it is assumed that commercial fisheries will develop. After deduction of the amounts required for subsistence and to be met by remedies the figures are:

Southern Zone	2,724 metric tons	
Central Zone	17,557 " "	
Northern Zone	Nil " "	(more difficult fishing conditions)
	20,281 " "	

It is, perhaps, doubtful whether the total yield estimated above could be caught, but assuming that the development of commercial fisheries would make it possible to catch 50%, the financial implications are considerable. Such a quantity of fish when cured (after deducting normal drying-out percentages) represents certainly not less than £E300,000 per annum at current export prices.

TABLE 273

ESTIMATE OF POTENTIAL YIELDS IN THE JONGLEI AREA AND REDUCTIONS UNDER THE EQUATORIAL NILE PROJECT

Zone	PRESENT RIVER REGIME			EQUATORIAL NILE PROJECT					
	Area Seasonally Inundated sq. km.	Area Productive in Fish[1] sq. km.	Present Potential at 20 kg.p.f. metric tons	Area still Productive under E.N.P. sq. km.	Future Potential at 20 kg.p.f. metric tons	Population (Juba–Jebelein)	Subsistence Requirements at 16 kg. per head metric tons	Deficit to be met by Remedies metric tons	Loss in Potential metric tons
SOUTHERN Juba–Tombe ...	309[3]	278	1,323	248[2]	1,180	52,300	837	—	143
SOUTHERN Tombe–Atem ...	787[3]	708	3,370	116[2]	552	49,330	789	237	2,818
CENTRAL	6,554	4,588	21,839	327[2]	1,557	267,618	4,282	2,725	20,282
NORTHERN	1,849	1,664	7,921	1,664	7,921	231,620	3,706	—	—
Total	9,499	7,238	34,453	2,355	11,210	600,868	9,614	2,962	23,243

(1) Areas productive in fish are calculated as being 90%, 70% and 90% of the total flood-plain inundated and exposed in the Southern, Central and Northern Zones respectively under present conditions.
(2) Calculated on percentage distribution of vegetation species. See p. 124.
(3) Gross area flooded, including permanent swamp. See Figs. pp. 22, 23.

6. RECOMMENDATIONS FOR FUTURE INVESTIGATION

The need for further investigation is manifest. Moreover, expenditure on such investigation would be justified because the information required is identical with that needed for a proper survey of potentialities which can be exploited whether the Project is started in the immediate future or is long delayed. Figures for potential yields, even though some may say they are exaggerated, indicate immense possibilities. In our opinion any programme of fisheries development must include not only the purely practical aspect—the training of personnel in fisheries techniques and methods of curing—but also a thorough co-ordinated investigation and survey of all other aspects. We can again do no better than quote from the report by Dr. E. B. Worthington already mentioned:

" FISHERIES RESEARCH. The main functions should be:

(*a*) ADVICE to all branches of the Sudan Government concerned and to the (Fisheries) Development section on problems requiring a scientific opinion.

(*b*) RESEARCH ON FISH OF NATURAL WATERS. This should be restricted in the early stages to those species of principal economic importance. It would include feeding habits and food relations, growth, breeding grounds and habits, and migrations.

(*c*) RESEARCH ON THE POSSIBILITIES OF FISH FARMING. This would include studies of suitable species (especially *Tilapia nilotica* and the introduction of *Tilapia melanopleura*, a weed-eating species which has proved its value in the Belgian Congo), growth and breeding rates, feeding, stocking and cropping rates, adverse factors including diseases.

(*d*) PRODUCTIVITY OF WATERS. This is concerned with both natural and artificial waters and includes the study of the F.B. (fish and bottom fauna) quotient. It involves studies of bottom fauna, algae, zooplankton and water chemistry as indicators of trophic standards and consequently of potential fish production.

FISHERY DEVELOPMENT.

(*a*) STUDY AND ASSESSMENT OF THE FISHERY AS IT EXISTS TO-DAY. Information would include the number of fishermen, boats and equipment in different fishery areas; an account of the methods employed; estimates of the total catch, in annual and seasonal figures, including notes on the most important fish and their sizes; descriptions of native fishing rights and marketing systems. This would lead to the establishment of an organization for collecting reliable statistics.

(*b*) Prospects of Development. This would include extensive trials of different kinds of fishing gear such as gill-nets of different meshes, seine-nets, trammels and long-lines. The latter are particularly important for establishing a balanced fishery by controlling predators. In all cases the catches and economic returns will require careful recording and analysis in relation to the fishing effort used. When the best economic methods have been determined, much work will be required in getting them introduced under adequate control, and this may require the establishment of a fishery school as part of a programme of simple technical education. Studies are required also of curing methods suitable to different branches of the fish trade. A great deal of work is also required on improving systems of marketing and distribution, and this may involve the establishment of some form of marketing organization on public utility lines, similar to the Uganda Fish Marketing Corporation.

(*c*) Introduction of Licensing and Control ".

We would add to this the necessity for a more careful investigation of the relative importance of fish in the present subsistence economy of the inhabitants—the productivity and consumption of fish in each reach of the river and its tributaries. This will necessitate a wide variety of sample surveys. Much work on these lines has already started, but we must stress, in the light of our own investigations, the need for research as well as practical training, and the obvious necessity for both aspects to be carried out simultaneously and as part of a combined operation.

NOTES AND REFERENCES

(1) Worthington, E. B., ' Notes on the Sudan ', July 1950. Unpublished Report.
(2) See Table 119. These figures refer to the Aliab Valley; for mean of whole Jonglei Area see Vol. 1, p. 165.
(3) Worthington, E. B., *Science in the Middle East*, H.M.S.O., 1946.

CHAPTER 5. OTHER EFFECTS

1. EFFECTS ON TOPOGRAPHY AND CLIMATE

TOPOGRAPHY

Though the Project will not have any marked effect on topography it is worth recording that in other instances where swamps have been dried out, such as in the Fens in England, and in Uganda and other parts of Africa, the process has been accompanied by a slow, steady lowering of the level of the land. For gravity irrigation from the river this will be a favourable trend. This lowering of the land level, caused by oxidation of the organic matter, will undoubtedly take place in areas covered with papyrus where a peat horizon exists at present. It will not take place to any appreciable extent on *toich* land where soils contain only a small amount of organic matter. The oxidation of organic matter in the soils from the point of view of fertility is discussed later (see p. 531).

CLIMATE

The possibility that rainfall may be affected by the drying up of some 7,000 sq. km. of the *Sudd* area, much of it permanent swamp, is often the first thought which occurs to the layman in connection with the Equatorial Nile Project in the Sudan. We have referred the matter to the Government Meteorologist, to whom we are indebted for the material on which the following exposition of the case is based.

In the first place, it is extremely difficult to assess the effects accurately for three reasons. Current controversies about the climatic effects of deforestation are evidence of the lack of knowledge in this field of meteorology. Secondly, the data available about the area concerned are extremely scanty, and in fact one has to try to assess the climate and its changes over an area of 7,000 sq. km. from the records of about half a dozen stations in and around it. Thirdly, some of the tendencies which one might deduce from the data do not augment each other but tend to cancel each other out, and an exact quantitative analysis is not possible.

There are three climatic anomalies which might be attributed to the swamps :

(1) The average annual rainfall at Fangak is about 1,100 mm. in an area lying between the 800 and 900 mm. isohyets.

(2) Temperatures outside the swamps at Malakal and Juba tend to be higher than within them at Malek, Bor, and Shambe.

(3) Humidities at the same places tend to be lower outside the swamps than within them.

Concerning the higher rainfall at Fangak, we may comment that no conclusion can be drawn from the records of a single station in an area where there were not, until very recently, other rain-gauges to confirm its readings or disprove them.

In Uganda the stations at Gulu, Ngetta, and Lira are situated in relation to Lake Albert much as Fangak is to the swamps and the rain-bearing south-west winds. The figures for average annual rainfall at those places are 1,544, 1,399, and 1,378 mm. respectively, whereas at other stations in the vicinity the average annual rainfall is nearer 1,300 mm. The similarity may or may not be a coincidence. The evidence is again too scanty for certainty. Lake Victoria appears to have some effect on the local climate, but its area is nearly 10 times as great as that of the swamps we are considering, and it is 12·5 times the size of Lake Albert.

Considered from a theoretical point of view, the average evaporation of river water amounts to about 4 mm. daily. Since the potential evaporation from a vegetated surface as calculated using Thornthwaite's formula does not, in any of the rainy months, greatly exceed rainfall, the Government Meteorologist concludes that rainfall will be unaltered. Assuming that the south-west wind is over the swamps for 12 hours (120 km. at 10 km.p.h.) it gains 2 mm. of water, which is quickly dispersed by convection and turbulence within the surface (10,000 ft.) layer of air which normally holds 40 mm. in the rainy season. It is improbable that a gain of 2 mm. in 40 has very much effect on rainfall locally.

If temperature and humidity are affected by the swamps, then when the latter are drained the increase in temperature will tend to increase convection which is the main cause of rainfall over the plains, while the decrease in humidity will tend to cancel out this effect.

Summarizing, we can say that since the South Atlantic Ocean is the main source region for rainfall in the Sudan, draining of the swamps will have no general effect on rainfall over the Sudan as a whole. It appears likely that temperatures may be higher and humidities lower within the present boundaries of the swamps, but that this will have no significant effect on precipitation.

2. EFFECTS ON CROP PRODUCTION

As we have seen in Volume I, the economy of the Jonglei Area is characterized by what we call the balanced utilization of all types of land. In animal husbandry all types of land, with the exception of *sudd*, play an integral part in assuring fodder supplies throughout the year. Crop production, however, is carried out more or less entirely in the inland areas on land which we classify as high or intermediate; and at present the riverain flood-plains are only of small importance in this sphere. Consequently the direct effects of the Project on the present crop production will be very small when compared with its effects on animal husbandry. However, the Project will affect the potentialities of crop production both directly and indirectly, a fact which is of the greatest importance in the future development of this part of the Sudan.

DIRECT EFFECTS ON PRESENT CROP PRODUCTION ON THE RIVERAIN FLOOD-PLAINS

In describing the agriculture of the Bari and Mandari peoples (see Vol. I, p. 363) we have pointed out the part played in their economy by crop production on the riverain flood-plains. Approximately three-quarters of this type of cultivation is carried out on that part of *toich* land dominated by *Phragmites communis*, i.e. the land which is only occasionally inundated, when the river exceeds its normal high level, but is nevertheless moist throughout the year owing to the high water-table. The remaining one-quarter of the present *toich* cultivation is carried out on the parts of the riverain flood-plain inundated every year by river spill. While on the *Phragmites toiches* cultivation is carried out almost throughout the year, the cultivation of deeper-flooded *toiches* is restricted to the dry season, which at present coincides with the period when the river is low.

We have noted that in the area inhabited by the Bari and Mandari people, though under the Project there will be a reversal of the present seasonal régime, an area of approximately 200 sq. km. (i.e. 47,500 feddans) will still have conditions essentially the same as those which favour *Phragmites* dominated *toich* and the moisture supply during the dry season will actually be improved. Consequently there should be ample room for the present quantity of crop production (roughly 1,500–2,000 feddans) to be continued on this type of *toich* land. Similarly, an area of approximately 200 sq. km. (47,500 feddans) will be flooded during the rainy season by spill from the Nile tributaries and by local run-off. As the major part of this annually inundated area will be in the Bari and Mandari district, there should be no difficulty in maintaining the cultivations (estimated to cover approximately 400–500 feddans) which these people at present have on this kind of land. It should be remembered, however, that the rainy season flooding, depending on a smaller catchment area (drained by local watercourses: see p. 418) than at present, will be more variable. Naturally the changes in the hydrological régime will result in at least some change in the actual localities where these cultivations are situated.

Some of the Dinka tribes inhabiting the northern part of the Southern Zone (Aliab, Bor, etc.) cultivate small plots of quick-maturing maize sown at the beginning of the rains and harvested before the river rises sufficiently to inundate the flood-plain. They also plant a little tobacco in this area in the middle of the dry season. The total area under these crops is probably not more than 150 feddans. In this part of the Southern Zone, where banking to prevent spill will be employed, there will be a considerable loss of *toich*. There will, however, still be some 200 sq. km. of *toich* land resulting from the fluctuation of levels in khors dependent on other catchments and on run-off. There will certainly be sufficient to accommodate all such cultivations on the present scale.

In the Central Zone dry season *toich* cultivation is limited to small plots of tobacco and very occasionally maize and vegetables. The area so cultivated probably does not exceed 150 feddans. As can be seen from the description of the hydrological effects of the Project, the area of flood-plain remaining under future conditions between the Atem barrage and Buffalo Cape will be about 362 sq. km. (approx. 85,700 feddans). Consequently there will still be more than ample room for dry season *toich* cultivations of this kind. The same applies in the Northern Zone between Buffalo Cape and Malakal. Farther north, the losses of the riverain flood-plain between Malakal and Jebelein will not exceed 35% and an area of approximately 630 sq. km. (about 150,000 feddans) will be available for cultivation during the dry season. In the area between Jebelein and Kosti only about 8% of the riverain flood-plain will be lost. It should, however, be remembered that the areas lost will be the lowest parts of the plain, where at present deep flooding prevents grass growth. The present period for which these areas are free of flood is too short to permit cultivation of all but very quick-maturing vegetables and consequently the areas, though obviously easier to cultivate, are utilized to a negligible extent. Cultivation on the higher parts of the flood-plain (at present approximately 3,000 feddans) will still be possible after the Project is put into operation, though it may be necessary to shift it higher up the flood-plain.

EFFECTS ON CROPPING POTENTIAL

At present the riverain *toiches* regularly inundated during the rainy season are cultivated only when exposed when the river drops during the rainless months. As will be seen later in Chapter 7 their cropping could be extended to include crops such as rice, which actually benefits from flooding. The technique of utilizing them for crop production is discussed in detail in connection with remedial measures and the discussion is not repeated here. The Equatorial Nile Project will affect the extension of crop production of the type practised at present (i.e. on exposed flood-plains), as well as the potentialities of crop production which aims at utilizing the natural rises and falls of the river and thereby reduces the risks because the river level fluctuations are less variable than the local rainfall. These effects can be summarized as follows:

SOUTHERN ZONE. In the Juba–Tombe reach the reversal of the seasons will actually improve cropping prospects provided that the right crops and varieties can be found for cultivation under flood during the dry season and under exposed conditions during the rainy season. On the other hand the drainage difficulties and resulting tillage difficulties should be noted (see p. 601). As flooding will be prevented by banks along the river between Tombe and the Atem barrage, 510 sq. km. of swamps (see Table 192, p. 437) will be reclaimed and will no longer be available for cultivation under natural flood conditions. This excludes the area dependent on khors discharging from other catchments and run-off. The possibility of replacing natural floods by gravity irrigation is discussed elsewhere (see p. 619).

CENTRAL ZONE. Approximately 6,192 sq. km. of swamps will be dried out as the result of cessation of spill. Consequently they will be lost for either cultivation in the dry season or cultivation dependent on natural flood irrigation. It is at present impossible to predict how much of the remaining 362 sq. km. will be permanently or nearly permanently saturated (i.e. *sudd* land), but the proportion of this area in which such conditions of permanent saturation will prevail will be comparatively small. On the other hand, if cropping of this remaining *toich* area were attempted, a serious clash between agricultural and pastoral interests would be unavoidable, since there will be much less *toich* grazing than before.

NORTHERN ZONE. The losses in different reaches have been estimated as follows:

Lake No to Malakal:	approx. 110 sq. km., i.e. 18%
Malakal to Jebelein:	approx. 285 sq. km., i.e. 31%
Jebelein to Kosti:	8% (see p. 428 above).

Competition between agricultural and pastoral interests, which will be intensified as a result of the effects of the Project, will also occur in this Zone.

In addition to losses, there will also be some advantage. Under future conditions the river discharges, and hence flooding, will be largely under control, and therefore predictable, in the Southern and Central Zones. The cropping of the remaining riverain flood-plains should therefore be easier to arrange. However in the Northern Zone, where the river fluctuations depend mainly on the fluctuations of the Sobat, this advantage will not exist. Moreover it should be remembered that in certain conditions flood-escape discharges will be exceptionally high and, although to some extent predictable, will limit considerably the possibilities of *toich* cropping. These problems are further discussed under the heading of remedies later in this volume (Chapter 7).

AGRICULTURAL SIGNIFICANCE OF CHANGES IN SOILS

Changes in the soils of the riverain flood-plains have already been discussed in a previous chapter (p. 463). It remains to consider briefly here their agricultural significance. We have already shown that the total organic matter content of the *toich* soils is generally well above 1% and often as high as 3% or even 5% (Vol. I, p. 123). At the same time the organic matter content of the intermediate land soils, especially those less liable to flooding, is usually about 0·5%. The high land soils have an even lower organic matter content. Thus the cessation of seasonal inundation, and hence seasonal anaerobic conditions, would result in the oxidation of a considerable proportion of the organic matter. How far it would affect the soil fertility is impossible to assess with any accuracy at this stage. The straightforward comparison of yields of different crops grown in our experiments carried out on high land and intermediate land with yields of the same crops grown on *toich* experiments is inconclusive, as the experimental techniques used did not permit separation of yield response due to a single factor, i.e. soil fertility. On the other hand there is little doubt that the stands of crops such as rice, jute, and Deccan hemp were usually better on the *toich* soils than on irrigated intermediate land soils, though a few bad patches and other factors causing yield losses resulted in the lack of significant differences in the numerical data (see Vol. III, p. 1012). We can, however, try to assess indirectly the degree of deterioration due to drying-out. If we assume that the superiority of *toich* soils is largely due to their nitrogen content, we can, by comparing the nitrogen status of *toich* soils with that of intermediate and high land soils (as measured by laboratory methods), assess the loss of nitrogen due to change in hydrological conditions, and calculate on the basis of the following formulae[1]

(i) 1 p.p.m. N=1·5 kg. N per 1 ft.×feddan

(ii) 1 kg. N=6·25 kg. Sodium Nitrate

the quantity of sodium nitrate fertilizer which would have to be applied to replace these losses (see Table 274). It should also be remembered that nitrogen in the form of artificial fertilizers is much more subject to leaching than nitrogen in the form of organic compounds; hence the annual application of further quantities of fertilizers would be required to preserve the nitrogen status at the level at which we find it in *toich* soils under the more aerobic conditions, similar to those of high and intermediate land soils, which will prevail.

TABLE 274

THE AVERAGE DIFFERENCES IN NITROGEN CONTENT OF 10 SAMPLES OF *TOICH* SOILS AND INTERMEDIATE AND HIGH LAND SOILS AND THEIR EQUIVALENTS IN TERMS OF SODIUM NITRATE FERTILIZER

Depth in feet	*Toich* Soils		Intermediate and High Land Soils		Difference N kg.p.f.	Equivalent Sodium Nitrate kg.p.f.
	Average of 10 samples		Average of 10 samples			
	N p.p.m.	N kg.p.f.	N p.p.m.	N kg.p.f.		
0–1	2,688	4,032	412	618	3,414	21,338
1–2	1,162	1,743	306	459	1,284	8,025
2–3	753	1,130	293	440	690	4,312
3–4	509	763	256	384	379	2,369
4–5	462	693	225	338	355	2,219
5–6	427	641	202	303	338	2,112
Total in 6 ft.	6,001	9,002	1,694	2,542	6,460	40,375

As will be seen from the above table, the change in hydrological conditions from those giving rise to *toich* soils to those giving rise to high land and intermediate land soils will mean a loss in nitrogen per feddan equivalent to over 40 tons of sodium nitrate. However, it should be realized that organic matter, including nitrogen, accumulates at present under undisturbed conditions. Cultivation, with attendant improved aeration, would in any case cause oxidation of at least a part of the organic matter in the *toich* soils. As yet we have no data to assess the speed of oxidation in ploughed *toich* land under temperatures prevailing in this area.

The drying-out of *toich* soils means therefore loss of fertility. It is possible to make some estimate of this loss for pasture utilization, but impossible to do so for crop production. Conversely, where the new hydrological conditions create *toich* soils from intermediate or high land soils, fertility will be enhanced by gains in organic matter. The quantitative assessment of this gain for the purpose of crop production is, however, impossible.

Under future hydrological conditions a certain proportion of nearly permanently saturated *sudd* soils will be preserved in the Southern and Central Zones, while new *sudd* soils will probably develop in the Northern Zone (see p. 100). *Sudd* soils are at present of no economic importance and their pastoral or agricultural utilization, requiring costly reclamation works, on the basis of our present knowledge would not be worth while financially. On the other hand a considerable area of *sudd* soils (at present impossible to assess) will be subject to drying-out as a result of the Project. The question of the value of those 'reclaimed' soils is therefore of considerable importance.

We have had no opportunity of studying the reclamation of these soils in our own area; the task proved impracticable with the staff available, and the proposed project of a pilot *sudd* reclamation scheme at Shambe would have been very expensive to carry out. The results would in any case have been of doubtful value in so short a period. However, experience of swamp drainage and subsequent agricultural utilization in Uganda and the Belgian Congo makes it clear that the problem is not simple and must be approached carefully, or drainage may lead to the rapid ' death ' of swamp soils so that they become useless for cultivation[2].

Various reasons have been given for the ' sudden death ' of reclaimed swamp soils. Berg[3] advanced the theory that the Uganda and Congo swamps dry from the bottom, causing a ' perched water horizon ' coupled with rapid deterioration of the soil structure, which leads in later stages to the drying of the whole mass of peat to below the wilting point.

Chemical changes due to drying, such as increased acidity and concentrations of toxic substances, may be responsible for the deterioration of these soils[4]. Pearsall[5] points out the effect of drying on the microbiological life of reclaimed soils—progressive microbiological inertia and a sharp drop in fertility. The same author, as well as others[6], shows that many changes in the structure and properties of soil colloids are irreversible, and therefore re-wetting of the soils cannot restore their properties completely and deterioration due to drainage may continue rapidly even in comparatively wet climates or under normal irrigation practice.

Consequently the problems of peat soils must be approached with great care. It should be remembered that the *sudd* soils differ considerably from the peat soils of Central Africa. The differences have been described in one of our reports[7]. The main difference is the much shallower organic layer in *sudd* soils when compared with the peat soils of Uganda and the Congo. The danger that a ' perched water horizon ' may form does not therefore exist in *sudd* soils, as the roots of plants growing in them penetrate well into the mineral layer below. Simple deep ploughing should be enough to mix the surface peat with the mineral soil and make it an ordinary soil with a high humus content. A primary consideration in reclaiming the soils must be to maintain the initial high organic matter status after drainage. The only means of ensuring this is to prevent as far as possible the destruction of organic matter by excessive aeration, and to ensure that it accumulates at the highest rate possible.

Consequently, if the fertility of *sudd* soils is to be maintained after reclamation, their moisture content should be kept always at a high level, and cropping should be designed to benefit from, or at least tolerate, constant wetness, to involve as little cultivation as possible, to provide continual good cover against insulation, and to supply the maximum amount of raw material for the forming of humus. Grass is, from all aspects, the most suitable crop. As for agricultural crops, perennial crops, in particular those which require mulching, are the most suitable ; sugar-cane is an obvious possibility. Of annual crops, rice, which thrives in water-logged soils, is the most suitable.

The economic side of the problem of cropping these soils and at the same time preserving their fertility is also of importance. We do not know what would be the value of increased yields as compared with the costs of management aimed especially at maintaining the organic matter status. These soils are situated on the flood-plains and consequently all installations necessary for their special management would be subject to the risk of destruction in the years of flood-escape discharges (see p. 619). Consequently it might prove more economic to incorporate the organic matter of the Ao horizon characteristic of these soils into the underlying mineral layer by simple deep ploughing when they have dried sufficiently as the result of the Project, and subsequently to treat them as other soils. If this plan were adopted partial destruction of organic matter would follow, but in the long run oxidation is inevitable as cropping of any kind requires improved aeration.

OTHER EFFECTS ON CROP PRODUCTION

We have already discussed in detail the effects of the Project on drainage (p. 433) and irrigation by gravity and pump (p. 433). We consider these matters again in connection with agricultural remedies (p. 605). The problems of inland domestic water supplies, which considerably affect present crop output, have also already been reviewed (p. 432), as have the problems of climate (p. 529) and communications (p. 534) which also affect agricultural production.

EFFECTS AT 80 M/D STAGE

The previous observations on the effects of the new river régime have been based on the predicted hydrological effects at the 55 m/d Canal stage. At the 80 m/d Canal stage, 100% of the flood-plain will be affected throughout the Jonglei Area, except in the Central Zone where discharges will not be increased and in those reaches in other Zones where banking will be employed to prevent spill. It is unnecessary to describe the effects on crop production at this stage of the Project for they will be the same as in the 55 m/d stage, but the disadvantages will be proportionately much greater.

INCREASED PRESSURE OF LIVESTOCK ON INLAND AREAS

In the Northern Zone especially, where there is *hariq* cultivation, the loss of riverain grazing will increase the conflict between grazing and cropping interests, which already compete for *hariq* areas in some parts of the Semi-Arid Region (see p. 376). It will probably be followed by an increase in the number of sheep and goats, since these smaller domestic animals are better able to exist without *toich* grazing. The effect of an increase in this type of livestock on soil erosion must also be taken into consideration when remedial measures are applied.

INCREASED RELIANCE ON CROP PRODUCTION (REORIENTATION OF PRODUCTION)

Finally, the most important effect of the loss of dry season grazing will be the increased reliance on crop production, and the loss of insurance against the failure of crops which exists at present in the form of cattle. Unless remedial measures designed to maintain the livestock population at its present level are successful, crop output must inevitably be increased, and above all be made more reliable. Otherwise the people will face gross malnutrition and periodic famine.

In conclusion it should be noted that the effect of the Equatorial Nile Project on existing crop production in its present stage of development will be negligible, especially if compared with the effects on domestic stock. On the other hand, the Project will considerably affect the crop potential of the area. If the entitlement of the local inhabitants to a share in the increased volume of water flowing through their country is accepted in principle, then the availability of adequate water for irrigation should more than compensate for losses of present naturally irrigated *toich* pasture, especially if sufficient capital is made available. Moreover the drastic changes in environmental conditions will necessitate considerable change in the whole economy and in the present form of livelihood of the people; a form of livelihood which is to them traditional and which patterns their outlook towards other methods of subsistence. Such changes may be sufficiently marked to create a situation in which their attitude will alter and provide an opportunity for modernization and improvement in crop production, which is at present far from efficient. This may at least facilitate the introduction of the remedial measures which we recommend and which are otherwise unlikely to meet with success.

3. EFFECTS ON COMMUNICATIONS

NAVIGATION

SOUTHERN ZONE

As explained in the survey of the Jonglei Area, navigational difficulties exist at present in the Southern Zone between Juba and Terakeka owing to insufficient depth of water and shifting sandbanks during the period of low river, and to velocities as high as 6 km. per hour in the flood season. The silting of this reach has been thought to be a phase in the cycle between high floods which improve navigation by scouring away the sandbanks. Further detailed study in connection with the effects of the Equatorial Nile Project has tended to disprove this theory, as the following explanation will show.

CORRELATION BETWEEN MONGALLA, JUBA, AND REJAF GAUGES

By plotting monthly mean gauges at Juba against those at Mongalla at five-year intervals from 1925 to 1940 (Fig. F 30), it can be seen that the river level at Juba has fallen steadily in relation to Mongalla level at the rate of 16 mm. per year at a discharge of about 60 m/d (Mongalla gauge 11·40).

A similar correlation for Mongalla and Rejaf, for which records are available covering the high flood years of 1916–19, at five-year intervals from 1915 to 1940 (Fig. F 31) shows that the river level at Rejaf has fallen in relation to Mongalla level at the rate of 42 mm. per year at a discharge of about 60 m/d, or over 1·0 m. in 25 years. Records at Terakeka began only in 1927, but those at Tombe are available for 1915 and 1940. The correlation between Mongalla and Tombe gauge-readings (Fig. F 32) shows that the river level at Tombe has risen in relation to Mongalla level at the rate of 15 mm./year at a discharge of about 60 m/d. The diagram of Mongalla and Rejaf gauge correlations (Fig. F 31) shows that the process is a continuous one, was accelerated by high floods between 1915 and 1919, and retarded by low discharges between 1920 and 1924. This will be investigated further later.

Plots of the monthly mean gauges at Mongalla against discharges for 1912, 1931, and 1950 (Fig. F 29) show that for a discharge of 60 m/d the water-level has risen at the rate of 7 mm. per year.

From these figures we can assess the absolute rates of rise or fall of the river level at a discharge of 60 m/d at Mongalla as follows:

Rejaf	minus 35 mm. per year
Juba	minus 9 mm. per year
Mongalla	plus 7 mm. per year
Tombe	plus 22 mm. per year.

These changes in river levels for a given discharge, which represent scouring and silting, have been plotted against distance along the river (see Fig. F 34). It will be seen that there is a point of stability about half-way between Mongalla and Juba. It is clear that this is a steady natural process which will continue to the detriment of navigation, and it remains to be seen whether the Equatorial Nile Project will hasten or slow down this natural phenomenon. We have noted above that the rate of change of level at Rejaf relative to Mongalla was increased during the high flood years 1915–19, and reduced in the years of low discharges from 1920–24, and there is clearly a connection between rate of change of level and discharge. This is brought out by Table 275 below, which is plotted in Fig. F 33.

TABLE 275

RATES OF DEGRADATION OF RIVER LEVEL AT REJAF

Period	Average annual flow at Mongalla in milliards	Average annual fall in water level at Rejaf relative to Mongalla in centimetres
1915–19	40·0	6·6
1920–24	19·5	1·0
1925–28	23·5	3·8
1930–34	28·2	5·4
1935–39	26·0	4·4
Mean	27·4	4·2

A curve has been drawn roughly through these points. The diagram demonstrates clearly that variable annual discharges in the past have resulted in a lower average rate of fall (42 mm./year) than will be the case in future under the Project when the discharge will be 27 milliards per year every year (50 mm./year). It is interesting to note that an extension of this curve downwards indicates that if the annual flow were only 18 milliards per year there would be no change in relative levels. (In the intermediate construction stages, which may last for 25 or 30 years, the discharge at Mongalla will first be reduced to 19·5 milliards and later increased in steps to 22·2, 23·4, and 27·2 milliards per year.)

The flow at Mongalla is derived from two sources; from Lake Albert which discharges silt-free water, and from the torrents whose waters are silt-laden. At the present time these two mingle during the rains when the river is highest and its ability to erode and transport silt greatest. In the four months from December to March when the discharge is usually lowest all the water comes from Lake Albert and is free of silt. Under the Project the flow from Lake Albert will be reduced during the rains to counterbalance the torrents which will be partly impounded in a balancing reservoir between Nimule and Rejaf. Since some of the torrents will not be impounded directly, the silt content of the flow at Mongalla will probably be much the same as at present. On the other hand during the dry season the flow from Lake Albert will be highest and the water will be silt-free, so there may be a further tendency to increase the rate of scouring and silting as described above.

Although the water-level at Mongalla has risen slowly but steadily, the width and water depth have remained approximately the same for similar discharges, as the diagram giving the average depths at Mongalla for 1922 and 1940 shows (Fig. F 29). Observation of the river elsewhere in this reach, however, particularly at the places where navigational difficulties are met, reveals considerable bank erosion, resulting in a wider and shallower section and increasing sandbanks.

The effects of the Project at the 55 m/d Canal stage on the factors considered above might be taken to be slightly disadvantageous, but there is another factor which will constitute a real benefit to navigation. Present navigational difficulties are due to shallows and shifting sandbanks at the lowest river discharges, and high velocities at the highest flows. Under the Project the discharge at Mongalla will never drop below 57 m/d, and normally never rise above 90 m/d. At the former discharge the average water depth at Mongalla is 2·90 m. (9′ 6″), and at the latter the velocity is one metre per second (3·6 km./hour), the maximum desirable speed to suit navigation. In the exceptional case when flood-escape discharges are passing, the flow will reach 120 m/d for long periods, and the velocity will be 1·2 m. per second (4·4 km./hour).

In the 46-year period from 1905 to 1950 for 24% of the time the discharge was less than 57 m/d, and for 22% of the time greater than 90 m/d, the latter including one period of exceptionally high floods when the velocity reached 1·68 m. per second (6 km./hour). The details of this analysis are given in Tables 276 and 277, pp. 539–40.

CONCLUSION

As far as can be seen at present the natural process of scouring in the upper part of the reach from Rejaf to Tombe and silting in the lower part will continue, perhaps at a slightly increased rate, under the Equatorial Nile Project in the 55 m/d Canal stage. In any case the effect will be small, and it would take an extremely elaborate and accurately controlled hydraulic model experiment to determine it exactly. This slight disadvantage is more than offset by the improvement in navigation which will result from regulating the flow at Mongalla to 57 m/d and 90 m/d in the untimely and timely seasons respectively.

CENTRAL ZONE

NAVIGATION IN THE JONGLEI CANAL

The first and most obvious effect of the Project in the Central Zone will be a tremendous improvement in through river communications resulting from the use of the Jonglei Canal as a waterway. Instead of 697 km. of river channel, in most reaches very tortuous, there will be 343 km. of dredged channel and straight canal from the Atem Head to the Sobat mouth, a saving of about 354 km.

In this connection we must draw attention to the discharges required in the untimely season in the Canal for navigation and prevention of weed growth. A glance at Table 187, p. 408, which gives proposed discharges in the Jonglei Canal at its head will show that the untimely season flow is the same, 17 m/d, in the 27·5 m/d and the 55 m/d Canal stages. This obviously needs correction as it is doubtful whether 17 m/d is sufficient to permit navigation in one 27·5 m/d Canal, let alone to prevent weed growth in the other as well. If we assume with previous writers, as we must for lack of more definite information, that 2·5 m. depth of water is enough to prevent weed growth, then with this depth in a canal 76 m. wide with a slope of 9 cm./km., ignoring any contribution to flow on the sloping sides, the discharge will be 12·5 m/d.

For navigation, it has previously been assumed that 4 m. depth of water is the minimum allowable. This in effect means that the Canal must run full at 27·5 m/d. These calculations show that a discharge of at least 40 m/d is needed to maintain navigation in one canal and to keep down weeds in the other. This figure makes it impossible to operate the Equatorial Nile Project as intended by Dr. Amin and Mr. Bambridge. Numerous solutions can be suggested, and these will be discussed in detail in the part of the report concerned with the Revised Operation of the Project. Here we must emphasize that a saving of more than half the distance of the alternative Bahr el Jebel route and of about 3 days (75 hours) on the upstream journey by using the Canal for navigation is of sufficient benefit to navigation to warrant special measures being taken to achieve it without wasting water.

In one 27·5 m/d canal, discharges corresponding to different depths of water are as under:

Depths m.	2·5	3·0	3·5	4·0
Discharges m/d	12·5	16·5	22·0	27·5

(Except in the case of 2·5 m. water depth, we have ignored the contribution to the discharge in those parts of the canal where the depth is less than 3 m.)

It must be added that the connection of the two canals by cross-cuts, as is intended, will make it impossible to run them at different levels and discharges.

NAVIGATION IN THE BAHR EL JEBEL

Navigation will still be possible in the Bahr el Jebel and the Bahr el Zeraf, where shuttle services will be able to operate as at present. Regarding the bottle-neck upstream of Lake Papiu, it should be noted that this point is just downstream of the projected Bahr el Jebel barrage through which the discharge will never be less than 30 m/d. Conditions will be no worse than they are today since the constriction and natural spill limit the discharge in the Bahr el Jebel upstream of Lake Papiu to between 14 m/d and 17 m/d whatever the discharge farther south, and steamers will be able to pass through the barrage by means of a lock. The barrage will also become a main port and the junction of steamer and land communications between Khartoum and Wau.

Today Shambe is the main port for Bahr el Ghazal Province and an all-weather road will shortly be constructed from there to Yirol. Until the completion of the Project as far as the 55 m/d Canal stage there will be no structures other than the Jonglei Canal head and tail regulators with locks. It will be many years before this stage is reached, and many years before there can be a port either at Jonglei or at the Atem Head, too long to justify postponement of the construction of an all-weather road to the present port of Shambe.

In February 1922 when the Mongalla discharge was 31·4 m/d, which is roughly comparable with 30 m/d at the Atem Head, the Shambe gauge-reading was 10·20 m. compared with a normal minimum of 11·25 m., or 1·05 m. (3′ 6″) less than the normal depth of water. Under these conditions it is possible that Shambe will still be usable as a port, since the depth of water in the lagoon is normally about 10 feet. But there is no reason to suppose that the Bahr el Jebel itself will ever become unnavigable and, if necessary, the port could be rebuilt on the river's edge and the road extended to it, a matter of some 3 km.

There will undoubtedly be vast changes in the vegetation of the *Sudd* region in the Central Zone as a result of the drying-up of the swamps and the indications are that papyrus, the source of *sudd* blocks, will disappear or be greatly reduced, so that we do not consider there will be any obstruction to navigation from this cause.

In place of *sudd* blocks it is quite possible that other types of grass may thrive, such as *Vossia cuspidata* which floats out into the stream from its roots at the edges; such vegetation might possibly impede navigation. However, there are very good reasons for thinking that the regular passage of vessels navigating rivers and canals is the most effective deterrent to weed growth. Where the depth is too great for weeds to be rooted on the bottom, the current and the passage of steamers breaks off the shoots of weeds floating out from the banks (see Vol. I, p. 152). Where the river or canal is shallow enough for weeds to grow on the bottom the passage of vessels stirs up the mud, and while it is in suspension underwater weeds are deprived of the sunlight which is necessary for their growth.

NORTHERN ZONE

Steamer services in this Zone operate on the main rivers, the Bahr el Ghazal, Bahr el Jebel, Bahr el Zeraf, the Sobat, and the White Nile from Lake No to Kosti. In general, since low river levels will be 1·54 m. higher than at present at Malakal, there will be an all-round improvement in navigation, particularly on the White Nile north of Malakal at Jebel Ahmed Agha, Ez Zeleit Rocks, and Abu Zaid Ford where difficulties are now encountered.

Since future maximum levels will be much as they are now, there will be no inundation of quays and landing-stages. On the Bahr el Ghazal our investigations have shown that although during the rains there are continuous water connections between the Bahr el Jebel and the Bahr el Ghazal, the channels are so wide and shallow and so heavily grassed that the quantity of water, if any, which the one system supplies to the other must be negligible. The exception to this rule occurs between Khor Doleib and the Bahr el Ghazal mouth at the exit from Lake No. The flow of the Bahr el Ghazal at Khor Doleib is 132 million cubic metres per year on the average, whereas at Lake No exit it is 634 million. Butcher has shown that losses on the Bahr el Jebel between Buffalo Cape and Lake No increase largely when Lake No levels are high, as they are when the Sobat rises, and the flow into Lake No from the Bahr el Jebel then decreases. At the same time the discharge of the Bahr el Ghazal at Khor Doleib decreases, while at the Lake No exit it increases. The inference is obvious. Spill from the Bahr el Jebel between Buffalo Cape and Lake No reaches the Bahr el Ghazal between Khor Doleib and Lake No, is collected by that river, and is returned to the White Nile at Lake No.

Lower discharges in the lowest reach of the Bahr el Jebel under the Project will not, however, result in any appreciable deterioration in navigation on the Bahr el Ghazal because the levels there will be determined by the level at Lake No, owing to backwater, and will be at the most 30 cm. lower in the untimely season (see Table 217, p. 451).

ROADS

The Equatorial Nile Project may affect roads in three ways: as a result of reversing the river seasons, present dry season roads may be flooded; the Jonglei Canal may cut across existing roads and will also provide new roadways on the canal banks; and, indirectly and as a result of the altered pattern of river transport, changes in the network of roads, particularly of those serving ports, will be needed.

The only existing dry season roads which might be flooded are those radiating from Juba where they cross dry beds of rivers such as the Kit, Luri, Koda, and other khors between Mongalla and Juba on the east bank. (There are also one or two khor crossings between Mongalla and Bor.)

The level of the bed of the Kit at the dry season crossing is R.L. 458·10 m., and the site is 800 m. above the mouth of the Kit where it joins the Bahr el Jebel. During January, February, and March 1952 the mean monthly flows of the Bahr el Jebel at Mongalla were 62, 60 and 59 m/d respectively. The reduced level of the water surface at the mouth of the Kit on 20.2.52 was 457·12; we can therefore say that the Kit crossing is one metre higher than the Bahr el Jebel level when the discharge is 57 m/d at Mongalla, equivalent to the present normal lowest flow in the dry season and the future lowest in the rainy period. The future normal maximum dry season flow, 90 m/d, is equal to the present normal maximum in the rains. From the 1912–42 normal gauge-readings at Rejaf (*The Nile Basin*, Vol. III, 3rd Supp.), which is 3 km. downstream of the mouth of the Kit, the normal range of river levels is 70 cm. from lowest to highest. The dry season crossing will therefore not be affected by higher discharges in the dry season under the Equatorial Nile Project. A further computation based on slopes, distances, and gauges at Juba and Rejaf for November 1942 when the discharge was 90·8 m/d gave a reduced level of the water surface of 457·94 at the mouth of the Kit.

Similarly we have been able to observe that the dry season crossing on the Luri, 4 km. from its mouth, was 2·52 m. above the water-level in the Bahr el Jebel on 29.4.52 when the discharge at Mongalla was 76 m/d. We can therefore say it will be unaffected, and we assume that the same applies to the Koda crossing.

On the east bank between Mongalla and Bor the experience of parties working in the field is that it is local rainfall running in local khors which cuts the road and not the Bahr el Jebel, though there are a few places which are obviously affected by the river. In any case it would be neither expensive nor difficult to align the road on higher ground to the east.

The Jonglei Canal on the ' Direct ' Line will cross the following roads:

From Awoi to Duk Fadiat
From Awoi to Ayod
From Fangak to Mogogh and Ayod
From Fangak to Sobat Ferry.

The only points where the Canal can be crossed will be at the head and tail regulators, and there will be 280 km. unbridged in between. Not only will Waat (an administrative centre) be cut off from Fangak, but the Canal without any bridges or ferries will interrupt the annual migration of the herds of cattle of which some 136,000 head cross the line of the Canal today. Under the Project riverain grazing will be reduced and possibly only 82,000 will need to cross in the future.

These are the main adverse effects, but on the other hand there will be ample room for an excellent road and a railway on the two banks of the Canal. It is not specified that the banks will be dressed to a shape suitable for a road (or railway), but it seems to us essential that they should be. The actual alignment of the road from Malakal and the position of the Sobat ferry may be changed to serve the mouth of the Canal in the future. Clearly some form of crossings must be considered, and this will be dealt with in a later chapter under the heading of remedial measures.

Apart from the re-alignment of the Bor-Malakal road on the Canal bank, as mentioned above, the main indirect effect of the change in the pattern of river transport resulting from the Project concerns the port for Bahr el Ghazal Province. At present this is at Shambe, and as explained previously many years are likely to elapse before the Project reaches the 55 m/d Canal stage when the Atem Head can become a main port, so that the construction of an all-weather road to Yirol should not be delayed. In the intermediate stages there will be no crossing over the Bahr el Jebel, though the Canal will be navigable in the 27·5 m/d Canal stage when the head and tail regulators of the Jonglei Canal will be built complete with locks.

Eventually it will be necessary to construct an all-weather road from Yirol to the site of the Bahr el Jebel barrage downstream of the Atem Head. We have given reasons for supposing that steamers will always be able to reach Shambe, and a shuttle service along the Bahr el Jebel will obviously be most desirable.

We must also draw attention to the improvement to be expected on the Ler-Wun Shwai road which joins Bahr el Ghazal Province with the port of Adok. Since there will not be any spill from the Bahr el Jebel, the flooding along the Bilnyang, which is the drainage system crossed by the road for 20 km. of its length, will be much reduced. Unfortunately this road lies on the Western Plain where the topography and soil are quite unsuitable for building an all-weather road, except at enormous expense. However, since flooding in this drainage system will be only that from the south-western torrents in the future, there may well be a marked improvement over the critical portion of the road. Adok is some 360 river km. from Malakal, compared with 343 from Malakal to the Atem Head by the Canal and dredged channel, but it is some 120 km. nearer to Wau by road via Tonj, though the soil is far inferior for building a permanent road. Nevertheless the point is worth recording.

TABLE 276

EFFECTS ON COMMUNICATIONS
NUMBER OF 10-DAY PERIODS DURING WHICH THE MONGALLA DISCHARGE EXCEEDED 90 M/D

Year	Number of 10-day periods above 90 m/d	Highest 10-day mean discharge m/d	10-day period during which highest discharge occurred
1905	24	121	September 1 and 2
1906	32	142	September 2
1907	31	118	September 2
1908	7	121	August 3
1909	14	136	September 3
1910	9	137	September 2
1911	—	87	September 2
1912	4	112	September 2
1913	—	84	May 1
1914	7	115	November 2
1915	9	104	October 1
1916	20	205	September 3
1917	36	245	October 1
1918	36	162	January 1
1919	8	110	September 1
1920	1	95	August 1
1921	—	65	October 2
1922	—	67	September 1
1923	2	101	August 1
1924	—	69	November 1
1925	—	67	November 3
1926	8	109	August 2
1927	—	79	June 1
1928	4	134	May 3
1929	—	77	May 1
1930	1	96	November 1
1931	11	116	September 1
1932	14	125	August 1 and 2
1933	7	123	September 2
1934	3	112	August 3
1935	—	84	May 2
1936	—	88	August 1
1937	5	99	July 1
1938	10	113	August 3
1939	—	80	August 3
1940	—	84	August 2
1941	2	109	June 2
1942	15	138	September 2
1943	4	94	August 2
1944	—	76	May 2
1945	—	88	August 2
1946	4	122	August 3
1947	10	124	September 1
1948	14	122	October 3
1949	7	114	August 1
1950	3	99	September 3
Total 1905–50	362		

TABLE 277

EFFECTS ON COMMUNICATIONS
NUMBER OF 10-DAY PERIODS DURING WHICH THE MONGALLA DISCHARGE WAS LESS THAN 57 M/D

	Year	Number of 10-day periods below 57 m/d	Lowest 10-day mean discharge m/d	10-day period during which lowest discharge occurred
	1911	4	55·5	February 3
	1912	17	43·2	March 2
	1913	11	46·4	March 3
	1914	13	48·7	March 3
	1915	—	59·9	March 2
	1916	—	57·0	March 2 and 3
	1917	—	96·2	March 3 and April 1
	1918	—	93·6	December 3
	1919	—	74·4	March 3
	1920	5	52·6	March 3
	1921	33	35·8	May 1
	1922	32	31·4	February 3
	1923	18	27·1	March 1
	1924	22	45·1	March 3
	1925	31	44·8	March 2
	1926	15	40·9	March 3
	1927	—	62·6	December 3
	1928	5	52·1	March 2
	1929	16	46·4	April 1
	1930	10	46·0	February 3
	1931	—	59·9	February 3
	1932	—	65·1	February 3
	1933	—	74·1	April 3
	1934	—	60·2	December 3
	1935	11	51·0	March 3
	1936	13	40·2	April 1
	1937	5	55·7	March 3
	1938	—	67·0	March 3
	1939	—	58·3	December 3
	1940	21	51·0	March 1
	1941	13	46·1	February 3
	1942	—	58·5	February 3
	1943	—	57·5	December 3
	1944	21	43·7	December 3
	1945	25	32·0	April 2
	1946	20	34·0	April 1
	1947	9	49·6	January 3, February 1 & 2
	1948	—	66·1	April 1
	1949	1	56·8	December 3
	1950	20	45·1	March 1 and April 1
Total	1905–50	391		

NOTE: During the period 1905–1910 the 10-day mean discharge was never less than 57 m/d.

NOTES AND REFERENCES

([1]) These formulae are based on the following assumptions: 1 ft. feddan = 1,500,000 kg. soil weight, since the apparent density of heavy soil = 1·2 (see Hall, A. D., *The Soil*, 5th ed., London, 1949, p. 60); sodium nitrate fertilizer contains 16% of nitrogen.

([2]) Berg, C. L., ' Notes on a visit to Ruanda to inspect swamp cultivation, August 1949 ', Uganda Govt. Report, unpublished.
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([3]) Berg, ' Swamp reclamation', op. cit.

([4]) Bulman, *Uganda Hydrological Survey Annual Report 1950*, op. cit.
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([5]) Pearsall, W. M., ' The investigation of wet soils and its agricultural implications ', *Emp. Jour. Exp. Agric. 72*, 1950.

([6]) Bontarie, A., and Thavenet, S., ' Recherches physico-chemiques sur les colloides humiques ', *Ann. Agron. 7*, 1937, p. 18 et seq.
Waksman, S. A., *Humus*, 2nd ed., London, 1938, pp. 309-14.

([7]) Jonglei Investigation Team, (Basinski, J. J.), ' Report on a visit to Uganda swamps, 1951 ', Sudan Govt. Report, unpublished.

PART II

DIRECT REMEDIES

INTRODUCTION

In the previous chapters we have attempted to assess the effects of the Equatorial Nile Project in the Sudan, beginning with the hydrological changes which will take place and then, through a whole chain of ecological events, the effects on pasture grasses and animal husbandry, on crop husbandry and fisheries, and on other more general interests such as navigation and road communications.

We have already stated that our investigation is based on the Project as proposed in Volume VII of *The Nile Basin*, subject to certain modifications set forth by Dr. Mohd. Amin and Mr. H. G. Bambridge. The effects of the Project thus proposed have been estimated in detail, and it is clear that the interests of the inhabitants of the Jonglei Area will be adversely affected and remedies must be found. These we refer to as 'direct remedies' since they must be applied if the proposed Project is allowed to go through without alteration. At a later stage in our report we shall turn to a more fundamental method of avoiding detrimental effects or at least substantially reducing them; this method we refer to as 'the Revised Operation'.

Whatever the other effects of the Project, it is manifest that the loss of dry season pasture is the most detrimental to local interests. Nearly all the inhabitants of the Jonglei Area depend to a greater or lesser degree on their livestock, and this dependence is the result of environment rather than inclination alone. We estimate that dry season grazing for 297,200 Animal Units will be lost. These animals at present make use of the flood-plains of the White Nile system—of what we call 'riverain swamp pasture'—during the dry months of the year, when the rivers are low and the pasture is accessible. Deprived of this asset they will be forced to rely on inland grazing which is generally of poor quality at that time of the year, even in optimum conditions, and varies in quality according to factors far more diverse and less reliable than the seasonal inundations of the rivers.

Assuming that the Project is to be carried out without modification of the present proposals, our first task is to find, by one means or another, alternative pastures to support animals during the critical time of the year—the dry season. It is clear that in present circumstances full use is not made of existing grasslands and that much wastage is caused by indiscriminate burning and uncontrolled grazing in the vicinity of water supplies. The exploitation of inland pasture by the provision of water-points and by improved pasture management is obviously the most economical method of remedying losses on the river-front. Such methods are, however, by no means universally practicable, so that additional aids must be applied in the form of artificial works to improve the value of existing indigenous grasses or to produce better ones. These methods range from comparatively simple engineering works, such as contour banking or the banking of watercourses, to more complicated operations involving irrigation by gravity or even by pump. As another form of remedy we must examine the possibilities of improving the quality of the livestock; in other words the reduction of actual numbers with an improvement in quality, aimed to maintain the present output of animal products.

The capital costs of installation and running costs naturally increase in direct proportion to the complexity of the schemes, the extent of the engineering works, and the degree of centralized control required. Our primary objective is to provide pasture remedies which are the least expensive and the least difficult to introduce to the people. In the first section of this part of our report we therefore examine the potentialities of animal husbandry and pasture management in general under four main headings: the fuller utilization of natural pastures; the improvement of natural pastures; the provision of alternative pastures and fodder crops by irrigation; the improvement of livestock.

These remedies may well prove impracticable or uneconomic in many areas, so that we must also consider what alternatives there are if there is no means of producing pasture. In most parts of the Jonglei Area, especially in the Flood Region, animal husbandry plays an all-important part in the economy of the inhabitants—though its importance is admittedly sometimes exaggerated—because crop husbandry is generally unreliable and gives small returns for great expenditure of energy. We must therefore examine the potentialities of crop production and attempt to discover ways and means of overcoming present agricultural difficulties. As we have seen, the flood-plains of the Nile system between Nimule and Kosti are not exploited for the growing of crops to any great extent, though the potentialities exist. Such small direct losses in crop husbandry as will result from the implementation of the Project must be considered, but our main object is to discover agricultural alternatives in those areas where no pasture remedies can be applied. This applies where it is simply not possible to provide the pastures by any of the means mentioned above, or where their provision is initially so expensive and the running costs so high that some other form of remedy is clearly more satisfactory and economic. In considering such alternative livelihood, we must again remember that in present circumstances the life and culture of the people is conditioned by seasonal movements and indelibly stamped with the traditions of a pastoral existence. A change from a migratory pastoral to a sedentary, or partly sedentary, way of life will mean drastic changes and in some cases even resettlement of the population. It is for this reason that we sometimes speak of ' agricultural alternatives ' rather than agricultural remedies.

The difficulties of crop husbandry in the Jonglei Area, and the limiting factors, have been described in the previous volume (see Vol. I, Chap. 5). The potentialities and possibilities of improvement are discussed below in general terms under the following main headings: agronomic improvements; enlargement of the area under cultivation; better control over environment; collateral improvements; the implications of animal husbandry; problems of developing agricultural potentialities to remedy losses under the Project. All these possibilities might provide an agricultural equivalent to losses in pasture and animal husbandry, but the difficulties of finding a suitable conversion factor are considerable. The way in which we have attempted the conversion is described later (see p. 612).

We then describe remedies for losses in other vital interests—communications, etc.—and consider the engineering aspects of remedial measures. Fisheries are discussed at a later stage (Chap. 9, p. 666).

Having covered the potentialities in general terms, we must select those which appear to be the most promising and, having done so, present them in terms of actual remedial schemes. Here we must give a word of warning. Although we have been able to carry out a number of short-term trials (see in particular Vol. III), most of them have been confined to the collection of basic information and numerical data not available at the outset of our investigation. The main object in designing these schemes is to provide a ' yardstick ' upon which some estimate of the costs of remedial measures can be based. We recommend the *type* of scheme we think most likely to be successful, but it would be manifestly absurd to suggest that they should be carried out exactly as we have planned them. A great deal more research and practical experiment in the form of pilot projects will be essential before any of our ideas can be put into practice. There will doubtless be many criticisms; these will be welcome because only by means of constructive criticism and practical trials can the most satisfactory solution be found.

We must also mention another criticism which is bound to be raised. This concerns the very real question whether any of the people concerned will take to such innovations in their present stage of development; whether any of our suggestions are likely to have the least attraction for the inhabitants of the Jonglei Area. We are well aware that the migratory pastoralists—especially in the Nilotic areas—are unlikely to turn of their own accord from a form of life in which cattle play a predominant economic, social, emotional and ritual role, to some other form of life, which is not only different, but requires a high degree of centralized control and a complex economic organization. Their attitude will largely depend on the degree of advance in other spheres in the interim, and the question is bound up with the whole problem of political, social, and economic development of the area. The question is probably unanswerable at this stage, even if it were possible to determine the multiple factors involved. Nor are we able to predict the course of future political events.

Finally, it would be logical to attempt some forecast of the results of the proposed schemes; the effects of the remedies on the people themselves. It is clear that if the people lose their livestock, particularly their cattle, a whole chain of economic and sociological repercussions will follow. Yet many peoples have been forced to abandon their livestock and have been able to adapt themselves to new conditions without the results being necessarily harmful. That there will be such repercussions should be obvious, and we have already attempted to describe in very brief terms the social structure of the tribes and the part played by cattle in their lives; a part which is by no means solely economic. Beyond very generalized statements we do not think that the effects of remedies in this sense are predictable, and confine ourselves to the one stipulation—that an alternative means of livelihood shall be provided and shall give opportunities to maintain a standard of life at least equivalent to that of the present, while also giving equivalent opportunities for material advance.

It is worth while adding here, though this is brought out in greater detail later, that our primary objective is to maintain the *status quo*; in other words to disturb the present social and economic equilibrium as little as possible. Our first aim is therefore to preserve the animal stock and all the natural resources upon which the present economy is based. We also aim to provide remedies as far as possible within the territory of the people concerned. Again these objectives may be subject to criticism. It may be claimed that our object should be to design a new way of life which makes better use of local resources as they will be when the Project is completed. In many cases it may seem that the most obviously profitable economic activities would not be those which we actually recommend. This is often true, but in many cases the most obviously economic schemes would involve very considerable reorientation and often even resettlement of population on a very large scale. We consider our method of approach—the application of remedial measures with the least possible social and economic disturbance—to be the correct interpretation of our terms of reference.

It will be noted that even in recommending agricultural alternatives, we aim to retain livestock within the schemes, though here the first objective is the maintenance of nutritional standards. To design a new way of life for the whole area, to provide a ' blue print ' of the best possible exploitation of natural resources, falls within the sphere of what is generally called ' economic development '. In many instances remedial measures and economic development necessarily overlap, but, since our instructions are to avoid problems of economic development as such, in many cases we have not examined the problems further. We hope, however, that much of the information recorded in this and other parts of our report will be of some use to those responsible for more immediate economic problems.

Having selected the types of remedial schemes and the forms of alternative livelihood which, in our opinion, are most likely to be successful, and having determined the unit costs of each, our next task is to consider which scheme is best suited to each specific locality. For this purpose we have divided the Jonglei Area into twelve main divisions, the classification being based on various factors which will be described later.

CHAPTER 6. PASTURE REMEDIES

In presenting our ideas and proposals for pasture remedies we must draw attention to those sections in the first volume of our report in which existing pasture grasses and their carrying capacities are discussed (in particular see Vol. I, Chap. 4). Reference should also be made to the description of the various trials and experiments carried out during our programme of field work (see Vol. III, Chap. 6).

1. THE FULLER UTILIZATION OF NATURAL PASTURES

PROVISION OF DOMESTIC WATER SUPPLIES

Although much of the grassland of the Jonglei Area remains unused, there are very few places where natural inland pastures are of value in the dry season. The reasons are discussed, Region by Region, below, and where additional water supplies would be useful the type and number per unit of area are recorded.

THE IRONSTONE REGION

In this Region inland grasses are mainly tall mixed annuals and perennials. At the end of the rains season they are coarse and largely unpalatable to stock. If this coarse growth is burnt off there is little or no regrowth produced until the early rains of the next season. Therefore there are virtually no natural pastures that could be exploited in the dry season by the provision of water supplies.

THE FLOOD REGION

Practically all inland pasture remaining unused in the dry season is found on intermediate land and is coarse and not nutritious. Only where it produces regrowth after the coarse growth is burnt is this type of grass of any value in the dry season. But its value is still further restricted; only in depressions, where soil moisture is retained and where green regrowth is produced throughout the dry season, is this type of intermediate land capable of supporting what is regarded locally as a good standard of livestock. As far as the Jonglei Area is concerned, intermediate pasture of this quality is only to be found along the western fringe of the Eastern Plain and the southern part of the Western Plain. From the information available we have estimated the stock-carrying capacity of this pasture to be 30 Animal Units to the square kilometre throughout the dry season. Water can be provided by excavating hafirs or by sinking deep-bore wells, the former supplying 750 Animal Units for the four months December to March and the latter supplying 2,500 Animal Units for the whole year.

Since this type of pasture is confined to drainage depressions, the area on the Eastern Plain is long and narrow and rarely more than 2 km. wide. On the basis of the figures recorded above, a deep-bore well services an area of 83 sq. km. and is therefore not suitable because the distance from the perimeter of the grazing area to water might be as much as 42·5 km. Hafirs, each watering 750 Animal Units, would supply an area of 25 sq. km. and would therefore be the most suitable form of water supply. But the quantity of regrowth is limited and not entirely reliable, so that we cannot recommend this method of providing alternative grazing.

The only large area of inland dry season pasture in the Flood Region not used at the present time is in the Machar Marshes. The edges of these swamps are already used as dry season grazing grounds by a few of the Nuer from the south (Eastern Jikaing) and by Dinka (Paloich) and Arabs (Rufa'a el Hoi) from the north. The western fringe is occasionally used by Dunjol Dinka when their normal dry season pasture is in short supply. The deterrent against the use of the western fringe is the waterless plain that lies between the permanent villages, along the Nile and Khor Wol, and the swamp. Accessible water supplies sometimes give out and people have been known to die of thirst either at the swamp or on the waterless plain on the way back.

To make available the dry season grazing in the Machar Marshes is simply a matter of supplying reliable water-points across the intervening plain and, in case of need, along the western fringe of the swamp. These watering points would be used only to supplement natural water supplies. It is not possible to say how much dry season pasture is available, but it is safe to assume that it is sufficient to accommodate several thousand Animal Units.

If hafirs provided on the route from the Khor Wol to the western fringe of the swamp were used for a maximum of four days over the double journey by any group of cattle, a single line of four hafirs, each 9,500 m^3., at 15 km. intervals would suffice for any number of livestock up to 26,000 Animal Units. Along the fringe of the swamp an additional reserve of three hafirs for every 6,000 Animal Units would be required to supplement the surface drinking-water of the swamp. This is sufficient for two complete months, or for very much longer if used only as a supplement.

We consider that in no other area is there sufficient reliable dry season pasture to be exploited as an alternative to riverain pasture.

THE SEMI-ARID REGION

Wherever natural pasture remains unused the reason is generally an inadequate water supply. In the dry season water is obtained from hand-dug wells in and around rains season pools and dried up watercourses, and these wells supply water for as many animals as the grassland within a day's walk is capable of supporting. Only a few places, well away from these well-centres, carry a surplus of grass and some of them, particularly in the southern part of the Region west of the Nile, have already been earmarked for agricultural development. For this purpose hafirs have been excavated at the few suitable sites, and this stored water is sufficient for cultivators and for the few domestic livestock required to provide milk and meat for their families. Sites for additional hafirs may not be found, for the local catchment is insufficient in this medium rainfall area (less than 600 mm. per annum). The water from deep-bore wells in this Region has been found to increase in salinity from Kosti latitude southwards to Er Rua'at where it contains 8,000 p.p.m. salts. This has been shown to have no ill effects on cattle over the short period of a week, but no prolonged tests have been carried out. In this Region a hafir of 9,500 m^3. capacity will cater for 500 Animal Units daily for the 7-month dry season and a deep-bore well can provide water for an average of 2,500 Animal Units daily over the year.

East of the Nile there is either no inland grass to exploit (north) or there is no pressing need to use it (south): west of the Nile there are two areas carrying a small surplus of grass at the present time and both might be worth exploiting. That around Jebel Megeinis is partly grazed in the rains season by the Kawahla of Kordofan Province, and its use by Ahamda of Blue Nile Province during the dry season would therefore be a source of friction. Between Jebel Megeinis and the Nile is slightly undulating country of alternating bush and grass plain, parts of which are grazed in the dry season, while water lasts, by Seleim and Ahamda animals. This area, extending as far south as the latitude of Jebel Ahmed Agha, measures approximately 2,000 sq. km. and we estimate that it would carry an additional 8,000 Animal Units during the dry season. Water for this number would have to be supplied either by three deep-bore wells or sixteen hafirs.

IMPROVEMENT OF PASTURE MANAGEMENT

Current pasture management in the Jonglei Area is designed for the convenience of the animal-owner and his livestock and takes little account of the effect of such management on the pasture itself. In the Ironstone and Flood Regions there is excessive grass growth in the rains season and, as far as flooding will permit, the livestock move over a large area. The result is that all except the high land grass becomes tall and coarse and its value in the dry season is restricted to the provision of roughage, or of regrowth after the coarse grass has been burnt. If during the rains season the livestock were herded on a limited area of intermediate land, the grass would be kept reasonably short and the stock-carrying capacity of that remaining at the end of the rains would be at least as high as an equal area of regrowth. Only limited areas could be treated in this way and there are difficulties because much of this land is flooded, but the method would undoubtedly lead to an improvement of existing pasture.

The coarse rains growth of grass on the plains of intermediate land is generally removed by burning in December and January. The possibilities of preventing this waste of naturally produced fodder by conserving it as hay and silage are considered in a later section. But in the Semi-Arid Region most of this surplus rains season growth dries on the root to the consistency of hay and can be grazed throughout the dry season. Much of this grass is destroyed annually by fires which are generally started unintentionally but which sweep uncontrolled over large areas of grass and bush. There is no need for burning grass in this Region except for *hariq* cultivation, in which case the fire is controlled, or to prevent the spread of bush when it is also controlled. To attempt to protect a very large area of grazing land by clearing fire-lines would entail considerable labour and expense; but control by regulation should be possible, the burden being carried by local communities.

Similarly no attention is at present paid to restricting the stocking of an area to its carrying capacity. Starvation and diseases are the two main factors controlling livestock numbers and every effort is being made to control disease by the Sudan Veterinary Service. It follows that efforts should be made to keep livestock numbers within reasonable limits, according to the pasture available. This applies mainly to Kosti District in the Semi-Arid Region, where, particularly west of the Nile, overgrazing is widespread and the deterioration of pasture is evident. The introduction of a policy to control numbers of animal stock is already overdue.

CONSERVATION OF FODDER

Thousands of square kilometres of grassland are fired every year in the Jonglei Area. This means that much potential fodder is wasted. The firing of grassland is either accidental as in the case of the short annual grasslands of the northern part of the Jonglei Area, or deliberate as in the tall annual grasslands (*hariq* grasslands) and perennial grasslands farther south. In the *hariq* grasslands it is part of the native method of crop husbandry; in the perennial grasslands it is a part of the native method of grassland and animal husbandry, for from the charred tussocks of the perennial grasses a limited amount of green regrowth is produced at the critical period in the dry season when the riverain swamp pasture is still unexposed. When the short annual grasslands are accidentally fired the fodder is completely lost for that dry season; when the perennial grasslands are fired some regrowth is produced, but, as many visitors to the Jonglei Area will have noted, the amount of green grass that is available as a result is only a fraction of the potential fodder that has gone up in smoke in producing it. Firing, by removing the old herbage, creates the stimulus for the production of the regrowth. Cutting the material would produce that stimulus equally well. There are, however, good reasons for not cutting and conserving this herbage instead of burning it. An examination of the grasses at this time (November–December) shows that they are tall (5–6 feet or more), stemmy, woody, and undoubtedly very unpalatable; further their feeding value is particularly low. No great benefit would be reaped if this herbage were cut and conserved since it would, at best, only provide poor roughage, no better than that which could be obtained if such areas were protected from fire.

Cutting such herbage (in November–December) for conservation as fodder is therefore not worth while. This is true of all areas. Material intended for conservation as fodder must therefore be cut at other times of the year. The growth period of all grasses is the rains season and it has been seen in Volume I (p. 256) how the nutritive value of the grasses decreases as the grasses grow older. To obtain worth-while material the herbage must therefore be cut at some time during the rains period; this applies to all types of pasture with the exception of herbage which is harvested from riverain swamp.

Before we proceed further we must consider what methods of conserving fodder are usually employed. The oldest method, that of hay-making, is the most obvious. Silage-making and grass-drying are alternative methods. But whichever method is employed, good quality material must be used. Old, stemmy, and woody herbage with high crude fibre and low crude protein values will remain poor or become even poorer when conserved as fodder. Below we consider the practical possibilities of conserving fodder by the above methods under the conditions prevailing in the Jonglei Area.

HAY

The underlying principle in hay-making is the reduction of the moisture content of the material from about 80% to about 16%. After this process has been carried out the material is sufficiently dry to resist decay by bacterial action when it is stacked. The desiccation of the material to the required moisture content is facilitated by wind, sunshine, low humidity, and the treatments prior to stacking. In the Jonglei Area it is possible to produce first-class hay from freshly cut material in the dry season (i.e. from riverain swamp pasture), but climatic conditions make hay-making difficult during the rains season. At this time the relative humidity is high and the drying of the material is not always possible. A further difficulty is that the land from which the grass is cut is usually saturated or even flooded; this applies to all areas with the exceptions of the *qoz* pastures (of the Semi-Arid Region) and the better-drained areas in the Ironstone Region. In the Flood Region in particular, the high relative humidity and the surface flooding of the large areas of intermediate land which produce the bulk of available material are the two main factors that make hay-making difficult.

In areas free from surface flooding the high relative humidity is the controlling factor, together with the unpredictable weather. In some years there are periods of two or more weeks without rain, during which time conditions may be reasonably favourable for making hay: in other years rain may fall regularly every few days throughout the season, thus rendering drying of the material almost impossible. Operations after cutting, such as swath turning and tedding, facilitate drying, but if a recent downpour has caused surface ground flooding no operations are possible. Even without surface flooding, continuous rain may cause loss of soluble constituents by leaching.

Although attempts at making hay have been made by the Team during the last two years, no really good hay has yet been produced; but given the proper machinery, which would hasten the operation (all attempts have so far been with hand labour), it is likely that reasonable hay could be produced. However, in most parts of the Jonglei Area the conditions under which mechanized implements would be required to work are generally unfavourable. On the intermediate land of the Flood Region the ground is particularly uneven and the grasses widely separated in large clumps. Furthermore the area is subject to flooding. It is doubtful if the normal implements used in hay-making could stand these conditions and it would be necessary in the first place to assess requirements and probably to have implements made to special specifications.

So far we have not considered the making of hay from riverain swamp pasture. It has been mentioned previously (Vol. I, p. 277) that McLaughlin has investigated the mechanization of hay production from material cut from the riverain flood-plain in Kosti District and a description of the method employed has been given. The method McLaughlin suggested in his report should prove valuable, but if applied farther south in the rains season the difficulties in drying would be similar to those already described. On the other hand if applied in the dry season reasonable hay could be produced. It would, however, be much more practicable to cut the grass from the areas inaccessible to livestock and transport it to the banks where it could be fed directly to the stock when fresh—as may well be necessary in the Southern Zone where, under the Project, some swamp pastures will be inaccessible in the dry season.

Silage

Conserving the rains growth of grass as silage would appear to have great possibilities because the chances of success are not so endangered by weather conditions as in hay-making, since the grass may be conserved in a succulent condition and no drying is necessary.

For good silage, young grass is desirable. In England grass cut between 6 and 8 inches provides a high protein silage if made correctly. Under Sudan conditions, especially on the intermediate grasslands of Upper Nile Province, vast areas would have to be cut before sufficient material at this stage of growth would be available for ensilage because of the poor ground cover. On the other hand the short annual grasses produced on the high land in the Flood Region and on the *qoz* pastures of the Semi-Arid Region would provide good material, although most of this is consumed by grazing animals in the rains period. In the Flood Region it would probably be necessary for the grass to reach the height of 12–15", at which stage it would still be 'young'. The material would therefore have to be cut in the early rains period and at this time it might prove possible to work on the intermediate land and to carry the material to the silo.

In normal practice the freshly cut material is usually transported directly to the silo where the process of ensilage takes place, although sometimes it is ensiled in the field in a trench or pit. It is also necessary that the silo should be well drained and tightly sealed once the material has been placed inside. Although various types of silos are used—such as concrete tower silos, brick silos, trench silos, or even stack silos where the material is merely stacked like hay with heavy material placed on top to give added consolidation—tall, round tower silos are regarded as the best. They are, however, costly and probably trench silos would serve the purpose in the Jonglei Area, although in this method there would be some wastage. Drainage of the silo would prove the most difficult factor, especially in the Flood Region where the land surface is so flat and where suitable silo sites would thus be hard to find. The difficulties of selecting suitable types of silo and sites could no doubt be overcome.

Although the initial results of silage-making at Malakal have not been encouraging, increased experience and the mechanization of the operations would probably ensure the production of reasonable silage. No molasses was used in the filling of the silo at Malakal and it is thought that the addition of sugars would not be practicable; it would certainly increase costs. In present circumstances the only sources of molasses in the Sudan are well outside the Jonglei Area and costs of transport would be high.

Hay and Silage Combined

The possibilities of taking cuts for silage, and later a hay cut, from the same area of intermediate land in the Flood Region are worth considering. It has already been mentioned that the intermediate land is invariably flooded when the grass is at the right stage for hay-making and that when the land becomes accessible again the grass is far past the stage when it could be made into hay. On the other hand when the grass is at the stage most suitable for silage-making the land is usually accessible—although the difficulties of cutting such short herbage (say 12–15″ high) with poor ground cover on very uneven land would have to be overcome by producing the right type of implement. It is worth considering therefore whether or not it would be possible to take one or more cuts for silage in the early rains period before the land became inundated, and then another cut for hay from the same area at the end of the rains season when the conditions for hay-making had improved. It is probable that the first silage cut would cause a set-back in plant growth which would result in the inability of the grass to reach the woody seed stage by the end of the rains season. More suitable and more valuable material would then be available for conserving as hay.

Unfortunately we have been unable to carry out experiments in this combination, but it is thought worthy of further investigation. Without further experiment it cannot be considered as a remedial measure.

Artificial Grass-drying

This is the most recent method of conserving fodder and is mainly employed as a means of producing a protein-rich concentrate. When grass is cut for drying, it is cut at a much earlier stage than when cut for hay or silage, usually (in Great Britain) when it is 5–10″ tall, the cuts being taken every four to five weeks. The young cut herbage is carried to the drier where it is dried by being brought into direct contact with hot air.

Grass-drying has the advantage of being largely independent of weather conditions in the same way as ensiling, since the herbage is not left at the mercy of the elements in the field. The cost of production is, however, high, and grass-drying is only economic if the product is a high protein concentrate for which there is a ready market.

Although grass-drying would appear to be an excellent way of conserving the surplus rains growth, there are both operational and economic drawbacks. The more obvious drawbacks are the difficulties of operating on the clay land of the Flood Region in the rainy season, because of flooding and the unevenness of the ground. These would make it almost impossible to take cuts from grass only 5–10″ tall. Under such conditions it is probable that only one cut could be taken and then only if a suitable machine could be designed. With the annual short grass pastures it is doubtful whether there would be sufficient material available for conservation, since most of these grasses are heavily grazed during the rains period.

Most grass driers are stationary constructions and the material has to be transported to the drier. This immediately presents a problem since most roads in the Flood Region are closed by the time the grass is suitable for cutting. Portable driers of normal design would not be practicable in this Region for the same reason. Further, it is necessary to have a supply of fuel on which to run the machine, so that there are additional transportation costs. The practicability of grass-drying in the Jonglei Area is therefore very questionable.

CONCLUSION

We conclude this section on the fuller utilization of natural pastures by saying that no large-scale alternative to riverain pasture is to be found in existing natural pasture, in its improved management, or in its conservation as hay and silage. Only in a few small areas is there unused pasture in the dry season and only in four places could this supply a partial remedy. These places are:

(i) The western edge of the Eastern Plain.
(ii) The southern part of the Western Plain.
(iii) The Machar Marshes.
(iv) The plain west of the White Nile extending to the Kordofan border from the latitude of Gelhak northwards to the latitude of Renk.

The pasture in areas (i) and (ii) could not be used on a scale sufficiently large to warrant consideration here, but a scheme for its improvement will be described later. The exploitation of the pasture in area (iii), the Machar Marshes, would be possible, and details are given in a later chapter (see p. 642). We have not sufficient information on the pasture and its carrying capacity in area (iv), or on the availability and potability of water, to justify our recommending the exploitation of this pasture as a definite alternative to riverain pasture lost under the Project.

The conservation of the surplus rains season growth of grass should certainly be investigated further, but we are unable to recommend the adoption of any of the methods described as a possible large-scale remedial measure. It is true that this conclusion is based on a very limited amount of experience and it is possible that in the light of further work suitable methods may be found. However, before dismissing this remedy completely, it must be mentioned that fodder conservation could play a big part in conjunction with other pasture alternatives, especially if pasture irrigation schemes were established and the land levelled and sown out with superior grass species. These areas would be primarily designed to provide grazing in the dry season and there would be a surplus of grass available in the rainy period. If it were possible to get on to the land at this time of year, it would greatly increase the productivity of such schemes if the surplus grass could be conserved as hay, silage, or in the form of dried grass.

2. THE IMPROVEMENT OF NATURAL PASTURES

Pasture could be improved by following a system of rational pasture management as described in the previous section. Further improvements could be made by:

- (i) Draining the land, thus permitting year-round grazing and preventing the grass from becoming rank.
- (ii) Increasing the flooding of intermediate land pasture and improving dry season regrowth.
- (iii) Increasing the area of pasture through the clearance of bush.
- (iv) The extension and introduction of superior grasses and legumes.
- (v) The banking of inland watercourses, thus producing greater quantities of green dry season pasture in their beds and flood-plains.

In our brief discussion of pasture management we have said that much could be done to raise the standard, but not in such a way as to constitute a remedy on a large scale for losses caused by the Project. It will not be considered further, but the other alternatives listed above are treated in more detail below.

DRAINAGE TO PERMIT YEAR-ROUND GRAZING

Throughout the Flood Region the land-slope is so slight and the clay soil so impermeable that surface flooding occurs during a large part of the rainy season. Houses are built on any raised land to reduce the risk of flooding, and in some parts, notably west of the Bahr el Jebel, these inhabited rises are protected from encroachment of flood-water by low bunds. Grasses on the higher ground are very heavily grazed during the rains, while those on the flooded land are allowed to grow rank because the underfoot conditions prevent concentrated grazing. It is this flooded grassland that produces regrowth in the dry season, but only those parts subject to the greatest degree of flooding produce regrowth which lasts for long after the rains have ceased; land subject to lighter flooding may produce regrowth but this is usually of little or no value after January or February. If this type of high intermediate land could be grazed during the rains and the grass kept down to a manageable height until about September, the grass remaining at the end of the rains would be reasonably palatable and would also supply useful bulk.

This type of land at Malakal, carrying mainly *Setaria* and *Hyparrhenia*, was accessible during the 1952 rains season and the grass was kept in check when stocked at the rate of one Animal Unit per feddan. There was plenty of grass until the end of September, but in October grass growth ceased and little remained by the end of that month. This indicates that this type of grassland, subject to intermittent flooding, can be prevented from becoming rank by stocking at the rate of one Animal Unit per feddan throughout the rains season, or at least until September. If the land were then rested before growth ceased, the remaining grass could be expected to provide about one Animal Unit month's grazing per feddan (see Vol. III, p. 1043).

Since flooding prevents this type of land from being grazed drainage is obviously necessary, but, because the slope of the land is so slight, drainage can only be carried out in the vicinity of a main river or larger watercourse. For the encouragement of agriculture drainage is possible in a few selected areas, but it is not possible for the improvement of great areas of range pasture. The idea is recorded but its application will not be considered further.

CONTROLLED FLOODING OF INTERMEDIATE LAND PASTURE

In the Ironstone Region there is very little intermediate land producing green regrowth in the dry season; in the Semi-Arid Region there is no intermediate land except in the southern transitional part where it is not of great value. Only in the Flood Region, and particularly in that part of it called the Eastern Plain, is there an area sufficiently large and receiving enough water from rain precipitation and run-off to justify attempts to improve the pasture on a large scale. The principal grasses here are *Hyparrhenia rufa*, *Andropogon gayanus*, and *Panicum porphyrrhizos*. A large part of the plain produces dry season regrowth after the coarse growth of grass has been burnt, but this regrowth is only robust in the vicinity of drainage-channels and in depressions (see Vol. I, p. 286, and, for full description, Vol. III, p. 1023). The reason for the location of this robust regrowth is the presence of adequate soil moisture. As long as there is available moisture in the soil, the regrowth remains green and may even grow as far as the flowering stage without the assistance of rain. The land-slope on the plain is very slight (approximately 10 cm./km., see Fig. A 27), and during the rains the thickness of the grass stand combines with this lack of slope to prevent drainage or to slow down the passage of water considerably. The effect of restricting drainage still further is evident along the motor road from Kongor to Duk Faiwil, where the grass to the east produces strong regrowth while that to the west either does not produce regrowth or does so only for a short time after burning. At some places, particularly near to Duk Faiwil, the intermediate grass to the east of the road has been ousted by *Echinochloa* and *Oryza*, both river swamp grasses producing good regrowth in the dry season.

On the Eastern Plain—or on that part of it which we have investigated on the ground—the soil is classified as 'cracking clay'. During the dry season surface moisture is lost rapidly, owing to high temperature, low humidity, and wind action, and surface cracks appear. These gradually increase in size and depth until by the end of the dry season some may be 20 cm. or more in width and more than a metre in depth. During the early light rains these cracks allow water to penetrate deeply and, as the soil becomes saturated and 'swells', the cracks gradually close; the edges of the cracks crumble and cave in, and by the middle or late rains the ground surface is almost impermeable and much moisture is trapped in the lower layers.

On the better-drained land the surface layers give up their moisture quickly as soon as the rains are finished, and cracking occurs. This allows loss of moisture from the deeper layers by evaporation and soon there is insufficient available moisture to encourage grass regrowth. On the other hand, on lower-lying ground and in drainage depressions surface water remains longer and grass growth is probably thicker, both factors delaying the loss of surface moisture. Cracking is therefore delayed considerably and there is moisture available for plant growth for a much longer period. The facts certainly support the theory that the longer surface moisture can be retained, so as to delay cracking, the longer will dry season regrowth be produced.

If by raising small banks across the plain at right angles to the line of drainage we can so flood the land as to retain moisture in the soil during the dry season, the regrowth on the intermediate land so treated should continue fresh and green until the next rains.

There are two possible objections to this proposal. In the first place it may be argued that rainfall alone will not be sufficient to provide robust regrowth throughout the dry season. The average rainfall at Bor for the months July to October inclusive is 505 mm. ; evaporation over the same period amounts to 244 mm. On the plain evaporation is greatly reduced by the thick grass cover, but transpiration must also be considered and we assume that evaporation and transpiration together amount to not more than 244 mm. over the 4-month period, as follows:

	Rainfall (a)	Evaporation and Transpiration (b)	Excess of (a) over (b)	
			Monthly	Cumulative
May	125	96	29	—
June	120	63	57	—
July	142	47	95	95
August	135	47	88	183
September	131	54	77	260
October	97	96	1	261
November	24	145	− 121	140
December	7	206	− 199	Nil

In April the evaporation rate is greater than the rainfall. In May and June there is probably sufficient excess of rainfall over evaporation and transpiration to saturate the soil. Therefore if the ground surface had no slope, the excess would accumulate from July onwards as flood-water, reaching a maximum depth of 260 mm. However, the slope of the plain is to be counteracted by banking and so in this way rainfall alone is believed to be sufficient to produce the degree of soil moisture content required for a robust regrowth of *Hyparrhenia rufa* throughout the dry season.

In the second place the superiority of swamp pasture over intermediate pasture which has only indifferent regrowth has been emphasized in previous chapters. As an example, we have suggested that the deterioration in cattle types from east to west in the Bahr el Ghazal Province has a close connection with this difference in the relative value of pasture types. But the regrowth produced by this banking is expected to be robust and green throughout the dry season. Theoretically it should be so, and on that basis we have designed a remedial measure, but its value can only be proved by large-scale and long-term experiment.

BUSH CLEARANCE

In that part of the Ironstone Region with which we are concerned much of the forest is broad-leaved woodland and the inland grasses are of little value in the dry season. The trees in the Flood Region are mainly *Acacia seyal* and *Balanites aegyptiaca* and they are generally dispersed, allowing grazing animals free movement and the grasses plenty of light and rain. In the Semi-Arid Region there are large areas covered with a thick growth of *Acacia mellifera* and minor shrubs, which is so dense that it prevents the passage of animals or people on foot. Little or no grass can grow because of the unequal competition for light and moisture. If these areas of bush were cleared there is no reason why they should not be replaced by useful pasture.

The area under discussion is that west of the Nile and north of Gelhak where the average annual rainfall is about 400 mm. spread over a four-month season, June to September, and the soil is clay-sand on the plains with an increased percentage of sand on the raised land. The grasses are predominantly annuals; all, or nearly all, are palatable when mature or even when dead, and they furnish good grazing throughout the long dry season wherever water is available.

Our meagre information from experiments at Jebel Megeinis indicates that grassland at this latitude, when not broken by trampling, has a carrying capacity of one Animal Unit to four feddans. This is deduced from one sample from an area of only 25 sq. m. and is therefore liable to very considerable error. The result of our investigation at a well-centre nearer to Kosti (Saba-Asuda well-field: see Vol. III, p. 1052) indicates that the carrying capacity of the surrounding countryside, grassland and bush, is one Animal Unit to 10 feddans, or approximately 25 Animal Units per sq. km., and the countryside appears to be overgrazed.

To the west of the Er Rua'at-Abu Rukba road there is a large tract of land, about 1,800 sq. km. in area, at present closed to grazing because of the encroachment of thick bush. To restore this land to useful pasture the area of bush should first be cleared; after clearance the natural pasture would have to be given time to establish itself or grass mixtures could be sown and established. It is essential that the two processes should follow closely together, otherwise the exposure of the land to sun, wind, and rain would invite serious erosion. Also, in eradicating the bush it would be desirable to leave a fair scattering of larger trees which would provide shade for grazing animals and edible pods of considerable nutritive value, and protect soil, grass, and animals from the wind. Since there are no natural perennial water supplies in the area, domestic water would have to be supplied by surface reservoirs or deep-bore wells. These would need to be so placed as to allow proper grazing management, and so organized as to prevent overstocking of the reclaimed area.

ERADICATION OF THORN BUSH

The bush, which has no large trunks or branches, has no value as timber. The larger parts would be useful as wood fuel and much of the remainder could be burnt for charcoal, but the distance from markets would be too great to allow its exploitation. It follows that no financial return could be expected from the felled trees which would therefore have to be disposed of on the spot. Thus whatever method of clearance was used, the operation would be expensive.

Where there are pure stands of *Acacia mellifera* (Ar. *kitr*) the area could be cleared simply by burning; and provided the bush were sufficiently dense with a fair percentage of old trees, the survivors would be few. But generally, and especially where *Acacia seyal* (Ar. *talh*) is dominant, some mechanical means of clearance would have to be employed. If such methods proved necessary, it would be essential that large stumps were not left to produce coppice growth. If a cutting device were employed the trunk should be cut below the junction of stem and root, a procedure which should prove fatal in most cases.

Because there is a very thin covering of grass in this bush country the regeneration of pasture land would necessarily take some time. It would be essential to ensure that regeneration of the bush did not take place after clearing and stumping and before the area was occupied. For this purpose various killing agents could be employed (paraffin and arsenical poisons); they are generally applied to each individual freshly cut stump or to the exposed tap root. Probably the simplest and most effective method of bush clearance would be to pull the bush out to expose the roots and then sever them. This method has been employed in clearing land for irrigation schemes along the White Nile and, though extremely laborious, it has proved effective. The areas cleared, however, were minute in comparison to the 1,800 sq. km. that we have in mind.

Where a large labour force is lacking, mechanical methods are indicated, and of these much can be learned from the bitter experience of bush clearance in Tanganyika. Felling was carried out by a team of three heavy tractors, one at each end of a length of anchor chain which they dragged through the bush, and the third following behind to push over any stubborn tree that was not felled by the chain. The bush was thus torn up by the roots provided work was carried out in the rains season, for in the dry season the soil in some locations set like concrete. After felling, the land had to be cleared. To prevent erosion of the exposed soil the felled bush was swept into windrows following the contours of the land, and there it remained till the end of the rainy season. When it was dry it was burnt on the spot.

The problems of stumping, root-cutting, and levelling do not apply in bush clearance for pasture, but it is worth noting that in Tanganyika all these processes were originally performed by machinery and that later manual labour was employed. A report of the Overseas Food Corporation explains: "The considerations which led to the introduction of hand clearing into the sequence and the elimination of machine operations . . . (piling, stumping, raking, levelling) . . . were the comparative inefficiency of the mechanical operations accentuated by rising costs, the pulverization and removal of the top soil and the difficulties experienced in conserving land which had been so disturbed . . . a new department was created to carry out by hand the tasks of stumping, piling, burning and twig-picking. Such an organization, requiring an average labour strength of 2,600 men per month for the preparation of 15,000 acres of land, was dependent entirely on the ability to recruit . . ."[(1)].

An earlier report (1948–49, para. 81) showed that windrowing took twice as long as any other operation and four times as long as actual felling. But in Tanganyika there was a certain degree of urgency; as soon as the land could be cleared it was to be cultivated and cropped. In clearing bush for grassland there should be no need for haste after felling except to prevent new growth by stumping or poisoning. The brushwood lying on the surface would prevent erosion and, if cleared slowly, would allow the grasses to establish themselves without disturbance from rain, wind, or trampling. In these circumstances a comparatively small labour force could clear a large area over a period of several years.

The use of chemical herbicides has, within recent years, been investigated and applied on a small scale. But different tree species react differently and no universal arboricide has yet been found. The combination of a hormone herbicide in emulsion with diesel oil has shown promise in eradicating *Acacia deterens* in South Africa, but no information is available as to the practicability of its application in the Sudan.

In the absence of more detailed information, we must assume that bush clearance would be carried out mainly by hand and that the use of chemical or other herbicides would be restricted to the control of bush regeneration.

Regeneration of Grassland

Where there has been thick bush there is generally a very sparse growth of grass because of the unequal competition for light and moisture. Natural regeneration would thus take a considerable time and the need for a quick grass cover to prevent soil erosion has already been mentioned. The best results would be obtained by sowing out seeds of the best indigenous pasture grasses or of such foreign improved grasses as have been shown to thrive under local conditions. In either case a large supply of seed would be essential since the areas to be sown would be measured in square kilometres (a total of perhaps 1,800 sq. km.). Seed production itself would thus be a fair-sized undertaking, involving fencing, establishment of pure stands, seed collection, drying, storage, and testing. Because of the flatness of the country, sowing by machinery would be relatively easy, but sowing from the air might be employed because of the large area to be covered.

Domestic and Stock Water Supplies

It is sufficient to say here that sites for surface storage tanks will not be easily found in the Semi-Arid Region; most, if not all, useful sites have already been exploited. A plentiful supply of water could be provided by deep-bore wells but a great drawback would be the high salinity. Water from test bores already sunk in the area contained 8,000 p.p.m. (at Er Rua'at). It has been shown that this has no adverse effects on stock over a short period, but whether or not such water will support people and livestock over a 7-month dry season has yet to be proved. With grassland having a stock-carrying capacity of 25 Animal Units to the square kilometre, one twin-bore water-yard would be required for each 100 sq. km.; one yard can comfortably water 2,500 Animal Units per day.

PASTURE IMPROVEMENT BY THE EXTENSION AND INTRODUCTION OF SUPERIOR GRASSES AND LEGUMES

This method of pasture improvement is now gaining ground in many African countries where the old natural pastures have deteriorated under poor systems of pasture management. Efforts are now being made to assess the comparative values of indigenous and introduced grasses and legumes, with a view to pasture improvement by the introduction of selected species into the natural pastures. Similar efforts are now being made in the Sudan. Usually such introductions are part of some major scheme. For example, pasture land selected for irrigation is usually improved by sowing out superior grass species; similarly land cleared of scrub is often broadcast with superior grass species to improve the grazing value of the area. Therefore although such investigations have barely begun in the Sudan it is necessary for us to consider the possibilities of such improvement in our search for suitable remedial measures.

It will be appreciated from the study of the natural pastures of the Jonglei Area given in Volume I (Chap. 4) that there is much room for improvement and that their value is limited because of a number of important deficiencies. If these deficiencies could be met by introducing other species, then the value of natural pastures would obviously be enhanced. These deficiencies are considered below.

Lack of Edible Feed in the Dry Season

The lack of edible dry season feed, if we exclude that which is available from the riverain swamp and inland khor-bed pastures, is a fact of great importance throughout the Jonglei Area. It will increase in importance when the Equatorial Nile Project comes into operation, since the only present reliable source of edible feed—the riverain swamp pastures—will be reduced considerably.

Edible feed is in short supply for two reasons:

(i) The extreme unpalatability of the mature grasses of the Flood and Ironstone Regions. The majority of these grasses, although providing large bulk in terms of dry matter, are almost useless when nearing maturity and are of little value as dry season feed because they are tall, coarse, and unpalatable. This also applies to some of the grass constituents of the Transitional Belt between the Semi-Arid and Flood Regions.

(ii) The small bulk produced by the grasslands of the Semi-Arid Region in the rains season—which is soon consumed—combined with the unpalatability of some of the pasture species.

Low Quality of Feed

In Volume I (Chapter 4), it was pointed out that the grasslands of the Jonglei Area are predominantly graminaceous and legume contribution is almost negligible. This is particularly true of the grasslands of the Flood Region and obviously affects the nutritive value of the pastures. During the early rains period the young grass provides a well-balanced feed, the crude protein in the dry matter being reasonably high. This, as we have seen, rapidly decreases as the grasses grow older. The possibility of introducing legumes into the pasture to offset this decrease in crude protein should be considered. The legume would further enhance the dry season feeding value of the pasture at the time when the percentage of crude protein in most of the dry grass is particularly low.

The selection of material for introduction should be based on the above requirements. Within the Flood and Ironstone Regions selection should be for species with dry season palatability. Bulk is not such an important consideration because of the vast area of natural pasture that is potentially available. The aim should therefore be to introduce species that are palatable and readily eaten by stock at all stages, especially in the dry state. Furthermore they should not be excessively tall, so that they may be readily accessible to the grazing beasts. Naturally it would be desirable to have the most nutritive grasses and again the introduction of legumes would be advantageous.

Within the Transitional Belt between the Flood and Semi-Arid Regions there are natural grasses (*Brachiaria obtusiflora*, *Sorghum purpureo-sericeum*, etc.) that combine bulk with dry season palatability and a reasonable nutritive value. These grasses could be selected and their extension facilitated by sowing. In addition, the inclusion and extension of legumes would be beneficial.

In the Semi-Arid Region the selection should be of those palatable (dry season) species which provide the highest bulk in terms of dry matter, and have a high dry season nutritive value. The first consideration should, however, be bulk, but not coarse bulk, such as we have in the grasslands of the Flood Region where the grasses grow 6–10 feet tall and where the beasts, lost in a sea of grass, are unable to graze in comfort. What is required is a compact sward of reasonable height. The nutritive value of the pastures could be adjusted by the inclusion of suitable legumes.

Availability of Suitable Material

There is a wide range of grasses throughout the Jonglei Area and selection of the most promising types should be the first consideration. Most of these grass types are limited in their distribution to certain areas, but it might be possible to extend the distribution of the more valuable species into other areas. Further, there is an even wider range of material elsewhere in the Sudan and in other countries which deserves investigating under the conditions of the Jonglei Area.

In respect of the indigenous species we have still only scanty data on nutritive values, yields, palatability, etc., and our estimate of the value of the different grass species is still mainly based on observation of form and attractiveness to stock. We have negligible data on such points as seed viability, germination, ease of establishment, etc.

We are similarly placed with information about exotic grasses and legumes, for it was only in the 1951–52 season that any major introduction of exotic species was attempted, and these species have only been tested on the alkaline clay soils under irrigation at the Malakal Experimental Station.

We have therefore very little information on which to base recommendations, but below we attempt to give some indication of the suitability of the most promising species for each of the main types of grassland, together with the method of their introduction.

Grasslands of the Ironstone Region

The grasses of the broad-leaved woodlands within this Region have not been fully studied, but there is undoubtedly a wealth of grass material that deserves investigation. The future of this woodland area lies in the adoption of a system of mixed farming[2] in which grass is used to build up soil fertility after land, cleared of forest, has been cropped for a number of years. The pastures thus created would provide grazing for stock in open areas from which it might be possible to exclude tsetse. Under such conditions it would be necessary to select suitable grasses for sowing out pastures, and at this stage it is not possible to stipulate which grasses would be most suitable. After a number of years this land would be ploughed and recropped. The term of the rotation has yet to be worked out and years of experimental work are necessary. Further, much work is required to establish the best system of management for both pasture and stock.

Grasslands of the Flood Region

The two main grassland types (excluding the riverain swamp pastures), the *Setaria incrassata* type and *Hyparrhenia rufa* type, are for the most part made up of the type species which are suited to the ecological conditions under which they grow. Few other species growing in association offer themselves as suitable material in place of the type species, mainly because they are unable to compete successfully.

At present *Setaria incrassata* is little grazed in the dry season because of its unpalatability when mature. Associated species are also little utilized for this reason. Furthermore, only negligible amounts of regrowth are produced from this type of pasture when burnt. *Hyparrhenia rufa* is similar in respect of palatability but it does produce regrowth on burning, though this is unreliable except where there is adequate soil moisture. In both cases the main requirements are that the grasses for introduction should be short, palatable when mature (which would obviate the need for burning), and tolerant of alkaline clay soils subject to heavy flooding in the rains followed by six months' drought.

From the exotic grass species grown at the Malakal Experimental Station (under irrigation) species meeting the above requirements may be found, but none has yet been tested under such conditions, so no recommendation is possible at this stage[3].

Some of the most promising material introduced in 1952 from Australia contains a wide range of *Paspalum* species. One of the best of these seems to be *Paspalum dilatatum*, a deep-rooted grass known to be suited to moist heavy clays. Like nearly all other *Paspalum* species grown at the Malakal Experimental Station, it is a pasture type grass which meets most of our requirements. However, so far we do not know if any of these species could tolerate the alternating heavy flooding and long drought periods on intermediate land in the Jonglei Area.

Of those legumes introduced and tested, *Phaseolus lathyroides* may prove a useful plant for sowing out on the rains season grazing grounds which are subject to heavy cropping. It seeds prolifically when mature, at which stage it also grows woody, though heavy grazing might keep it at a more palatable stage. It has proved useful in Queensland, Australia, where a single planting of 1 lb. of seed over 10 acres led, within twelve months, to complete legume dominance over a stand of *Paspalum scrobiculatum* on an area of 100 acres[4]. Unfortunately little is known of the feed value of *Phaseolus lathyroides* or of the other legumes now introduced at the Malakal Experimental Station, but work carried out at the Brisbane Laboratory seems to indicate that all legumes, whether Mediterranean or tropical, can be classed as good feed for stock[5]. The introduction of *Phaseolus lathyroides* into the intermediate land grasslands of the Flood Region should not prove difficult and hand-broadcasting of the seed in the early rains might well suffice. Further study is clearly necessary.

Phaseolus lathyroides might also prove useful for introduction into high land pastures. These pastures are, however, limited since most of the high land is taken up by villages and crops. Other legumes have been tried at the Malakal Experimental Station, but at this stage it is impossible to say of what use they would be under the various conditions of the Flood Region.

Grasslands of the Semi-Arid Region

In Volume I (p. 268) we have listed the species found in the annual short grass pastures of the Semi-Arid Region according to whether they occur on the *qoz* sands, the non-cracking clays, or the cracking clays. As mentioned, none of these types produces much bulk and their dry season nutritive value is low; some species are, however, better than others, primarily because they are more palatable to stock in the dry season. We might therefore obtain more feed from these areas if we increased the present areas occupied by the more palatable types.

The most valuable grasses on the sandy *qozes* are *Dactyloctenium aegypticum* and *Brachiaria* sp. *aff. xantholeuca* since they appear to be palatable in the dry season. They are also high in nutritive value compared with other species. Harrison[6] has suggested the introduction of *Cenchrus setigerus* to replace the widespread *Cenchrus biflorus*. The former does not possess the burrs on the seed coat and is therefore palatable to stock in the dry season. A legume indigenous to the *qoz* pastures, particularly those with a red ferruginous surface, is the inconspicuous *Zornia diphylla*. Although it is small, its value is reputed to be high and its extension is obviously desirable. Of the exotic species examined at the Malakal Experimental Station the trailing legumes *Clitoria ternata*, *Glycine javanica* (a perennial legume), and species of *Desmodium* might be successful, although they have not been tried out under the conditions of the Semi-Arid Region.

The majority of the grasses found on the non-cracking clays have little value, with the possible exception of *Chloris pilosa*, *Tetrapogon* sp., *Dactyloctenium aegypticum* and *Sporobolus marginatus*, which could perhaps be extended at the expense of less valuable species. We are unable to recommend any exotic introduction because of the lack of information.

On the cracking clays of the *Acacia mellifera* sub-region the best indigenous grass available is probably *Sehima ischaemoides*, and in connection with the clearance of *Acacia mellifera* (considered in the preceding section) it would be desirable to have sufficient seed of this species available to sow out immediately after bush eradication. This would help to establish the dominance of the pasture quickly and to prevent the entry of less desirable types.

In the Transitional Belt or *hariq* grassland area by far the most valuable grass is *Brachiaria obtusiflora* since it combines bulk with dry season palatability and a reasonable nutritive value. At present its distribution is limited, probably because it is heavily grazed. This grass produces seeds profusely and there should be no difficulty in getting it established. In this area, however, the improvement of grassland for stock is subsidiary to the use of the area for *hariq* cultivation and grain production.

Practical Operations Involved

In all cases it would be necessary to establish seed production plots for the selected species in order that there should be sufficient seed available for large-scale introductions. Ploughing up of the old grassland, seeding by drill, and harrowing in of seed are not to be recommended since the cost would undoubtedly be high. Once the seed is available it should not be necessary to do more than broadcast it immediately before or at the beginning of the rainy season. Broadcasting of the seed could be done by hand or, if necessary, from the air by means of a helicopter or other type of aircraft.

In Kosti District much of the *qoz* pasture is found on land resting after cultivation. Here the grasses are usually inferior species of *Eragrostis* and *Aristida*. The basic principle, in semi-arid conditions, of resting land under fallow to ensure a sufficient supply of soil moisture at the right level at the time of planting for the next crop would not be unduly affected by establishing improved pastures, since the grasses would be short-rooted annuals[7]. If sown to pasture such areas could provide better grazing than they provide today.

In *hariq* areas the sowing out of the selected species after a good burn would ensure their early establishment and early dominance in the pasture (i.e., on grassland without cropping). In the *Acacia mellifera* areas re-seeding should go hand in hand with bush clearance. If mechanical means are used in the clearance, a good tilth should be available on which to sow the introduced species at the beginning of the rains period.

Riverain Grasslands

There is little difference in the constituent species of these pastures throughout the whole of the Jonglei Area and at present no grasses better than the indigenous *Echinochloa stagnina* and *Echinochloa pyramidalis* have been found. The replacement of *Phragmites communis* on *toiches* in the southern parts along the Mongalla–Juba flood-plain by more valuable species is, however, desirable.

Conclusion

The introduction of superior grasses and legumes from abroad, or the selection and extension of the better indigenous species, cannot in itself provide any large-scale remedial measure. It could, however, enhance other remedies—for example, the eradication of scrub in the Semi-Arid Region and the production of better pasture under irrigation. It must be appreciated that many of the better grass species require improved conditions such as drainage and better soil fertility. More important still, they usually require better management, and it is important that suitable systems should be adopted to ensure the continued dominance of the better species after they have been introduced. Without good management, the introduction of higher quality grasses does not give the maximum benefit. Suitable systems of management can, however, only be devised after many years of research.

THE BANKING OF INLAND WATERCOURSES

In the beds of inland watercourses and along their flood-plains the grass species are determined by the degree of flooding; the greater the depth and the longer the duration of the flooding (within certain limits) the better are the pasture grasses available in the dry season. The effects and importance of depth and duration of flooding have been described in considerable detail in the previous volume (see Vol. I, p. 152 et seq.).

The inland watercourses of the Flood Region have, in general, a very gradual slope to the main river and are of two kinds. First there are those which have a wide, flat channel, e.g. Khor Liet on the Zeraf Island. Secondly, there are those which have a deep, narrow channel with high deltaic banks and a broad flood-plain beyond, e.g. Khor Adar near Melut. The difference is significant and must be emphasized.

The grasses of the wide, flat channels of the first kind are generally of the shallow-flooded swamp type, i.e., *Echinochloa pyramidalis* and *Oryza* spp., with a narrow strip of the deep-flooded type, i.e. *Echinochloa stagnina*, in the centre of the channel. In the early dry season the coarse rains growth of the shallow-flooded species is removed by burning, after which regrowth is produced giving valuable dry season grazing. The small amount of deep-flooded pasture in the centre of the khor is left unburnt and when it becomes accessible also provides excellent pasture. The relative grazing values of these two types have been given previously (see Vol. I, p. 272), and it has been shown that the stock-carrying capacity of the deep-flooded type is in the region of three times that of the shallow-flooded type. The replacement of the shallow-flooded by the deep-flooded grasses would therefore obviously bring about great benefits along such khor systems. Since the spread of *Echinochloa stagnina* outwards from the centre of the khor is limited, because of the lesser depth and duration of flooding to which these outer areas are subjected, it should not prove difficult to create the necessary conditions over the rest of the channel-bed by constructing banks, behind which the water could be held up to the required depth and regulated so that it would remain on the area for the required period. Where the whole of the channel is covered with *Echinochloa stagnina* (deep-flooded type), as is sometimes the case, banking of this type of khor would be of little value.

Along inland waterways of the second kind (i.e. Khor Adar) the construction of banks, and the changes that would result, would differ from those explained above. The grasses found along the flood-plains of watercourses of this pattern are mainly of the intermediate land types, e.g. *Hyparrhenia rufa*, which often produce only a small amount of regrowth after burning. These flood-plains are only inundated from the khors in years when their discharges are unusually high, and then only for short periods. They receive most of their moisture by direct rainfall and run-off, which are sufficient in themselves to cause some flooding during the rainy season. In the dry season, since these flood-plains produce only very limited regrowth, the stock-carrying capacity is naturally low. By constructing a bank across the main channel and extending it beyond the deltaic banks across the flood-plain, water could be held up in the main channel and made to inundate the flood-plain. The amount of banking required would be much greater than that needed for watercourses of the first kind, but the area irrigated would be proportionately larger. Many square kilometres of unproductive land could be brought into use by subjecting it to sufficient flooding by these means, thus ensuring a reliable supply of regrowth in the dry season from the existing grasses.

By use of the above methods it should also be possible to bring about a change from the intermediate type pasture (i.e. *Hyparrhenia rufa*) to the shallow-flooded type pasture (i.e. *Echinochloa pyramidalis*) on some flood-plains, and from the shallow-flooded type to the deep-flooded type (i.e. *Echinochloa stagnina*) in the beds of other khor systems. There are unfortunately many practical and economic uncertainties attached to such schemes. We are uncertain (because of the lack of time to conduct detailed surveys) which khor systems are suitable for this form of improvement, since success or failure depends on impounding a sufficient depth of water upstream of the banks for a specified period. Detailed surveys would therefore be necessary before we could estimate what area of improved grazing could be produced by these methods. Without knowledge of the slope and discharges of these inland watercourses it is difficult to predict whether sufficient water is available, or would be available with banking, to produce the more valuable grass types over larger areas than at present.

Moreover it is clear that a full survey is required to determine the total area suitable for the application of these methods of producing pasture, and this would be a lengthy undertaking in view of the widely scattered network of watercourses. We cannot therefore recommend their application as a general pasture remedy over the whole area or on a large scale. Later, under the heading of ' combined remedies ', we draw attention to the potentialities of banking schemes for the provision of pasture in combination with other objectives; these include drainage for cultivation, domestic water supplies, and fisheries. The advantages obtained might more than justify the comparatively inexpensive engineering works required and, whether intended for remedial purposes under the Project or not, would certainly lead to a better system of land utilization in the Flood Region.

3. THE IRRIGATION OF PASTURES AND FODDER CROPS

As a general rule, wherever (from the engineering point of view) it is possible to irrigate land there is no technical reason why pasture should not be grown. However, bearing in mind the poor quality of the animal stock in the Jonglei Area, it seems doubtful whether the production of dry season pasture by irrigation would be economically sound. This applies in particular to areas where irrigation could only be carried out by mechanical pumping, a system which involves not only expensive installations, but also centralized control and highly trained staff. Where it will be possible (under the Project) to irrigate by other means (i.e. gravity and flush irrigation), the technical and administrative organization would not need to be so complicated and the cost of producing irrigated pasture might be much less. Even this method, however, might well prove uneconomic.

Under present-day conditions the inhabitants of the Jonglei Area are provided with dry season grazing as the result of natural irrigation by the normal seasonal fluctuations of the main rivers; no organized or rigid system of grazing control is necessary. If irrigated pasture were provided, both grazing by stock and the movement of the inhabitants would have to be strictly controlled. Such control over their movement would not readily be accepted by the inhabitants, especially in the Nilotic area where irrigated pasture might be provided along the line of the Jonglei Canal. This would involve a complete reorientation of the seasonal migrations of the people. It would also mean a reduction in the supply of fish, an important consideration since fishing is a valuable economic activity in the dry season along the flood-plains of the main rivers. Under such circumstances it might well be necessary to provide additional attractions in those areas where alternative pasture was provided by offering opportunities for growing crops or harvesting fish from established fish farms. Where irrigated pasture could be produced along the river there would still be opportunities for fishing. It is desirable therefore that irrigated pastures should be sited as close as possible to the main rivers, although this may not always be possible.

Below we consider what methods of irrigation would be the most practicable; what types of pasture could be produced; how they could be produced and maintained; what would be their stock-carrying capacities; and how such pastures should be managed.

METHODS OF IRRIGATION

Considerable thought has been given to the possibility of irrigating the flood-plains, or *toiches*, by a simple method of flush irrigation. The drawbacks in the Southern Zone to such a method may be summarized as follows :

(i) Since the river will be high in the dry season, the *toiches* or lagoons could be flooded by this method, but they could not be drained without resort to pumping.

(ii) Because the *toiches* will not be flooded by the river (where banked) but subject only to rain precipitation, the vegetation on them will change. The deep-flooded grasses which provide the best grazing will give place to perhaps shallow-flooded and intermediate land types of grasses of lower grazing value.

Any scheme of irrigation both in the Southern and Central Zones on what are now the river flood-plains would have to be protected from inundation from flood-escape discharges in the river itself. The cost of protective banks would be high. In the one instance of the Aliab Valley, where the protection bank between the river and its flood-plain will be constructed as part of the engineering works of the Project itself to reduce water losses, it would be possible to establish a pasture irrigation scheme. Even in this case there are no specific proposals for dealing with exceptionally high floods, which would probably inundate such a scheme.

Similar drawbacks to flush irrigation will occur in the Northern Zone. Here the river levels will be comparatively high throughout the year. Thus, though simple methods of flush irrigation could be applied by banking off lagoons and depressions, drainage could only be carried out by pumping, an operation which would increase the costs enormously. For these reasons and because the levels both in lagoons and depressions and on the flood-plains generally are very irregular, we consider that simple methods of flush irrigation would be impracticable. The problem needs further investigation, including contour surveys of some of the larger lagoons. Meanwhile we must conclude that if pasture is to be irrigated at all, much better results could be obtained by irrigating under a properly controlled system, complete with distributory and drainage-channels, which would allow the establishment of improved perennial grasses.

TYPE OF PASTURE FOR IRRIGATION

Two types of pasture would be suitable, permanent pastures and semi-permanent pastures (or leys), and their merits are discussed below.

PERMANENT PASTURE

The grasslands of the Jonglei Area are composed of predominantly perennial grasses (e.g. the riverain and khor-bed grasslands and the *Hyparrhenia rufa* and *Setaria incrassata* type grasslands) and, if irrigated, would provide permanent green pasture. Only in the northern part of the Jonglei Area (north of the 640 mm. isohyet) are the grasses inland predominantly annuals, and here, if permanent pasture were required, it would be necessary to sow out perennial grasses. Farther south inland pastures such as those which could be irrigated by gravity flow from the Canal are composed of tussocky grasses with a very poor ground cover, each clump being isolated from its neighbour by a large patch of bare ground. Loss of irrigation water from such bare surfaces would be considerable. Further, the stock-carrying capacity and productivity of such pastures would be low. On the basis of our experimental work carried out at Malakal on irrigated natural *Setaria incrassata* type grasslands, we estimate that the stock-carrying capacity would be in the region of one Animal Unit to two or more feddans. Furthermore the natural growing period for these grasses is the rainy season; forcing them to continue growth throughout the dry season—and over an indefinite number of seasons—might result in a reduction in their over-all seasonal production. The natural *Setaria incrassata* type grassland when irrigated produced less herbage in the second dry season than the first; this, however, may have been due to faults and changes in the experimental technique (see Vol. III, p. 1053 et seq.).

The grasses of the flood-plains are much more productive; with natural irrigation only, the stock-carrying capacity of *Echinochloa stagnina* is estimated at one Animal Unit per feddan at least, and that of *Echinochloa pyramidalis* at one Animal Unit to between two and three feddans. The water requirements of these grasses are, however, high (see Vol. I, p. 165) ; it might not be possible to maintain their dominance in the pastures unless their full water requirements were met. We therefore consider that irrigated pastures, especially where contour banking and controlled watering would be necessary, should be pastures composed of selected grasses and legumes rather than natural pastures, for the following reasons:

(i) Natural pastures are predominantly graminaceous; established pastures could include legumes in the mixture, thereby increasing the feeding value.

(ii) By careful selection, the pastures could be made to consist of the most palatable, nutritious, and productive species. Since they would then carry more stock, the area under irrigation could be proportionately reduced. A saving in water used and in water lost by evaporation would result.

(iii) Pasture grasses and legumes which have the lowest water requirements could be selected.

The establishment of permanent pastures of this kind appears to have many advantages, but it must be realized that it would involve an increase in capital and running costs. The method would demand a high degree of control over watering and grazing. Moreover, in order to make grazing control easier, it might be found necessary to fence. The pastures would have to be maintained and renovated regularly, though the degree of maintenance and renovation is not predictable at this stage. The extent of the work involved would depend on the type of pasture established (i.e. a close sward or grasses and legumes grown in rows). Because of irrigation in the dry season and flood conditions in the rainy season it is obvious that the soils would be poorly aerated (under present conditions the cracking of the clay soils in the dry season allows aeration) and grass growth would obviously be affected. Methods which provide for proper aeration of the soil would therefore have to be employed. Such an operation would certainly be difficult on a close sward and it might therefore be necessary for the pasture to consist of grasses and legumes grown in widely spaced rows in order to allow regular deep cultivation. Also regular light cultivating and harrowing might be necessary whether the grasses were in rows or in swards. In addition it might even be necessary to provide such irrigated pasture land with drainage in order to carry away surplus water.

Costs of producing and maintaining irrigated permanent pastures are therefore likely to be high. Furthermore, with the present standard of livestock and the poor marketing facilities, little or no return could be expected from irrigation schemes carrying permanent pasture. All running costs would have to met by annual subsidies from government funds or provided from other sources.

Semi-Permanent Pasture (Leys)

In Australia the most economical way of producing irrigated pasture is to grow it in rotation with arable crops. Oats and rice are the most favoured crops in the rotation. In the Murrumbidgee irrigation areas of Australia on large area farms the raising of fat lamb on irrigated pastures comes second in importance to rice-growing, and the pasture is suited to a rotational system of cropping. On the other hand in the southern riverain irrigation districts the main emphasis is on fat lamb production and crops are of secondary importance[8]. In both areas, however, the sale of crops helps to offset the costs of providing irrigated pasture, although in the former area the method is primarily designed to maintain the fertility of the soil for the production of rice. Both methods are agronomically and economically sound and the principles, though not necessarily the products, are certainly worth considering in the Jonglei Area.

During the last few years both the Ministry of Agriculture and the Team have carried out experimental work on rice production in the Jonglei Area. Preliminary results show considerable promise in the Central Zone if rainfall is supplemented by irrigation. Adoption of the Australian rice-pasture rotation therefore has possibilities. The length of the ley in such a rotation would depend on how long it proved desirable to crop the same land with rice. This cannot yet be determined, but we have assumed that it will be in the region of five years of rice followed by five years of pasture, the land being divided equally between the two. Besides being a cash crop which would help to offset the running costs of providing irrigated pasture, rice straw and stubble would provide additional dry season feed. If this were taken into account, the amount of irrigated pasture land could be reduced in proportion. In the Southern Zone an alternative to the rice crop might be sugar-cane.

Later, when we consider such schemes in detail, we shall describe the type of pasture (permanent or semi-permanent) which we consider to be the most suitable in different areas. There are, however, certain principles and problems common to both types, such as establishment, maintenance, stocking numbers, grazing system, etc. These are considered below.

ESTABLISHMENT OF IMPROVED PASTURE UNDER IRRIGATION

The most desirable type of pasture is that with a well-balanced grass-legume composition, a high stock-carrying capacity, and requiring the least amount of attention and renovation. In order to produce such a pasture the selection of the right type of grass and legume should be the foremost consideration. The selection would depend on the type of pasture to be produced (permanent or semi-permanent) and on the conditions under which it would be grown. Where drainage was not desirable, as might be the case where pasture was grown in rotation with certain types of rice, selection would have to be based not only on the suitability of the species to irrigation but also on their tolerance of flooding, i.e. rains season flooding. In general the following determine the choice of species:

(i) Availability of viable seed.

(ii) Palatability of species to stock.

(iii) Dry season herbage production.

(iv) Ability to stand up to heavy grazing in the dry season.

(v) Feeding value.

(vi) Suitability to irrigation and to soil type.

(vii) Water requirements.

(viii) Tolerance to flooding where there is no drainage (i.e. waterlogging in the rainy season due to rain precipitation and in the dry season due to irrigation water).

(ix) Persistency, especially in the case of permanent pastures.

(x) Ease of control in irrigation channels, as well as ease of eradication in the case of semi-permanent leys.

In considering the suitability of indigenous species our choice is mainly limited to the perennial grasses of the Flood and Ironstone Regions and to the grasses found along the flood-plain. The Team has not had the time nor the facilities to conduct a complete programme of investigation into the suitability of all the indigenous species available, and at the present time we are unable to give any definite indication of which species to select, on the basis of feeding values, stock-carrying capacities, and water requirements. Plots of indigenous grasses have been established at the Malakal Experimental Station, but a full comparison of values has not been made (see Volume III, p. 1067). We have already pointed out the disadvantages of such grasses as *Hyparrhenia rufa* and *Setaria incrassata*, which we consider unsuitable for irrigated pastures. On the other hand we consider that *Echinochloa pyramidalis* and *Echinochloa stagnina* might prove very useful on irrigated land which is poorly drained and subject to waterlogging and flooding in the rainy season. It might, however, prove very difficult to maintain these grasses in the pasture since they are suited to ecological conditions different from those produced under artificial irrigation. The various *Panicum* spp. might also be valuable, but *Panicum repens*, producing a pasture which superficially appears promising, would prove most troublesome in the irrigation channels and would also be difficult to eradicate from fields due to be sown out with arable crops. *Panicum maximum*, which is indigenous to the Southern Sudan, might prove valuable, although as yet it has not been grown at Malakal (as an introduced grass from Australia it has not done as well as expected). Other grasses also indigenous to the high rainfall areas of the Southern Sudan such as *Setaria sphacelata* and *Chloris gayana* might also prove useful. No indigenous legume has as yet been grown successfully. As a generalization therefore indigenous species do not offer as much suitable material as one would hope, though our investigations and experiments have not been sufficient to warrant final conclusions on this point. Moreover the final selection of species would depend on the conditions under which the pasture was to be produced and these would vary according to locality. Thus it may be that if irrigated pasture were produced alongside the line of the Jonglei Canal (i.e. on intermediate land), no grass or grasses other than *Hyparrhenia rufa* and its associates would be able to tolerate the flood conditions of the rainy period. Therefore our choice might well be limited to the narrow range of species at present found on intermediate land. Introductions from outside the Sudan might help to widen the range.

During the last few years introduced species (grasses and legumes) have been studied at the Malakal Experimental Station and some have now become firmly established. Some of the most promising material has been obtained from Australia, especially the wide range of *Paspalum* spp. Many of these, notably *Paspalum dilatatum* and strains of *Paspalum notatum*, have done well in small plot and row trials. These species were, however, only introduced in 1952 and it is therefore much too early to judge their full worth, but there are amongst them some valuable strains which should prove suitable for irrigated pastures. In Australia *Paspalum dilatatum* is one of the major constituents of irrigated pastures, where it is grown with white clover to form a perennial summer pasture with a high stock-carrying capacity. Furthermore it is tolerant of very wet conditions, so that it is useful for pasture formation on poorly-drained and waterlogged lands. Although temperate clovers (white clover, red clover, and subterranean clover) have been established at the Malakal Experimental Station, it is considered that they would have little use in pasture formation in the Jonglei Area. However, it should be possible to produce *Paspalum* pastures (probably *Paspalum dilatatum*) including legumes that are more suited to our conditions. Sowing out *Paspalum dilatatum* in rows alternating with a legume would probably prove the best method, since in that way both watering and cultivating would be easier. The most promising legumes so far examined at Malakal are *Clitoria ternata* and *Phaseolus trilobus*, perennials which are known to be particularly attractive to stock in some tropical countries; also *Stylosanthes gracilis* (stylo) and *Glycine javanica*. The rôle of these legumes in pasture formation cannot at present be determined and much further work is still required.

Although at this stage we are unable to predict with any certainty what grasses and legumes would constitute the pastures and therefore what would be their carrying capacity, we have assumed that reasonably productive pastures could be produced under irrigation. It is likely that such pastures would be of the composition given above (i.e. *P. dilatatum* grown in rows with a legume), although it is also likely that a close sward could be obtained with some of the more prostrate creeping strains of *Paspalum notatum*, provided a similar prostrate type of legume could be found.

It is desirable that pasture should be established from seed since propagation by rootings would require considerable staff and organization, thereby increasing the cost of production. At the present time seed supplies of the majority of tropical grasses and legumes are meagre and unreliable. A major reason for poor germination of pasture species in Australia is the unreliability of the commercial supply. In the Sudan and in the Jonglei Area in particular a prerequisite to the establishment of improved pastures under irrigation would be the provision of production plots from which seeds could be harvested, threshed, and dried to the right moisture content and then stored ready for the large-scale sowing operations. As mentioned above, seeds of *Paspalum* spp. are available commercially in Australia, but it would probably prove advantageous to establish production plots within the Jonglei Area. Certainly if indigenous species were selected, such plots would have to be produced, together with the facilities necessary to prove the quality of the seed harvested.

Seed-Bed Operations

Although an unreliable supply of seed often results in poor germination in the field, the way in which the seed-bed is prepared and the initial waterings determine to a considerable extent the number of deaths in the young seedlings. Unsuitable soil temperatures and too much or too little watering may result in poor germination, after which drying out of the seed-bed or too deep a covering of the seeds with soil may result in the dying out of seedlings. A frequent occurrence at Malakal, especially where the seeds were sown on the flat, was the failure of the young seedlings to penetrate the hard surface crust formed on the soil surface after irrigation. This crust formation is a common feature on heavy clay soils when irrigated. The difficulty is experienced in Australia where it has been found that sowing seed on a cloddy seed-bed, instead of on the usual fine seed-bed, produces better seedling establishment. In the United States, on soils where flooding causes breakdown of soil structure in the surface layers, thus reducing seed germination, the formation of corrugations is recommended. The irrigation water is conducted along the channels between the rises of the corrugations and then moves laterally through the soil of the ridges, thus largely eliminating surface flooding. Alternatively sprinkler irrigation in the early stages is suggested, but this, of course, would be prohibitively expensive in the Sudan.

The cultivations involved in the production of the seed-bed would naturally depend on the above factors, and also on the type of pasture to be produced. We have already pointed out that it would be more economical to grow pasture in rotation with rice and possibly sugar-cane; therefore the type of seed-bed would have to conform to the demands of these arable crops. For rice the land must be levelled, and a system of corrugations and ridges suitable for pasture could not be easily adopted in a combined scheme of this kind. In Australia pasture seeds are sown directly on the rice stubble without any prior preparation. It is likely that this method would prove satisfactory in the Jonglei Area and it would have the following advantages:

- (i) No seed-bed cultivation would be required.
- (ii) Little time would be lost between the harvesting of the rice crop and the establishing of the pasture.
- (iii) Sufficient moisture should be available in the soil to ensure the germination and establishment of the seedlings.
- (iv) There would be less surface crust formation and therefore establishment would be easier.
- (v) The stubble would help to protect the young germinating seedlings from the north wind and also from stock in the early grazing periods.

It is therefore recommended that pasture seed should be sown by drill directly on to the rice stubble to a depth of ½ to 1 inch, followed by a light harrowing to cover the seed.

If it were found necessary to grow pasture by itself and not in rotation with arable crops, i.e. permanent pasture, it would be possible to adopt a ridge and furrow system with the grasses grown in rows on the ridges. Even on the flat it might be advantageous to grow pasture grasses in spaced rows, a method which is discussed later (see p. 644).

Time of Sowing

The natural growing period for all grasses in the Jonglei Area is the rainy season. During this period moisture is available, temperatures are generally lower, and the milder south winds supersede the harsh, penetrating winds from the north. From the point of view of quick seedling establishment the best time to sow would therefore be the early rains period, supplementing rainfall with irrigation if necessary. However, where pasture was grown in rotation with rice, there would be much to be gained by sowing on the stubble directly the rice had been harvested. The rice crop would have been grown in the rains with supplementary irrigation, and between November and January should have been harvested (depending on the variety sown). If the pasture seeds were sown immediately after the harvest, i.e. either in December or January, sufficient moisture should be available after germination and establishment without the need for application of large quantities of irrigation water during the first dry season.

MANAGEMENT OF ESTABLISHED PASTURE

We are concerned here with aspects of pasture management other than the application of irrigation water. The problem of how much water to apply and how frequently to apply it is considered elsewhere (see p. 623 et seq.).

After pasture is sown in January, it should be fairly well established by the middle of the following rainy season. At this stage it might prove advantageous to graze or cut back the herbage. On undrained land this might be impossible because of waterlogging or surface flooding; the grass would therefore grow unchecked throughout the rainy season, so that by the following dry season the herbage would be considerably advanced and coarse. Cattle turned into such pastures at the beginning of the dry season might find the grass unpalatable and not easy to graze, although this would depend on the species constituting the pasture. This coarse grass would therefore have to be either cut back or grazed down by temporarily overstocking the pasture before the normal dry season watering and grazing system could be put into operation.

GRAZING SYSTEM FOR IRRIGATED PASTURE

Several factors would determine the system of grazing to be adopted with irrigated pastures:

(i) Stock numbers. Understocking results in poor control of herbage growth so that cattle select the more palatable grasses, thus leaving the less valuable grasses to attain dominance. Overstocking also leads to deterioration by the complete grazing out of the more valuable species. Stock numbers would therefore have to be controlled and adjusted to the production of the pasture.

(ii) While pasture is being irrigated and as long as it is waterlogged or muddy, cattle should not be given access to it since they would cause deterioration both to the soil by puddling and to the pasture by trampling the leaves and shoots into the mud. At the same time conditions would be unpleasant for stock.

(iii) Sufficient interval after irrigating should be allowed to ensure that enough herbage had been produced before the cattle were let in to graze.

(iv) Continuous grazing might lead to soiling of the pasture with the result that animals would tend to avoid such areas. At the same time such areas would provide suitable conditions for the development of animal parasites.

The above points indicate that irrigated pastures should be grazed on a rotational basis, the stock numbers being carefully controlled by adding or withdrawing cattle from the pasture according to its seasonal production. In order to control cattle on such schemes, particularly where pasture was grown in rotation with rice or other arable crops, fencing would clearly be necessary. Some of the fencing would have to be of a permanent nature, but for the subdivision of paddocks temporary single-strand electric fencing would be most suitable although, in the Jonglei Area, its maintenance would involve many obvious difficulties. Permanent fences could be made by establishing thick hedges.

The term of a grazing rotation can only be determined by experience since it depends on the herbage produced by the pasture. A reasonable indication of the type of rotation which might be suitable is given below, and it has some basis of experience since it was adopted at the Malakal Experimental Station:

First day	... Paddock 1 grazed.
Second day	... Paddock 1 grazed.
Third day	... Paddock 1 watered and cattle moved to Paddock 2.
Fourth day to Eighteenth day	Paddock 1 rested while cattle graze Paddocks 2 to 9 in rotation, spending two days in each.
Nineteenth day ...	... Cattle enter Paddock 1 and graze.
Twentieth day ...	... Paddock 1 grazed.
Twenty-first day ...	... Paddock 1 watered and cattle moved into Paddock 2 . . . . . and so on.

On the above basis nine paddocks are necessary to ensure continuous grazing, and cattle are moved from paddock to paddock on the third day. There is therefore a considerable amount of changing. On large-scale schemes it would be more desirable for cattle to graze in one paddock for longer periods, say 7 to 10 days or more, thus reducing the amount of movement and the supervision necessary to ensure that they graze the right pastures.

CARRYING CAPACITY OF IRRIGATED PASTURE

As a remedial measure, irrigated pasture would be required only in the dry season, and we are therefore only concerned with the stock-carrying capacity of such pastures during that period. Our experience at Malakal with irrigated natural *Setaria incrassata* type grassland has shown that one feddan of such pasture can support no more than one Animal Unit. We have already shown, however, that irrigated pasture must include grasses of a better quality, and we expect that such improved pasture could carry 1·5 Animal Units per feddan throughout the dry season (approx. 150 days). Stocking rates of one Animal Unit and over to the acre are obtainable in Australia where the superior type of animal requires higher feeding standards than the lighter, less productive beasts of the Jonglei Area. Even allowing for local difficulties, we therefore consider that stocking at the rate of 1·5 Animal Units per feddan on improved irrigated pasture is not over-optimistic. In all future calculations connected with irrigated pasture in the Jonglei Area this figure is used.

MAINTENANCE OF IRRIGATED PASTURE

Depending on the length of time the pastures had been established, various treatments would be required in order to keep them in full productivity. Where pasture was grown in rotation with rice it would not be established long enough to require any drastic treatment, although the health of both the pasture and the stock would benefit from occasional light harrowings designed to spread animal droppings and to loosen up the soil. We have already mentioned that heavy flooding in the rains followed immediately by irrigation might adversely affect aeration of the soil and retard plant growth. This disadvantage would apply even more acutely to permanent pastures where the land would not be allowed to dry out or be ploughed at any time unless to resow the pasture. Naturally this would depend on the degree of watering in the dry season, but it is probable that deep cultivating would be necessary to loosen the subsoil and increase aeration at least once in the season. This process would be desirable for other reasons. Many plants become sod-bound, and in order to rejuvenate the plants it is usually found necessary to cultivate deeply around the roots. In Australia, where this condition occurs in *Paspalum*-white clover pastures, it has been found that harrowing with heavy drag-harrows fitted with deep points partly overcomes this difficulty. This operation is of course made easier and more effective where the grasses are grown in rows, the mechanical cultivator being dragged between the rows.

Pasture grown in rotation with rice would not require the application of artificial manures because there would be some residue of the fertilizers applied to the rice. However, if irrigated pasture were to be grown alone, light applications of nitrogenous fertilizer prior to irrigating in the dry season would probably give extra production during the early part of the dry season.

Removing old growth by cutting might be necessary during the dry season if the pasture were understocked, and it would almost certainly be necessary after the rains season. Such herbage could be conserved either as silage or hay, and would therefore provide valuable additional feed in the dry season. If this operation were found too costly or impossible because of a shortage of labour it might be necessary to burn. This would, however, depend on the type of pasture established. If the pasture were composed of short grasses (1–2 ft. high) it might be possible to get rid of the old rains growth by grazing, although the difficulty would be to find sufficient cattle to do so.

ANIMAL MANAGEMENT ON IRRIGATED PASTURE

The grazing of irrigated pasture should never be done in a haphazard manner. There should be a definite schedule for the application of water to the plots and the ground should be allowed to dry before livestock are turned on to it. The movements of animals from plot to plot should follow the irrigation schedule. In the Jonglei Area this would obviously require close supervision until a routine had become established.

In the design of a scheme for irrigated pasture the size of the unit is also important. When dealing with thousands of Animal Units, supervision cannot be given to scores of small herds. Probably the best size of unit would be one supporting 500 Animal Units throughout the dry season. This number is similar to that in many of the dry season cattle-camps (Dinka and Nuer) and would require an area of approximately 200 feddans under pasture.

Livestock normally graze during the daytime only, and at night they are herded together in thorn enclosures (as in the Arab part of the Semi-Arid Region and in parts of the Ironstone Region) or in camps where each animal is tethered to its own peg (as in the Flood Region). This is done partly to facilitate their protection against mosquitoes and biting-flies by smoke fires, and partly as a protection against beasts of prey which abound in most parts of the Jonglei Area. It would be necessary to set aside sufficient land, free from irrigation, within or near each unit for the establishment of such a cattle-camp. From observation we consider that 500 Animal Units and their owners would require (for the short period of the year involved) 10 feddans as 'living space'. Lanes leading from this tethering paddock to the grazing plots should be so constructed as to prevent damage to the irrigation channels. If crops, such as rice, were to be grown in rotation with pasture, their protection from livestock would also have to be ensured.

The provision of adequate water-points would also be an important consideration. If livestock and people were allowed to drink from irrigation channels, diseases such as fascioliasis and bilharzia might well reach major proportions in areas where they are already endemic, or even in areas where they are not found at present. The best methods and sites for watering are details which need not be discussed here, but the need for such facilities must be stressed. The provision of timber for fuel and for the construction of temporary shelters would be another important consideration, since irrigation schemes might well be sited in treeless areas, or in areas where the trees had been cleared as part of the preliminary work of cultivation. This might provide one of the answers to the problem of fencing. The suggestion of using light fencing (electric) to control rotational grazing has already been made, but that refers to internal fencing; the perimeter of each unit and the division between cropping and pasture sections must be fenced with something more permanent. The practicability of growing trees and shrubs for these purposes requires full investigation.

The concentration of animal stock on irrigated pasture schemes presents another problem. The possibility of disease in epidemic proportions is greatly increased, especially because livestock dependent on irrigated pasture cannot be moved elsewhere in order to avoid infection. It follows that close veterinary supervision would be required and units should be so arranged that strict quarantine could be enforced. The fact that the movements of livestock would be restricted to the units in which they graze would also facilitate the administration of prophylactics and therapeutics. In the same way the administration of public health services would be made easier and their scope increased. In the introduction of irrigated pasture schemes the aim should therefore be the greatest simplicity consistent with good pasture management, animal health, and general public health.

FODDER CROPS AND SOILING

Fodder crops might be grown on irrigated land either in place of the short ley in the rice-pasture rotation or in place of permanent pasture, but it appears that their inclusion would not be practicable or economic for the following reasons:

(i) In the rice-pasture rotation drainage would not be necessary for swamp varieties of rice but might be desirable in the case of upland varieties. The inclusion of artificial drainage would necessarily increase the costs and should be avoided where possible.

(ii) However, without drainage it is unlikely that annual or perennial fodder crops could be established.

(iii) Moreover, even if drainage were supplied and fodder crops established, their conservation in the rains season would be difficult (see p. 551). It might be possible to leave the crops until later in the year when climatic conditions favouring conservation prevail (i.e. November or December), but by that time the quality of the herbage would have deteriorated, since it would have reached an advanced stage of maturity.

(iv) The alternative would be to grow fodder crops in the dry season, but here again there would be difficulties. In the first place the crops would be required for feed by January. Since the initial processes of cultivation could not begin before October, when the land begins to dry out, there would not be sufficient time to produce the fodder by the date required unless a very quick-maturing forage mixture could be found.

The difficulties are therefore obvious. It might, however, be possible to use such crops or mixtures for 'soiling' in place of conserving them as fodder.

Soiling, the system of cutting forage crops when green and feeding them either in the same field or carting and feeding at another site, is practised in England and could doubtless be applied in the Jonglei Area. The main object is to ensure an uninterrupted supply of green fodder throughout the dry season by a regular programme of sowing and cutting.

A forage mixture such as sorghum and velvet beans, which is quick-maturing, i.e. approximately three months (for other forage mixtures see p. 1004), if planted in early November would be ready for cutting and feeding early in January, i.e. at approximately the period at which cattle would require feed as an alternative to riverain swamp pasture. Only limited irrigation would be required to produce this first crop, since sufficient moisture from the previous rains would probably still be available in the soil. This crop, if properly managed by controlled cutting and grazing, should carry the stock for a limited period before it was exhausted—say for approximately 5–6 weeks. If water were applied when the crop was nearing exhaustion some regrowth might be produced. If another forage mixture were to be planted two or three weeks after the first crop, i.e. in the middle or at the end of November, and another forage mixture two to three weeks later still and so on, a regular supply of green forage should be available throughout the dry season. All these later forage mixtures would require full irrigation. The cutting and feeding would have to be done by the herd-owners, but electric fencing would probably be necessary to protect the young forage mixtures. The area required to produce a regular continuous supply of green fodder throughout the dry season would depend on the yield and quality of the forage crop.

The main drawback to the production of forage crops for soiling purposes is that they would require annual ploughing and cultivation, etc., possibly the application of fertilizers, and cutting before feeding. Costs of production would therefore necessarily be high and organization complicated. It is moreover still uncertain whether suitable forage mixtures could be found for cultivation by these methods. The subject requires further investigation and trial.

If drainage were provided on irrigated schemes the growing of fodder crops would be possible in the rainy season, although again the difficulties of conservation under the climatic conditions of that period would be a limiting factor. During the same period such crops could also be grown on drainage schemes alone (without irrigation). It would be possible, on such drainage schemes, to plant the forage mixtures later in the rains season so that they would be ready for cutting late in October or early November, when climatic conditions are more suitable for conservation.

4. THE IMPROVEMENT OF LIVESTOCK

In Volume I (Chaps. 3 and 4) we have described how throughout the whole Jonglei Area livestock are one of the main interests of the people and play a large part in the local economy; and we have recorded that numbers are considered to be of more importance than the quality of individual animals. There is no system of breeding—males are allowed to run with the herds and flocks—and there is no feeding supplementary to natural pasture. Apart from primitive housing and the relief from biting insects provided by smoke fires, domestic livestock have no protection against unfavourable environmental conditions—torrential rain, flooded land, high humidity, high temperatures, drought, and other adverse factors which have determined the local variations in type. As a result, the level of animal production is generally low. Beef cattle require five to seven years to mature and many are of poor quality even then, though the best are of a fairly high standard. Mature milking cows may give no more than two pints of milk a day in addition to the small quantity that the calf is allowed to suck (it is quite common for a cow to produce a calf but not enough milk to feed it). Similarly, Nilotic sheep commonly produce twin lambs, but there is often sufficient milk for only one and the weaker either dies or grows up stunted, thus reducing still further the low standard of the flock.

Most of the Jonglei Area is inhabited by Nilotic peoples who still have the custom of using cattle as bridewealth (Vol. I, Chap. 3). Thus there is a continual change of ownership which is, and will continue to be, a source of discouragement to breeding for quality. The result is that all female stock are used for breeding, no matter how poor or ill-conformed. Under such conditions the standard of cattle must inevitably be low, and no improvement in the general level can be expected until numbers cease to be all-important.

However, the cattle have shown themselves to be capable of surviving and reproducing almost unaided under the difficult conditions prevailing, and their improvement is one of the natural lines of development in this part of the Sudan. The potentialities of local stock must first be determined. Under experimental conditions we must ascertain the effects of adequate housing, of protection against biting-flies, of supplementary feeding with grass, agricultural by-products, and cultivated fodder crops. In other words we must study the degree of improvement that is possible under an improved environment. Only in this way can it be determined which types are low producers because of environment and in which types the genetic constitution is the limiting factor.

When the most promising types are known, blood-lines must then be established, and only then can extension work on the up-grading of local stock begin. The improvement of local stock by the introduction of breeding stock from temperate climates is not considered possible because of the very different ecological conditions; but the introduction of good Zebu stock from countries having similar ecological, particularly climatic, conditions will require investigation.

The continuance of this discussion is outside the scope of this report. We consider that the standard of livestock production could be greatly improved and the raising of the standard would undoubtedly enable a smaller number of livestock to supply the equivalent quantity of human food from a smaller area of pasture. But too little is known of the potentialities of indigenous stock and the possibilities of their improvement to enable us to recommend livestock improvement as a remedy to offset the loss of dry season riverain pasture under the Equatorial Nile Project.

NOTE

Food Requirements of Domestic Livestock in the Jonglei Area.

Cattle are the most important animals in the greater part of the Jonglei Area and we have expressed present land utilization and future losses of pasture in terms of Animal Units, one Animal Unit being one adult ox or its equivalent (8 sheep or 8 goats). In calculating the value of animal fodders we talk in terms of Starch Equivalent and Protein Equivalent required daily by one adult ox (1 Animal Unit).

The estimated average live weight of an adult ox in the Jonglei Area is 300 kg. Using British feeding standards such an animal requires 2 kg. S.E. daily for maintenance; for production 3 kg. S.E. is required for every 1 kg. live weight increase. On the basis of figures obtained from one experimental herd kept on riverain pasture, we consider the average daily liveweight increase to be 0·2 kg. per head over the dry season (see Vol. III, p. 1040). On this basis the requirement for production is 0·6 kg. S.E. daily. Thus, the total nutritive requirement per Animal Unit day is 2·6 kg. S.E. (2 kg. + 0·6 kg.). Using the recognized nutritive ratio of 10 : 1, Starch Equivalent : Protein Equivalent, the total daily nutriment requirement of one Animal Unit is 2·6 kg. Starch Equivalent and 0·26 kg. Protein Equivalent. For ease in calculation we will consider the daily requirement of P.E. to be 0·25 kg.

Most of the fodders we envisage have a fairly low protein content and, because roughage is generally available, the important item is Protein Equivalent; a ration having adequate Protein Equivalent will in all probability contain adequate Starch Equivalent. If it does not, the S.E. can easily be obtained from natural roughage. But, as far as ruminants are concerned, Protein Equivalent and Digestible Crude Protein may be considered to be equal; and in estimating the value of fodders, we have used the percentage Digestible Crude Protein (D.C.P.) as our yardstick.

NOTES AND REFERENCES

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(2) Harrison, M. N., ' Report of a Survey of the Grazing Areas of the Sudan ', unpublished Sudan Govt. Report.
(3) See list of species tested at Malakal and their possible value, Vol. III, p. 1067 et seq.
(4) Paltridge, T. B., ' Some Problems Related to the Selection of Species for Subtropical Pastures ' (unpublished).
(5) ibid.
(6) Harrison, M. N., op. cit.
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CHAPTER 7. AGRICULTURAL ALTERNATIVES

1. INTRODUCTION

At the outset of this chapter it is necessary to explain our reasons for coining the phrase ' agricultural alternatives ', instead of calling the measures which we suggest here ' agricultural remedies '. This distinction in phraseology is used in order to emphasize the basic difference between the retention of the *status quo* by pastoral remedial measures and the substitution of a completely, or at least mainly, agricultural for a predominantly pastoral mode of life, with all the economic, social, and possibly political repercussions of such a step. Though from a technical point of view this seems possible, the administrative difficulties would certainly be very considerable and the change not without danger. However, the human race has always shown a remarkable degree of adaptability to environmental changes, and we do not think that a complete change in economy and mode of life should be excluded from our recommendations if it is economically essential, provided the people are given technical and educational assistance.

The Jonglei Area offers considerable agricultural potentialities, which will not be substantially diminished, and in some areas will be improved, as a result of the Equatorial Nile Project. At present the development of these potentialities has only just begun. The necessity for agricultural alternatives may be lessened by development measures taken prior to the implementation of the Project, if those people likely to be affected by the Project are concerned in such measures. On the other hand, such development introduced before the Project comes into operation may prejudice the possibility of developing certain potentialities as remedial measures by using them first in the course of normal development. This may not result in hardship, but in some cases may cause difficulties if the potentialities are fully utilized by peoples other than those adversely affected by the Project.

We may even go a step farther and say that agricultural alternatives are nearly identical with normal agricultural development, as they aim to use agricultural potentialities which already exist. Therefore in the long run they cannot be regarded as compensation for lost pastoral potential, which could only be replaced by the allocation of sufficient water and the provision of sufficient capital to grow a quantity of dry season fodder equivalent to that at present found on the *toiches* of the White Nile system.

BASIS OF RECOMMENDATIONS

We wish to stress here that the proposals outlined in this chapter cannot be accepted as ready-made plans which can be applied without further investigation, trial, and experiment. The reader must realize that the foundations for our recommendations are very limited; they are based on:

(i) Information gathered during a necessarily rapid agricultural survey of the area in order to assess the main limiting factors of crop husbandry, local husbandry methods, and agricultural potentialities which could be utilized more profitably by the application of modern techniques.

(ii) Agricultural experiments carried out by us at Malakal and elsewhere to confirm the soundness of our ideas and to provide the necessary minimum of numerical data.

(iii) Information in technical literature concerning agricultural experience in other parts of the Sudan and in comparable areas of the world.

(iv) A study of reports of a number of agriculturists, etc., who have worked in this area before us.

When it is considered that the major part of this material was gathered by the agricultural member of the Team in only 23 months (i.e., on the basis of 8 hours a day, rather less than 2 minutes per square mile of the area under investigation for all work, including survey, experiments, and necessary reading), the limitations of the recommendations should be clear.

The survey could be carried out only during the dry season when communications were easier, when the majority of crops had been harvested and before sowing had started in earnest, since time did not allow for slow travel during the rains. The information gathered cannot therefore be accepted as either fully reliable (time was too short for sufficient checking and cross-checking) or even adequate. It is not necessary to stress the limitations of work on agronomic problems which was confined to three seasons. Indications rather than definite conclusions were all that were possible. The difficulties of consulting technical literature when 500 miles from the nearest library, even allowing for the Sudan Government leave system which permitted a certain amount to be done in England, are also obvious. Finally, lack of a proper archive system made the use of even the scanty reports and papers which were available concerning the area difficult.

It is therefore necessary to give a warning that the material in this chapter is no more than a collection of suggestions, the applicability of which, both technical and economic, must be tested by experiments and pilot schemes.

RETENTION OF THE MAXIMUM NUMBER OF LIVESTOCK

One of the main objectives of agricultural alternatives must, in our opinion, be the retention of the maximum possible number of livestock even under future conditions. This area is eminently suitable for animal husbandry. Even though the Project will reduce the amount of dry season grazing available, the other factors which dictate this type of husbandry will remain unchanged. Furthermore the retention of as much livestock as possible should be our aim in order to affect as little as possible the existing social, economic and political structure of the people; not because change in all spheres is undesirable, but because too rapid change may have detrimental repercussions.

A certain number of livestock will be necessary to provide the inhabitants of this area with a nutritional standard of even minimum quality. As far as the future economy of the Sudan as a whole is concerned, the production of an exportable surplus in animal products from this area is a sound objective. The population in the northern towns, growing in wealth and number, will demand with increasing insistence meat and milk, which this area will eventually supply. The demands of the inhabitants of the tsetse belt farther south are also likely to increase as time goes on. Finally, the value of the livestock of the Jonglei Area as a source of exports in exchange for manufactured goods from overseas cannot be disregarded. The economy of the Sudan, relying as it does almost entirely on a single crop—cotton, must be aimed at the diversification of the sources of its wealth. Any serious loss of livestock in the area affected by the Equatorial Nile Project will have a great effect on long-term economic stability and the well-being of the country as a whole.

ARRANGEMENT OF THE MATERIAL

The material in this chapter is arranged as follows. We first review in general terms the agricultural potentialities of the area and, on the basis of our limited knowledge and experience, suggest ways and means of improving their utilization in order to increase crop output. Then we discuss the problems of developing the agricultural potentialities of this area as a remedy for pastoral losses due to the Project, beginning with the most difficult problem, that of finding the basis for the quantitative aspects of the assessment of agricultural alternatives. At a later stage we list the most promising alternatives.

2. AGRONOMIC IMPROVEMENTS

The object of 'agricultural alternatives' is to increase crop production in this area and reduce as far as possible its present unreliability. This can be achieved by:

(i) Increasing yields per unit area.

(ii) Increasing the area cropped.

(iii) Attaining better control over environmental factors at present responsible for crop failures.

Before studying the possibilities which already exist in these directions and those which will be created under the Equatorial Nile Project, let us again sound two notes of warning. First, none of the possibilities discussed below have been given sufficient trial to make their success certain—many of them, on further examination, may prove disappointing. Secondly, before any attempt is made to replace any existing local methods of crop husbandry by innovations from elsewhere, the reasons underlying these local methods, if discoverable, must be closely examined, and we must be sure that real and lasting improvement will result from the substitution of new methods for old.

The agronomic improvements discussed below aim mainly at better yields, though if successful they should also diminish the risks of crop failure and have an indirect beneficial effect upon the acreages cropped.

BETTER CARE OF CROPS

IMPROVEMENT IN LAND PREPARATION

We have already emphasized in Volume I of this report (pp. 334-7) the inefficiency of local methods of land preparation. The purpose of tillage is first to destroy as far as possible all weeds which compete with the crop, which when young is especially susceptible to such competition, and secondly to improve the physical characteristics of the soil, particularly its water-absorbing capacity and penetrability to roots. The present method of shallow hoeing, with a weeding or Dutch hoe, is laborious and only partly effective in achieving the first objective, and generally ineffective as far as the second objective is concerned. Moreover as this method is very slow, weeding has to be done either too early (i.e. before the majority of annual weeds have germinated) or too late, so that sowing is postponed beyond the optimal date or the crop is sown without prior weeding and has already suffered from weed competition before weeding is done. Moreover late tilling is often carried out when the soil is too wet, and does more harm than good to its physical properties.

Improved preparation of seed-beds could undoubtedly be achieved by the use of heavier implements. A tractor or animal-drawn plough could not only assure better initial weed control, but also, by breaking the surface, increase infiltration and hence reduce the loss by evaporation of early rainfall, which is often a limiting factor. This is especially important on clay soils, on which ploughing should also improve soil conditions for early root growth and thereby promote stronger and better stands. Experiments carried out at Kodok and at Tonj (unfortunately on observation plots and for two seasons only, and therefore inconclusive) showed an increased yield of cotton and sorghum as a result of ploughing[1]. Experiments at Kodok, where groundnuts were planted on ploughed and unploughed plots, resulted in no increase in yield due to ploughing, but the costs of harvesting were halved on ploughed plots. How far land preparation could be improved by the use of better hand implements would depend on the discovery of those especially suitable for local conditions and the ability of the local cultivator to use them. In any case no spectacular improvements could be expected from the introduction of hand implements.

The need for better land preparation exists throughout the Jonglei Area, though it is less urgent where *hariq* grassland is present. In other areas, where land preparation is as a rule inadequate, an increase in yields would undoubtedly result. Fortunately sorghum, beans, cotton, and groundnuts, the main crops, do not require an elaborately prepared seed-bed, though even these crops would show response to such improved methods.

IMPROVEMENT OF METHODS OF CROP ESTABLISHMENT

Present sowing methods, either with sowing-stick or by broadcasting, generally result in uneven, haphazard spacing, uneven stands, a seed-rate usually heavier than is necessary, and finally additional labour in thinning and transplanting.

With regard to spacing, it should be realized that the experience of generations should make the average spacing employed for local crops not far from optimal (see Vol. I, p. 337). The chief fault here is irregularity of spacing. As investigation of spacing is laborious and optimal spacing depends on crop, variety, soil, and very variable climatic conditions, the improvement in spacing of local crops should aim first at uniformity based on the local average distance between plants. Groundnuts, which may be regarded as a local crop, are an exception requiring immediate further investigation, as our impression, confirmed by preliminary experiments, is that present spacing is not close enough for the best results. With introduced crops and varieties, especially those which, unlike cereals, cannot correct the cultivator's faults by tillering, etc., the investigation of spacing under different conditions is immediately necessary. If mechanization is considered, local crops will have to be included in such investigations because the space between plants must be adjusted to the requirements of the machines, and this may affect factors of importance in mechanized cultivation, such as uniformity of maturation, etc.

Present heavy rates of sowing and subsequent thinning and transplanting permit the formation of more uniform crop stands, reduce risks of germination failure, and may, in some cases, actually assist germination. For example, sowing 10 to 15 seeds per hole instead of 2 or 3, the minimum essential for the final stand, helps the young seedlings to break through the soil crust which often occurs at this stage. On the other hand it obviously results in wastage of seed and in competition between the young plants, which is especially serious when thinning is done too late. Moreover thinning involves additional work in correcting the initial lack of care. On the whole our experience in experimental work, where the sowing-rates used were generally below those universally employed by the local cultivator, suggests that the amount of seed at present habitually used could be reduced.

To what extent the timing of sowing could be improved is uncertain; there is little doubt that in many cases the difficulty of preparing fields, and particularly the lack of water supplies, leads to sowing being done too late for the best results. In the case of rain-grown crops, yield response to early sowing must depend also on subsequent rainfall and therefore be uncertain. It is our impression, however, confirmed by the limited amount of experimental data available (see Vol. III, p. 993), that earlier sowing would be generally beneficial. In the case of irrigated crops there can be little doubt that yields, particularly of cotton, often suffer from late sowing, which is sometimes done as late as September. Reduction in yields is particularly serious when, for various reasons, irrigation water has to be cut off early.

Though methods and timing of sowing could undoubtedly be improved, no very great increases in yields can be expected from this alone, and much investigation work is necessary.

IMPROVEMENT IN WEED CONTROL

We have noted in Volume I (p. 315) that weeds are often a serious obstacle to improved yields in this area. However, the problem of their control is not as simple as it may appear at first glance. The local cultivator is here faced with the problem of dividing his efforts between keeping his fields clean and extending the area under cultivation. It should be remembered that he has to guide him generations of experience, accumulated by trial and error, as to the best compromise between these two conflicting demands, and that therefore the decision he reaches cannot be far wrong. The only improvement which we can suggest here, based on observation and some experimental data (see Vol. III, p. 994), is to abandon the late weeding of the early crop—which is a universal practice but probably of little value—and to use the labour saved for the extension of the area and better care of the late crop. Early weeding, however, when the weeds are still in the seedling stage, is most important.

Major improvements in the cleanliness of the fields should be brought about not by upsetting the present compromise, but by the provision of better means of weeding; mainly better tools and animal or even tractor-drawn implements.

Chemical methods of weed control, in which there have been considerable advances recently and which now offer a sufficient degree of selectivity to be suitable for local crops[2], would demand a change in the technical and economic system of farming at present practised here. However it is worth considering this method for cash crops on pump schemes. If the present peasant farming system were modernized, or replaced by a co-operative or plantation system, this method of keeping the fields clean would become more practicable. It has obvious advantages in this area, where low labour output is a very important factor limiting crop production.

MAINTENANCE AND IMPROVEMENT OF SOIL FERTILITY

As we have seen from Volume I, Chapter 2, soils in the Jonglei Area differ in inherent fertility, susceptibility to overcultivation, and, according to the sites where they occur, in the amount of cultivation to which they are subjected. Thus in the Ironstone Region, where soils are least fertile, soil nutrient exhaustion is most likely to become a serious limiting factor on any intensively cultivated site. In the rest of the area soil moisture conditions are the most important consideration, as the soils are inherently fertile but often suffer from a lack or surplus of moisture or both in turn. Except where irrigation is practised, plant nutrients are unlikely to be exhausted. On the other hand deterioration in the physical qualities of soil, due to overcultivation, is a serious problem. Signs of overcultivation are quite common, and the causes have already been discussed in Volume I (see p. 327).

Measures to maintain soil fertility or to improve it are urgently necessary where misuse of the soil is greatest, though economic considerations limit such measures to cultivations on which valuable crops are raised by intensive methods (e.g. schemes producing cash crops by irrigation).

ROTATION OF CROPS

The maintenance and improvement of soil fertility is one of the most important objectives of the rotation of crops. Other objectives are considered elsewhere; here we limit our discussion to the possibilities of introducing or improving crop rotations with a view to improving soil fertility. The reader will realize the need for time in which to experiment on rotations. The time allotted for our investigation was insufficient for any experimental work of this type; consequently all suggestions are based on theoretical considerations and require confirmation by experiment.

The objectives of crop rotation as a means of improving soil fertility may be summarized as follows:

(i) Improvement or maintenance of plant nutrient status and its optimal utilization.

(ii) Optimal utilization of soil moisture.

(iii) Improvement or maintenance of soil structure.

Leguminous crops are usually included in the rotation to increase the level of nitrogen in the soil. To ensure this, effective strains of suitable symbiotic bacteria[3] are essential, and nodulation of roots of introduced legumes is not a criterion, as nodules may be formed by ineffective strains. Unfortunately we have no data which would enable us to find out if, and what, effective strains are present in our soils. Furthermore while bacteria fix nitrogen, they also make demands on the associated plant carbohydrates, and consequently the roots of leguminous crops respire at a higher rate and therefore need well-aerated soil[4]. Many of the soils of this area are insufficiently aerated, and it may be expected that on such soils the introduction of leguminous crops would not necessarily be followed by increased nitrogen supply. The amount of nitrogen fixed by *Rhizobium* bacteria depends also on the availability of phosphorus, known to be a limiting factor in some of our soils, as well as calcium potassium and molybdenum. Moreover the more vigorous the growth of the crop, the more nitrogen is fixed; consequently the poor leguminous crops often observed here are probably of little benefit to the soil. Forage legumes, particularly those which grow on the same land for more than one season, are more effective in enriching the soil with nitrogen than annual leguminous crops grown for seed[5]. At present no perennial leguminous crops are grown in this area.

Availability of nitrogen must be considered as well as nitrogen fixation. Rotation experiments at the Gezira Research Farm have showed that at least one season's fallow after the leguminous crop is necessary for the nitrogen fixed by the legumes to become available[6].

The same experiments have shown that the sorghum crop considerably reduced the nitrate-nitrogen content of the soil in the following year and depressed the yield of the following crop (cotton). Similar effects of a sorghum crop on the yields of succeeding crops were observed in America[7] where Conrad[8] ascribed these effects to the high sugar content in the crown roots of sorghum, which caused the nitrates to be locked by micro-organisms during the decomposition of these roots. Sorghums were found by this author to be much worse in this respect than other cereals. The place in rotation of this, our most common crop, therefore requires special consideration. Following sorghum by fallow is an obvious solution. The fallowing of land can itself be an important factor in increasing available nitrogen. Experiments at the Gezira Research Farm[9] have shown the value of keeping the fallow clean of weeds to increase available nitrogen for the following crop; clean fallowing, however, would be most difficult and laborious in the areas of heavier rainfall.

Research work at the Gezira Research Farm has also shown the existence of a considerable store of available nitrogen at deeper levels of the soil where root penetration is poor[10]. The existence of a similar store in some of our soil may be expected, and the inclusion of deep-rooted plants in the rotation would improve the use of this nitrogen and, to some extent, bring it to higher soil levels. We have shown in Volume I, Chapter 2, how flooding of the soil increases its nitrogen content. Consequently the value of an irrigated rice crop and its place in the rotation should be considered, as it may be expected to improve the soil nitrogen status.

The other element necessary in quantity for plant nutrition, and likely to be a serious limiting factor in our soils, is the availability of phosphorus. It is known that some plants are better able than others to extract soil phosphorus from less available sources; it might therefore be possible to use these plants to convert some soil phosphorus compounds into more easily available forms. Unfortunately lupins, which are known to be specially efficient in this respect, were a failure in our crop introduction experiments. On the other hand millets are generally good extractors of phosphorus[11]. *Glycine javanica*, which did well in our experiments (see Vol. III, p. 1073), was found by Jones[12] to increase the nitrogen content by 130 lb. per annum, and in nine years to double the available phosphorus in the top 9 in. of poor soil in Kenya. Hence the inclusion of phosphorus-extracting crops in the rotation merits consideration. It is also known that different crops make different demands on soil nutrients, so that growing them in rotation is less likely to exhaust the supply of any available nutrient than is the cultivation of a single crop over a number of years.

The water economy of the crop-soil system must also be considered in connection with crop rotation. The effect of shallow-rooted crops on the water supply of the succeeding crop is probably nil, as drying conditions during the rainless season are the main factor determining the moisture content of the top layer of the soil when the new crop is planted. Deep-rooted crops such as sesame, however, may exhaust soil moisture at the level of their roots beyond the quantity which can easily be replaced by the next season's rainfall, particularly in the Semi-Arid Region. Consequently the succeeding crop, if similarly deep-rooted, is affected. In these conditions alternations of deep and shallow-rooted crops are desirable. The effect of clean (i.e. weedless) fallow on soil moisture supply in the Semi-Arid Region requires further investigation, as the value of preventing dry season transpiration losses from weeds may be considerable and make clean weeding of fallow an economic measure.

Our field observations have led us to the conclusion that prolonged cropping leads to deterioration in the already poor structural make-up of local clay soils (see Vol. I, p. 103). Unfortunately we have no data on the effect of different local crops on soil structure. It is known that some crops are worse than others in this respect. We have already noted that sorghum—the main crop in this area—adds considerable quantities of sugar to the soil Breazeale[13] in the U.S.A. has noted that the ensuing decomposition of these sugars has an unfavourable effect on soil structure. Consequently continuous cropping with sorghum may be specially deleterious for soil structural properties. The value of grass leys in building up soil structure is well known in both temperate and tropical conditions[14]. Grasses and legumes differ considerably in their value for soil structure building, and investigation of the respective values of indigenous and introduced species must be carried out before their place in rotation can be considered. Our observations suggest that a rice crop may be valuable in this respect. The effect of deep-rooted crops on soil porosity should also be investigated; decomposing roots may provide pores which did not previously exist and improve water penetration and aeration of the deeper levels of the soil, permitting deeper rooting by the succeeding crop.

Though soil erosion is not serious in the greater part of the Jonglei Area, in places where it does occur (e.g. in some localities in the Semi-Arid and Ironstone Regions) a well-designed rotation should be able to prevent it, and in these conditions structure building as well as the cover value of crops must be taken into account.

In planning rotation, economic demands and environmental limitations must be considered. In the Jonglei Area, with a present economy largely based on a self-sufficient family unit, a high proportion of food crops must be included in the rotation. Cash crops can occupy only a secondary place. Under the new river régime, with the consequent loss of *toiches*, the inclusion of fodder crops may be desirable, especially if they serve a double purpose as a source of animal food and as soil improvers. As far as environmental limitations are concerned, the main factors are the limited soil moisture available in the Semi-Arid Region and the danger of waterlogging or even flooding in the Flood Region. The former may be altered by the provision of irrigation and the latter by the provision of drainage, thus extending the scope of cropping and hence the possibilities of rotation.

On the basis of the above discussion of physical factors affecting the planning of rotation, we must now consider the possibilities of rotations in different conditions in this area, mainly with regard to their effect on soil fertility.

In the Ironstone Region the land suitable for cropping is less limited than farther north. On the other hand the soils, being generally poorer, are more in need of balanced rotation if subjected to intensive cultivation. The present system of shifting cultivation maintains soil fertility if the frequency of shifts is sufficient, and should be encouraged by the provision of better means of land clearance. Where intensive cultivation is desirable legumes, especially the phosphorus extractors, should be included if economically possible. As intercropping (i.e. planting of mixed stands) does not interfere with hand cultivation it should be encouraged as a simple form of crop rotation as well as an anti-erosion measure.

In the Flood Region some form of crop rotation is most urgently needed for patches of high land at present intensively mono-cropped with sorghum. The inclusion of leguminous crops is obviously desirable. While the desirability of long periods of rest is undoubted, we are not certain if short fallows for one or two seasons only have much value in restoring soil fertility, which depends largely on the physical properties of the soil. Unless future experiment proves that our conclusions derived from observation alone are wrong, we suggest that periods of cropping, including a succession or interplanting of the different crops, should be followed by periods of rest not shorter than 3 to 5 years. Cash crops, being in general the most valuable, should follow the rest period. Cereals, if grown on the same land for more than one year, should be diversified as far as possible, other cereals being grown before sorghum rather than after it. On peasant cultivations the planting of mixed stands should be encouraged, though it should be remembered that while cereals benefit from such association the leguminous crop generally suffers. Groundnuts are especially apt to be affected by competition, and cereals grown with this crop can also be upset by the disturbance of their roots while the groundnuts are being harvested (see Vol. III, p. 994).

On intermediate land, unless drainage is provided, the problem of rotation is more difficult, as waterlogging limits the range of suitable crops. Under present conditions rainy season cropping of this land is limited to sorghum, the only crop able to survive both flood and drought if these are not too severe. Moreover, as intermediate land is virtually unlimited, shifting cultivation eliminates the urgent need for crop rotations. However, if drainage and irrigation were introduced on this land, the capital investment necessary for such measures would necessitate more intensive cropping of the improved area. Where drainage alone or drainage combined with irrigation was introduced, the problems of rotation would be similar to those of high land cultivations, though more cash crops would be needed to pay for the capital invested.

If rice were introduced as one of the main crops of this area, it could be grown on intermediate land with supplementary irrigation without the necessity for special drainage measures. Two types of rotation can be practised on such land. The first is the simple alternation of rice and irrigated ley used for pasture. The practicability of this rotation is limited by the present low quality of the livestock, and livestock improvement would be necessary for economic success. The second possibility is to follow or precede the rice crop with some other crop grown in the dry season with or without supplementary irrigation. As far as the maintenance of soil fertility is concerned, rice mono-culture might prove successful without crop rotation. However the introduction of legumes, preferably as short ley or green manure, and if possible a legume able to act as a ' phosphorus extractor ', would be very desirable.

The rotation suitable for *toich* soils would depend on drainage possibilities. If sufficiently good drainage could be provided, rotations of crops similar to those suitable for high land should also be successful on the reclaimed *toich* land. On the other hand if the conditions at present prevailing on *toich* plains were materially unaltered a rotation involving rice crop and pasture leys, with the possible addition of ' catch crops ' planted as soon as the floods recede, should prove possible.

The *qoz* soils of the Semi-Arid Region are, more often than not, already subject to excessive cultivation. Though the value of fallowing is realized by many cultivators and a simple form of rotation is practised (see Vol. I, p. 375), the introduction of an orderly crop succession would be most beneficial. As the supply of soil moisture is here most limited, short fallows, especially if weeded to reduce transpiration losses, should be valuable in conserving soil moisture. The lack of moisture, as well as the generally poor nutrient status of these soils, demands alternation of deep and shallow-rooted crops feeding at different depths. The value of gum-bearing *Acacia* spp. (especially *Acacia senegal*) as restorers of soil fertility, dune fixers, and at the same time valuable cash crops, makes the introduction of a regular ' gum garden ' phase into *qoz* rotation well worth considering.

On *bildat* land sorghum is the only suitable crop in drier conditions, while under heavier rainfall it is desirable to extend the cultivation of cowpeas, already grown by some cultivators. Unfortunately demand for this crop is limited, but may increase when its value as a fodder crop is appreciated. On these cultivations, however, reducing the period under crop and increasing the length of fallow is probably the most practicable solution of the problem of the maintenance of fertility. These and similar measures cannot be successfully introduced on land where shifting cultivation is practised until domestic water supplies are improved.

Mixed cropping as a form of rotation should be investigated under the conditions in the Semi-Arid Region. The mixture of two crops with different root-systems would utilize the limited water supplies better than a single crop, but the soil would be dried out more thoroughly and fallow would therefore have to follow. The mixture of a leguminous crop with a crop of a similar shallow root-system, however, would probably lead to serious root competition for water, especially as it is known that in general the root-inhibiting substances of leguminous and non-leguminous crops, being specific, do not prevent interpenetration by such a mixture,[15] and yields will be lower than if two such crops were grown in succession.

We shall return to the subject of rotation later in this chapter when rotations suitable for the different types of farms suggested will be discussed.

MANURING

Another method by which soil fertility can be maintained or improved is the manuring of crops. In the Jonglei Area information on the application of manures is limited to the results of a few experiments carried out at Malakal since 1950, and to trials of the value of dung in the Bahr el Ghazal Province (see Vol. III, p. 991). The results of experiments carried out in the Gezira also provide some information applicable particularly in the Semi-Arid Region. Our suggestions, based on this scanty information, must therefore be regarded as tentative.

The results of experiments at Malakal indicate that, unless soil moisture conditions are controlled by supplementary irrigation and drainage or both, no worth-while response can be expected from supplementing plant nutrients in the soil by the application of artificial fertilizers. Yet when soil moisture deficiencies can be improved, the application of nitrogen and phosphorus on heavy soils like those of the Malakal Experimental Farms can produce considerable response. On some lighter soils potash may also increase yields. It is also possible that the application of nitrogenous fertilizers on freshly opened land might be worth considering, even without irrigation.

These conclusions are probably valid for both the Flood and Semi-Arid Regions. In the Ironstone Region, where soils are generally poorer and the danger of flood and drought is less, the application of nitrogenous potash, and especially phosphoric fertilizers, is more likely to be worth while without irrigation, though problems of phosphorus fixation in these soils must be investigated. Further investigation into the need for improvement in the soil status of minor elements, particularly zinc, is also necessary since they may prove to be serious limiting factors which could be economically controlled.

In the Bahr el Ghazal Province, experiments have demonstrated the very considerable value of the Aweil Dinka practice of tethering cattle on the field to be planted. Similar experiments were carried out in the Gezira[16], where it was found that the main fertilizer value of this treatment can be ascribed to the urine rather than the dung, so that the tethering of cattle cannot be replaced by the application of dung collected elsewhere.

Cattle-tethering in the Tonj, Thiet, and Aweil experiments nearly doubled the yields of cereals, though it depressed the yields of groundnuts and sesame. In the Gezira trials a yield response of sorghum was also noted. Experiments at Malakal have given erratic and inconclusive results, again suggesting that moisture conditions are more important here than soil nutrient status. However, if cattle are available, this method of manuring is well worth encouraging, being the most practical under present conditions and requiring neither money nor much additional labour.

The manurial value of *path* (see Volume I, p. 328) has yet to be assessed; similarly a single experiment with the application of gypsum carried out at Malakal (see Volume III, p. 991) cannot be regarded as conclusive. Gypsum application trials in the Gezira have shown that improvement of the physical characteristics of the soil, leading to increase in yield, can be expected. The amount of gypsum required, however, is considerable[17].

We have no information at all about the value of composts or green manures in this area. It is doubtful if any appreciable part of the organic matter added in this form would survive the oxidising conditions of the dry season. If this is the case, the labour involved in growing green manure or preparing compost would hardly be worth while. Because of dry season oxidation the replacement of mineral fertilizers by organic fertilizers such as cotton seed cake or sesame cake could probably be justified only by the difference in price per unit of the nitrogen or phosphorus which they contain. In the Gezira experiments no special response was noted from the application of nitrogen in organic form when compared with the equivalent supplied in mineral form[18]. The C/N ratio of any organic manure will have to be assessed before application, as the addition of an unbalanced quantity of carbo-hydrate would cause nitrogen fixation in organic form and lower the yields.

In considering the application of artificial fertilizers, including gypsum, the economic aspect must be kept in mind. In a country where a cash economy is still far from being universal, it is difficult to assess their value, except for cash crops. Even for cash crops we still have insufficient knowledge, though for cotton and rice the application of fertilizers is certainly promising. Further work in assessing the response of different crops to different fertilizers at varying rates must be done. Moreover changes in price of both fertilizers and crops are constantly taking place. It is therefore impossible to predict if and how far the application of fertilizers will prove economically successful. It must be stated, however, that no outstanding economic gains are likely from the introduction of fertilizers, and the economics of their application will have to be closely watched. Moreover before artificial fertilizers can be introduced there must be a greater dependence on cash economy in the peasant farming system. At the moment the only type of farming in this area where fertilizers can be used with profit is on private pump schemes, where cash crops are intensively cultivated.

INTRODUCTION OF IMPROVED VARIETIES AND NEW CROPS

The present range of crops and varieties in the Jonglei Area, particularly in the Flood Region, is very limited, and its extension is desirable for both technical and economic reasons. Improvement in yields of existing crops may be achieved by the introduction of better varieties selected from elsewhere for their yielding qualities and resistance to adverse factors such as drought, flood, pests, and diseases. The introduction of exotic crops may lead to the better utilization of existing environmental potentialities and of land at present misused. It may also mean better use of labour, which is at present scarce, and improvement of the diet and the standard of living of the inhabitants. New crops are desirable for the design of optimum rotations, for the control of *Striga hermonthica* parasite, and for the provision of cash needed for agronomic and other improvements. They may also permit the cultivator to spread, and so diminish, his risks connected with climatic variations.

The introduction of new crops and varieties is not limited to those from outside the Jonglei Area. Some crops cultivated in one district may well be worth introducing in others where at present they are not grown. It must further be noted that the successful introduction of many new crops and varieties depends on the simultaneous improvement of the general level of crop husbandry. Many are much less tolerant than local varieties of sorghum, beans, etc., and will not produce economic returns unless properly cared for. Many will probably require fertilizers or manure to give economic yields. Furthermore many of them cannot replace local crops; they can only be considered as additions. Consequently they cannot be introduced until there is a total increase in production by local cultivators.

The experimental work which forms the basis of our recommendations was mainly carried out in Malakal, and at Yirol, Aweil, and Thiet in Bahr el Ghazal Province[19]. It may be found that the results obtained at these stations are not directly applicable to other areas. For the Semi-Arid Region in particular there is very little experimental data, though some results from the Gezira Research Farm may be applicable for irrigated crop production in this Region. The time allowed for our experiments did not allow us to reach definite conclusions, but useful indications were provided.

CEREALS

Sorghum (see Vol. III, p. 995)

A large number of introduced varieties of sorghum of different origins was tried at Malakal, Yirol, and Thiet, and in other places in Upper Nile and Bahr el Ghazal Provinces. With a few exceptions local sorghums out-yielded those which were introduced from elsewhere. Moreover at Malakal local varieties gave yields less subject to seasonal variations than those of introduced varieties. However, in the Bahr el Ghazal trials some quick-maturing varieties introduced from Uganda proved significantly better than the local quick-maturing type. In some of the trials the superiority of introduced varieties was spectacular enough to warrant the policy of their immediate substitution for well-tried local types.

Two varieties from Equatoria, reputed to be specially flood-resistant, were tried on intermediate land in Malakal with very disappointing results.

Generally speaking, however, experimental work indicates that no great improvement in yield can be expected from the introduction of outside varieties of sorghum. Selection and breeding from local stock may prove more promising. Introduction may, however, be necessary if varieties with special characteristics, e.g. for mechanical cultivation or for cultivation as post-flood catch crops, are required quickly. Such varieties should be available from the great number of sorghum strains and varieties cultivated throughout the sub-tropical and tropical areas.

Maize (see Vol. III, p. 996)

At present maize is not cultivated on a large scale anywhere in the Jonglei Area, and the hybrids grown do not appear to be heavy yielders. The extension of maize cultivation and its partial substitution for sorghum may be desirable in some areas because it is not susceptible to bird damage and matures quickly. Some introduced varieties tried at Malakal gave promising yields, and their quality was much superior to that of local products.

Bulrush Millet (see Vol. III, p. 996)

Bulrush millet is grown in both the Semi-Arid and Ironstone Regions, but is practically unknown in the Flood Region. In trials at Malakal the average yields of introduced bulrush millet varieties were generally at least equal to those of sorghum. Moreover it was observed that *Striga* infestation was less serious in this crop. The awned varieties have the further advantage of being less prone to bird damage than sorghum. There are therefore good prospects of spreading this crop in the Flood Region for cultivation on high land soils. In trials in Bahr el Ghazal Province local varieties of bulrush millet proved generally better than the introduced varieties tried.

Finger Millet (see Vol. III, p. 996)

At present this crop is grown only in the far south of the area. Experiments at Malakal and in Bahr el Ghazal Province suggest the possibility of its extension on well-drained soils farther north, though Malakal must be regarded as the probable northern boundary. The introduction of this crop to these districts would further diversify cereal production, diminish risks, and help in controlling *Striga* infestation. Its superior storage qualities should also be considered.

Rice (see Vol. III, pp. 1010, 1012)

For many sites in the Flood Region where drainage is poor and flooding common rice is the most promising, and indeed the most obvious, crop. Experimental work on this crop has been carried out spasmodically for a considerable time, and the results of these experiments can be described as promising. Since 1951 large-scale experiments have been carried out at Malakal by the Development Officer, Ministry of Agriculture, and the Agricultural Section of the Team. These trials covered both the intermediate type of land and *toich* land, with and without means of controlling flooding. These experiments have shown that :

(i) It is possible to cultivate certain varieties of rice under the natural flood conditions at present prevailing on the *toich*. Unfortunately the most successful variety (*Fellata*) was of poor quality, and its other characteristics make it unsuitable for mechanized cultivation. It is, however, suitable for manual cultivation on small plots on the riverain flood-plain by peasant cultivators for their own consumption. Among the many varieties of rice known, others of better quality and more suitable for *toich* cultivation should be available.

(ii) Mechanical cultivation of rice on the riverain flood-plain would be very difficult with the existing river régime without protective banking to give flood control. Those varieties tried matured before the natural floods receded, and consequently, without protective banking, it seems clear that they would have to be harvested in water, a most difficult task to mechanize. The corrugations formed by the series of alluvial banks common on White Nile flood-plains would have to be levelled before mechanical cultivation, which requires large fields, would be possible. The expense of this might prove prohibitive (see p. 673). The prospects of rice cultivation on the riverain flood-plains when the Project is in operation are further discussed on pp. 605-9 of this chapter.

(iii) On intermediate land, though the majority of yields were disappointing, the results can generally be regarded as promising. The natural fertility of this type of land is probably insufficient to produce optimal economic yields. However we are convinced that, given good farming practice, this fertility can be built up. Much investigation work is still necessary to discover, or even to breed, the most suitable varieties and to find the best methods of cultivation.

(iv) Experimental work further indicates that on intermediate land supplementary irrigation will probably be necessary, even for upland varieties. On the other hand drainage, though it may be desirable, does not appear to be essential. Mechanization problems on this type of land do not present any outstanding difficulties. They are mainly confined to finding the most suitable type of machinery.

There are therefore good prospects that this crop can be introduced on a large scale and in time may become the most important crop of the Flood Region, both on peasant holdings and on large mechanized production schemes. It could become not only an important source of food, supplementing and replacing sorghum grain (its yields, being much less subject to seasonal floods and drought, should be much less variable), but also the chief cash crop of this area. The Sudan economy as a whole requires an alternative to cotton, and rice is one of the most promising alternatives.

The failure up to now of attempts to spread rice culture is mainly due, in our opinion, to lack of facilities for hulling. Hand-hulling is very laborious and discourages the cultivator. There are a number of inexpensive hullers on the market at present, and this obstacle should not be difficult to overcome.

Other Cereals (see Vol. III, p. 997)

The results of trials at Malakal of other millets can be classified as follows on the basis of the possible, probable, or improbable success, or impossibility of their introduction as one of the local crops :

Yellow Manna—*Setaria italica*—probable
Pearl Millet—*Pennisetum glaucum*—probable
Job's Tears—*Coix lachryma jobi*—impossible
Buckwheat—*Fagopyrum esculentum*—improbable.

There are a number of other cereals which are worth trying, but unfortunately no seed was available. *Echinochloa* spp. and *Hyparrhenia* spp., cultivated in some countries, are especially in need of trial.

OIL CROPS

Sesame (see Vol. III, p. 997)

Sesame is at present cultivated in the Ironstone and Semi-Arid Regions, but only occasionally in the Flood Region. Experiments in Bahr el Ghazal Province have indicated that local varieties, especially when sown in mixture, are usually superior to introduced varieties. Experiments at Malakal gave disappointing results, indicating that sesame is probably not a suitable crop for the Flood Region.

Other Oil Crops

Experiments with sunflower (see Vol. III, p. 997) suggest that this crop, though susceptible to waterlogging and termite damage, may prove suitable for the Flood and Ironstone Regions.

The difficulty of extracting the oil is the main deterrent to its wider introduction. It is perhaps worth while trying to introduce the habit, universal in some countries of Eastern Europe and Asia and the Middle East, of chewing the kernels and spitting out the husks, a valuable addition to diet. Sunflower may also prove a useful cash crop. The investigation of factors affecting its pollination is essential before large-scale production is attempted.

Safflower (see Vol. III, p. 998) and *Hyptis spicigera* Lam. (see Vol. III, p. 998) were both tried in Malakal; the former may be classified as 'probable' for dry season cultivation as a cash crop; the latter requires a longer growing season than is generally possible in Malakal. It should be tried farther south.

Castor (see Vol. III, p. 998) trials at Malakal gave very disappointing results. Yields were extremely low and the crop did not survive the dry season. On the other hand single bushes of castor can often be found growing near Nilotic homesteads. Attempts to introduce this crop should be continued both in the Flood and Ironstone Regions, as it may prove valuable as a cash crop.

LEGUMINOUS CROPS

Groundnuts (see Vol. III, p. 998)

This crop is universally grown in parts of the Ironstone and Semi-Arid Regions. Attempts to introduce it in the Flood Region have failed, for three main reasons: its susceptibility to waterlogging, difficulties of harvesting on heavy clay soils, and elephant damage in Bor District where the soils are particularly favourable for its production.

Experimental work in Malakal suggests that excellent yields can be obtained on very heavy soils of the high land class, though admittedly harvesting is more difficult than on lighter soils. Introduced varieties, especially at close spacing, have generally given better yields than the local spreading variety. Yields of over 1 ton of unshelled 'nuts' were not uncommon. Consequently, provided the local cultivator is shown how to grow this crop properly, some better method of harvesting is devised for heavy soils (possibly the use of ploughs), and elephants are controlled, there is no reason why this crop should not become one of the staple food and cash crops on high land soils in the Flood Region.

In experiments in Bahr el Ghazal Province local spreading varieties have given, over a number of years, yields significantly higher than those of introduced varieties. Unfortunately the spacing used was not recorded, and the inferiority of introduced varieties may be due to the fact that, being erect, they require much closer spacing than local spreading types. Work on the introduction of new varieties is well worth continuing in the Ironstone Region and starting in the Semi-Arid Region. If this crop is to achieve importance as a source of cash, the provision of oil mills is obviously essential.

Cowpeas (see Vol. III, p. 1000)

These are cultivated throughout the area. The results of trials at Malakal, though inconclusive, suggest that some introduced varieties may prove superior to those cultivated locally. The selection of the best from among a multitude of local types and varieties is also to be desired.

Other Leguminous Crops for Human Consumption

Green gram (see Vol. III, p. 1001) is almost universally grown in the Ironstone Region. In trials at Malakal yields of this crop were on the whole promising, indicating that its cultivation on the better-drained soils of the Flood Region is worth encouraging.

Bambara groundnuts (see Vol. III, p. 1001) are also cultivated by some peoples of the Ironstone Region. Trials at Malakal gave very poor yields, suggesting that this crop is probably unsuitable for the Flood Region.

Soya bean (see Vol. III, p. 1000). Although yields in the Malakal trials were not outstanding enough to warrant an attempt at the immediate expansion of production of this crop as an export commodity, they were at least as good as those of other legumes, including local strains of cowpea; further the exceptional nutritional qualities of soya bean make its immediate introduction for local consumption desirable. Also, from among the great number of varieties of this crop grown all over the world it should be possible to find one really suitable for this environment.

Pigeon peas (see Vol. III, p. 1001) in our trials gave generally unsatisfactory yields. They do not survive the dry season and must be replanted every year. They may be worth considering for cultivation with supplementary irrigation; they may prove a valuable crop not only because of yield but also because of their deep-rooting habit and effect on soil nitrogen status.

Tepary beans (see Vol. III, p. 1001) require special mention not only because yields in our trials were generally satisfactory but also because they are exceptionally quick-maturing (just over two months).

Chick peas (see Vol. III, p. 1001), while unsuitable for cultivation early in the season, gave satisfactory yields when sown at the end of the rains. They may prove a valuable crop for rotation with rice[20].

Other legumes (see Vol. III, p. 1001) which, on the basis of Malakal trials, might prove worth while in the Flood Region are cluster bean, black gram, *babun* (*Vigna vexillata*), velvet bean and Jack bean.

General Remarks on the Introduction of Leguminous Crops

As may be seen from the above review, the range of leguminous crops could be considerably extended on high land soils in the Flood Region, where legumes generally grow very well. On the other hand we were unable to find a leguminous crop which could be considered even remotely suitable for intermediate land cultivation.

In the Ironstone Region the range of cultivated legumes is already greater, and undoubtedly both better varieties of existing crops and new crops suitable for local environment will be found as work in this direction continues.

In the Semi-Arid Region rainfall is the limiting factor, restricting the number of suitable legumes to those able to withstand prolonged droughts and able to mature in 3 to 4 months. Further investigation is urgently required in this connection.

FIBRE CROPS

Cotton (see Vol. III, p. 1001)

Rain-grown American cotton is, or was at one time, cultivated throughout the Flood and Ironstone Regions. On better-drained soils, given sufficient care, it does well. The factors which limit the spread of its cultivation are mainly economic. Future cultivation of cotton on a commercial scale in areas where at present it is not grown depends on improvement in quantity and regularity of production of food crops, on the profit which cotton can give the cultivator, and on advance in agricultural technique sufficient to overcome the present shortage of labour. Considering the Sudan economy as a whole, the cultivation of a cash crop other than cotton should be aimed at in these areas, economics and technical difficulties permitting.

As far as long staple cotton is concerned, experiments and past experience indicate that it could be grown, with supplementary irrigation, in the Semi-Arid Region and in the Transitional Belt between this and the Flood Region. Farther south, approximately south of 10° N., two factors limit the possibility of its cultivation; shortage of well-drained land and the prevalence of blackarm disease. The first obstacle could be removed by the provision of drainage, though this might prove difficult. The removal of the second obstacle depends mainly on the success of plant breeders in producing strains of blackarm-resistant varieties; results of work with these in Malakal are promising but require further confirmation.

Jute (see Vol. III, pp. 1003, 1012-3)

Jute trials in Malakal gave disappointing results. This crop starts flowering here when only 1·5 to 2 m. tall. Earlier planting may improve yields but is not generally possible at Malakal latitude without irrigation of the land prior to sowing. Work in Equatoria has shown that planting as early as April is probably necessary to achieve economic yields[21]. Therefore this crop should be tried in the southern part of the Flood Region and on the richer soils of the Ironstone Region.

As fertile soils are essential for economic production of jute, the utilization of *toich* soils for its cultivation should be considered. In the Malakal experiments, jute grown on *toiches* gave the best yields.

Deccan Hemp (see Vol. III, pp. 1003 1012-3)

The prospects of introducing Deccan hemp are similar to those for jute. At the latitude of Malakal the length of the growing season is generally insufficient for its full development. Cultivation farther south might prove more successful economically[22].

Sunn Hemp (see Vol. III, p. 1012-3)

The same remarks apply to this crop, if grown for fibre extraction. It should provide high enough yields to make it worth considering as a green manure.

MISCELLANEOUS CROPS

Sweet Potato

This crop is cultivated at present in the southernmost parts of the Jonglei Area, and gave satisfactory yields in trials at Tonj[23], indicating that cultivation could be extended throughout the Ironstone Region. Farther north it does not survive the dry season without supplementary irrigation.

Cassava

This is another useful anti-famine crop at present grown in the Jonglei Area only by some Bari and Mandari in the south. Tonj trials again indicate the possibility of extending its culture farther north.

Sugar-Cane

This crop, together with cotton and rice, is the most promising cash crop for the southern part of the Jonglei Area. Experimental work carried out by Ferguson[24] on *toiches* near Juba led to the conclusion that it could be grown satisfactorily, though many problems still require investigation and solution. These experiments, together with work done by Messrs. Boxall and Co.[25], show that the sugar-cane cultivator of the future must choose between growing it on the higher parts of the flood-plain or on land beyond this plain not subject to flooding by the river. In the former case he might be able to dispense with irrigation altogether or, if artificial watering proved essential, to cut the water so applied to the minimum. On the other hand the risk involved in cultivating this crop on the riverain flood-plain without protective banks is considerable. This risk could be avoided by growing the cane on high land, but a considerable volume of water would be necessary for irrigation and, as the high land soils are markedly poorer, the possibility of expenditure on fertilizers must be taken into account.

The possibilities of sugar-cane cultivation on the riverain flood-plain under the Equatorial Nile Project are governed by two factors : if banking-off of the *toich* is carried out in the Southern Zone (see p. 676) this will automatically protect these areas from the normal flooding, and, because of the reversal of the seasons, gravity irrigation during the rainless months should not be difficult; on the other hand the provision of adequate protection for this land at the high discharges necessitated by flood-escape river control would be most difficult and expensive. Without such special measures we consider that cultivation of sugar-cane on the riverain flood-plain would be too risky to be economic (see p. 664).

PROTECTION AGAINST PESTS AND DISEASES

The amount of damage done by pests and diseases in this area varies from season to season, district to district, and crop to crop, but average losses are considerable, and often one or both of these factors, combined with an adverse season, causes complete crop failure and great hardship in consequence.

Our experimental programme did not include trials of disease and pest control; very little has been done in this area by specialists in pathology and entomology, and work has been limited to identification of samples. Therefore the suggestions outlined below are based on experience elsewhere, and their effectiveness in this area must be confirmed by trials in local conditions.

The suggested steps to control crop diseases may be outlined under the following headings:

(i) Selection of Planting Material. Greater care could be taken in the selection of healthy seed stock. It is known that diseases such as smut, *Helminthosporium*, leaf stripe, and *Piricularia*, causing rice blast disease, are seed-borne, and therefore use of seed from an infected crop, which often happens at present, perpetuates and intensifies the disease.

(ii) Disinfection of Seed. If disease-free seed cannot be obtained, or if the origin of the seed is unknown, disinfection of seed may be an economic precaution. The dressing of seed with copper carbonate has been successful in reducing sorghum smut, and this treatment could be profitably extended. Experiments in disinfection of groundnut seed in Kordofan have also shown very promising results[26].

(iii) Use of Resistant Varieties. The main hope for the control of virus and bacterial diseases is the use of resistant or tolerant varieties. Considerable advance has been made in the Sudan with the breeding of cotton varieties resistant to blackarm and leaf curl diseases, and some of these varieties, of both Egyptian and American types of cotton, were successful in trials at Malakal (see Vol. III, p. 1001). The other common crop which requires work in this direction is sesame, which often suffers from attacks of what is known in Arabic as *marad ed dam*, a disease caused by *Bacterium sesamicola*.

(iv) ROTATION OF CROPS. "One amongst many advantages of crop rotation on one piece of land is to avoid piling up of disease organisms"[27]. The replacement of present sorghum mono-culture on some intensively cultivated classes of land by an orderly succession of different crops would probably have a pronounced effect upon diseases of sorghum which, though not spectacular, cause quite considerable damage.

(v) FUNGICIDES. The use of fungicides may be considered where losses due to fungoid diseases, often serious in this climate, are great enough to make it economic. It would, however, be most difficult to organize except on centralized crop production schemes.

(vi) OTHER MEASURES. Other measures, including plant sanitation (removal and burning of diseased plants and post-harvest debris), soil sterilization, removal of alternative hosts, plant quarantine, etc., might be necessary in special cases, e.g. with newly introduced cash crops of greater value.

Crop pests are even more serious than diseases in this area. As we have seen in Volume I, Chapter 5, they range from the minute *Contarinia sorgicola* to elephants. Possible control methods can be summarized as follows:

(i) INSECT PEST CONTROL. Hand-picking is laborious and, with the majority of these pests, ineffective, though the *andat* bug, for example, can be controlled in this way, provided the work is well supervised[28].

The present universal habit of leaving the stalks of sorghum on the field until they rot or are eaten by animals undoubtedly encourages and perpetuates stem-borer infection. Cutting the stalks and either burning them or removing them for fodder, after thorough sunning, has proved effective elsewhere and should if possible be made compulsory where intensive cultivation of this crop is carried out. The obligatory clearing and burning of cotton debris, including pulling out of roots, has proved effective in control of cotton stem-borer and bollworm, and probably helps in the control of other pests and diseases. Disinfection of seed which is known to carry pests (e.g. cotton Pink Bollworm) should be obligatory.

The number of insect pests present in this area could be controlled successfully by the use of stomach or contact poisons. Petrol was used successfully in Malakal as a fumigant for termite nests. These troublesome pests, which cause much damage, have also been successfully controlled by the application of 'Paris Green'; poison bait containing arsenicals has been successful in the control of locusts, grasshoppers, crickets, etc. In Blue Nile Province damage by *andat* bugs has been reduced by spraying with paraffin, a costly but effective method[29]. The newer insecticides, such as D.D.T., Gammaxene, and particularly systemic insecticides, open fresh possibilities for the control of some tiresome insects, and their use avoids the risk involved in issuing arsenical poisons to the uneducated cultivator. The spraying of jute and hemp with D.D.T. was successful in the Malakal experimental scheme in protecting them against almost complete defoliation by flea beetle. The control of water which irrigation gives may be successfully used to combat some insects by flooding, e.g. cut worm (*Laphygma exigua* Hb., Ar. *sufra*) can be controlled in this way.

When the crop is of sufficient value, clearance of alternative hosts harbouring pests in the vicinity of the cultivation or in fallows should be carried out, though this is often impossible on a large enough scale, especially in areas of heavier rainfall.

Further investigation of the use of trap crops, timing of sowing (e.g. early sowing proved successful in partial control of Sudan Bollworm in cotton), and possibilities of biological control is necessary.

At present the climatic conditions during the dry months of the year are not conducive to the increase of insects; moreover crops are not grown during this period and, as part of agricultural policy in connection with cotton, roots and debris are cleared and burnt, with the result that many insects are destroyed. These factors are obviously most effective in the Semi-Arid Region and least effective in the Ironstone Region. If perennial irrigation is introduced in connection with necessary remedial measures when the Project is in operation, the effect on the insect population will have to be closely watched, as the damage they do may be expected to increase.

Finally in this connection, improved protection of stored produce against insect damage must be considered. Improvement in the cleanliness of storage space and containers and in dryness of both store and stored products is most important. If necessary, fumigants should be used where possible. Petrol was found to be a useful fumigant for stored sorghum and beans[30]. Carbon disulphide and tetra-chloride, methyl bromide and hydrocyanic acid may also be used. The dusting of grain with Gammaxene or D.D.T. has also proved successful. For large-scale storage, grain-conditioning plants may be necessary.

(ii) CONTROL OF BIRD DAMAGE. At present bird damage is mainly controlled by scaring, which is ineffective and laborious, and it is doubtful if the introduction of modern methods of scaring by mechanical gadgets would improve matters. How effective is the destruction of birds by the use of high explosives in the roosting areas cannot yet be assessed, as this method has only very recently been introduced in the Jonglei Area (see Vol. I, Chap. 5). The most promising measure in the long run is probably the evolution of bird-resistant varieties (e.g. awned varieties of bulrush millet), and, where it is not possible to control the damage, the replacement of a susceptible by a non-susceptible crop, e.g. sorghum by maize. The possibilities of poisoning and biological control should also be studied.

iii) CONTROL OF DAMAGE BY MAMMALS. Present methods of scaring and ineffective fencing could be greatly improved; moreover we venture to predict that if the Equatorial Nile Project results in a considerable reduction in cattle numbers, 'protein hunger' will increase the incentive for hunting and the game population may be considerably reduced. If this does not happen, the use of poisons, traps, and firearms, or even the introduction of the bow and arrow to Nilotic areas, will be necessary to give enough protection to the crops. The whole 'game policy', already due for revision, will have to be modified, and outside scheduled reserves all animals responsible for damaging crops will have to be exterminated as far as possible.

CONTROL OF WITCHWEED (*STRIGA HERMONTHICA* BENTH.)

As we have seen in Volume I (p. 354) the *Striga* parasite is one of the most serious causes of low yields, especially on high land cultivations in the Flood Region. We have estimated that average losses due to *Striga* infestation in the Flood Region are probably of the order of 30%. Control measures are urgently needed and methods by which the damage due to this parasite could be reduced can be summarized as follows:

(i) AVOIDANCE OF PROLONGED MONO-CROPPING WITH SORGHUM. As witchweed infestation is cumulative, this is the most obvious method. Where shifting cultivation is practised, the appearance of *Striga* should lead to immediate abandonment of the infested field. However, the local cultivator, with his rudimentary tools which make the opening-up of virgin land difficult and laborious, continues to cultivate the infested land until the yields are only a little above the seed expended in sowing. Consequently the improvement of tools should indirectly reduce damage done by *Striga* by encouraging more frequent shifts. Further investigation is needed into the length of fallows necessary to clean the field from *Striga hermonthica*, and the factors affecting it. At present this period is estimated at 7 to 10 years.

(ii) CROP ROTATION. Where more intensive cultivation is for various reasons desirable, mono-cropping with sorghum should be replaced by a crop rotation designed to keep witchweed infestation down to a minimum. To do this, the sequence must include cleaning crops. Rose and Lochrie[31] have found that a number of non-host plants can induce germination of *Striga asiatica*. Andrews' work in the Sudan[32] has confirmed that the same is true for *Striga hermonthica*. The plants which he found to be able to induce germination of *Striga* are listed in the table below:

TABLE 278

PLANTS WHOSE ROOT EXCRETIONS CAN GERMINATE THE SEEDS OF *STRIGA HERMONTHICA* BENTH.

LEGUMINOSAE	
Dolichos lablab Linn.	bonavist bean(¹)
Vigna unguiculata Walp.	cowpea(²)
Arachis hypogaea Linn.	groundnut(²)
Cicer arietinum Linn.	chick pea
Cajanus cajan Millsp.	pigeon pea
Phaseolus vulgaris Linn.	French bean
Lupinus termis Forsk.	lupin
Vicia faba Linn.	broad bean
Glycine soja (Linn.) Merr.	soya bean
Pisum sativum Linn.	peas
Medicago sativa Linn.	lucerne
Crotalaria juncea Linn.	sunn hemp
GRAMINEAE	
Sorghum spp.	sorghum(¹)
Pennisetum spp.	bulrush millet(¹)
Paspalum commersonii Lam.	—
Panicum miliaceum Linn....	French millet(¹)
Panicum miliare Lam.	little millet(¹)
Oryza spp.	rice(¹)
Cynodon dactylon Pers.	Bermuda grass(¹)
Setaria italica Beauv.	Italian millet(¹)
Euchlaena mexicana Schrad.	teosinte(¹)
Zea mays Linn.	maize(¹)

OTHER FAMILIES

Gossypium barbadense Linn.	cotton	*Malvaceae*
Sesamum orientale Linn. ...	sesame... ...	*Pedaliaceae*
Helianthus annuus Linn. ...	sunflower ...	*Compositae*
Cucumis melo Linn. ...	melon	*Cucurbitaceae*

(¹) Susceptible to parasitism by *Striga hermonthica* Benth.
(²) Slightly susceptible to parasitism by *Striga hermonthica* Benth.

As it is known that *Striga* seedlings die unless they are able to form parasitic connections with the host plant at early stages, the value as cleaning crops of the non-host plants which are able to induce *Striga* germination will be appreciated. Some plants, such as cowpeas and groundnuts, though susceptible to some damage by the parasite, probably do not provide it with sufficient nourishment, as they do not bring it to maturity, and can therefore be valuable in its extermination.

Apart from cleaning crops of this kind, the rotation should include the maximum variety of the graminacious crops. All cereals grown here are susceptible to *Striga* parasitism. It has been noted, however, that change from sorghum to bulrush millet or finger millet seems to reduce *Striga* infestation. The parasite probably requires a certain time to adapt itself to a new host. Constant changes from one host crop to another might therefore reduce the damage. Fallowing of land for short periods, especially if the fallow will support grasses susceptible to *Striga*, is probably of little value.

Suitable anti-*Striga* rotations would probably be on the following lines, taking into account only those crops which are already cultivated or easy to introduce:

For the Ironstone Region:
sorghum—pulse crop—bulrush millet—groundnuts—finger millet—sorghum.

For the Flood Region:
sorghum—groundnuts—cotton—bulrush millet—sorghum—pulse crop.

For the Semi-Arid Region:
(*a*) sorghum—bulrush millet—cowpeas (for clay soils).
(*b*) sorghum—bulrush millet—groundnuts (for sandy soils).

As with all problems of rotation, these suggestions require confirmation by prolonged experimentation, which could not be done within the time allotted for our investigation.

The value of intercropping cereals with legumes—simultaneous rotation—for control of *Striga* should also be investigated, as field observation suggests that interplanted sorghum suffers less from the parasite.

(iii) Use of 'Trap Crops'. Planting of 'trap crops'—i.e. crops susceptible to infestation which, after inducing germination of the witchweed, are ploughed in—is widely practised in South Africa to control *Striga asiatica*. Cereals as well as grasses are used[33]. Saunders claims that double trap cropping (i.e. two trap crops per season) for two years will practically free the land from *Striga asiatica*[34]. However, apart from the capital necessary for the production of crops which are not immediately valuable, it would obviously be very difficult to introduce and popularize a complex practice of this sort among the backward cultivators of the Jonglei Area.

(iv) Weeding. Hand-pulling of *Striga*, though laborious and having only a limited effect, should in the long run be a certain method of controlling the parasite. To be successful it must be done for a number of years, and before the *Striga* flowers and sets seed. It should be remembered that even green ovaries picked from the plant produce viable seeds[35]. If therefore pulling out cannot be completed early enough and some *Striga* plants start to flower, they must be burnt after pulling. This method, to be successful, needs to be carried out simultaneously over a wide area; otherwise one infested field would cause re-infestation of cleaned fields in the vicinity. Enforcement of anti-*Striga* measures has been introduced with some success in parts of Kenya, where losses of grain due to *Striga* were estimated at 200 lb. per family[36]. The effectiveness of pulling out the parasite has also been shown by experimental work in Tanganyika[37]. Our own experimental work has not been continued long enough to show the ultimate results of this treatment. It does, however, show that the weeding out of *Striga* cannot be expected to produce much response during the first season (see Vol. III, p. 994). Indeed there is some evidence that, until the intensity of infestation is reduced by a few seasons of weeding, the destruction of the aerial parts by pulling stimulates the parasite, which in turn makes bigger demands on the host crop and weakens it[38].

(v) Control by Flooding. We have already noted that the inhabitants of parts of Western Nuer District attempt to keep witchweed under control by judicious flooding. They maintain that the sorghum crop, though affected by flooding, withstands it better than does the parasite (see Vol. I, p. 355). The effect of prolonged periodic waterlogging on *Striga* infestation has also been observed in Tanganyika, where a formerly badly infected field grew good rice though *Striga* plants were still occasionally present[39]. Our experiments with this form of control in sorghum crops proved inconclusive, as *Striga* infestation was slight and not uniform, while technical difficulties prevented the setting up of properly replicated and randomized experiments. This method of control is certainly worth further enquiry. If rice could be introduced on irrigation schemes as a food-cash crop, its inclusion in rotation with sorghum, cotton, and legumes would provide an easy and economic means of controlling *Striga* by flooding. On the rice plots at Malakal only a few plants of *Striga* were observed, though the land was undoubtedly infested. These few plants were found on unflooded patches.

(vi) Chemical Means of Control. Saunders[40] and Timson[41] reported successful extermination of *Striga lutea* by application of sodium chlorate. A high concentration of this compound killed sorghum as well as *Striga*. Andrews[42] reported that attempts to control *S. hermonthica* attack by means of seed dressing (borax, copper sulphate, manganese sulphate, zinc sulphate, and gum arabic) were unsuccessful. Similarly spraying with 10% sulphuric acid proved ineffective. In recent years application of the hormone type of selective herbicides was tried in the Northern Sudan[43]. In the 1952–53 season a large-scale experiment was undertaken, involving three levels of concentration (½, 1, 2 lb.p.f.) of sodium 2, 4-D, and four dates of spraying (2, 3, 4, 5 weeks after sowing). Five types of sorghum on four fields infested to various degrees were tried to confirm and clarify the results of previous work[44]. The results of this trial are summarized as follows:

> "The over-all effects of strength, dates and varieties were found significant as judged by two different measures of *Striga* infestation, and by the yield of ripe heads of dura. Increases in yield and decreases in infestation were found with increasing strength of treatment. Decreases in yield and increases in infestation were found as a result of delaying treatment beyond the

third week after sowing of the dura. All varieties responded to treatment on heavily infested land, but milo, which shows some resistance to light infestation, nowhere gave a significant response ".

The importance of timing of spraying was made clear by this trial. The spraying should be delayed long enough to let the crop pass its most susceptible stage, and yet not too long because the susceptibility of *Striga* seedlings decreases with their age. To kill the germinating parasite the herbicide must come into contact with its seedlings. Consequently, control of witchweed in rain-grown crops is much more difficult than with irrigated crops, as the success of the application of herbicide depends on the delay between spraying and the next rain, necessary to wash the weed-killer into the soil. This at least partly explains the lack of response to spraying in our experiments in Malakal in the 1952–53 season. The experiments carried out in the same season at Doka (between Gedaref and Gallabat)[45], where rainfall was favourable, resulted in excellent response to spraying, especially when a higher rate of application of weed-killer (2 lb.p.f. of sodium 2, 4-D) was used. This method reduced only early attacks, the infestation in later stages being not significantly affected,

The investigation of the suitability of the wide range of selective herbicides and formulations available is urgent, because some of them may prove better than sodium di-chlorophenoxy-acetate by showing a higher degree of effectiveness at the later stages of witchweed growth and being more persistent in the soil. Wilson Jones[46] has discussed the economics of spraying and has shown that, under the conditions of his experiment, it should provide considerable returns and should not prove too difficult to organize. In considering the returns from the application of selective herbicides, the effect of reduction in *Striga* infestation on the yields of subsequent crops as well as on the one actually sprayed must be taken into account.

(vii) Breeding of Resistant Strains and Varieties. Some success has been reported in evolving strains of sorghum resistant to *Striga asiatica*[47], but Doughty[48] found no correlation in the genetic resistance to *Striga asiatica* and *Striga hermonthica*. However, it has been observed that the milo strains in the Central Sudan seem to possess at least a certain degree of resistance to *Striga hermonthica*. An enquiry into the relative resistance of various strains of different local types of sorghum is urgently needed, and should be followed by breeding of the resistant strains. This work requires time and the services of a specialist.

(viii) Other Methods. It has been observed that heavy doses of fertilizers are generally effective in reducing witchweed damage. There are two possible explanations of this fact[49]. Either the better nourished crop acquires a superior resistance to the parasite's attack, or enough food is supplied by manuring for both host crop and witchweed. If the latter is the true explanation, a build-up of infestation to a new equilibrium with soil fertility can be expected and the benefit of manure application would be only a temporary one. It has also been observed that organic manures, especially green manures, are better than artificials in reducing *Striga* damage. This may be due either to the absorption or destruction of the *Striga* germination stimulant as a result of chemical or biological reactions following the ploughing in of organic materials, or to the production of stimulants for the germination of *Striga*, which then dies in the absence of a suitable host crop.

The relation of the intensity of *Striga* attack to seasonal climatic variations and date of sowing and maturation periods of susceptible crops should also be studied, as some correlation between these factors has already been noted.[50]

ESTIMATED FUTURE YIELDS

The need for the various agronomic improvements reviewed above varies in the different Regions and in the different circumstances within the Jonglei Area. Much work still needs to be done to determine the main limiting factors under each particular set of conditions and then decide what methods should be used to counteract them. The success of any method will depend on the gravity of the limiting factor as well as on the effectiveness of the method. It is impossible to review here all the different sets of conditions met with in the Jonglei Area, and to say which agronomic improvements should be given priority. However on the basis of experimental data we estimate that a general improvement in yields of the order of 10% to 20% could be achieved by agronomic improvements. For the purpose of this report it is necessary to estimate future yields which could be achieved by better crop husbandry methods.

This estimate has been attempted on the basis of :

(i) Experimental data accumulated by the Team and the Development Officer, Ministry of Agriculture, working in close association.

(ii) The results of experiments carried out at various times in the Jonglei Area by the staff of the Ministry of Agriculture.

(iii) Average yields reported from the Gezira Scheme and by the Gezira Research Farm.

The reader is warned that the information listed above provides no more than the foundations for an ' intelligent guess ', which is obviously open to considerable error. Moreover we have assumed that the standard of husbandry is at least equal to that found at present on government agricultural schemes, which require a high degree of supervision by properly qualified staff, both technical and administrative. Therefore in our calculations we have used the figures in Table 279 only for centralized remedial schemes. For scattered holdings they should be reduced by 25%, on the assumption that improvement in husbandry methods will take place but will be more difficult and slower.

For the sake of simplicity we have not differentiated between the various Regions, but have given what we consider a fair average. Table 279 does not include 'estimated future yields' of by-products useful for animal feeding or fodder crops. These are given in Table 285 (p. 611) in the section dealing with the implications of agricultural remedies on animal husbandry.

TABLE 279

AVERAGE 'ESTIMATED FUTURE YIELDS' ON ALTERNATIVE LIVELIHOOD SCHEMES

Crop	Estimated Future Yields Per Feddan		Remarks			
	Rain-grown	Irrigated				
1. CEREALS						
Sorghum grain;						
quick-maturing ...	250 kg.p.f.	600 kg.p.f.				
slow-maturing ...	325 kg.p.f.	800 kg.p.f.				
Maize grain	250 kg.p.f.	—				
Bulrush millet grain ...	250 kg.p.f.	—				
Finger millet	250 kg.p.f.	—	Suitable for southern part of Flood Region and Ironstone Region only			
Rice	—	750 kg.p.f.	Unhulled: 450–500 kg.p.f. hulled. (Hulling % = 60–66%)			
2. LEGUMINOUS CROPS						
Cowpea seed ...	150 kg.p.f.	—				
Green gram	250 kg.p.f.	—				
Black gram	250 kg.p.f.	—				
Velvet bean	300 kg.p.f.	—				
Tepary bean	125 kg.p.f.	150 kg.p.f.	Useful as catch crop after quick-maturing irrigated crop, e.g., rice			
Chick pea	125 kg.p.f.	150 kg.p.f.	Useful as catch crop as above			
Cluster bean	150 kg.p.f.	—				
Dolichos lablab ...	—	100 kg.p.f.	Does not flower early enough in Flood and Ironstone Regions			
			Extractable oil %	Oil per feddan (rain-grown)	Oil per feddan (irrigated)	
3. OIL CROPS						
Groundnuts (unshelled)	400 kg.p.f.	400 kg.p.f.	30	120 kg.	120 kg.	Irrigation may be desirable in Semi-Arid Region only
Sesame	150 kg.p.f.	—	45	60 kg.	—	
Sunflower	300 kg.p.f.	—	25	75 kg.	—	Containing 45% kernels and 55% husks
Safflower	200 kg.p.f.	300 kg.p.f.	20	40 kg.	60 kg.	Irrigated, grown as catch crop after rice
Cotton seed:						
American	120 kg.p.f.	330 kg.p.f.	20	24 kg.	66 kg.	Cotton containing 33·3% lint and 66·7% seed
Egyptian	—	420 kg.p.f.	20	—	84 kg.	Cotton containing 33·3% lint and 66·7% seed
4. FIBRE CROPS						
Cotton:						
American type ...	1·3 kantars p.f.	3·5 kantars p.f.	(1 kantar = 315 rotls = 141·75 kg.)			
Lint only... ...	0·33 bales p.f.	0·90 bales p.f.	(1 bale = 400 lb. = 181 kg.)			
Egyptian type ...	—	4·5 kantars p.f.				
Lint only... ...	—	1·12 bales p.f.				
5. MISCELLANEOUS CROPS						
Sugar-cane	—	25 tons p.f.	Ironstone Region only			
Cassava	3,000 kg.p.f.	—	Ironstone Region only			
Sweet potatoes ...	1,500 kg.p.f.	—	Ironstone Region only			
Plantains	—	5,000 kg.p.f.	Contains 50% edible material			

N.B.—These yields should be reduced by 25% for estimating future yields on native holdings.

3. ENLARGEMENT OF THE AREA UNDER CULTIVATION

Agronomic improvement aimed chiefly at increasing output per unit area can have only limited success in increasing total crop production. In this sparsely populated country there is more scope for increasing present production by extending the acreage under cultivation. The introduction of better husbandry methods, new crops and varieties, etc., will need considerable time for research work, followed by implementation of the results. On the other hand, given sufficient capital, increase in the cultivated area could be achieved more quickly. It should be noted, however, that for economic reasons improvements in both directions should proceed simultaneously.

The two main obstacles to increasing crop output by extending the area of cultivation are:

(i) The present scarcity and low standard of efficiency of labour.

(ii) The risks of crop failure, due to frequent droughts and floods, which discourage the local cultivator from sowing more than the bare minimum.

We shall discuss ways and means of reducing these risks in the next section, but before doing so we must consider problems connected with the improvement of the labour position.

THE PROBLEM OF LOW LABOUR EFFECTIVENESS

We have concluded in Volume I, p. 355, that the two main factors affecting crop production are labour scarcity and low standards of effectiveness. Scarcity of labour is the outcome of:

(i) Low density of population.

(ii) Limits imposed on the time available for cultivation by annual migrations to dry season grazing grounds.

(iii) Waste of time involved in walking the often long distances between homesteads and out-cultivations.

Little can be done about the low density of population, though judicious resettlement (see p. 613) of the population might lead to better utilization of natural crop production resources in different parts of the area.

Changes resulting from the Equatorial Nile Project will in themselves result in less need for annual migrations, though in many parts of the area migration to dry season grazing grounds will still be necessary. The organization of these migrations, however, could be improved so that a much smaller proportion of the able-bodied population would be away from the cultivation areas for the greater part of the dry season. Even the present holding in cattle requires only a fraction of the number of people migrating to the cattle-camps to tend it. If inland water supplies were assured, a large proportion of these people could remain in the cultivation areas to carry out preparations for the next season's crop. If alternative dry season grazing grounds are developed to replace the *toich* grazing lost under the Project, they should, as far as possible, be located close to the cultivation areas, so as to reduce the need for long annual treks by a large part of the population. As will be seen later this will not always be possible, but it should be a primary objective in the application of remedial measures.

The distribution of out-cultivations in relation to homesteads depends on the location of the higher patches of land. Consequently wherever high land is extended by artificial drainage, or where crop production schemes based on drainage, irrigation, etc., are organized, the aim should be to settle the people as near as possible to their cultivations, and so reduce as far as is practicable the present wastage of time involved in walking to and fro between homestead and fields. Here again the importance of dry season domestic water supplies must be emphasized.

The low standard of effectiveness (a factor more serious than scarcity of labour as far as our problems are concerned) is due partly to the present lack of physical ability to carry out the heavier tasks involved and partly to the present attitude towards crop husbandry, which is coloured by the people's preoccupation with cattle. It is also due to the very obvious difficulties of the environment and to lack of knowledge. Finally, the lack of incentive is responsible for the absence of any great desire to improve crop output.

Improvement in general health, especially better control over the many endemic diseases which at present sap the strength of the inhabitants of this area, together with better diet, should increase the people's stamina. The loss of domestic stock which may result from the Equatorial Nile Project, and the consequent increased necessity for crop production to balance these losses, should provide the necessary incentive and awaken interest.

The provision of better means of cultivation, which we discuss below, together with the knowledge of how to use them in the best manner, is most important if the area under cultivation, and hence crop output, is to be increased.

BETTER MEANS OF CULTIVATION

As may be seen from Volume I, p. 355, both the labourer and his tools are ineffective. Most of the tools used for cultivation in this area are very rudimentary (see Vol. I, p. 334). No attempt has been made by the vast majority of the inhabitants to harness their domestic animals to help in tilling the fields. It is therefore not surprising that in this country only a very small proportion of the land, virtually unlimited for the present population, is used for crop growing.

BETTER HAND TOOLS

The provision of better hand tools is the most simple method of extending cultivation, but we have had no opportunity of investigating possibilities in this direction. There are many gardening tools on the market which might be worth considering. However, it should be noted that most tools are designed for cultivators with greater stamina and differently clothed, e.g. a spade or garden fork would be of little use to the bare-footed Nilotic. Moreover the physical stamina of the inhabitants of this area sets narrow limits to the possibilities of any improvement in this way.

USE OF ANIMAL-DRAWN IMPLEMENTS

The possibilities of enlarging areas under cultivation by the introduction of animal-drawn implements are considerably greater. In other countries of Africa animal-drawn implements have increased agricultural output as well as the standard of living of their users and there seems no reason why this should not be so here, though there are many obvious difficulties. Biggs[51] calculated, on the basis of area per unit man-power (man=1 unit, woman=1 unit, child=½ unit), that the possession of a plough increased the area under cereals in Busoga District, Uganda, by 93% and the area under cotton—the main cash crop—by 32%. His other observations might be of particular interest to the inhabitants of the Jonglei Area; he found that while owners of ploughs possessed on an average 1·6 wives, people not owning them had to be content with 1·4 wives!

Other interesting information from Uganda on the results of the successful introduction of ploughs[52] is given in Table 280 below:

TABLE 280

RELATION BETWEEN THE NUMBER OF PLOUGHS AND COTTON ACREAGE IN THE TESO DISTRICT, KIOGA BASIN

Season	Number of ploughs	Cotton acreage
1923–24	282	68,000
1924–25	734	87,500
1925–26	1,154	97,500
1926–27	2,710	99,320
1927–28	2,941	69,737
1928–29	3,400	132,000
1929–30	6,170	117,265
1930–31	6,423	118,813
1931–32	7,849	115,626
1932–33	8,280	134,481
1933–34	9,913	112,222
1934–35	11,615	112,329
1935–36	13,726	116,812
1936–37	15,388	156,878

In the new conditions created by the Equatorial Nile Project the number of cattle retained should always be at least sufficient to provide working animals, though in some cases it may be necessary to grow a certain amount of fodder crops for them. Apart from the ultra-conservatism of the majority of local cultivators, the main obstacle to the introduction of cultivation by draught animals is the special ritual position which cattle hold in the lives of the people. This obstacle does not exist among the Baggara tribes, but with the Nilotics it it a formidable one. It will be very difficult indeed to persuade the Shilluk, Nuer, or Dinka to put his 'song bull' into a yoke. Another difficulty is the fact that though work with animal-drawn implements is more effective, it is not lighter but requires even more physical effort than present hand methods of cultivation.

In Table 281 we summarize the daily output of a yoke (a pair) of oxen at Malakal, and for comparison give the figures for the Gezira Research Farm, kindly provided by the Chief Agronomist, Research Division. It should be remembered that the Malakal soils are more ' difficult ' than those of the Gezira, and this applies to most of the soils of the Jonglei Area. The lower output at Malakal is also partly due to the inferior training of operators as well as of the draught oxen. Finally it should also be noted that, while in the Gezira a man and a boy are normally used with each team of oxen, at Malakal only one man was used.

TABLE 281

DAILY OUTPUT OF ONE YOKE OF OXEN AT MALAKAL EXPERIMENTAL FARM AND GEZIRA RESEARCH FARM

Type of work	Daily Output in Feddans	
	Malakal Experimental Farm	Gezira Research Farm
Ploughing with ' ET ' plough	$\frac{1}{4}$ to $\frac{1}{3}$	$\frac{2}{3}$
Ploughing with ' Levant ' plough ...	$\frac{1}{3}$ to $\frac{1}{2}$	—
Ploughing with locally-made plough ...	$\frac{1}{3}$	—
Ridging with ' ET ' ridger	$\frac{2}{3}$	$2\frac{1}{2}$
Harrowing with peg harrow	2	—
Hoeing with ' ET ' hoe	—	$2\frac{1}{2}$
Hoeing with ' Garet ' hoe	—	5

While we do not think that using another man for a single pair of oxen would improve output, the output of a larger span (say four oxen) with two men to operate a single plough should be investigated.

We have found that, even on heavy Malakal soils, land cultivated during the previous rainy season can be ploughed throughout the dry season, though when these soils are completely dry the operation is slow and the oxen cannot work more than four hours a day. On heavy soils on fresh land carrying tufted indigenous grasses, ploughing cannot be carried out after mid-January until the early rains soften the ground sufficiently. Moreover on heavy land ploughing cannot be done efficiently after the rains have moistened the soil above the ' sticky point '. On sandy soils there should be no difficulty in ploughing throughout the year.

Two types of steel plough were tried at our experimental farms; Ransome's ' Levant ' and ' E.T.' The former proved a very suitable implement. It is simple, strongly constructed, and light—a considerable advantage for the local cultivator. The chief weakness of the ' E.T.' plough is the cast-iron swivel-bolt which, in the rough hands of local ploughmen, soon becomes unserviceable. Moreover local cultivators dislike ' E.T.' ploughs because of their weight. On the other hand these implements are easily convertible into ridgers and hoes. The ridger we found very useful, but attempts to carry out inter-row cultivation by ' E.T.' hoe were generally unsuccessful since, through lack of training of both oxen and operator, the crop suffered as much as the weeds. A locally-made wooden plough was also tried and found strong enough for heavy clay soils.

Further experimental work may reveal among the numerous ploughs now on the market a better implement than those tried by us. Investigation of the suitability of wheeled ploughs and disc ploughs is especially necessary.

As already mentioned, experimental work in Kodok (1936 and 1937) and Bahr el Ghazal Province (1942–46) suggests that crops respond to deeper cultivation by plough. Ploughing also to some extent reduces subsequent weed infestation, but the ploughs which we have tried, being of the ' digger ' type, do not invert the furrow sufficiently to bury the weeds. However if ploughing is done at the beginning of the dry season the desiccation of the uprooted weeds gives excellent results.

On light soils where the breaking of the surface is probably not so essential and where sufficient depth of cultivation could be achieved with implements other than ploughs, lighter hoeing implements should be tried. On the Kordofan sands good results were obtained with ' Garet ' hoes[53].

Ploughing, or other methods of land preparation with animal-drawn implements, is most important, as the inability to carry out pre-sowing cultivation is probably the main factor limiting the area sown at present.

The use of animal-drawn implements for weeding will necessitate the planting of crops at regular spacing and the thorough training of operators and animals. It will therefore be more difficult to introduce than ploughing, but previous ridging should make hoeing operations easier. If full use is to be made of the opportunities of increasing acreage offered by animal-drawn implements, weeding by hand must be replaced by hoeing with oxen. The operator with a hand hoe cannot weed much more than 0·2 feddans per day, but with an ox-drawn hoe it should be possible to cover $1\frac{1}{2}$ to 2 feddans per day, even though two men to each team of oxen may be necessary.

Other operations for which draught oxen may be used are:

(i) Ridging—especially beneficial for some crops such as cotton and groundnuts; comparatively easy even for an unskilled operator.

(ii) Sowing—the introduction of simple drills may be considered economic, particularly if regular spacing necessary for hoeing with oxen is required. The majority of crops would respond to the regular spacing and depth obtained by drilling instead of the present haphazard method of broadcast sowing.

(iii) Harvesting—crops like groundnuts, especially on heavy soils, would be easier to harvest if first ploughed up.

(iv) Threshing—though at present this can easily be done by hand and stick since the volume of the crop is not large, it may be done more quickly, if not better, by simple trampling by animals should the quantity require it.

(v) Pressing of oil crops—at present carried out with sesame in the northern part of the area by using a simple press operated by bulls or oxen. If the growing of oil crops is extended to the south, extension of the use of simple animal-operated presses may be necessary.

(vi) Irrigation—*sagia* water-wheels are already used in the Semi-Arid Region. Their use in the south for dry season irrigation and supplementary irrigation depends largely on overcoming the Nilotic's aversion to using oxen or bulls as working animals.

Apart from the use of oxen and bulls in the process of crop production, their use as draught or even pack animals would benefit crop production indirectly. During the rainy season motor transport cannot be used, and river transport, which in any case does not reach all places of importance in this area, is overloaded. A serious obstacle here is the absence of good timber and skilled artisans for the construction of simple but effective carts. The present price of a cart which is far from ideal for farm use, offered by Stores and Ordnance Department, is approximately £50. This puts it outside the buying range of the local inhabitant and would in any case make it hardly economical with such a high overhead cost and the obvious difficulties of maintenance and repair.

MECHANIZATION OF CROP PRODUCTION

We have already seen in the preceding sections that it is doubtful whether the introduction of better hand tools and animal-drawn implements could be sufficiently effective to achieve the considerable increase in the acreage cultivated per head of population required to balance losses in pasture due to the Equatorial Nile Project. We have also seen that the use of cattle as draught animals would be most difficult to introduce, especially in the Nilotic areas. Even if this could be done much time, which may not be available, and much money would be needed for propaganda, instruction, and even some measure of coercion. Finally the economic and social upheaval resulting from the drastic change in environment due to the Project will offer an opportunity for the modernization of local agriculture. To replace the most primitive hand hoe by the only slightly more advanced ox-drawn plough would mean that the opportunity had been missed. Mechanization of key agricultural operations may therefore be the best form of remedy.

The Possibilities Offered by Mechanization[54]

Apart from the effect of mechanization on acreage under cultivation, the tractor's power offers special possibilities in this area. The heavy clay soils cannot be tackled efficiently during the dry season, when they are exceptionally hard, by anything less powerful. The tough root-systems of indigenous *toich* grasses make initial cultivation by hand or ox-drawn plough too laborious to be economic. In certain conditions deep ploughing, which can only be done by tractor, may be found essential for weed control (e.g. control of *Cyperus rotundus*), surface drainage (ridging), etc. The speed with which mechanized cultivation can be done is also important. On the majority of soils in this area fine tilth can only be attained within a certain narrow moisture range which occurs during the limited time at the beginning and end of the rainy season. During these short periods tillage operations are easy and effective, and with mechanized methods large areas of good seed-beds can be prepared. Cultivation of some riverain flood-plains under future conditions will be possible only during a very short period of time (see pp. 605–9), so that without a certain minimum of mechanization no cropping on a large scale will be possible.

A tractor with a modern range of implements can tackle almost any job which requires power or speed, so that a bottle-neck in crop production can be avoided. Apart from direct agricultural use, tractors should be of great value for transport in this part of the country, where there are still few graded roads. A tractor with trailer should be able to move without bogging down at almost all times of the year, even when other means of inland transport are completely useless.

While the introduction of animal-drawn implements will be very difficult, we consider, from our very limited experience, that the introduction of mechanized cultivation, which will relieve the native of this area of the most laborious tasks of crop growing, should prove popular and therefore comparatively easy. At the same time the introduction of mechanization will necessitate greater centralization and control. This is no great disadvantage since other aspects of crop production also require greater control, as well as more modern systems of marketing and credit organization. If the time allowed for implementation of remedial measures is limited, this indirect opportunity offered by mechanization (the " 'stalking horse' through which other substantial improvements are introduced "[(55)]) may be as important as its direct use to increase output per cultivator.

Economic Aspect of Mechanization

As a measure of ordinary agricultural development, mechanization of crop production must be subjected to stringent economic tests before it is introduced. As a remedial measure such tests are also necessary and the introduction of mechanization must be conditional on its at least paying for itself, unless crop production cannot be increased by any other means.

From the economic point of view the distance of the Jonglei Area, particularly its southern part, from Port Sudan (see Table 174, Vol. I, p. 362) and the present under-developed system of communications, resulting in costly and unreliable transport, are among the main obstacles to the introduction of mechanization. Not only are they responsible for high overhead costs, but they also reduce the profit margin on exportable cash crops (see Vol. I, p. 361). Improvement in communications may in time reduce the cost of transport per ton/mile (the Project itself should have a beneficial effect in this direction) ; the distance will, however, remain a great obstacle to a cash economy and the mechanization of agriculture.

The introduction of mechanization also brings problems connected with the reduced flexibility of production costs. Charges for capital invested in tractors, implements, and other improvements, maintenance and running costs, as well as the salaries of technical staff, are obviously much less variable than yields and prices of local crops. Moreover the world price variations of the few cash crops on which the mechanized schemes must depend for financial solvency are likely to vary more than the general level of prices. Financial risks therefore increase with the degree of mechanization.

These economic factors make it essential that the capital involved in mechanization, and the running costs, should be kept to the minimum by :

(i) Restricting mechanization to essential operations only.
(ii) As far as possible restricting mechanization to the northern part of the Jonglei Area and locating the schemes near the river—a natural line of communication—unless railways are built.
(iii) Reducing as far as possible the time in which the machinery lies idle.
(iv) Reducing the unproductive movements of machinery to the minimum (e.g. mechanization of cultivation of scattered patches of high land in the Flood Region should definitely be avoided as uneconomical).
(v) Enforcing the highest possible standards of care and maintenance of machinery.
(vi) Avoiding any non-essential capital investment in collateral improvements.

The reduction of overhead and running costs will automatically diminish risks connected with crop price and yield variations. However, additional steps must be taken to increase yields and reduce yield variations by agronomic improvements and the provision of drainage and irrigation to diminish the main environmental risks. The cropping system should be made as flexible as possible, to provide for price variations. Finally the necessary financial provision must be made to insure the schemes and the cultivator against acute financial difficulties.

Risks can be borne much better by a large body such as the government, and the individual cultivator must be guarded against them ; therefore the organization of mechanized schemes should be based on sharing the output, rather than on payments in cash for the mechanical services.

Human Problems

It is obvious that further difficulties are likely to arise because the inhabitants are quite unused to machinery. Although they do not lack mechanical aptitude it will clearly take time for them to develop the 'machine mindedness' necessary for the economic running of mechanized schemes. At the moment these people can drive a tractor and show ingenuity in improvising repairs, but the daily routine inspection, essential for efficient maintenance, is often forgotten. They also only too often forget to set an implement attached to their tractors. Moreover, being semi-nomadic, they lack the discipline and spirit of co-operation which mechanical crop production will require.

Environmental Suitability for Mechanization of Different Parts of the Jonglei Area

Apart from economic factors, environmental factors—topography, soil, climate, and natural vegetation—determine the suitability of different parts of the Jonglei Area for mechanization of agriculture. Thus probably the most suitable part, where no major collateral improvements are necessary, is the Transitional Belt between the Semi-Arid and Flood Regions. Here the rainfall, while generally sufficient for a wide range of crops, is at the same time insufficient to make flooding a serious problem. Grassland and open savannah types of vegetation predominate, making initial clearing easy and inexpensive. The topography is flat and the soils, though heavy, are generally more tractable than in the centre of the *Sudd* basin.

In the Semi-Arid Region the rainfall is too low and variable to permit even the minimum capitalization of crop production required by mechanization without a parallel reduction of risks by the provision of irrigation. The experience of the Mechanized Crop Production Scheme on the better soils of the Gedaref district proved that mechanized crop production in areas with an average annual rainfall below 600 mm. (or even 650 mm.) must be regarded as economically risky. However, a combination of irrigation and mechanization has considerable possibilities.

In the Flood Region the areas of high land are generally too small and too scattered to offer much opportunity for economic mechanization. Crop production on the vast intermediate land grass plains could well be mechanized, however, provided a suitable farming system were found. Such a system can be developed only if drainage or supplementary irrigation, or both, is provided to guard against the risk of flood or drought.

In the Ironstone Region, apart from the great distance from the nearest port, the uncertain quality of the soils and the necessity for initial bush clearance are the main obstacles to mechanization.

Agricultural Operations Most Urgently Requiring Mechanization

As we have noted, for economic reasons mechanization must be restricted to the most essential operations. At present labour is short mainly for the initial preparation of the land, especially the opening-up of new fields. However, increased production is likely to create ' bottle-necks ' at later stages of cultivation, e.g. should a large area of cotton be desirable, it might be necessary to drill the sorghum crop in order to release labour for cotton-sowing.

The degree of mechanization and intensity of cultivation must obviously vary according to the environmental conditions in different parts of the area, on various types of land and with different farming systems, e.g. cultivation must be more thorough in the Flood Region than in the Semi-Arid Region, where indigenous vegetation is less vigorous. For this reason *toich* land—flooded during the greater part of the year—requires the most thorough cultivation.

Organization of Mechanization

Though in theory collective or even state and plantation farming (on the lines of the Israeli ' kibutz ' and ' kvutz ') may be the most economic, we doubt if it would be acceptable and practicable in this area. Yet lack of local capital prevents the mechanization of individual holdings by their owners. Mechanical services will therefore have to be provided by a central agency or public board or by the government. In the present stage of their development the inhabitants of this area cannot be expected to enter into a purely contractual agreement with such an agency, and, for reasons already mentioned, to pay in cash for its services. Moreover to be most efficient financially, mechanization must be associated with other improvements which could not be implemented for a long time without strict control over the methods and efficiency of the local cultivator. This leads us to the conclusion that the method of organization must be based on share-cropping, the central agency providing mechanical and other services and the cultivator participating. The former must be able to cover at least the running costs and depreciation on capital investment; the latter must obtain from the partnership a reasonable diet and income.

For the purpose of accounting it is desirable to separate the cost of mechanical services from that of other agricultural operations, and to charge for the mechanical operations on the basis of actual costs, which must be recovered from profits over a number of seasons but not necessarily in one season if yields and prices or both are below average. This separation is also desirable because a minimum economic mechanical unit may be too big for a single agricultural scheme, and may have to be shared between two or more. From the point of view of full utilization of machinery such sharing, not necessarily confined to agricultural schemes (e.g. road-making, etc.), may be found very desirable or even essential.

Consequently mechanized crop production should be based on:

(i) A machinery depot (tractors and tractor-drawn implements, workshops, etc., and its own technical staff, possibly working on a share or wage plus bonus basis) providing mechanical services.
(ii) The cultivator, responsible for all hand labour and the operation of animal-drawn implements.
(iii) An agricultural administration, responsible for general management and technical supervision.

As initial ploughing and levelling of virgin land in the Flood Region and parts of the Ironstone Region will probably be carried out most economically by heavy machinery drawn by D 6 or D 8 tractors, a separate unit with special machinery will be needed. The costs of these initial operations should be kept separate and regarded as part of the initial capital expenditure. This unit might also be used for drainage (e.g. Killifer ridging) and irrigation work.

Mechanization Experiments in the Jonglei Area and Relevant Data from Other Parts of the Sudan

The only mechanization experiments carried out in the Jonglei Area were those at Malakal Experimental Farm. The tractors used were of the Fordson Major type. Their output, especially during the 1951 season, was very small compared with theoretical output. It should be remembered that this was the first season. All work was done on virgin land, often under very difficult conditions. The personnel (tractor drivers, etc.) lacked experience and training. The 1952 results were better, but indicated that the old type Fordson Major is not the ideal tractor for the implements used under local conditions and is not powerful enough. Another considerable difficulty experienced at Malakal was lack of spares, partly due to distance from the Fordson agents and partly to lack of stock in the Sudan.

Some interesting observations have been made at Malakal. Probably the most important is that on clay soils on intermediate land, cultivation becomes practically impossible above the 'sticky point', but once these soils have standing water on them, tractors can work without difficulty, even without 'extension rims'. Another important observation is that drilling on wet soil is often most difficult, and a broadcaster type of implement is desirable. As far as implements are concerned, the Massey Harris one-way disc proved most useful. The tandem disc is too light to make much impression on local soils except in ideal conditions. The other implements are useful, but better ones could, and no doubt in time will, be found. Apart from a broadcaster, the implement most urgently required is a simple but effective land planer for levelling the constant slight unevenness typical of intermediate land.

Experiments in mechanization carried out in 1949 in Bahr el Ghazal Province[56], though strictly outside the Jonglei Area (at Tonj and Yar), are applicable to conditions prevailing in many parts of the Ironstone Region within our area. They have shown that some of the soils in this Region are abrasive and would need a special type of implement to prevent undue wear. On Tonj *toich* soil the discs on a Ransome plough lost between $1\frac{1}{2}''$ and $2\frac{3}{8}''$ after only 52 feddans of land had been ploughed. The fertility of soils like the Tonj *toich* soils is so doubtful that in any case mechanized crop production would almost certainly be uneconomic. It was found that cultivation of cracking clay soils on the intermediate type of land (at Yar) could be carried out successfully and without undue difficulty. The tractor used in these experiments was an International W.9 (50 B.H.P.) type. The average output achieved with various types of implements is given in Table 282 below.

TABLE 282

OUTPUT ACHIEVED BY INTERNATIONAL W.9 TRACTOR DRAWING VARIOUS IMPLEMENTS IN BAHR EL GHAZAL EXPERIMENTS 1949[57]

Implement	Output in Feddans per Hour	
	Tonj	Yar
Disc plough Ransome	0·61	1·02
Double disc tandem harrow Ransome ...	2·58	2·44
Ditto plus Massey Harris peg-tooth harrow...	3·45	3·12
Ridging plough	2·97	4·32

Average fuel consumption per hour (all operations): ... 3·27 gallons

We have also drawn on experience acquired by the Mechanized Crop Production Scheme in the Gedaref area[58], which is applicable to conditions in the Transitional Belt between the Flood and Semi-Arid Regions, as well as on information from the Gezira, for which we are grateful to the Chief Agronomist, Research Division. It applies mainly to the production of irrigated crops in conditions similar to those of the Semi-Arid Region. Even with this additional information the bases of our detailed recommendations (given later) are extremely slender, and the recommendations themselves, and especially the costs, must be treated with extreme caution.

HARIQ FARMING

Hariq cultivation provides the easiest and probably the cheapest method of extending the area under cultivation, and hence agricultural production. Unfortunately, as we have already noted (see Vol. I, p. 329), the opportunities for large-scale development of this method are confined to the Transitional Belt between the Semi-Arid and Flood Regions.

In Volume I (p. 330) we have drawn a distinction between *hariq* as a method of opening up new fields or extending old ones, and as a system of farming; for the latter purpose, *hariq* must be incorporated into a simple but strict rotation consisting of one to three seasons under a crop and three or more seasons under fallow protected from fire. The function of the fallow is not only to promote the re-establishment of suitable grass but also to maintain soil fertility.

To utilize fully and efficiently the areas of suitable grassland by *hariq* methods, such areas must be protected by fire-lines from accidental burning. While on schemes based on peasant holdings and involving permanent settlements (see p. 658) fire-lining could be carried out without difficulty by the cultivators themselves, the present hand methods of fire-line clearance would have to be replaced by mechanical or chemical methods if really large-scale crop production should be attempted. As far as mechanical methods are concerned, those used at present for de-grassing roads should be suitable. One de-grassing at the end of the rainy season and one about February to clear all regrowth should be sufficient. Once permanent fire-lines have been cleared it should not be difficult or expensive to keep them clean by mechanical methods.

Chemical methods of establishing and maintaining fire-lines should also be investigated. Provided that the right herbicides are chosen, these methods have the advantage that the application of chemicals can be carried out during the rainy season, when there is no lack of drinking-water in the inland *hariq* areas. A wide selection of herbicides is available[59]. The choice depends on their inherent toxicity, their behaviour in soils of different types, the climate, the tolerance of species to be eradicated, the problems of their application, and their price. A lot of research work will obviously be required before the most suitable chemicals can be selected. Apart from the contact and translocated herbicides, soil sterilants should be tested. Permanent soil sterilants, which remain poisonous for relatively long periods and therefore do not require annual application, may prove more economic. Chlorates, borates, and substituted phenol compounds should be tried. Arsenic compounds, though very effective and comparatively cheap, would probably be impracticable in this area owing to their poisonous character. The recently discovered phenol compound, CMU (3(para-chlorophenol)-1, 1 dimethyl urea), though still expensive merits special consideration as a soil sterilant.

The size of the *hariq* blocks, and consequently the amount of fire-lining necessary, depends on the size of the settlement. This in turn depends on the provision of domestic water supplies in *hariq* areas. If they are provided by means of large hafirs, settlements of considerable size can be expected to develop round them. In this case *hariq* blocks can be few in number but large, each of them, after burning, being divided among the numerous families of the settlement. If, on the other hand, water supplies can be improved by the damming of khors, a ribbon pattern of settlements along the khor banks can be expected, and the *hariq* blocks will be smaller but more numerous to avoid the waste of time involved in travel between homestead and cultivations.

The provision of inland water in *hariq* areas is equally essential, as without it cultivators are unable to remain inland long enough to harvest their crops, and often cannot return to their rains season settlements early enough to complete the necessary preparatory work. Means of improving these supplies are discussed elsewhere.

We have already pointed out in Volume I that *hariq* farming requires not only capital but also ability to organize. As it would probably not be economic to provide each family with its own *hariq* area, this system of farming would have to be done on a communal basis. Such important operations as fire protection and the timely burning of the grass require both discipline and organization. Trained staff would therefore be essential.

Hariq farming as described above can be practised easily and efficiently only in the ' true *hariq* area ', i.e. in the Transitional Belt between the 500 mm. and 700 mm. isohyets. In areas of lower rainfall the period of grass recovery would have to be extended and the cost of fire protection would therefore be higher. At the same time rainfall in these semi-arid conditions is very unreliable, and rain-grown crop production very risky. It should be remembered that *hariq* cultivation, requiring enough rain to germinate seeds dormant in the soil before the grass mat is burnt, increases these risks, especially in areas where the rainy season is short. Therefore it is not recommended that *hariq* as a system of farming be established in areas north of 12° N. latitude. In areas of higher rainfall the delicate competition balance between annual and perennial grass species is disturbed by regular burning at the beginning of the rains, and, if *hariq* is practised regularly, annual grasses are replaced by perennials unsuitable for this method. It is therefore not suited to this area, and outside the Transitional Belt *hariq* must remain a method employed only sporadically for opening new fields and extending existing ones.

The distribution of existing *hariq* areas is shown on Fig. E 14. We have estimated this area at over 4,500 sq. km., i.e. approximately 1,100,000 feddans. Thus on the basis of one year under crop and three years under fallow—a conservative estimate—275,000 feddans of land in the Transitional Belt could be cultivated every year by this method. It should also be noted that large areas in this belt at present covered by acacia bush could probably be turned into *hariq* land if the bush were cleared and burning practised regularly.

BETTER CONTROL OVER ENVIRONMENT

As can be seen from Volume I, crop output in the Jonglei Area is limited by the very variable rainfall, as well as by peculiarities of soil and topography, resulting in frequent droughts and floods which ruin the crops and discourage the cultivator from sowing more than he considers an essential minimum. In this uncertain environment most attempts at introducing improvements aimed at an increase both in yields and in the area sown are doomed to failure unless ways and means of reducing the risks of crop husbandry are found. Water conditions create the greatest risks, and these could be controlled by the provision of drainage and irrigation.

Before discussing methods of modifying the environment to suit crops, let us consider briefly the possibilities of further adaptation of present crop husbandry to suit the environment. These possibilities are limited. It is doubtful if any increase in crop output could be achieved in the Semi-Arid Region by the further introduction of drought-resistant crops and varieties. In the Flood Region crops are subjected to both flood and drought, and as already mentioned (see Vol. I, p. 339) crops more suited to these conditions than local varieties of sorghum would be extremely difficult to find. A certain amount could be done here by concentrating on quick-maturing crops planted as soon as possible after the danger of flooding has passed. This is already done to some extent by the local people (e.g. Shilluk and Dinka *angul* and Nuer *pan* crop). The difficulty is to prepare and sow a large enough area in the short time available between the heaviest rains and the dry season. This could probably be achieved by mechanizing these operations, but owing to the risks inherent in this system (e.g. the timing of sowing is extremely difficult) the economics of mechanization are doubtful.

In our opinion therefore only drainage and irrigation, in many circumstances a combination of the two, could be relied on to produce the necessary improvement.

DRAINAGE

The hydrological aspect of improvement of drainage in different parts of this area has been discussed elsewhere (see p. 627). It will, however, be realized that this discussion is confined to the question of the removal of water standing on the surface, and does not deal with the problem of waterlogged soil. The majority of crops require a soil layer sufficiently aerated for good development of their root-systems, which is essential for optimal growth and hence best yields. Therefore it is not enough to drain off the water standing on the surface.

The object of drainage from an agricultural point of view is to offer a quick means of escape for water that is causing harm; in other words ' free water ' filling all major soil pores to the exclusion of air. In the Flood Region, where drainage is most important, this problem is extremely difficult as the majority of soils are heavy and impermeable. In such soils an increase of downward water movement would be beneficial even without appreciable increase of air-filled pore spaces because of the replacement of stagnant by fresh and oxygenated water. As the impermeability of these soils is due to their structural inferiority, improvement in porosity appears to be the first step towards their drainage. This could probably be achieved by very heavy applications of gypsum, but the cost of this would almost certainly be prohibitive. (It has proved so in the Gezira, which is nearer to a natural supply of this material[60].)

Similarly the impermeability of these soils makes any of the usual sub-soil drainage systems, such a stile drainage, impracticable[61]. Neither does 'mole' drainage offer any solution in these cracking clays, as it would not last a single season. Therefore the only method likely to be successful is the old system of ridge and furrow, practised centuries ago on heavy soils in the English Midlands. The building up of ridges, using the soil from the furrows, makes a layer of soil raised above the flood level. The 'drowning' of crops, especially serious when they are in the seedling stage, is thus avoided. It is doubtful if the provision of field-drains only could give similar safeguards, as the removal of the surface water on the very flat land with impermeable soils would not be quick enough. With ridge and furrow drainage, the water collects in the furrows, and if some system of field-drains could be combined with this method, the soil of the ridges should be aerated enough for the development of crop root-systems. Without field-drains, the water would be liable to stand in the furrows for long periods, so that there would be insufficient aerated soil in the ridges, and crops would suffer.

Experimental ridging of intermediate land, using a Killifer ditcher, was carried out at Malakal in 1951, and a number of crops was grown experimentally on this area (see Vol. III, p. 1005). In a season of average rainfall (1951–52 with 787 mm.) ridging made the difference between complete crop failure on unridged 'control' plots and at least partial success of the same crops grown on ridges. Trials carried out during that season indicated that, with the exception of sorghum and shallow-rooted legumes, the volume of aerated soil was insufficient for optimal development of the root-systems, and therefore for good yields. Cotton yields, for example, were disappointing, and excavation showed that the root-system was mainly confined to the layer of soil above the level of the water in the furrows. Field-drains to remove this water were not available, but would undoubtedly improve the crops considerably. During the 1952–53 season, rainfall was exceptionally light (498 mm.) and this ridging system was given no test.

Work at Malakal has shown that the growth habit of the crop and consequently the optimum population per unit area is important. On land ridged with a Killifer ditcher (i.e. with ridges 1½ to 2 m. wide and furrows approximately 1½ m. wide) only just over half of the actual area can be used for sowing. Crops requiring wide spacing, such as cotton and sorghum, can be planted at closer spacing along the rows than is normal for planting on the flat, so that reduction in number per unit area can be avoided. Though a certain reduction in yield may be expected from increased root competition, competition between aerial parts is not seriously increased as the space above the furrows can be used by the marginal rows; with a crop planted at three rows per ridge, only the middle row is subject to such competition. With crops normally planted at close spacing, however, this spacing cannot be further reduced, and planting on ridges means a great reduction of the total plant population per unit area, and therefore of yield. Moreover close spacing means more rows per ridge, and only the two outside rows benefit from lack of competition. As the majority of these crops are dwarf, even the plants in the outside rows cannot make full use of the free space above the furrows. Consequently, with this system of ridging, crops requiring close spacing can only be expected to yield in proportion to the area which they can utilize, i.e. to give just over half the yields of unridged but drained land.

Killifer ridging is therefore not an ideal system; on lighter soils and where slopes are sufficient for comparatively quick removal of the surface water, small ridges made by an ordinary ridging plough should be sufficient. Spacing can be adjusted to the needs of different crops. In more difficult conditions, ridges broader than those made by a Killifer ditcher and occupying a greater proportion of the ridged area are desirable. Such ridges could be made by deep ploughing with specially designed sub-soiling ploughs, now on the market. The ridges so obtained would have more gentle slopes and would therefore require less maintenance than those made by a Killifer ditcher. Though cultivation on the large ridges would be difficult to mechanize, ridges made by the sub-soiling ploughs could be made broad enough to allow at least partial mechanization.

Any form of drainage requires a certain amount of capital investment; therefore cultivation on drained land must be as intensive as possible. To achieve this a suitable rotation would be necessary, as mono-cultivation of this land with sorghum would soon lead to infestation with *Striga hermonthica*.

As we have seen, the range of crops suitable for rotation with sorghum in Killifer-made ridges is small, especially if no field-drains are provided to remove the water from the furrows. Yields of cotton and legumes in our experiments on the ridged land were barely economic. It might be possible to extend the range of suitable crops by providing field-drains and making the narrow Killifer ridges wider, so that rotations suggested for high land cultivation (see p. 580) could be used on ridged intermediate land. If this proved impossible and sorghum were the only crop likely to give economic yields on ridged land, then other methods of *Striga* *hermonthica* control, such as weeding and spraying with herbicides, might make its cultivation possible with only the minimum of fallow.

The value of large ridges for growing irrigated crops should also be investigated. Not only would the furrows facilitate application of water, but waterlogging of land carrying young seedlings could be avoided, which is impossible on flat or plough-ridged land. The layer of soil in which the root-system of the young crops develops could be gently moistened from below by seepage of water from the furrows. It would also be possible to apply greater quantities of water at less frequent intervals than on flat land. Finally, as there would be a higher ratio between the volume of water applied and its surface area exposed to evaporation, a saving of water might result, though further study of the rates of infiltration is necessary. Obviously the size of the ridges would have to depend on the water gradient in the soil and hence its permeability.

IRRIGATION

As we have seen from Volume I, the Semi-Arid Region is characterized by a limited volume of rainfall, a short rainy season, and a very considerable variation in monthly and annual rainfall figures. Though rain-grown crops have always been produced in this part of the Jonglei Area, output is still extremely variable and failures frequent. Furthermore only a small range of crops, drought-resistant and quick-maturing, can be grown with any degree of success. It should be technically possible, with sufficient capital, to extend the average rain-grown crop output as a form of remedial measure. The economics of this and its adequacy are, however, questionable. First, as already pointed out (p. 597), it is doubtful whether the investment of capital necessary for the mechanization of crop production would be economically justifiable in this area of marginal rainfall. Secondly, as increase in production must make good the losses of domestic stock, much capital would have to be frozen in the form of stored produce, or money, to provide a measure of insurance for years when crops fail from drought. Without this, the local population would suffer unjustifiable hardships. Thirdly, it is doubtful if a sufficient range of rain-grown crops could be grown to assure a diet of a quality equal to that enjoyed at present. This leads us to the conclusion that the capital necessary for the provision of alternative means of livelihood should be invested in extending irrigation facilities in this Region rather than in attempts to increase the uncertain production of rain-grown crops.

Irrigation offers a means of control over the main limiting factor in crop environment, and very greatly reduces the risks involved in crop growing. It also makes possible the extension of the growing season for as long as required for the production of all necessary crops. Moreover in this part of the Jonglei Area it should not be difficult to provide drainage together with irrigation.

Finally, for the making of quantitative assessments and the costing of necessary remedial measures in this report, we have for our foundation the experience accumulated in the Gezira scheme, the White Nile Alternative Livelihood schemes, and private pump schemes already operating in the Semi-Arid Region. The effectiveness of any steps to increase rain-grown crop production is uncertain and impossible to assess on the basis of our necessarily limited work in this Region. A quantitative assessment of such steps would therefore be impossible at this stage.

While, in our opinion, irrigation is essential for assured crop production in the Semi-Arid Region, it is also desirable in many circumstances in the remaining parts of the Jonglei Area. Though the average annual rainfall exceeds 650 mm. in the Flood Region, and over the greater part of the area is between 800 and 950 mm., its variations and consequent unreliability should be remembered. Experience in the Flood Region suggests that at the height of the growing season at least 100 mm. of rain per month are necessary if the crops, even if drought-resistant, 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 Tables 23–27 (Vol. I) will show that, in 25 out of 100 years, rainfall at Bor will not reach even the lower figure and will barely do so at Malakal. This clearly shows the need for irrigation.

The length of the rainy season is also of importance. The crops at present grown in this part of the Jonglei Area are adapted to the average length of the rainy season, but even these suffer when the rains begin late, and especially when they stop early. If irrigation were provided to lengthen the growing season, many other crops could profitably be introduced. Long staple cotton is probably the most obvious, but experimental results (see Vol. III, p. 1002) suggest that short staple cotton would also benefit from an extension of the growing season by irrigation. Castor, a possible cash crop, could not be grown economically during the limited rainy season alone. Other crops, including even local sorghum varieties, would, in many years, respond well to one or two additional waterings at the end of the rains. In the Ironstone Region, where rainfall is generally heavier and better distributed, the three or four rainless months make cultivation of perennial crops difficult and generally uneconomic. Such valuable crops as sugar-cane could be grown there if the gap between the end of one rains season and the beginning of the next could be closed.

We have noted in Volume I that cultivation of crops on intermediate land is precarious since alternating conditions of drought and waterlogging occur annually on this type of land. Intermediate land occupies by far the greater part of the Flood Region and, as already mentioned, the best method of utilizing it is to grow a crop not susceptible to waterlogging, such as rice. Rice, however, is very susceptible to lack of moisture, and therefore cannot be grown on this land without irrigation.

The use of irrigation in the Flood Region is not only desirable but also justified by the fact that here it can be used most efficiently for crop production. We wish to emphasize that as the amount of irrigation water available is the main factor limiting crop output in the Sudan and Egypt, from the technical and economic point of view this water should be used to supplement rainfall rather than replace it, though the reasons for this may not be immediately evident. The technical reasons why a more efficient use of irrigation water can be made in the Flood and Ironstone Regions rather than farther north can be summarized as follows:

(i) Rainfall in these Regions is generally enough to supply the major crop water requirements; irrigation is essential to supply the small part which makes the difference between success and failure.

(ii) Rainfall is a more efficient form of water application than the methods of irrigation practised in the Sudan. Therefore, cubic metre for cubic metre, the crop makes better use of rain than of irrigation water, and hence less of the former is needed.

(iii) The climatic factors of this part of the Jonglei Area favour the economical use of water, since evaporation losses are small with the high humidity and comparatively low temperatures. The transpiration coefficient, being "especially associated with factors influencing rates of evaporation "[(62)], should here be lower than farther north, and the physiological efficiency of transpiration higher.

Unfortunately we have insufficient data to make a full estimate of the comparative efficiency of a unit of irrigation water (i.e., of the crop yield which is produced, on an average, by such a unit) applied here and farther north. We wish, however, to quote an example which, though open to criticism on the grounds of inadequacy, illustrates the advantages of using irrigation water to supplement and not to replace rainfall.

The average yield of cotton in the Gezira is 4·5 Kantars (315). The average quantity of irrigation water required to produce this yield is 6,300 m^3.p.f. (i.e., 14 applications of 450 m^3.). The average yield of irrigated long staple cotton varieties at Malakal Experimental Farm in the 1952–53 season was also 4·5 Kantars (315), but only 2,250 m^3.p.f. of irrigation water were used. Rainfall during this season was 498 mm., i.e. approximately 2,200 m^3.p.f. As can be seen from these figures:

(i) In this exceptionally dry year, the same crop grown at Malakal used only just over 35% of the irrigation water normally applied in the Gezira to produce the same yield.

(ii) 2,200 m^3. of rain-water was as effective at Malakal as 4,050 m^3. of irrigation water in the Gezira (i.e nearly twice as effective).

The Drainage Problem

The main obstacle to the introduction of crop irrigation on a large scale in the Flood Region is the difficulty of providing at the same time an efficient drainage system, essential for nearly all crops. Since even without irrigation lack of drainage is a serious problem in this part of the country, it is obvious that lack of adequate drainage would cancel all advantages derived from the application of additional water, except in the case of rice. A drainage system combined with irrigation must be designed to make it possible to remove quickly any surplus water resulting from unexpected rain falling soon after irrigation.

Water Requirements and the Need for Further Research

The methods adopted in estimating water-duties, as well as our assessment of water requirements of different crops, are discussed elsewhere in this report (see pp. 623–6). It remains here to emphasize once again the urgent need for further experiments required to assess the economic application of water for different crops; e.g., experimental work in the Gezira (confirmed by observations of some irrigated cotton grown in the Jonglei Area) indicates that a good deal of water could be saved by discontinuing irrigation earlier than is done at present for Egyptian cotton, without any appreciable loss of yield. Ferguson[(63)], who analysed water application experiments in the Gezira, gives the following example:

TABLE 283

EFFECT OF EARLY STOPPAGES OF WATER ON YIELD OF EGYPTIAN COTTON IN THE GEZIRA SCHEME

Season	Number of Comparisons	Total Area Treated feddans	Last Application Date	Effect on Yield kg.p.f.	Number of Waterings Saved
1947–48	10	900	Feb. 7 & 8	−0·30	Approx. 3
1948–49	8	612	Mar. 6	+0·12	Approx. 1
1949–50	20	600	Feb. 21 & 22	−0·01	Exactly 2

Other methods of saving water (decreasing water-duty or frequency of application) proved to be of little value. Fig. G 7 (after Ferguson) illustrates the results of Gezira water economy experiments. It can be seen from this that considerable saving of water and, more important, considerably increased output per cubic metre of irrigation water could be achieved.

The data quoted above provide a good example of the urgent need for experimental work on water application even in areas such as the Gezira, where irrigated cotton has been grown for many years and experiments in water application started as far back as 1918. In the Jonglei Area the need is immeasurably greater. All our assessments concerning water requirements will be modified as experiments go on. We have tried to make certain that we over-estimate rather than under-estimate water requirements. This must be taken into consideration if some of the figures given in this report seem unreasonably high.

The Economics of Irrigation

The future agricultural development of this area of extremely variable and unreliable rainfall can only be based soundly on the provision of water to replace the rains when they fail. We consider that the rights of the inhabitants of this area to the amount of water which at present produces the pastoral wealth on which their present livelihood is largely based should be admitted and upheld.

As far as the economics of irrigation are concerned, the additional cost would be handsomely repaid by increased yields. For example, in the Flood Region nearly all crops would require drainage as well as supplementary irrigation. We have estimated that the difference in the capital cost of the engineering works involved between providing drainage only and providing both irrigation and drainage is approximately £E.11.000 $^{m}/_{m}$ per feddan. The difference in the annual cost of operating gravity irrigation and drainage schemes and drainage schemes only is estimated at £E.0.300 $^{m}/_{m}$. Therefore the addition, due to irrigation, of about £E.0.850 $^{m}/_{m}$ (5% interest on £E.11.000 $^{m}/_{m}$ equals £E.0.550 $^{m}/_{m}$ plus an annual difference in running costs of £E.0.300 $^{m}/_{m}$) to the average value of the crop per feddan would fully cover engineering costs. If another £E.0.250 $^{m}/_{m}$ per feddan is added for additional agricultural costs, an annual increase in crop value of £E.1.100 $^{m}/_{m}$ would pay for the provision of irrigation. This is the approximate value of 55 kg. of sorghum, or about one-tenth of a kantar of Egyptian cotton. There is therefore no doubt that from the economic point of view the provision of irrigation is most desirable.

UTILIZATION OF RIVERAIN FLOOD-PLAINS

The riverain flood-plains, though reduced in area as a result of the Equatorial Nile Project, will still offer special opportunities under the new river régime. Moreover under the Project the engineers controlling river discharges will be in a position to predict the extent and period of flooding of any given part of the flood-plain in the Southern and Central Zones, and thus to permit the agriculturist to plan his cropping ahead. In the Northern Zone, since the variable discharge from the River Sobat cannot be controlled, exact forecast will not be possible. However, even now the variability of river discharges, and hence of intensity of flooding, is much less than that of the rainfall, and the effect of the Equatorial Nile Project will be a slight reduction in these variations.

There are, however, some considerable obstacles to the possibilities of cultivation of the riverain flood-plain on a large scale and with a wide range of crops:

(i) The deltaic formation of a large proportion of these plains means that much capital expenditure would be necessary for levelling before large-scale cultivation of irrigated crops could be attempted. The higher but more level flood-plains of the Central Zone will probably be impossible to irrigate by gravity under the new régime, as command, even during the period of high discharge, will be limited.

(ii) For crops requiring drainage as well as irrigation, expensive protective banks would be necessary, and in the majority of cases even these would be inadequate for efficient drainage. Pumps for removing surplus water would be needed.

(iii) Every so often the necessity for exceptionally high flood-escape discharges will arise (see p. 435), making the cultivation of the riverain flood-plain, requiring considerable capital investment, an extremely risky proposition. These high discharges would probably ruin all earthworks and permanent installations and any perennial crops growing in the areas affected. As they will be predictable, they need not affect annual crops. Moreover as these discharges may continue over a considerable period, they will preclude the possibility of cropping the *toich* for a number of seasons, and hence disorganize systematic crop production.

Consequently no enterprise involving large capital investment can be proposed until the risks mentioned above can be assessed and weighed against the advantages offered by cultivation of the riverain flood-plains over cultivation of other types of land. On available data we cannot assess the flood risks (see p. 709) nor have we enough knowledge for a quantitative assessment of the advantages of *toich* cultivation. Therefore we recommend that, unless a future analysis of more adequate data shows that advantages outweigh risks, no crop production requiring large capital investment should be attempted on the riverain flood-plains, particularly if based on perennial crops.

On the other hand it is possible to devise a cropping system which would not require much capital expenditure, and could therefore stand the risks of flooding. Rice production must obviously be the backbone of the system. Rice varieties will have to be found to suit both the period and the depth of flooding, but this should not be too difficult. Moreover some varieties can tolerate a certain variation in depth of flooding, so it is not essential that the ground should be absolutely even.

The possibilities of introducing other crops for rotation with rice depend mainly on the drainage prospects of different parts of the riverain flood-plain. Where drainage is difficult, a system of rotation of rice with pasture grass or with fish farming might be considered.

In areas where the ground is especially uneven (i.e. in the greater part of the *toich* areas) large-scale mechanical cultivation will be impossible, and production will have to be by small land and labour units—i.e. peasant family units—with only a minimum of mechanical help. The risks discussed above make it essential that rice production on the *toiches* should be a part only of a farming system which produces other crops elsewhere. It should also be designed so that, when necessary, labour and machinery can be shifted to cultivate other crops slightly less profitable but unaffected by flood-escape discharges.

The choice of rice varieties and the possibility of introducing the cultivation of other crops on the *toiches* must depend on the river régime and engineering works in the three Zones, as well as on the environmental characteristics of different localities. Thus in the Southern Zone, as can be seen from Chapter 2, p. 418 and p. 419, reversal of the flooding season and banking of the Atem and Aliab valleys offer special opportunities for the production of perennial crops, including sugar-cane and fruit, both for local consumption and for export.

Drainage may be difficult in parts of these areas, but as they are intersected by a number of watercourses, and slopes are greater here than farther north, the provision of an adequate drainage system may be practicable. The southern end of the Aliab Valley is, from the point of view of drainage, especially suitable for cropping. Slopes here are of the order of 18 cm/km., the natural watercourses could be developed as a drainage system, and the soils are generally more permeable than those farther north.

The risks involved in flood-escape discharges will, of course, exist throughout these banked-off areas. However, the banks will be erected as part of the engineering works of the Project, and cannot therefore be assessed as part of a purely agricultural investment, which consequently should not be excessive. The special advantages offered by this area for the cultivation of perennial crops should again be carefully weighed against the risks of floods, particularly if protective banks (as part of the Project) are designed to withstand all but the highest floods. These are unlikely to occur more often than once in 50 or more years. There is at present no proposal to bank off the Mongalla-Gemeiza *toich*. The utilization of natural flooding here for rice cultivation would in any case be difficult. First under the new hydrological régime the river will rise very quickly, attaining its maximum in 10 days from the beginning of the rise. The crop would therefore have to be planted early enough to achieve a stage of development at which the rapid flooding would not kill it. Also, it would be inadvisable to plant the crop where flooding was likely to exceed 75 cm. as the young plants must not be completely submerged. Secondly, the duration of flooding predicted for this area is 192 days (December 10th to June 20th). If we add to this a period in which the crop can develop to a flood-resistant stage, and another 30 or 40 days for the *toich* to dry sufficiently for harvesting to be carried out on dry land, the total period will be well over 8 months. It is unlikely that a variety with so long a maturation period could be found, so that harvesting would have to be done while the fields were submerged. Thirdly, rice here must be a winter crop, and a variety with a long day photoperiod must be found. Fourthly, it must be remembered that there will be a gap between the rains and the beginning of the flood; if therefore the late rains are light or fail, it may be difficult to establish the crop before flooding starts. This is probably the biggest risk, and if steady rice production is wanted, it might be necessary to have pumps installed and standing by to give the crop one or two waterings between the late rains and the beginning of the floods. This, of course, would add to the overhead cost considerably. Finally, it should be noted that the land will be free from river flooding only during the rainy season; it may therefore be found difficult to carry out cultivation because of excess moisture in the soil.

These facts lead to the conclusion that large-scale mechanized cultivation of rice in the Juba-Tombe reach is unlikely to be successful; small-scale cultivation by the peasants would, however, be a practicable measure if combined with the cultivation of other crops on higher land. Rice would provide one more alternative to dura, and its cultivation would be done at a time when the demand for labour for other agricultural work is always at its lowest.

The acreage of that part of the Mongalla–Gemeiza *toich* suitable for rice cultivation (i.e. ground which will be flooded to a depth of 75 cm. or less) is estimated to be approximately 13,000 feddans.

The crops other than rice which could be grown in this area on *toich* during the rainy season, when the *toich* will not be flooded, will be determined by the comparatively short duration of this period. The river will fall at the end of June but, this being the rainy season, it is unlikely that the ground will be dry enough for cultivation till about the end of July. The crops must be harvested by the beginning of December at the latest. Therefore the only suitable crops are those with a maturation period of not more than 110–120 days. The inclusion of quick-maturing legumes in rotation with rice (not necessarily immediately preceding it) would obviously be desirable. A crop grown on the riverain flood-plain during the rainy season would certainly not suffer from shortage of moisture, but might easily do so from excess.

In the Central Zone an area of approximately 362 sq. km. will be flooded by spill from the river to various depths from the end of June to mid-December, i.e. about 170 days. During this period approximately 1 m. of flood-water will be applied. The river here will rise very rapidly (in theory in 2 days), but flooding by spill over the high bank will be more gradual. The main difficulty in growing rice on the flood-plains of this Zone would be in establishing the crop. Sowing should start here in the second half of May and as the early rains in this area are unreliable they would, in many years, be insufficient for the crop to reach the stage at which it benefits and does not suffer from flooding. However, on carefully chosen sites it may be possible to regulate early flooding to suit the young crop by the provision of comparatively small and inexpensive banks. If a suitable variety with a maturation period of over 180 days could be found, and sown at the beginning of July, it would mature at the beginning of January, when the ground should be dry enough to allow harvesting on dry land by machinery. Since the ground of the flood-plain is very uneven, careful choice of sites is necessary, and the possibilities of large-scale mechanized production are probably again strictly limited.

The risks connected with a flood-escape discharge are most serious in the Central Zone and should be kept in mind, but as these discharges will be predictable, it should be possible to move the rice cultivation to a higher part of the flood-plain in years when high discharges are likely, thus avoiding complete interruption of production.

Figs. F 19 and F 20 illustrate in diagrammatic form the hydrological conditions which will prevail in the Northern Zone between Malakal and Jebelein and show approximate future gauges and areas flooded. They have been drawn on the following assumptions:

(i) Discharges under the Project will be as calculated by Amin and Bambridge.

(ii) In December and January the fall and sharp rise indicated by these theoretical calculations will in practice be eliminated by manipulation of Canal discharges. The discharge in the Canal will be increased in graded steps instead of in one operation.

(iii) In June and July the Canal discharge will in practice be reduced in graded steps instead of in one operation, so that discharge at Malakal will remain constant at about 93 m/d.

(iv) The areas flooded are those determined from the curve of areas flooded against Malakal gauge-readings for steady river conditions (see Fig. F 19).

(v) For the months from September to February the Jebel Aulia Reservoir will be full, and for the months from April to June it will be empty. For March, July, and August, the areas are interpolated between the curves for the reservoir full and empty.

The data illustrated by these diagrams are given in numerical form in Table 284 (p. 609).

The methods by which the range of maximum depth of flooding (given in the last four columns of this table) was estimated need explanation. Variation in depth of flooding in the Northern Zone under the régime of the Equatorial Nile Project will depend on the unpredictable discharges of the River Sobat. Standard deviation of these discharges, on the basis of 38 years' readings (1905–42) is 10 m/d. If normal distribution is assumed, the standard deviation multiplied by 1·1 and subtracted and added to the mean will give the range of variation in 75% of years. Assuming further that the mean maximum flooding corresponds to 12·50 m. on the Malakal gauge, the standard deviation multiplied by 1·1 and converted (on the basis of Fig. F 19) is 27·5 cm., say 28 cm. Consequently by adding and subtracting 28 cm. to and from the mean maximum depth of flooding we estimate the range of maximum depth of flooding valid for 75% of years. Similarly the range valid for 95% of years can be assessed by subtracting and adding 50 cm. (i.e. twice the standard deviation) from and to the mean maximum depth of flooding.

It is much more difficult to assess the variation in duration of flooding; we can only say that these variations will almost certainly be less than those of maximum flooding depth.

The figures in Table 284 make it clear that, owing to uncertainty of flooding, rice cultivation on the riverain flood-plains in the Northern Zone will be risky and production unreliable. Because of the unevenness of these plains no large-scale schemes will be possible without the prohibitive expense of ground levelling; here again, cultivation on numerous small fields by local cultivators should be attempted. These fields should be located at different levels, again to spread the risks of uncertain flooding. The varieties planted should be as tolerant as possible to variations in maximum depth of flooding. The *Fellata* variety tried at Malakal grew successfully in less than 5 cm. of water and in over 85 cm. of water. Unfortunately it is a very ' primitive ' variety with many drawbacks, though not a bad yielder. No cultivation should be attempted on those parts of the *toich* where the mean maximum flooding is 10 cm. or below, as there is about a 30% chance (assessed on the assumption of normal distribution of variations) that these parts will not be flooded. On the lower parts of the *toich* the possibility of growing rice will depend mainly on whether there is a long enough dry period to permit cultivation and establishment of the crop; at least 3 months without flood are needed, though if cultivation is to be done by ordinary tractor and implements, and not those specially designed to work under swamp conditions, this period should be at least 4 months. Only the higher parts of the riverain flood-plain, where mean maximum flooding does not exceed 60 cm., could therefore be used for rice production unless protective banks were built. However, even within these limits (i.e., between 10 cm. and 60 cm. mean maximum depth of flooding) the total area is estimated at 290 sq. km.

By the provision of protective banks with simple regulators, the maximum depth and duration of flooding could be controlled; these banks would have to be somewhat higher than the maximum depth of flooding shown in the last column of Table 284, to give flood control in 95% of years. For complete control another 100 cm. would have to be added to these figures. If these banks were provided, giving control over the flooding of the lower parts of the *toich*, no rice cultivation on the higher parts (i.e., where the mean maximum flooding is below 50 cm.) should be contemplated, as these parts are not always commanded by the river level (see column (9) in Table 284) and therefore not always irrigable.

Other crops, including legumes, could also be grown in the banked-off areas in rotation with rice, being planted after the rains and if necessary watered by gravity up to late February or even later. Special care would have to be taken that no more water than necessary was applied, as the draining off of surplus water would be very difficult, if not impossible.

The unevenness of the *toich* plains in the Northern Zone does not preclude almost complete utilization of the banked-off areas. To utilize such areas fully it would be necessary to divide them by low banks (not more than 25 cm. high) into a number of small, nearly level fields, each of which would then be planted with a rice variety suitable for the depth and duration of flooding, which could easily be predicted for each field. Moreover protective banking would permit shortening of the flood duration, and harvesting of the crop in standing water could be avoided. Also the dry period could be extended, making tillage easier.

The economics of such schemes would obviously be based on the cost of banking per feddan of area protected. Such examination of the costs as has been made indicates, however, that they would be very high, perhaps prohibitively high. Further investigation may reveal ways and means of reducing them.

TABLE 284

APPROXIMATE DEPTHS AND DURATIONS OF FLOODING

NORTHERN ZONE (MALAKAL–JEBELEIN)

Time of Flooding		Duration of Flooding	Speed of Rise of Flood	Area Flooded	Depth of Flooding				
					Mean Maximum Depth cm.	Range of Maximum Depths			
						For 75% of years		For 95% of years	
Average dates of flooding from	to	Average number of days	Average number of days to maximum	Approx. sq. km.		Minimum cm.	Maximum cm.	Minimum cm.	Maximum cm.
(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
11.10	30.11	51	21	40	0– 10	0– 0	28– 38	0– 0	50– 60
21. 9	10. 1	112	41	40	10– 20	0– 0	38– 48	0– 0	60– 70
11. 9	20. 1	132	51	45	20– 30	0– 2	48– 58	0– 0	70– 80
21. 9	31. 1	164	72	75	30– 40	2–12	58– 68	0– 0	80– 90
11. 8	31. 1	174	82	80	40– 50	12–22	68– 78	0– 0	90–100
1. 8	20. 2	204	92	60	50– 60	22–32	78– 88	0–10	100–110
21. 5	20. 3	304	164	60	60– 70	32–42	88– 98	10–20	110–120
11. 5	20. 3	314	174	150	70– 80	42–52	98–108	20–30	120–130
11. 5	31. 3	325	174	160	80– 90	52–62	108–118	30–40	130–140
Whole year		365	174	40	90–100	62–72	118–128	40–50	140–150

4. COLLATERAL IMPROVEMENTS

Agronomic improvements, improved methods of cultivation, and control over environment cannot alone achieve an increase in agricultural output. Other collateral improvements will also be necessary.

We have already mentioned several times in the preceding sections that present inland drinking-water supplies are insufficient, and in order to enlarge the area cropped, as well as to improve the care given to crops, they must be increased. This is mainly an engineering problem, and is discussed in detail elsewhere (see pp. 620–3).

In Volume I (p. 361) we have pointed out how the present inadequate communications and expensive transport militate against the development of cash crop production and particularly against mechanization of agriculture. Unless the system of communications can be radically improved and costs of transport lowered, it will be very difficult from the economic point of view to recommend agricultural alternatives based on any large degree of cash crop production and exchange economy. Furthermore these difficulties make it advisable to design remedial measures so that the present self-sufficient economy is retained to a great extent. This becomes more and more necessary as one goes farther south and away from markets and supply centres. The cash crops to be included in remedial measures must be of the maximum value per unit of weight and bulk.

The short-comings of trade in this area have also been discussed in Volume I (p. 357). For some of the remedial measures outlined below, better organization in the marketing of agricultural produce and the supply of essential imported commodities (implements, fertilizers, machinery, etc.) will be necessary, while all the measures suggested in this chapter would be easier to implement and more effective if trade were improved. One of the present characteristics of local trade, the irrational movement of grain, is likely to increase as the remedial measures designed to enlarge total crop output are applied, unless steps are taken to prevent this movement. It is therefore essential that local storage facilities be improved.

If, as a result of the Equatorial Nile Project, the number of cattle is reduced and the inhabitants of the Jonglei Area have to rely to a much greater extent on crop production, the provision of adequate grain storage will become of even greater importance. Even with all agronomic improvements, improved drainage, and the provision of irrigation, it is clear that crop yields will still vary considerably from one season to another. In years when yields are above average an adequate reserve of staple foods must therefore be stored to provide for the lean years which may follow. We have insufficient data to estimate the necessary storage capacity with any accuracy, but it would be unwise to keep less than the equivalent of one year's requirement in reserve. This allows for three successive years with yields 30% lower than average, not an excessive insurance in this country of great variations in rainfall and undeveloped, expensive transport. Storage provision for cultivators engaged in the production of rain-grown crops only should be even higher, probably two years' requirements in reserve.

Fortunately storage facilities should prove comparatively inexpensive if provided on a large enough scale; sorghum grain, if properly dried and treated with insecticides, can be stored for a number of years in pits dug in the soil. In the heavy clays predominating in this area, lined pits will almost certainly be necessary, except in the Semi-Arid Region and on the lighter soils of the Ironstone Region, less liable to flooding, where simple unlined pits should be adequate.

As pit storage can be carried out economically only on a large scale, special organization will be necessary. Storage services could be provided by merchants, as long as their charges were for that purpose alone, without the addition of speculator's profit. Otherwise the service would have to be provided by the government, though its costs might be charged to the cultivator.

Sorghum varieties of the Ironstone Region have a bad reputation for storage, and it may be necessary to introduce varieties which store better, to devise different methods of storing, or to replace sorghum with finger millet, which is much easier to keep.

5. IMPLICATIONS OF ANIMAL HUSBANDRY

As already stated in the introduction to this chapter, even if the present mode of life of the people of the Jonglei Area has to be replaced by one based mainly on crop production, the inhabitants should not suffer any decrease either in the quality or the quantity of their diet. Therefore to assure a diet of sufficient quality, a certain number of livestock must be preserved. As already mentioned, besides supplying milk and meat, cattle may be needed as working animals for tillage operations and even for transport.

We can assume that during the rainy season grass will be available to feed the animals. Therefore alternative supplies of fodder will have to be provided only for the period during which the cattle are at present on the *toich* grazing grounds. This period varies from approximately 120 days in the Bari and Mandari areas to approximately 150 days in Kosti District. It should also be noted that during this period dry grass and other roughage is likely to be available for feeding in unlimited quantity except in parts of the Semi-Arid Region. For the purpose of calculation we assume that, while completely devoid of digestible protein, the starch equivalent of this roughage equals 20.

By-products of crops grown for human consumption (straw, stovers, oil cake, etc.) offer an alternative source of fodder supply. Only if the quantity or quality of these by-products were insufficient for the essential minimum number of cattle would the use of grain, otherwise available for human consumption, or the growing of fodder crops be necessary.

In Table 285 we summarize feeding values (based on published data acquired elsewhere), estimated yields per feddan, and output per feddan in terms of starch equivalent and digestible crude protein of the by-products of crops grown for human consumption, grain and seed of crops normally grown for human consumption, as well as fodder crops most likely to be grown in the various parts of the Jonglei Area. We have not attempted to calculate the protein equivalent, as all domestic stock in this area are ruminants, and consequently digestible crude protein should be a good enough guide to the feeding value of different fodders.

In Table 286 we give the theoretical feeding requirements of different classes of cattle according to British standards (based mainly on Kellner's work) and, for comparison, the calculated starch equivalent and digestible crude protein ration as given to cattle on the Gezira Research Farm[64]. As can be seen from this table the actual rations fed at the Gezira Research Farm correspond reasonably closely to the theoretical fodder requirements.

Table 285 is used later in this chapter (in the section dealing with the discussion and costing of the most promising agricultural alternatives) as a basis on which demands for fodder and means of supply are assessed.

TABLE 285

FEEDING VALUE, YIELD AND PRODUCTION PER FEDDAN IN TERMS OF STARCH EQUIVALENT AND DIGESTIBLE CRUDE PROTEIN OF BY-PRODUCTS AND CULTIVATED FORAGE CROPS

Feeding Stuff	Starch Equivalent	Digestible Crude Protein	Source (See below)	Average Yield of Fodder per Feddan		Approximate Average Yield per Feddan				Remarks
				Irrigated	Rain-grown	Irrigated		Rain-grown		
						S.E.[5]	D.C.P.[5]	S.E.[5]	D.C.P.[5]	
	—	%		kg.	kg.	kg.	kg.	kg.	kg.	
1. BY-PRODUCTS										*Losses in handling and storage not taken into account*
(a) Straws and Stovers[6]										
(i) Cereals										
Sorghum stover	26	2.0–1.5	(2)(3)	2,500	1,750	650	50	450	35	Digestible crude protein in irrigated quick-maturing sorghums 2·0%; in rain-grown slow-maturing sorghums 1·5%
Maize stover	29	2·5	(2)	—	1,500	—	—	435	37	
Bulrush millet stover ...	22	0·5	(2)	—	1,500	—	—	330	7	
Rice straw	22	0·5	(4)	1,000	—	220	5	—	—	
(ii) Leguminous Crops										
Groundnut stover	50	3·5	(4)	—	500	—	—	250	17	Calculated on the assumption of digestibility similar to that of trials at Shambat
(b) Seeds										
Cotton seed (American type) ...	80	13·5	(1)	330	120	264	45	96	16	
Cotton seed (Egyptian type) ...	80	13·5		420	—	336	57	—	—	
(c) Oil-Seed Cakes										
Cotton-seed cake (Undecorticated)										
American type	42	17·0	(1)	265	95	111	45	40	16	
Egyptian type	42	17·0	(1)	335	—	141	60	—	—	
Groundnut cake (Decorticated)	73	42·0	(1)	—	145			106	61	
Sesame cake	73	40·0	(1)	—	90	—	—	66	36	
(d) Other By-Products										
Sugar-cane tops	—	0·6	(4)	3,000	—	—	—	—	—	Assuming 10% of total yield to be tops
Sorghum bran	76	7·5	(2)	—	—	—	—	—	—	Usually not available
Rice bran	58	7·5	(2)	75	—	43	6	—	—	Yield = 10% paddy
Rice husks	6	0·5	(2)	150	—	9	0·7	—	—	
2. CULTIVATED FODDERS										
(a) Grain and Seeds										
(i) Cereals										
Sorghum grain	72	9·0	(1)(3)	700	250	504	63	180	22	
Maize grain	78	8·0	(1)	—	250	—	—	195	20	
Bulrush millet grain ...	59	7·5	(2)	—	250	—	—	147	19	
Rice grain	70	6·0	(1)	750	—	525	45	—	—	Assuming digestibility approx. equal to barley grain
(ii) Leguminous Crops										
Cowpea seeds	82	21·5	(3)	—	150	—	—	123	32	
Groundnut seeds (Decorticated)	131	24·0	(1)	—	265	—	—	347	64	
Velvet bean seeds	86	20·0	(2)	—	300	—	—	258	60	
Gram seeds	67	15·0	(1)	—	250	—	—	167	37	
(iii) Oil Seeds										
Sesame seeds	133	18·5	(1)	—	150	—	—	200	27	
Sunflower seeds	100	13·0	(1)	—	300	—	—	300	39	

Source: the numbers in this column signify the following works:
(1) Ministry of Agriculture and Fisheries (U.K.), *The Composition and Nutritive Value of Feeding Stuffs*, Bull. 134, H.M.S.O. 1942.
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(5) S.E. = Starch Equivalent; D.C.P. = Digestible Crude Protein.
(6) Stover = stalks and leaves left on the field for animals to feed on.

TABLE 286

THEORETICAL REQUIREMENT AND RATIONS OF GEZIRA RESEARCH FARM CATTLE

in kilogrammes

	Tillage Bull (live weight 450 kg.)			Milch Cow (live weight 300 kg.)		
	Quantity	S.E.	D.C.P.	Quantity	S.E.	D.C.P.
Theoretical Requirements						
Maintenance ...	—	2·75	0·27	—	2·00	0·20
Production						
6 hours' work ...	—	3·00	0·30	—	—	—
1 gallon milk ...	—	—	—	—	1·35	0·30
Total	—	5·75	0·57	—	3·35	0·50
G.R.F. Rations						
Sorghum straw	5·85	1·54	0·12	3·60	0·95	0·07
D. lablab hay ...	1·35	0·46	0·15	1·35	0·46	0·15
Concentrates:						
Sorghum grain	1·80	1·30	0·16	1·50	1·08	0·13
Cotton cake ...	0·90	0·37	0·16	0·75	0·31	0·13
Total	—	3·67	0·59	—	2·89	0·48
Deficit satisfied by grazing roughage (S.E. 20%) ...	10·00	2·08	—	2·50	0·55	—

6. PROBLEMS OF DEVELOPING AGRICULTURAL POTENTIALITIES TO REMEDY LOSSES UNDER THE PROJECT

In the previous sections of this chapter we have attempted a general assessment of agricultural potentialities in the Jonglei Area. We have no doubt that these potentialities could be developed to replace the primarily pastoral losses which will result from the Equatorial Nile Project. In order to achieve this object, development must result in the provision either of a sufficient amount of fodder to retain the present livestock in this area or of an equivalent wealth in the form of crops.

Two further stipulations are necessary. The change from the present leisurely nomadic life, in which the existing environment provides sufficient resources for the upkeep of livestock without any great effort on the part of its owners, to a much more laborious life based on crop cultivation, demands a commensurate increase in the standard of living. We wish to emphasize strongly that the additional work which crop production entails fully justifies an additional income. Consequently, even if the present animal stock can be retained by agricultural means, agricultural alternatives must be designed so as to reward the cultivator for his additional labour. Furthermore, if perpetual subsidies are to be avoided, these alternatives must produce sufficient income to pay their running costs, including depreciations, and hence provide for the replacement of the capital originally invested in them.

THE DIFFICULTY OF FINDING A CONVERSION FACTOR

We have considered a number of possible ways in which the present value of livestock could be equated to the output of crops. This is the most difficult and most fundamental problem to be considered in connection with the quantitative aspects of replacing animal by crop wealth.

In countries in which a cash economy is established, this equation could be done simply on the basis of relative prices. In the Jonglei Area, however, where the economic life of the inhabitants is still almost entirely based on the self-sufficiency of family units at subsistence level, the prices of crops and cattle cannot be regarded as representing their relative values. Moreover these prices, as might be expected in an area of undeveloped trade and communications, vary greatly from time to time and from place to place. A bad harvest increases sharply the price of grain and at the same time lowers considerably the price of cattle. Therefore even if local prices could be accepted as a criterion it would be impossible to determine their relative levels, especially as there are no records from which average prices could be calculated.

Furthermore in this area the local prices bear no relation to world prices. At the same time, absence of economic data prevents any assessment of what the relation of world to local prices should be. Therefore the relative value of livestock and crops cannot be measured by their cash values in the world market or even in the markets of the Northern Sudan. We therefore conclude that prices cannot provide the basis for this most important equation.

We have also tried to assess the relative values of livestock and crops on the basis of their nutritive value to the local inhabitants. As we have already mentioned (see Vol. I, p. 250), the present relatively high quality diet, containing a high proportion of protein, vitamins and minerals supplied by animal products, could not be retained by substituting crop products. We do not consider it sound to make the assessment on calorific values alone, and we could not find a satisfactory formula based on nutritional values for this equation. A formula may exist, but there was no expert with a specialized knowledge of nutrition on the Team.

We have also tried to assess the size of the agricultural alternatives required on the assumption that a certain proportion of the population will lose its livestock entirely, and will have to be provided with a reasonable livelihood from crop production alone. Not only is this assumption unrealistic, as in practice the losses will be distributed over the whole population of the area affected, but we have also found it impossible to assess what proportion of the population would lose their livestock if this assumption were correct. It would be completely false to assess this proportion on the basis of the ratio of humans to Animal Units, as it would appear that the peoples who possess the smallest number of animals, and therefore rely on them least, would in theory suffer greater losses than those possessing a large number of animals.

After reviewing these possibilities, we are of the opinion that the best basis for the consideration of the quantitative aspects of agricultural alternatives is the fodder value of the by-products of food and cash crops, with the proviso that the crops chosen should produce the highest possible combination of food or cash and fodder value and at the same time conform to the dictates of good husbandry. In this way it should be possible to retain the present number of livestock and to reward the inhabitants of the area for the additional labour which they would have to give.

PROBLEMS OF RESETTLEMENT

The present pattern of population settlement is determined by an environment eminently suitable for animal husbandry, and hence largely by the location of dry season *toich* pastures in relation to higher ground. The Equatorial Nile Project will change this environment, and as the sources of livelihood will also change from pastoral to agricultural, the present pattern of settlement will become unsuited to the new conditions and a new pattern, based on crop producing potential, will have to replace it. Also, as agricultural alternatives will require a high degree of cash economy, the distances from markets, supply centres and natural lines of communications will have to be taken into account when the locations of the schemes are decided upon.

This might require large-scale resettlement. In a more highly developed country it could be assumed that this would be carried out almost automatically, but in this area, where tribal distinctions are still of great importance, it would be most difficult, for example, to resettle the Gaweir Nuer in Paloich or Dunjol Dinka country. How difficult it will be in future is impossible to predict, as it will depend on social, economic, and political developments in the interim.

In the designing of the agricultural schemes we have, as far as possible, avoided suggestions for large-scale resettlement. In practice, when the Jonglei Canal is built, resettlement may prove unavoidable, but by then may not be so difficult.

METHODS OF DEVELOPING AGRICULTURAL POTENTIALITIES

There are two basic methods of developing agricultural potentialities: first there are extension methods, whereby the existing system of crop production on small peasant holdings can be retained but improved; secondly there is the creation of centralized crop production schemes. The choice of method must depend largely on (a) the time available for agricultural development, and (b) the type of agricultural undertaking.

Extension methods, relying on propaganda and persuasion, aim at educating the people, and must necessarily be slow. In centralized schemes a high degree of supervision—which would be prohibitively costly in the case of scattered peasant holdings—can be provided, and a high standard of husbandry enforced, even if the individual cultivators do not understand the reasons for certain operations and processes. Increased output can therefore be achieved much more rapidly.

Some types of agricultural production which require considerable capital outlay, highly specialized technical knowledge, and managerial ability, all of which will be limited in this part of the country for a long time to come, could be undertaken only on large centralized schemes. Irrigated crop production, mechanized agricultural schemes, and even *hariq* farming on a large scale can only be carried out within large schemes, financed and managed by a central authority.

The retention of the present peasant structure of local agriculture, with improvement of output by extension methods, has social, political, and economic advantages. It would not produce the complications involved in a rapid change from the present system to a completely new and, to the semi-nomads inhabiting this area, foreign economic system. It would also make this area more independent of price fluctuations and the other evils of modern exchange economy than would centralized schemes.

Of extension methods, improvement by example is sure to be the most successful in an undeveloped area. Good examples are best given by model and economically successful holdings. Extension work also requires[65] :

(i) Oral methods (personal contact, general meetings, discussions, farm tours, etc.).

(ii) Visual methods (demonstrations of farming methods and results, single factors and farming systems; mobile demonstrations, films, slides, photographs, exhibitions and shows).

(iii) Competitions (shows, fairs, etc.).

(iv) Financial methods (grants and premiums for improved farming, rural credit, trade organization including producers' and consumers' co-operatives, etc.).

(v) Agricultural legislation.

(vi) Agricultural education (agricultural schools, courses, camps, farmers, clubs, etc.).

This work obviously requires not only time but also sufficient personnel of all grades, which at present is sadly lacking in the Jonglei Area. Junior personnel must, as far as possible, be recruited from the local people, as only they can secure, in time, the confidence of their fellow tribesmen without which no extension work can be successful. If it is decided to concentrate on remedial agricultural development by extension methods, this work should be started as soon as possible and with adequate facilities, as the number of man-hours it will require from technical and administrative staff in order to achieve the same results as centralized schemes will be considerably greater.

Possible types of centralized crop production schemes can be classified as follows:

(i) Direct labour schemes (e.g. plantations run by private individuals, or by the state, or partly by the state as in the Mechanized Crop Production schemes in the Gedaref area).

(ii) Co-operative production schemes in which the land is not divided into individual holdings.

(iii) Share-cropping schemes (e.g. the Sudan Gezira scheme, White Nile Alternative Livelihood schemes and many private pump schemes).

The last type of organization has obvious social, political and economic advantages, and in considering our remedial schemes we have based them, where possible, on a share-cropping system, though we realize that, at least in the initial stages, the ' direct labour ' type may be technically and economically more efficient.

NORMAL AGRICULTURAL DEVELOPMENT AND AGRICULTURAL ALTERNATIVES

We have already mentioned in the introduction to this chapter that normal agricultural development may in some cases prejudice the remedial measures which we suggest. The existing agricultural potential may be developed in the course of normal economic development before the Equatorial Nile Project creates the necessity for the remedies. As long as the local population is absorbed in the new development schemes the problem of providing agricultural alternatives is diminished. If, however, the schemes absorb mainly immigrant labour, the problem is aggravated.

The new private pump schemes in the Semi-Arid Region are, to a considerable degree, manned by cattleless sections of the local population as well as immigrants. If this development continues all the most suitable land may be taken up in time by pump schemes which will absorb only a small part of the local cattle-owners, and when implementation of the Project finally calls for remedial measures, the local inhabitants who are reliant on livestock as a primary source of livelihood will then have to be settled on ' second best ' land, if such can be found.

Again, it is not impossible that the best land in the Transitional Belt between the Semi-Arid and Flood Regions may be taken for large-scale mechanized cash crop production, in which only comparatively few local people will be absorbed, before the time when, we suggest, it should be developed as an agricultural remedial measure.

If the sugar scheme in the Mongalla-Gemmeiza area starts production within the next few years, it will almost certainly employ only a small proportion of the cattle-owners. These people in particular will be directly affected by the Project, and will therefore be most in need of the alternative source of livelihood which the scheme could provide.

These are only a few examples; we do not suggest that the best land should be reserved for agricultural remedial measures, thus prejudicing more immediate development ; we ask, however, that the problems which the Equatorial Nile Project will create be taken into consideration when such development is planned.

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(54) This and the other section concerning mechanization is largely based on the excellent analysis of the problems in African conditions in *Report of a Survey of Problems in the Mechanization of Native Agriculture in Tropical African Colonies*, by Higgs, J. W. Y., Kerkham, R. K., and Raeburn, J. R., H.M.S.O., 1950.

(55) Higgs, Kerkham and Raeburn, op. cit.

(56) Sherwood, J. H., op. cit.

(57) ibid.

(58) Laing, R. G., *Mechanization in Agriculture in the Rainlands of the Sudan 1948–51*. To be published shortly by the Sudan Government.

(59) For details see Robbins, W. W., Crafts, A. S., and Raynor, R. N., *Weed Control*, 2nd ed., McGraw-Hill, London, 1953 pp. 126–7, 241 et seq.

(60) Tothill, *Agriculture in the Sudan*, p. 450–2.

(61) ibid., pp. 452–3.

(62) Klages, K. H. W., *Ecological Crop Geography*, Macmillan, New York, 1942, p. 178.
Montgomery, E. G., and Kiesselbach, T. A., 'The relation of climatic factors to water used by the corn plant', *Nebr. Agric. Exp. Stn. Ann. Rep. 1910*, p. 94.

(63) Ferguson, H., private information.

(64) Hattersley, M. C., 'Livestock and crop potential for Gezira irrigated areas', Sudan Min. of Agric., Res. Div., *Misc. Paper No. 56*.

(65) For example see *Agricultural Extension and Advisory Work with Special Reference to the Colonies*, Colonial Office Bulletin No. 241, H.M.S.O., London.

CHAPTER 8. THE ENGINEERING ASPECTS OF REMEDIAL MEASURES

1. ENGINEERING POSSIBILITIES

We summarize briefly below the main possibilities of remedial measures considered purely from the engineering point of view. Topographical and hydrological factors must obviously be suitable before certain remedies can be considered at all.

SOUTHERN ZONE

IRRIGATION BY GRAVITY FLOW

The topography of the country flanking the Bahr el Jebel between Nimule and Rejaf rules out any possibility of irrigation schemes in this reach.

North of Rejaf as far as the Bahr el Jebel barrage downstream of the Atem Head, the *toiches* or flood-plains, as shown by our surveys of the Mongalla-Gemmeiza and Aliab valleys, are topographically suitable for irrigation by gravity flow from the river in the dry season. There are two difficulties to be overcome. First, these flood-plains are extremely uneven and the best form of irrigation might be simple flush watering for pasture through regulators at the heads of natural spill-channels. The water could be spread by cross-banks designed to divide the valleys into a number of basins and to pond water to a suitable level in each basin, controlled by spillways or sluices in the cross-banks.

Such a rough-and-ready method of irrigation would overcome the unevenness of the ground and would be suitable for some pastures. Very few other crops could tolerate such heavy and variable flooding, and should the aim be to irrigate crops other than pasture it would be necessary to survey the area carefully, lay out irrigation channels, and level the ground mechanically. The extent and the degree of levelling by mechanical means would depend on economic considerations. In any case it would probably be found that even for pasture the above method was too inefficient, and it would probably be more economical to invest in a properly laid out irrigation scheme.

The second main difficulty concerns flood-escape discharges. We have seen from the surveys (p. 823) that under normal operation in the 55 m/d Canal stage, when the discharge at Mongalla will be 90 m/d, the Mongalla-Gemmeiza *toich* will only be flooded through spill and backwater channels. A comparatively small amount of work would be necessary to control irrigation completely. On the other hand it is shown that under a flood-escape discharge of 120 m/d at Mongalla the whole of the same area will be flooded completely, and banking would be necessary to prevent this. In the Egyptian proposals the left side of the Bahr el Jebel from Tombe to the barrage will be banked, but we are left to assume that such banking will be strong enough to confine a flood-escape discharge of 120 m/d to the river channel. Thus, although under normal operation in the 55 m/d Canal stage these *toiches* may be suitable for irrigation, they will be liable to inundation during a period of flood-escape unless special measures such as banking or canalization are employed to transmit higher discharges in safety. It would always be less of a risk to irrigate pastures as they would not suffer from flooding in the same way as other crops, and some useful pasture might be made available if the discharge could be reduced during the grazing period. The above argument assumes that complete control of high floods will be possible, and the force of the argument is strengthened when it is realized that discharges even higher than 120 m/d will occur for short periods.

PUMP IRRIGATION

Pump irrigation of the high land outside the limits of the *toiches* in the Southern Zone would not be a simple operation on the west bank owing to the undulating nature of the country. On the east bank of the Bahr el Jebel, however, though levels on the river bank are unsuitable for irrigation between Rejaf and Kursomba, as our cross-sections show (Figs. A 10 to A 12), north of Kursomba we infer from these levels and from the cross-section at Malek (Fig. A 13) that pump irrigation would be possible. The river hugs the east side of its valley from Gemmeiza northwards, so that there should be no difficulty in finding sites for pumping stations.

DRAINAGE

Since the Bahr el Jebel will be low during the rains, the *toiches* will be drained naturally towards their northern ends, and our surveys clearly show that this will be possible, except under flood-escape discharges.

On the west bank from Nimule to the Bahr el Jebel barrage the country bordering the river is drained naturally by the many small torrential watercourses which are found there. On the east bank the ground slopes towards the river, and some watercourses provide similar natural drainage as far north as Kursomba (lat. 5° 30′). Farther north again and as far as the beginning of the Jonglei plain, about 15 km. downstream of Bor, there is sufficient difference between ground and river levels for artificial drainage schemes to be installed to serve areas within a limited distance of the river. Farther north the level of the river rises above the plain and drainage would be possible only in a northerly direction.

DOMESTIC WATER SUPPLIES

Should additional water-points be required on the south-eastern plain, they could be provided by wells drawing from about 100 feet or less.

Hydrological conditions which give rise naturally to the establishment of *Hyparrhenia rufa*, or other grasses which need even heavier flooding conditions, will also be suitable for filling surface conservation tanks, or hafirs. Unfortunately the soil does not appear to be altogether suitable for hafirs. In the bore-hole east of Kursomba, sands and sandy clays were found beneath a thin surface layer of clay 2 ft. thick.

CENTRAL ZONE

IRRIGATION BY GRAVITY FLOW

First, in the Central Zone there are areas of swamp which will be dried out because excess water will be by-passed in the Jonglei Canal. These swamps are today irrigated naturally by gravity from the river. A cross-section also shows that the level of the ground in the depression bordering the river is below the level of the river and the depression is separated from the channel by alluvial banks. It would therefore be technically possible in the future to irrigate the land in these depressions under control by gravity flow from the river.

However, our comments about the extreme unevenness of the ground in the Southern Zone will almost certainly apply to the Central Zone, and it would be better to irrigate pastures than anything else. Again we must note that remedial measures based on irrigation schemes on these dried-out swamp lands will be extremely vulnerable to flood-escape discharges, and if the discharges proposed by Dr. Amin and Mr. Bambridge were to be applied they would be a total loss.

Secondly, ground levels on the plain are suitable for feeder canals to take off upstream of the Jonglei Canal Head regulator and irrigate extensive areas on the Eastern Plain both east and west of the Jonglei Canal. East of the Canal overland flooding will be aggravated, but west of it the ground will be protected from flooding by the Canal itself. There are also natural drainage-channels west of the Canal, such as Khors Ding, Jurwel, and Gurr, which drain into the Bahr el Zeraf and which could be utilized in the future since the levels in the river will be low.

If the Jonglei Canal were to be re-designed to command the plain it traverses, gravity irrigation from it would be possible without the need of feeder canals. It will be seen later that there are complications when communications are considered, and it might be better to have separate feeder canals for irrigating the Eastern Plain. The point is an important one and the problem complicated. It will be dealt with fully later under the ' Revised Operation ', where our recommendations on the design of the Canal are given in full. One great advantage of applying such a remedial measure in this region is that the plain would not be liable to be flooded by the river at any time.

On the west bank south of Lake Nuong levels are not suitable for gravity irrigation, except in the immediate vicinity of the river where there are swamps today. Northwards from Lake Nuong the ground falls towards the Bahr el Ghazal, as well as to the north, and gravity flow irrigation is technically possible. The slopes are, however, very small (from 4 to 7 cm/km.), and any irrigation project would require a barrage across the Bahr el Jebel north of Lake Nuong. Gravity flow irrigation is also technically possible on the Zeraf Island, but again slopes are small; a barrage would be necessary, and it would be expensive to install and maintain.

PUMP IRRIGATION

There would be little advantage to be gained by using pumps for irrigation in the Central Zone as large areas could be commanded by gravity flow. It has been pointed out that the water-levels in the Jonglei Canal, as designed, will conform to ground levels, and in that case pumps would have to be used to irrigate from it. Similarly for irrigation on the Western Plain and the Zeraf Island pumps could be used in place of barrages to obtain the necessary command.

DRAINAGE

If, as seems likely, the depressions bordering the river in the Central Zone, where there are now permanent swamps, are similar to those surveyed in the Southern Zone, we can say that drainage in them will be directed northwards parallel to the river. The discharges in the river will increase slightly, from 30 to 35 m/d, in the rainy season instead of being reduced as in the Southern Zone, so the flood-plains will not be drained as effectively as farther south, but nevertheless large portions of each valley will be well drained.

On the Eastern Plain ground-slopes are suitable for large-scale drainage schemes both east and west of the Jonglei Canal. East of the Canal, where rain-flooding will be aggravated by the Canal, any such drainage schemes would have to terminate either in one of the tributaries of Khor Fullus or in Khor Chieth (the upper Khor Atar), both of which would have to be enlarged if flooding was to be avoided in their lower reaches. Since this area is now dominated almost exclusively by the perennial grass *Hyparrhenia rufa*, and since its main characteristic is creeping flow, there is little advantage to be gained in attempting to drain it. On the contrary, we should perhaps try to increase the inundation by irrigation from the Canal, or by contour banking suitably designed and fitted with automatic or natural spillways. The few natural drainage-channels which are to be found in this area would also have to be banked. On the other hand the land west of the Jonglei Canal will be protected from overland flooding by the Canal itself, and is already provided with some natural drainage-channels such as Khors Ding, Jurwel, and Gurr which lead to the Bahr el Zeraf and which could be developed. It would be better to drain this area for crop production, with perhaps supplementary irrigation.

West of the Bahr el Jebel conditions are somewhat different. As far north as Lake Nuong the direction of natural drainage is towards the Bahr el Jebel, as for instance in Khor Moich. From there northwards the major slopes run northwards and later westwards from the Bahr el Jebel. The Western Plain is also flooded by run-off from the south-western torrents, the Tonj, Gel, Na'am, and Lau, and there is little prospect of being able to reduce flooding by artificial drainage as ground-slopes are so small. Here too the conservation of rainfall by contour banking appears to be one of the few remedies which could be applied.

In the region west of Adok and on the Zeraf Island there are two possibilities. In Volume I we have shown how these two areas are intersected by intricate networks of shallow, wide, and heavily grassed inland water-systems. In the first place these watercourses could be banked (as for example at Chotyil on Khor Tiak) to prolong the inundation for grasses. This would be a particularly suitable type of remedy because the same watercourses will be deprived of river spill, and it would be necessary to conserve rainfall and local run-off by artificial means. (Hafirs should be included in such banking schemes for domestic and stock water supplies.) In the second place it has been noted that the banks of these inland watercourses are alluvial in formation and provide high land which is drained sufficiently for crops and habitations today. More land outside the banks could be drained by artificial cuts through the banks, and at the same time flooding increased in the watercourses to improve pasture. The application of this remedial measure depends first on suitable levels and secondly on the extent of the watercourses. Unfortunately its advantages were not appreciated until the survey was completed, and we have not a practical example of it levelled in the field, nor sufficiently accurate maps to estimate the extent of its application. We have a number of cross-sections typical of these channels which show that there is usually enough difference in level inside and outside the khor to give confidence in the practicability of the principle[(1)]. The experiment of banking at Chotyil on Khor Tiak proves that there need be no danger of flooding habitations on the alluvial banks.

DOMESTIC WATER SUPPLIES

The drilling programme of deep bores has shown that water can be found almost anywhere in the Central Zone at about 150 feet below ground. The excellent examples of open wells in Bor District which reach water usually at 100 to 120 feet (exceptionally at 170 feet) show how domestic needs can be satisfied by them. It would be laborious to water large numbers of cattle by hand, and stock watering would require mechanical pumps and tube wells. These would suffer from the disadvantage of lying idle in an area of high humidity for 8 or 9 months in the year, and mechanical maintenance would be an expensive item. Assuming that *Hyparrhenia* regrowth can support one beast per 13 feddans from January to May and that the limit of grazing within walking distance of a watering-point is a radius of 7½ km., then each water-point would be required to serve 3,200 head of cattle. It would clearly be suitable to install a twin-bore water-yard, which is capable of watering about 3,000 head of cattle per day.

On the other hand hafirs can be sited almost anywhere where hydrological conditions are suitable for *Hyparrhenia rufa* pasture. In the bore-holes sited around the Eastern Plain clays were found down to 20 or 25 feet (6 to 7½ m.), and below the clays were mixtures of fine sands and clays. The ground is therefore quite suitable for hafirs up to 6 m. deep. The average size of 23 hafirs already dug in the Northern Zone is 9,500 m^3. with an average depth of 5·6 m. Assuming these dimensions for a hafir at Bor, we have calculated that 750 head of cattle could be supported in the dry season. For watering stock the advantages of hafirs are that they would be easily sited and filled and would require maintenance only after long periods, amounting merely to the excavation of silt.

NORTHERN ZONE

IRRIGATION BY GRAVITY FLOW

The *toiches*, or flood-plains, of the river in the Northern Zone could be utilized for irrigating a pasture or other type of crop provided it could tolerate a wide range of flooding conditions. Parts of the same *toiches* could be protected by banking and irrigated by gravity flow when the river was high. Under normal operation in the 55 m/d Canal stage the river will reach a maximum of at least 12·39 m. on Malakal gauge and the protection banks would be called upon to withstand a head of about 1·0 m. there. However, the Sobat component of the flow at Malakal is uncontrolled and this was responsible for levels of 13·03 m. and 12·92 m. in 1909 and 1946 respectively. In addition, under flood-escape conditions, levels as high as 13·30 m. on Malakal gauge are to be expected, and we must conclude that this type of remedy too is vulnerable to high floods.

The Machar Marshes form the only other example of gravity irrigation in the Northern Zone. The development of this area would be a gigantic undertaking. Any scheme of control must entail both canalization of the Machar, Yabus, Daga, and Adar, and control works on the Sobat to store water during the flood for irrigation subsequently in the dry season. While such a scheme is undoubtedly highly desirable, it is hardly a practical proposition as a remedial measure. It would involve the resettlement of several tribes if its potentialities were to be developed to the full. However, without any such engineering works these swamps produce pasture in the dry season which could be made available by providing watering-points on suitable access routes.

PUMP IRRIGATION

As far as we can judge from the levels shown on existing surveys, pump irrigation could be applied almost everywhere on the banks of the Bahr el Zeraf downstream of Fangak, of the White Nile east of Lake No, and of the Sobat west of Abwong and as far as Kosti[2]. Several natural pump sites can be found on the river today and others could be created artificially if necessary by dredging channels across the flood-plain, which averages no more than 2 km. in width north of Malakal.

The Project itself will facilitate this form of irrigation because it will reduce the range of levels in the river, as we have explained previously when discussing its effects (p. 433). A very rough approximation of the areas which might be irrigated in this way amounts to 10,000 sq. km. on the White Nile (about 2,500,000 feddans), plus 1,000 sq. km. each on the Bahr el Zeraf and Sobat.

DRAINAGE

Our cross-sections (Figs. A 22, 23, 24) show that the hinterland behind the ' Shilluk ridges ' on both sides of the White Nile varies in level from 3 metres to half a metre above normal high river level between Tonga and Melut. There should therefore be no difficulty in applying artificial drainage over a large part of the area. Since the river level will be about 1·0 m. above normal at the highest discharge to be expected under flood-escape conditions, some of these drainage schemes might not function during such a period, but the height of the Sobat flood at Malakal occurs in November, three months after the height of the rains in August, so that the river will not be at its highest when drainage is needed most. Generally speaking the land up to 10 km. or more from the river could be drained artificially. Drainage schemes would in any case have to be complementary to the pump irrigation schemes suggested above.

As in the Central Zone, there are several inland water-systems to which drainage schemes could be attached, as for instance the Nyadwai, Adar, and Wol systems and their minor branches.

DOMESTIC WATER SUPPLIES

HAFIRS

South of the 640 mm. isohyet in the Northern Zone there are a number of inland water-courses and depressions such as the Raqaba where hafirs could conveniently be sited for water-points. North of this line, in the area of lighter rainfall, in order to be assured of ample run-off hafirs must be sited at the foot of hills or rocky outcrops. Such sites are extremely limited in number, and in fact are almost all utilized at present. In Renk District a number of hafirs has been successfully sited at the foot of *gardud qozes*. These dune-shaped mounds lie in an area where the average annual rainfall is 600 mm., and, far from being pure sand, these so-called *qozes* are formed by weathering of the rock *in situ*. On the west bank of the river there is an area in the ' sweet veldt ' region where additional grazing could be provided if water-points were available. Unfortunately the *qozes* in this district are Kordofan sands, and the sub-surface soil, being also sandy, is unsuitable for hafirs—even if the rainfall were sufficient, which it is not.

DEEP BORES

As far as underground supplies are concerned water was found in bore-holes at depths varying from 200 to 400 feet. Analysis shows proportions of dissolved salts as high as from 5,000 to 8,000 p.p.m. Whether cattle can tolerate such high salinities has yet to be proved, but the indications are that they prefer salty water to river water at least for a short period.

2. OTHER ENGINEERING CONSIDERATIONS

In this section we discuss further the qualitative aspect of remedial measures in general terms; the question of water-duties and drainage or run-off factors is first dealt with. Controlled irrigation schemes will of necessity figure largely in our suggested remedies, and it is vitally important to estimate how much water would be required for them. Below we review the information from all available sources on the subject of water-duties and present our conclusions on the water requirements of pasture, other common agricultural crops, and rice. Complementary to irrigation in the control of moisture conditions is drainage. We describe below the formula on which run-off is calculated and estimate the capacity of drains required in the Flood Region to serve areas subject to rainfall alone, and to drain areas under irrigation in addition to rainfall. We then turn to descriptions of methods of irrigation outside the Sudan which have a bearing on remedial measures in the Jonglei Area, such as pasture irrigation in Australia and America. A short summary of some small irrigation schemes in Uganda is included to show the value of supplementary irrigation in an area where rainfall is greater and less variable than in the Sudan.

WATER-DUTIES

This subject, which is concerned with the water requirements of remedies involving irrigation, is obviously of considerable importance. The most satisfactory method of obtaining the necessary data is by direct experiment in the area, and this was appreciated early in the investigation by our predecessors, who planned to establish experimental pump schemes at Malakal, Jerkwot, and Shambe. As we have already mentioned (see Vol. I, p. 43), for various reasons the Malakal experimental area was the only one to be developed and a certain amount of information has been obtained from it. It was also realized that an experiment on irrigated crops lasting only 3 years could not possibly give completely accurate results, and in fact the Jonglei Committee directed that the objective should be to obtain, in the time available, only approximate answers to the many different problems confronting the Team. Another difficulty in obtaining data was the recruitment of a specialist who could design the experiments and carry them out. We have already drawn attention to the fact that the Agriculturist spent little more than two complete field working seasons with the Team, and the Pasture Research Officer considerably less.

Furthermore all the experiments were designed to estimate the irrigation requirements during the dry season, whereas the results of the Team's investigations have shown that it is equally, or perhaps more, important to supplement rainfall with irrigation water. The water-duty of artificial pastures was the original objective of the experimental pump schemes, whereas it will be seen later that irrigation of other agricultural crops is equally important.

The data obtained from the experiments have been supplemented by practical experience in other parts of the world, notably in the Gezira Scheme in the Northern Sudan, in Australia, and in America. This provides some indication of the water requirements in the Jonglei Area, after due allowance is made for differences in climate, soil, and topography.

Finally we have studied the possibility of applying theoretical methods, based on meteorological records, for estimating water-duties, as for instance Penman's formula which is based on rainfall, temperature, humidity, and insolation. At Malakal there are no records of the hours of sunshine, but all the other data are available. In fact we have not made any practical use of these methods. We have divided the subject of water-duties into separate parts concerning pasture, other agricultural crops common to the Sudan, and rice.

IRRIGATED PASTURES

For the Flood Region, where artificial pastures will be most needed, we must consider grasses of the perennial type such as those which occur on intermediate land, though it is, of course, hoped that pasture experiments will be continued and will lead to the introduction of better pastures than those which occur naturally. The perennial grasses of the intermediate land rarely start to grow at Malakal and Bor before May, when rainfall begins to be sufficient. Their greatest vegetative growth occurs in July and August when the average monthly rainfall is in the region of 150 mm. (Tables 11 and 19, Vol. I, pp. 54, 58). Since at this time there is frequently rain flood-water standing on the surface of the ground this amount is probably in excess of requirements. In the dry season, on the other hand, the losses by evaporation will be much greater, and 150 mm. can be reasonably taken as the measure of irrigation water required per month, particularly since irrigation is not as efficient as rainfall in supplying the soil with moisture and some of the water applied to the surface must be lost by evaporation in the time taken by the soil to absorb it. This figure of 150 mm. is equivalent to 630 m^3.p.f., and on this basis 3,780 m^3. would be required in the six-month dry period from December to May inclusive.

In the Murrumbidgee irrigation areas of Australia, where irrigation is used to supplement low rainfall, approximately 32 in. to 40 in. of water are supplied in 8 or 10 applications over seven months from September 15th to April 15th to a pasture composed of *Paspalum* and white clover. This is equivalent to 3,410 and 4,370 m^3.p.f. in a seven-month period or 490 and 630 m^3.p.f. per month in addition to rainfall.

The results of the Malakal experiments have shown clearly that the amount of grass produced increases directly with the total amount of water supplied up to intensities of 600 to 800 m^3.p.f. per month. In this experiment higher yields were obtained by even heavier applications of water, but the increases in yields were not in direct proportion to the additional water supplied, and the results were not consistent in two consecutive seasons. For example the application of about 1,600–1,700 m^3.p.f. per month gave the highest yield in the first year and the sixth highest in the second; and the highest yield in the second year was obtained from the application of 876 m^3.p.f. per month. The application of 600 m^3. every 21 days (860 m^3.p.f. per month) gave reasonable yields in both years, although the same amount of water applied in smaller quantities at 7-day intervals produced higher yields. It appears likely that the most suitable water duty is 860 m^3.p.f. per month (30 days) or 5,160 m^3.p.f. over an irrigation period of 6 months. This figure is applicable mainly to the Flood Region. In the Ironstone Region and Semi-Arid Region the figure might vary from 800 to 950 m^3.p.f. per month.

FREQUENCY OF APPLICATION

From our experience of irrigated pastures at Malakal, it was obvious that it was impracticable to supply irrigation water weekly as there was not enough time between irrigations to dry out the land so that the cattle could be put on to graze. Even an interval of 14 days was insufficient, particularly with the heavier applications.

Under a system of rotational grazing in which a paddock is watered, allowed to dry out, grazed close, etc., the interval between watering and grazing must also be sufficiently long for the plants to recover and produce enough growth to carry the stock over the period scheduled for grazing in the rotation. This latter should be as long as possible so as to reduce the work of management. At Malakal the complete rotation took 18 days. The pasture, which consisted largely of the natural indigenous grass *Setaria incrassata*, was grazed for 2 or 3 days before watering, which took only a few hours, leaving 15 or 16 days for drying out and regrowth.

There were nine paddocks, and the cattle were moved every third or fourth day. The grazing period was really too short but it was the longest the rather poor quality pasture would allow. Better grasses might be introduced which would carry the stock for longer, but experience on this point is wanting. On the whole the indications of our experiments are that the watering should be applied every three weeks at the rate of 600 m^3.p.f. (860 m^3.p.f. per month, or 5,160 m^3.p.f. from December to May).

OTHER AGRICULTURAL CROPS UNDER IRRIGATION

During the rainless months, when the climate in the greater part of the Jonglei Area is not essentially different from the climate of the Gezira, where soil and topography are also comparable, we assume that the water requirements of similar agricultural crops will be the same. Normal irrigation in the Gezira is at the rate of from 400 to 450 m³.p.f. on the average every 14 days, or approximately 950 m³.p.f. in a calendar month. This must be considered as a fair estimate of irrigation water requirements in the dry season in the Jonglei Area.

We must now consider the requirements during the rainy season. The irrigation intensity given above corresponds roughly to 225 mm. of rainfall. Elsewhere it is stated that our experiments suggest that in the Flood Region 130 mm. of rainfall per month is enough for good yields of local crops. This can be explained by the lower evaporation and transpiration losses during the rains when cloudy weather and high humidity predominate, by the higher effectiveness of rainfall as a means of applying water, and by the different varieties of local crops which are naturally suited to the environment. Under irrigation some rain or irrigation water would inevitably be wasted because the distribution of rainfall is so variable and unpredictable, and the complementary drainage systems would be used more frequently than in the Gezira. Moreover in years of low rainfall, when irrigation will be most needed to supplement the rain, climatic factors are likely to favour higher transpiration and evaporation. The general indications are that though the water requirements during the rainy season will be less than in the Gezira, they will be considerably more than the irrigation equivalent of 130 mm. of rainfall monthly.

We have made the following assumptions:

(i) In the northern part of the Semi-Arid Region, in Kosti District, the water-duty will be the same as in the Gezira, namely 950 m³.p.f. per month less rainfall.

(ii) In the southern part of the Semi-Arid Region, from the Kosti District boundary to the 11th parallel, the water-duty will be 840 m³.p.f. per month (equivalent to 200 mm.) less rainfall.

(iii) In the Flood Region the water-duty will be 750 m³.p.f. per month (equivalent to 175 mm.) less rainfall.

(iv) In the Ironstone Region the water-duty will be 630 m³.p.f. per month (equivalent to 150 mm.) less rainfall.

These estimates are largely 'intelligent guesses' for reasons which by now will be obvious, though they probably err on the safe side. Further experimental work is essential to confirm or correct them.

On the above assumptions we have prepared a table showing the probable irrigation requirements to supplement rainfall in the Flood Region, where such remedies will be largely needed. The figures are given for Juba, Bor, Malakal, Renk, and Kosti, and correspond to years of 'median' and 'low' rainfall (see Table 288 below).

The figures for 'median' rainfall are the requirements expected in 50% of the years, whereas those for 'low' rainfall are the probable maximum requirements. The latter were arrived at by assuming the monthly distribution of rainfall to be the same as in the line of the rainfall-chance tables in which the monthly figures add up to the lowest rainfall on record (Tables 23 to 27, pp. 61–3).

These figures are the estimated requirements for a crop which has reached full vegetative development. They are much in excess of the water requirements of a young crop, especially if sown on a wide spacing and if transpiration is reduced by keeping the fields reasonably clear of weeds. In practice, provided that rainfall is not abnormally low, no irrigation will be necessary for at least a few weeks after germination.

IRRIGATION OF RICE

The water-duty for irrigation rice is well above that of other crops (2½ times as great in Egypt) and must be considered separately. The only data available in the Jonglei Area are the results of rice trials carried out at the Malakal Experimental Farm during the 1951-52 and 1952-53 seasons by the Development Officer of the Ministry of Agriculture in conjunction with the Team. The experiments are described in the annual report of the Development Officer for 1953[(3)]. From these records it appears that 3,500 m³.p.f. on land heavily watered in the previous season and 4,500 m³.p.f. on land not previously irrigated may be taken as the total water requirement of moderately quick-maturing rice (120 days). It should be noted that with one exception the varieties of rice grown at Malakal were of the upland type; it may be found that swamp varieties have heavier water-duties, and that the figure of 4,000 m³.p.f. should be substituted for 3,500 mentioned above. Also if slower-maturing varieties are grown, the total water requirements must be increased by at least 1,500 m³.p.f. for every additional 30 days maturation period.

On these assumptions, which probably err on the safe side, we have estimated the total water and supplementary irrigation requirements for varieties of different maturation period sown in the first fortnight of July in the Flood Region, Malakal being taken as the representative locality. The results are given in Table 287, where ' median ' and ' low ' rainfall have the same definitions as before, effective rainfall being that falling after July 1st.

TABLE 287

ESTIMATED TOTAL WATER AND SUPPLEMENTARY IRRIGATION REQUIREMENTS FOR RICE IN THE FLOOD REGION

Item	Unit	Crop Sown on July 1st					
		Land Previously Irrigated			Land Not Previously Irrigated		
Maturation Period	days	120	150	180	120	150	180
Total Required	m³.p.f.	4,000	5,500	7,000	5,000	6,500	8,000
Median Rainfall	mm.	537	537	537	537	537	537
Rain Water	m³.p.f.	2,250	2,250	2,250	2,250	2,250	2,250
Supplement Needed	m³.p.f.	1,750	3,250	4,750	2,750	4,250	5,750
Low Rainfall	mm.	359	359	359	359	359	359
Rain Water	m³.p.f.	1,500	1,500	1,500	1,500	1,500	1,500
Supplement Needed	m³.p.f.	2,500	4,000	5,500	3,500	5,000	6,500

TABLE 288

ESTIMATED TOTAL WATER AND SUPPLEMENTARY IRRIGATION REQUIREMENTS AT JUBA, BOR, MALAKAL, RENK, AND KOSTI

Item	Unit	Rainfall or Irrigation							Dry Month
		April	May	June	July	Aug.	Sept.	Oct.	
				Juba					
Basic Requirement ...	m³.p.f.	630	630	630	630	630	630	630	950
Median Rainfall ...	mm.	103	141	131	136	126	108	85	—
Rain Water	m³.p.f.	430	590	550	570	530	450	360	—
Supplement Needed	m³.p.f.	200	40	80	60	100	180	270	950
Low Rainfall ...	mm.	75	104	103	97	99	82	59	—
Rain Water	m³.p.f.	310	440	430	410	420	340	250	—
Supplement Needed...	m³.p.f.	320	190	200	220	210	290	380	950
				Bor					
Basic Requirement ...	m³.p.f.	750	750	750	750	750	750	750	950
Median Rainfall ...	mm.	73	119	114	137	127	118	89	—
Rain Water	m³.p.f.	310	500	480	580	530	500	370	—
Supplement Needed...	m³.p.f.	440	250	270	170	220	250	280	950
Low Rainfall ...	mm.	32	73	74	92	81	61	48	—
Rain Water	m³.p.f.	130	310	310	390	340	260	200	—
Supplement Needed...	m³.p.f.	620	440	440	360	410	490	550	950
				Malakal					
Basic Requirement ...	m³.p.f.	—	750	750	750	750	750	750	950
Median Rainfall ...	mm.	—	78	121	164	177	128	68	—
Rain Water	m³.p.f.	—	330	510	690	740	540	290	—
Supplement Needed...	m³.p.f.	—	420	240	60	10	210	460	950
Low Rainfall ...	mm.	—	40	85	119	128	72	40	—
Rain Water	m³.p.f.	—	170	360	500	540	300	170	—
Supplement Needed...	m³.p.f.	—	580	390	250	210	450	580	950
				Renk					
Basic Requirement ...	m³.p.f.	—	—	840	840	840	840	840	950
Median Rainfall ...	mm.	—	—	75	124	139	88	40	—
Rain Water	m³.p.f.	—	—	320	520	580	370	170	—
Supplement Needed...	m³.p.f.	—	—	520	320	260	470	670	950
Low Rainfall ...	mm.	—	—	44	85	106	63	22	—
Rain Water	m³.p.f.	—	—	180	360	450	260	90	—
Supplement Needed...	m³.p.f.	—	—	660	480	390	580	750	950
				Kosti					
Basic Requirement ...	m³.p.f.	—	—	950	950	950	950	950	950
Median Rainfall ...	mm.	—	—	40	101	129	50	—	—
Rain Water	m³.p.f.	—	—	170	420	540	210	—	—
Supplement Needed...	m³.p.f.	—	—	780	530	410	740	950	950
Low Rainfall ...	mm.	—	—	—	54	72	21	—	—
Rain Water	m³.p.f.	—	—	—	230	300	90	—	—
Supplement Needed...	m³.p.f.	—	—	950	720	650	860	950	950

NOTE.—Total maximum supplementary irrigation requirements in six months from May to October are:
Juba ... 1,490 m³., or 248 m³.p.f. per month.
Bor ... 2,690 m³., or 448 m³.p.f. per month.
Malakal ... 2,460 m³., or 410 m³.p.f. per month.
Renk ... 3,810 m³., or 635 m³.p.f. per month.
Kosti ... 5,080 m³., or 847 m³.p.f. per month.

DRAINAGE FACTORS

There are two aspects to the problem of drainage: the hydrological aspect which is concerned solely with estimating the run-off from a given area so that the engineer can provide sufficient capacity in the drainage system to carry the water off; and the agricultural aspect which is concerned with moisture conditions in the soil itself.

The former has been treated in the following way. We have two sets of conditions to consider in the Flood Region; drainage systems to carry off excess rainfall only, and drainage systems to deal with a combination of irrigation and rainfall. It is unfortunate that there are no practical examples of either in the Jonglei Area, and pilot schemes are required so that experience can be gained to confirm or correct our theoretical deductions. In the Flood Region the maximum monthly rainfall may be as high as 250 or 300 mm., and is normally about 200 mm. (see Tables 23 to 25, pp. 61–2). If we assume that as far as drainage is concerned 300 mm. of rainfall alone is equivalent to 200 mm. of irrigation water plus a normal maximum rainfall of 100 mm., then it seems to be reasonable to adopt criteria which apply to the Gezira, where the latter conditions are found, in the Flood Region where the former occurs.

In the Gezira an equation of the following form is commonly used to determine the run-off from a given area:

$$Q = KA^n$$

Where Q = Run-off
A = The area of the catchment
K = A constant depending on the maximum intensity of rainfall
n = An index whose value is less than unity, depending on the character of rainfall.

With values for the constants derived from practical experience in the Gezira inserted, the formula becomes:

$$Q = 0{\cdot}174 \text{ (area in feddans/1,000)}^{0{\cdot}67} \text{ cumecs.}$$

The run-off from 1,000 feddans from this formula is 0·174 cumecs, which is equivalent to 100% of 107 mm. rainfall on 1,000 feddans in a month, in addition to irrigation of 200 mm. We have adopted the following formula for the Flood Region without irrigation:

$$Q = 0{\cdot}162 \text{ (area in feddans/1,000)}^{0{\cdot}8}.$$

The differences between this and the Gezira formula are made for the following reasons: the constant K, based on the run-off from 1,000 feddans, is the equivalent of 100 mm. of rainfall, not 107 mm. as in the Gezira formula, and the index n is increased to allow for the less erratic distribution of rainfall. Estimates of the run-off from areas up to 10,000 feddans from this formula are as follows:

Area in Feddans	Run-off in Cumecs
100	0·025
200	0·043
300	0·060
400	0·077
600	0.107
800	0·136
1,000	0·162
1,500	0·230
2,000	0·290
3,000	0·400
4,000	0·500
6,000	0·700
8,000	0·880
10,000	1·040

Where drainage is combined with irrigation in the Flood Region we have adopted the values for the constant and index shown in the following:

$$A = 0{\cdot}325 \text{ (area in feddans/1,000)}^{0{\cdot}8} \text{ cumecs.}$$

In this case the constant K is equal to run-off which is 100% of 200 mm. rainfall on 1,000 feddans in a month in addition to irrigation, and the following figures have been computed from the formula (the areas given below correspond to typical areas in various parts of the 100,000 feddan irrigation and drainage scheme, which is described in detail later):

Area in Feddans	Run-off in Cumecs
130	0·065
2,200	0·610
4,400	1·020
4,700	1·120
17,500	3·200
35,000	5·800
70,000	9·700
104,000	13·300

This concludes our discussion of the hydrological aspects of drainage in the Flood Region, and the reader is referred to another section of the report (p. 601) where the agricultural aspect is discussed.

IRRIGATED PASTURES IN AUSTRALIA

In New South Wales and Victoria, Australia, some 800,000 acres are irrigated, and grow lucerne, pasture, and other green fodder crops. At first glance this fact appeared to hold considerable promise in solving the pasture problems confronting the Jonglei Investigation Team. We had hoped to be able to base our estimates of the cost of irrigating pasture on practical experience in Australia. For a variety of reasons this hope was not fulfilled, but a study of Australian methods is helpful in that it provides a standard by which to judge proposals for the Southern Sudan and clarifies the difficulties which must be overcome before irrigated pasture can be considered a practical proposition there.

CLIMATE

We should explain at the beginning the fundamental differences between Australia and the Southern Sudan which rule out the application of experience in one country to the other. For a comparison of the climates of the two countries the reader is referred to Table 290 (p. 629). The bulk of Australian irrigated pasture lies at a latitude south of the equator which is comparable with the latitude of Algiers north of it. The difference in average annual rainfall figures is more important than a direct comparison indicates for the reason that the theoretical boundary—the 640 mm. isohyet—between pastures which are on the whole palatable in the dry season and those which are not lies between the two. The grasses which grow naturally under rainfall in Australia are good fodder, whereas those of the Southern Sudan become lacking in nutriment when mature and dry. In general the difference between the two countries can be summed up in the words ' temperate ' and ' tropical ' applied to the climate of Australia in those places where pasture is irrigated and to the Southern Sudan respectively. The sources of our information are listed in Table 289 below.

In a letter (ref. 3 (a), Table 289), the Principal Research Officer of the Water Conservation and Irrigation Commission, New South Wales, noted the climatic differences and mentioned that pasture irrigation under Sudan conditions might present ' formidable problems '; in particular the main consideration was the effect of temperature in inhibiting growth (presumably of Australian pasture grasses) and he suggested that a better solution might be found in extending the useful rainy season by supplementary irrigation rather than by irrigating in the hot season. From several different sources we have heard that extensive pasture irrigation is only practised in the southern part of the continent under temperate conditions and only for specific purposes such as feeding dairy cows and raising quick-maturing lambs for meat. It is not an economic proposition otherwise.

IRRIGATION METHODS (See Fig. G 22)

Three methods of irrigating are commonly employed in Australia, namely (i) Border Check, (ii) Border Ditch, and (iii) Contour. The first two methods are similar, except that in the second the check banks are replaced by drainage-channels. These two methods require fair slopes because the feeder channels run almost parallel to the contours and the flow over the borders follows the major slope. The contour method is used for heavy soils and gentle slopes. The feeder channel runs down the major slope and is opened on to the bays formed by contour banks. It would appear that this is a most suitable layout for the Southern Sudan. It is regarded as the cheapest to construct and to operate because large areas (up to 60 acres) can be handled with the minimum of supervision. The topmost bays are watered first, and then drained on to lower bays by openings in the contour banks at the same time as water from the feeder channel is switched from the higher to the lower bays.

PASTURE TYPES AND WATER-DUTIES

The following five types form the main pastures in Australia: (a) perennial rye-grass and white clover; (b) *Paspalum dilatatum* and white clover; (c) Wimmera rye-grass and subterranean clover; (d) *Phalaris tuberosa* and subterranean clover; (e) lucerne. Without exception these grasses are grown for dairy cows or for raising lambs, and their use in the Sudan does not appear suitable for either climatic or pedologic reasons, or both. The statutory irrigation season for irrigation areas (Crownlands) and districts (private landowners) is from September 15th, the spring, to April 15th, the autumn, though in practice the season is extended earlier and later to suit the weather. Irrigation is normally practised for seven months and is supplementary to rainfall. In Table 291 below we have listed, for ease of comparison, the water-duties and carrying capacities of the five main Australian pastures; (a) and (b) have similar treatments and carrying capacities; (c) and (d) are of special interest because they are not irrigated in the summer but only in addition to winter rains. Their carrying capacity per cubic metre is the lowest of the three divisions, the third being (e) lucerne. The figures do show that even in the temperate Australian climate at least 3,150 m³.p.f. (750 mm.) are required to irrigate one acre of pasture supporting one Animal Unit for seven months. Higher temperatures and evaporation in the Southern Sudan would at least offset the shorter length of the dry season, and the figure might indicate the order of requirements of water. Other factors such as the total annual rainfall must also be taken into account.

It is worth adding that in September 1951 Mr. M. N. Harrison, Pasture Research Officer, reported that Mr. Miles (ref. 5, Table 289) was interested in collecting suitable species of tropical pastures as the Australians were beginning to investigate them, and for that purpose he came to Malakal to see the experimental pump scheme.

TABLE 289

IRRIGATED PASTURES IN AUSTRALIA
SOURCES OF INFORMATION

1. *Irrigation in Australia* by J. C. Ridell. Notes on a paper issued by the P.W.D., New Zealand, compiled and submitted by H. A. W. Morrice.
2. *Water is Life in Dry Australia* by Edgar Bee. A summary of irrigation in Australia issued by the Australian Government Representatives in London.
3. Letters, in reply to a questionnaire, from:
   (*a*) Water Conservation and Irrigation Commission, Sydney, New South Wales.
   (*b*) State Rivers and Water Supply Commission, Melbourne, Victoria.
4. *Irrigated Pasture in Victoria* by A. Morgan.
5. Report on interview with J. F. Miles, Senior Plant Introduction Officer, Department of Plant Industry, Council for Scientific and Industrial Research, Brisbane, Queensland.
6. *University Atlas*, Philip and Darby.

TABLE 290

COMPARISON OF CLIMATES, ETC.
AUSTRALIAN PASTURE DISTRICTS AND THE SOUTHERN SUDAN

Item	Unit	Australian P.D.	Southern Sudan
Latitude North or South of the Equator	Degree	35°	5° to 10°
Average Annual Rainfall	mm.	240 to 500	800 to 900
Rainy Season	Months	12	6
Average Temperature January...	° Fahr.	72 to 80	80 to 88
July		48 to 56	72 to 88
Maximum Temperature January	° Fahr.	90°	100°
July		40°	70°
Mean Annual Cloudiness	%	40	40
Classification of Climate		Warm Temperate	Tropical Rain
Vegetation		Temperate Grassland	Tropical Grassland

TABLE 291

IRRIGATED PASTURES IN AUSTRALIA

Type of Pasture	Waterings			Carrying Capacity per Acre
	No.	Total m³.p.f.	Interval	
(*a*) Perennial Rye-grass and White Clover	8–10	3,150	1 month Spring 1 month Autumn 14 days Summer	1 milking cow
(*b*) *Paspalum Dilatatum* and White Clover	8–10	3,150	1 month Spring 1 month Autumn 14 days Summer	1 milking cow or 8–10 ewes
(*c*) Wimmera Rye-grass and Subterranean Clover	1–2	1,050	In Autumn (March) supplements Winter rain	4 ewes
	1 or 2	840	In Spring (Aug.–Sept.) supplements Winter rain	
	Total	1,890	Not watered in Summer	
(*d*) *Phalaris tuberosa* and Subterranean Clover	1–2	1,050	In Autumn (March) supplements Winter rain	4 ewes
	1 or 2	840	In Spring (Aug.–Sept.) supplements Winter rain	
	1	420	Occasionally in Summer	
	Total	1890 to 2310		
(*e*) Lucerne (cut for hay)	6–7	4,200	6 weeks Spring 6 weeks Autumn 3 weeks Summer Less frequently when grazed	12 ewes

IRRIGATED PASTURES IN AMERICA

Though not comprehensive, some information about irrigated pasture in America has been gleaned from one or two sources[4]. One interesting fact mentioned by the lay writer is the coincidence in America of (a) the cattle line, (b) the short grass line, (c) the 500 mm. (20 in.) isohyet, and (*d*) the 98th meridian. The plains west of the 98th meridian stretching from Texas to Montana on the Canadian frontier are 'cattle country'. The similarity to the 'sweet veldt' region in the Sudan (and South Africa) is notable. East of the 98th meridian the average annual rainfall varies from 500 to 1,000 mm. and is spread evenly throughout the year—there are no rainless months—and the climate is temperate. Here the main products are wheat, maize, and Kentucky Blue grass and clovers.

The definition of the animal unit in America is the amount of pasture consumed by a 1,000 lb. breeding cow or its equivalent for a grazing season. The length of the season is not clear, but from inferences it appears to be about 155 days (5 months). The value of irrigating pasture and introducing legumes is illustrated in Table 294 below.

METHOD OF IRRIGATING

When the slopes are less than 3% (1/33) the border method of irrigating is advocated. The strips are often ridged in the direction of the major slope; they are of small area, from $\frac{1}{20}$ to $\frac{1}{2}$ an acre, and the intention is to apply 5 cm. (210 m^3.p.f.) every 7 to 15 days. The resistance of the grass often necessitates a heavier application of water (7·5 cm. or 315 m^3.p.f.). See Tables 292 and 293 below.

PASTURE MANAGEMENT

A suitable schedule for irrigation, regrowth, and grazing is worked out to suit the soil and the type of grass. Table 295 gives figures of typical schedules followed in America and, in a footnote, similar details for the rotational grazing scheme experiment on the Malakal Pump Scheme. In the latter case 420 m^3.p.f. of irrigation water was applied at intervals of 18 days. The experiment was designed to give information about the stock-carrying capacity of indigenous grasses, and there is nothing to indicate whether the schedule chosen from practical considerations was the best. Other experiments are intended to show this later. Intensive grazing for a short period ensures uniformity of cropping and regrowth, and if properly timed the grass can be grazed when in its most nutritive stage. The importance of choosing the best type of grass to suit irrigation, the climate, and the soil is also stressed.

OTHER IRRIGATION METHODS

Generally speaking three methods are in use in America, which go by the names Border (or Flood), Corrugation (or Furrow), and Ridge (or Bed) methods. The first two are used for alfalfa grass, clover, and pasture, and where major slopes are greater than 1/2,500. The third, or Ridge, method is invariably used in almost flat country. The Border method has been described on p. 628. The Ridge method is the one we are familiar with in the Gezira, and is therefore a suitable method for the Jonglei Area where the slopes are similar or less. The Corrugation method is used on steeper slopes, the direction of the corrugations (or small furrows) being chosen to prevent erosion and to distribute the supply evenly. The importance of even distribution to avoid over-irrigation which is harmful to the soil is emphasized, and leads to the use of balancer channels and spiles, or wooden pipes of rectangular section, to control the flow from the balancer channel in between the ridges. Some figures on water-duties have been extracted and tabulated in Table 296.

TABLE 292

BORDER STRIP DIMENSIONS FOR IRRIGATED PASTURES

in metres

Type of Soil	Border Width	Strip Length	Ridges: Spacing	Ridges: Length
Sandy	4 to 6	60 to 90	0·45	60
Medium loam	6 to 9	90 to 120	0·60 to 0·75	90
Clay	9 to 12	120 to 200	0·45 to 0·60	135

TABLE 293

MOISTURE AVAILABLE TO ROOTS AFTER IRRIGATION

Type of Soil	Watering Frequency days	Water available to roots (*) cm.
Loamy sand	5–12	2·0
Sandy loam	7–14	2·5
Silt loam	12–18	3·3
Clay loam	7–14	2·8
Clay	7–14	2·3

(*) After application of from 5 to 7·5 cm.

TABLE 294

CARRYING CAPACITY OF IRRIGATED PASTURES

Type of Grass	Value in Animal Units per acre	Value in Animal Units days per acre per year
Kentucky Blue	0·98	152
Irrigated Grass-Legume	1·60	248
Irrigated Ladino Clover...	2·10	328

TABLE 295

ROTATIONAL GRAZING SCHEDULES

in days

No. of Pasture Units	Rotation Cycle	Periods of		Irrigation Interval (*)
		Regrowth	Grazing	
3	18	12	6	9
	21	14	7	10
	24	16	8	11
	27	18	9	12
	30	20	10	13
4	16	12	4	7
	20	15	5	8
	24	18	6	9
	28	21	7	10
5	15	12	3	5

(*) i.e. the least time between one irrigation and the next.

Note: On the Malakal Pump Scheme there were 9 Pasture Units. Rotation Cycle 18 days, Regrowth 16 days, Grazing 2 days, Irrigation Interval 18 days. (Irrigation took from 4 to 5 hours only.)

TABLE 296

CROP WATER-DUTY

Water Applied m^3.p.f.	Type of Crop	Tonnage of Produce per feddan
1,440	Potatoes	6·60
1,495	Oats	1·26
2,560	Sugar Beet	15·00
2,780	Alfalfa Grass	5·00

SOME SMALL IRRIGATION SCHEMES IN UGANDA

During our investigation one engineer was able to visit some small irrigation schemes built for ' famine insurance ' in the Karamoja district of Uganda, where the climate is somewhat similar to that east of the south-eastern mountains, and where there are some torrents with flashy run-offs resembling some of the streams which drain these mountains.

Three types of irrigation were seen:

(i) Schemes in which water, from torrents whose flow consists of intermittent spates, is diverted into small basins.

(ii) The construction of banks in the bed of a very wide, sandy river to collect silt on which crops are grown when the river subsides.

(iii) Schemes based on perennial streams.

BASIN IRRIGATION FROM TORRENTS' SPATES

The idea of utilizing spates from torrents in basin irrigation was introduced in Uganda by an official who had served in Aden. Rainfall in Aden is about 50 mm. per year, and the Arabs of the Yemen are adept at making use of such flash-flows as occur in the Hadramut. Though the rainfall in the Karamoja district is between 800 and 900 mm. and the slopes steeper, the same Yemenis were brought from Aden to demonstrate their methods of building contour banks with scraper boards drawn by bulls. After preliminary successes the ground was surveyed and banks laid out more economically on contours.

Nadunget

One such scheme was seen at Nadunget. Here the parent stream is a sandy-bedded khor 15 m. wide and 1½ m. deep which drains the western slopes of Mount Moroto. The canal offtake is sited on the outside of a sharp bend. An earthen bund, its nose heavily armoured with brushwood and further protected by brushwood spurs, is built across the bend, and the water from a spate flows behind this bund and enters the feeder canal. As the formation of the ground outside the channel is deltaic, the slope is away from the river. The canal follows the course of an old river channel diagonally across the ground-slope, falling at the rate of about 1/2,000, and leads to a series of basins originally constructed by the Yemenis in areas of one feddan but now rebuilt along contours at 50 cm. intervals, averaging 3 feddans each. The banks are built by scraper boards drawn by bulls.

Watering procedure is somewhat haphazard as there is practically no warning of the arrival of a spate. So as to make use of the small spates which are the first to arrive, a small earth bank is built across the gap between the end of the bund and the river bank opposite. This bank is topped and washed away by higher spates. Further regulation within the scheme is achieved by simple wooden structures, brushwood, and mud. The total area of this remote scheme is 15 feddans, and the crops grown are dura, simsim, *dura shami* and *ads sudani*.

Ngiminto

The Ngiminto River, draining the western slopes of a mountain called Lokatmio, is 15 m. wide and 3 m. deep and is trained to irrigate some 20 feddans in the same way as at Nadunget, with the addition of cotton to the crops grown. The main difference is that the river bed is well below ground level at the head, and it has been necessary to construct a weir across the bed to raise the water-level for command. The weir is made of stakes driven into the bed, interwoven with brushwood and filled in with earth.

Subsidiary offtakes farther down the stream make use of nearly all the flow, and the channel issues from beyond the scheme 7 m. wide and 1 m. deep. Heavy silt deposits have raised the river at the downstream end. It has been found best to flood the basins as deeply as possible, retain the water for a week or 10 days, and then drain it off.

Crop Yields

Yields on these two schemes in the first year are given in tabulated form below, where they are compared with average yields for the same crops grown on rain in Karamoja in 1950 and in Uganda as a whole on rainfall alone.

YIELDS OF IRRIGATED AND RAIN-GROWN CROPS IN UGANDA
in lb. per feddan

	Irrigated		Rain-grown Karamoja 1950	Rain-grown Average yield in Uganda
	1949	1950		
Dura	2,008	964	282	1,500
Dura shami	1,075	1,055	Total failure	1,600
Groundnuts (shelled)	927	1,861	184	420
Pigeon peas	—	360	—	—

SILT BANKS IN RIVER BEDS

Lotome Scheme

Basically the principle applied here was to aggravate slack flow on the inside of a bend of a wide, sandy river by constructing brushwood spurs. A small opening was left on the land side of the spurs which it was hoped would form a small canal for watering crops later. The scheme depends for its success on the quantity of silt in suspension in these flashy torrents, and is subject to the hazards of torrential streams on which erosion and changes of course are frequent occurrences. The river at Lotome is very similar to the River Singaita north of Kapoeta.

PERENNIAL STREAMS

NAMALU SCHEME

South of Ngiminto the Kamajoko, a small stream, drains Mt. Debasien where rainfall is in the region of 1,270 mm. annually. Since the stream forms a swamp upstream of Namalu, a small but steady flow results which is perennial. A simple irrigation scheme is laid out, the water from it feeding an area of 20 acres, and a large variety of crops, such as sugar-cane, bananas, sweet potatoes, rice, cassava, and maize, is grown. Irrigation is used only to supplement rainfall. Another similar scheme was seen at Agoro on the southern side of the Imatong Mountains, run entirely by the local people off the Aringa, a perennial tributary of the Pager.

The costs of these small schemes worked out at between £E30 and £E40 per feddan, but with experience costs are being lowered.

3. COMMUNICATIONS

NAVIGATION

The effects of the Equatorial Nile Project on communications have been discussed in detail in a previous chapter (Chap. 5, p. 534). There we were first concerned with navigation in the Bahr el Jebel between Juba and the Atem barrage. The designers of the Project were aware of the need to maintain navigation in this reach and arranged that the discharge in the untimely season would not fall below 57 m/d. Our investigations indicate that the natural process of silting and scouring will not be radically altered by future control of the river. Navigational difficulties are due to the formation of sandbanks, and it appears from the information available that any slight adverse effects the Project may have will be more than compensated for by the improvements derived from artificial control of the flow in the river. As long as the discharge at Mongalla is regulated to between 57 m/d and 90 m/d no other remedies are called for.

In the Jonglei Canal, on the other hand, we have shown that with the discharges proposed for the untimely season there cannot possibly be sufficient depth of water for navigation. The remedy here is to re-design the Project so that there is normally 3·5 to 4 m. depth of water in one of the canals. After correspondence with the General Manager of the Sudan Railways, it was agreed that a depth of 2·5 m. could be accepted for a limited period of about two months if thereby substantial quantities of irrigation water could be saved (of the order of half a milliard or more). We must also draw attention to the fact that it is a disadvantage to have the canals interconnected. With a bed width of 76 m. and 4 m. depth of water when full, each canal will be 92 m. wide on the surface; the maximum width of a steamer with a tow is 24 m., so that there will be plenty of room for steamers to pass and only one canal need be used for navigation. The flow in the other canal during the untimely season can then be cut down to the minimum necessary to prevent weed growth, but if the canals were to be interconnected this could not be done. In the Bahr el Jebel in the Central Zone there is no reason to believe that navigation will be adversely affected, nor that the effectiveness of Shambe as a port for Bahr el Ghazal Province will be less than it is now. It is very desirable to know when the Project will be constructed and whether the barrage across the Bahr el Jebel will be at the Atem Head or at Jonglei. In the event of the Shambe lagoon becoming unnavigable, which seems doubtful, it would be necessary either to dredge a channel for steamers to reach the existing quays or to build a road to the edge of the Bahr el Jebel and rebuild the port there. In the Northern Zone, as we have pointed out, higher minimum levels in the timely season will result in an all-round improvement in navigation, especially where difficulties occur today.

Summarizing the remedies required for effects on navigation we may say:

(i) Provided the flow of the river at Mongalla is normally regulated between 57 m/d and 90 m/d, no other measures will be needed to maintain navigation between Juba and the Atem barrage.

(ii) The Project must be re-designed so that at least one canal is suitable for navigation. The requirements are normally a water depth of from 3·5 to 4 m. and a surface width of not less than about 75 m. For limited periods of about two months a water depth of 2·5 m. may be accepted, provided that it can be shown that water will thereby be saved for irrigation. (It will be seen later that a separate canal of small capacity (5 m/d) will be required for gravity irrigation schemes on the plains west of the Canal.)

(iii) Because through communications from Khartoum to Bahr el Ghazal Province by way of the Jonglei Canal will be quicker than via the Bahr el Jebel and Shambe, it is highly desirable to know when the Equatorial Nile Project will reach the 55 m/d Canal stage and whether the barrage across the Bahr el Jebel will be at Jonglei or at the Atem Head regulator site.

(iv) It may be necessary to dredge a channel for steamers from the Bahr el Jebel to the existing quays at the edge of Shambe Lagoon.

(v) The Project includes provision of locks on all control regulators which is satisfactory for through navigation.

ROADS

The Jonglei Canal will cut a number of road communications in Central Nuer and Bor Districts. Considerable numbers of cattle and other animals cross the line of the Canal in their annual migrations between dry and wet season grazing grounds. As designed there will be crossings at the control regulators only, that is to say at the head of the *Sudd* Diversion Channel, at the Atem barrage, and at the Jonglei Canal Head and Tail. The distance between the first two is some 50 or 60 km., so that it will not be necessary to have intermediate crossing-points. The Jonglei Canal is 280 km. long, and crossing-points will be needed between its head and tail regulators (see also p. 487 et seq). No useful purpose would be served by relating the number and distribution of crossing-points to present concentrations of cattle when migrating, because the location of artificial remedies will alter any such distribution. We propose that on the average there should be crossing-points at 40 km. intervals, i.e. six crossing-points between the control regulators 280 km. apart. The best form of crossing from the veterinary aspect is discussed elsewhere (see p. 477). From the engineering point of view, assuming that there will be one canal for irrigation, one for navigation, and one other to carry the remainder of the required flow, the best form of crossings would be as follows. The most suitable form of crossings for each of the two largest canals would be cable-ferries capable of carrying 50 head of cattle. For two canals, two ferries would be needed at each crossing-point. The irrigation canal would be of small capacity, say 5 m/d, and if the siting of irrigation scheme head regulators did not coincide conveniently with the siting of crossing-points then additional masonry bridges would have to be provided.

The only other way in which road communications will be affected will be indirectly to suit the changes in river transport. For this reason in particular it would therefore be better to have the port for Bahr el Ghazal Province at the Canal Head at Jonglei with a barrage across the Bahr el Jebel there. Consequently a new road from Yirol will have to be built, but it cannot be said that communications via Shambe will be adversely affected and no compensation could be claimed for the construction of a new road, even though Shambe may fall into disuse as a result. Summarizing we may say that the only important remedy necessary is the provision of 12 cable-ferries for crossing the two major canals at 6 points, and bridges for crossing the irrigation canal.

NOTES AND REFERENCES

(1) See cross-sections of Khors Adar, Wol, Fullus, Atar, Nyin Yar, Neang, etc. (Figs. K 25-26, D 57, D 29, D 31, D 54). Khor Adar was extensively surveyed, but it is an exceptionally large watercourse with a wide flood-plain and not typical of the many small channels to which the remedy of banking and draining could be applied.

(2) Other sections taken by Sir Alexander Gibb and Partners for their survey of irrigable areas between Malakal and Kosti modify this generalization considerably, but even so, more suitable areas are available than will be needed for remedies.

(3) Moir, T. R. G., ' Water requirements of a rice crop under pump irrigation ', Malakal Agricultural Station Report 1952-53, Ministry of Agriculture, Khartoum, 1953, unpublished.

(4) United States Department of Agriculture, *Farmers Bulletin No. 1973*.
Gunther, J., *Inside U.S.A.*, Hamish Hamilton Ltd., 1947.

CHAPTER 9. SOME SELECTED REMEDIES

INTRODUCTION

In introducing this chapter of our report there are certain observations, already made, which must be stressed again. First we must emphasize once more that our proposals are designed primarily to enable us to estimate the ' order of the costs in money and water of remedial measures '. We call them ' Selected Remedies ', but none could be applied in the Jonglei Area without further research, trial, and then pilot schemes. Secondly, there are many very obvious difficulties which would have to be faced before such remedies could be introduced. Not the least of these would be the natural reluctance of the people concerned to turn to an altogether new and unfamiliar way of life. Training, education, and guidance would be a major, and probably costly, feature of the application of these remedies, and the period of reorientation could only be measured in decades. Thirdly, it should be noted that some of the suggested remedies may be applicable throughout the Jonglei Area, others only to specific localities; this causes many difficulties of presentation. For convenience the remedies have been numbered (I–XXIII); of these, only the first ten are recommended for application. The remainder, which have been considered in such detail as time has permitted, are only suggestions which require further study.

The first section deals with purely pastoral remedies, the second with agricultural alternatives, though the latter, as already explained, are designed primarily to accommodate animal stock displaced from dry season riverain grazing as the result of the Project; we have pointed out the difficulties of a reasonable conversion factor (see p. 612). We then turn, in the third section, to combined remedies, i.e. remedies in which pasture, fodder, and food crops are produced on the one scheme. In the fourth section we consider fisheries remedies designed to meet both difficulties of catching fish (mainly in the Northern Zone) and actual losses in fish (mainly in the Southern and Central Zones). In the fifth section we describe very briefly other forms of remedy which we believe would warrant further investigation and trial. In the sixth section a note on domestic water supplies, required in connection with several forms of remedy, is given. Finally we record certain special stipulations concerning the operation of the project.

As an appendix to this chapter we include a summary of unit costs—capital, maintenance and running—of these remedial measures. The details upon which these estimates are based have been recorded, but are not reproduced in this report; they have been submitted to the Sudan Government, but there are reasons for their exclusion here. For one thing the value of money, the cost of machinery and materials, are bound to fluctuate with the passage of time. For another there are some, though not all, estimates which are based on scanty data; figures taken from other parts of the Sudan or the world may well not be applicable in the Jonglei Area.

In Chapter 10 which follows we consider the most suitable remedies, on practical and economic grounds, and their application to the various parts of the Jonglei Area. From this our final forecast of the costs of remedial measures in money and water has been drawn up.

LIST OF SELECTED REMEDIES

1. PASTURE REMEDIES

Remedy No.

I. IMPROVED INTERMEDIATE LAND PASTURE
   CONSERVATION OF RAINFALL BY CONTOUR BANKING

II. IMPROVED KHOR-BED PASTURE
   KHOR ADAR

III. FULLER UTILIZATION OF INLAND PASTURE
   A. BY PROVISION OF WATER SUPPLIES
      (i) Baggara West Bank
      (ii) Machar Marshes
   B. BY BUSH CLEARANCE AND PROVISION OF WATER SUPPLIES

IV. GRAVITY IRRIGATED PASTURE SCHEMES

2. AGRICULTURAL ALTERNATIVES

V. IRRIGATED CROP PRODUCTION SCHEMES (COTTON-SORGHUM-LEGUME SCHEMES)
   A. GRAVITY IRRIGATION SCHEMES
      Irrigation from the Jonglei Canal
   B. PUMP IRRIGATION SCHEMES
      (i) Semi-Arid Region
      (ii) Southern Zone and Remainder of Northern Zone

VI. DRAINAGE SCHEMES
   A. FANYIKANG
   B. EASTERN PLAIN

VII. *HARIQ* SCHEMES

3. COMBINED REMEDIES

VIII. RICE AND PASTURE GRAVITY IRRIGATION SCHEMES

4. FISHERIES REMEDIES

IX. THE DEVELOPMENT OF COMMERCIAL FISHERIES

X. FISH FARMING

5. OTHER POSSIBLE REMEDIES AND ALTERNATIVES

XI. UTILIZATION OF INLAND WATERCOURSES

XII. IMPROVEMENT OF PASTURE MANAGEMENT

XIII. CONSERVATION OF FODDER

XIV. IMPROVEMENT OF NATURAL PASTURE BY DRAINAGE

XV. EXTENSION AND INTRODUCTION OF SUPERIOR GRASSES AND LEGUMES

XVI. IMPROVEMENT OF LIVESTOCK

XVII. INCREASE OF OUTPUT ON PEASANT HOLDINGS BY THE INTRODUCTION OF ANIMAL-DRAWN IMPLEMENTS

XVIII. MECHANIZED CROP PRODUCTION SCHEMES

XIX. FODDER PRODUCTION SCHEMES

XX. *TOICH* BANKING SCHEMES

XXI. OTHER TYPES OF DRAINAGE SCHEMES

XXII. OTHER TYPES OF IRRIGATION SCHEMES

XXIII. SUGAR SCHEMES

1. PASTURE REMEDIES

I. IMPROVED INTERMEDIATE LAND PASTURE

CONSERVATION OF RAINFALL BY CONTOUR BANKING

The principle underlying the production of dry season pasture by encouraging the regrowth of perennial grasses after the coarse rains season growth has been burnt has already been described (see pp. 554–5) and further details are given later (see Vol. III, p. 1021).

The application of this principle to a scheme for the production of reliable dry season pasture on intermediate land seems to us promising, particularly on the Eastern and Western Plains. Available information indicates that intermediate land with less than 20 cm. depth of flooding does not produce the best regrowth, and that the optimum degree of flooding is between 20 and 40 cm. depth. Since this alternative pasture would not be required until the beginning of January, the objective should be to retain rain-water on the land until the end of November. Water retained in this manner could be released in stages according to the requirements of the pasture. The procedure would be to burn off the coarse grass as soon as it was dry, and an interval of three weeks would be left to allow sufficient regrowth before livestock were put on to graze.

We expect that 8 feddans of this type of pasture would carry one Animal Unit throughout the dry season from January to May. In addition to fresh, green regrowth, the stock would require a certain amount of roughage, and we consider that one feddan of roughage per Animal Unit should be sufficient. It is not necessary to house cattle during the dry season, therefore only sufficient land for an open cattle-camp would be required. A sub-unit to carry 625 Animal Units would be a convenient size; this number of animals would require an area of 5,000 feddans of fresh regrowth plus 625 feddans of roughage plus 10 feddans for the camp area, making a total of 5,635 feddans. This is approximately 24 sq. km., which is therefore taken as the area of a sub-unit of such a scheme. A unit consisting of 16 sub-units would accommodate 10,000 Animal Units.

Engineering and Hydrological Considerations

The outstanding characteristic of the Eastern Plain east of the Jonglei Canal is the phenomenon of 'creeping flow', or overland flooding. All investigations have shown that this is largely due to local rainfall falling on an area of impermeable soil, to the absence of defined watercourses, to the small slope, and to the heavy growth of grass which impedes the movement of water. In years of abnormally heavy rainfall it is possible that rain-floods are supplemented by run-off from the south-eastern mountains.

The object of a contour banking scheme would be to conserve the rain where it fell, so that the ground would still be covered with water at the end of the wet season. Such a remedial measure would still depend for its effectiveness on the intensity of local rainfall. From the table of statistics (Vol. I, Tables 11 and 12) it will be seen that the average annual rainfall at Bor and Pibor is about 900 mm., with a standard deviation of about 200 mm. Though the distribution is slightly skew for individual rain-gauge stations, it has been shown that the distribution of the average intensity of rainfall over a large catchment is normal or Gaussian[1].

When the distribution is normal, 95% of the cases lie within a range of twice the standard deviation above and below the mean. As a rough guide it is therefore safe to assume that in 95% of the years the rainfall on the Eastern Plain will not be below 500 mm. From the table of estimated percentage points of monthly rainfall, an annual rainfall of 500 mm. corresponds to the 25% lower point for monthly rainfall at Bor (Table 24, p. 61). This gives some indication of the minimum rainfall by months which may be expected in 95% of the years.

Description of Scheme

A suitable sub-unit in the area would be 24 sq. km.; 4 km. between contour banks, and 6 km. between side banks. With an average slope of 10 cm/km. the water would have to be 0·4 m. deep—the depth of water required to produce robust regrowth—at the bottom bank in order to flood the whole surface. The bank would be 1·0 m. high with 2 m. top-width; this would be strong enough to retain that depth of water. Masonry spillways would be incorporated in each bank so that the water from a storm of 200 mm. intensity would be discharged into the next unit in a fortnight. It is reasonable to assume that such a storm would never be general over a wide area but concentrated over a part of it. The water discharged over the spillways would eventually be absorbed by ponding in other units outside the area of concentration of rain. A field outlet pipe with a valve would be built into each spillway so as to drain the remaining standing water when required.

Engineering Works

The quantities required for 16 such sub-units would be as follows:

Earthwork

Contour Banks	16 No. @ 24,000 m^3. =	384,000 m^3.
Side Banks	20 No. @ 11,500 m^3. =	322,000 m^3.
	Total ...	706,000 m^3.

Structures

Spillways: Excavation	192 No. @ 30 m^3. =	5,760 m^3.
Masonry	192 No. @ 12 m^3. =	2,304 m^3.

Field Outlet Pipes 192 No.

Domestic water could be supplied either by hafirs (surface storage) or by deep-bore wells. Hafirs would fill easily and would be the obvious choice, though there might perhaps be objections on grounds of public health. Otherwise, provided animal stock were watered at troughs outside them, hafirs would have the advantage of requiring little maintenance, and there would be no risk of mechanical break-downs. In this area one hafir of 9,500 m^3. capacity would provide water for about 600 head of cattle for five months. Therefore one hafir would be required for every sub-unit of 24 sq. km. The alternative (deep-bore wells) produces clean water and the supply is usually assured, though not without considerable maintenance and skilled supervision. One twin-bore water-yard would supply water for 2,500 Animal Units to be accommodated on four sub-units of 24 sq. km. The pumping plant for this type of supply would be lying idle for seven or eight months of the year in an area of high humidity, and its running costs would be high for the rest of the year. For this reason we recommend the use of hafirs, but it would perhaps be prudent to provide one water-yard for each unit of 16 sub-units.

Grazing Management

From our present knowledge of the production of dry season regrowth it seems that the burning of units or parts of units in rotation during the dry season is unlikely to increase the quantity of regrowth. This is because the amount of regrowth produced after burning appears to be directly related to the moisture content of the soil, so that the sooner the grass is burnt after surface water disappears the better. The only other requirement here, additional to those already specified, would be that part of the grazing paddock of 24 sq. km. should be protected from fire, so that some unburnt grass would remain to provide the necessary roughage. This is an essential operation, and would simply be a matter of cutting fire-lines before burning begins. The obvious part to set aside for roughage would be a strip along the southern end of each sub-unit, i.e. that part which would be subject to least flooding and therefore expected to produce least regrowth. A strip 450 m. wide across the 6 km. length of each paddock or sub-unit would furnish about 1 feddan of roughage per Animal Unit.

Fencing

It would be desirable to establish permanent hedges, but this might not be practicable. For this reason we recommend the use of local timber for fencing posts and the erection of 3-strand barbed wire fences, which should be sufficient for the control of grazing. The initial capital costs of this form of fencing would be relatively small, but it is worth noting here that, owing to the poor quality of local timber, fencing posts would have to be renewed frequently and maintenance costs would therefore be high. Experience has shown (Malakal, Pengko) that such a fence will not keep out wild animals which are attracted by the green pastures in the dry season. The smaller animals (tiang, kob, Mongalla gazelle, etc.) could be controlled by a more formidable fence at a greater cost, but even this would be useless against herds of elephant, giraffe, buffalo, etc. The exclusion of game from the improved pastures would undoubtedly be a problem at the beginning of any pasture scheme in this area. The presence of the people and their cattle would help to keep game off, but it might be necessary to take the usual steps to control it as well.

PERSONNEL

As the grassland would be managed according to local practice, no permanent supervision by senior staff should be necessary. Veterinary and grassland supervision could be combined and one head stockman and four stockmen should be sufficient for the control of one unit of 384 sq. km. Houses and dispensaries would certainly be needed, but only in the dry season, so that mud and thatch buildings should be adequate. In addition to houses for the staff, rest-houses would be needed for visiting officials from the Administrative, Public Health, Veterinary or other services, on the scale of one rest-house per unit of 384 sq. km.

II. IMPROVED KHOR-BED PASTURES

KHOR ADAR

A scheme to improve the pastures in the bed of the Khor Adar is one particular example of the 'utilization of inland watercourses' which we describe later (pp. 669–71). We give this example here because a detailed survey of the Khor Adar channel and flood-plain was carried out by the Team in the course of its investigation of the Machar Marshes, and, as will also be seen later, this example could be applied as a remedy for the small losses in grazing in the Dunjol and Paloich Dinka area. The principle involved in the remedy is to dam the watercourse with an earth bank extending across the flood-plain so that, by suitable regulation, water could be ponded during the rainy season to a level at which the flood-plain would become inundated. The water would then be released in the dry season and as the plain dried up the grasses would become accessible for grazing. The grasses would have to be either burnt off so that the subsequent regrowth could be grazed, or grazed directly, depending on the type of pasture produced. The only works necessary would be engineering ones; the construction of the dam and regulator, and housing for the staff necessary to control the extent of flooding. No elaborate pasture management would be involved.

The Khor Adar is a particularly suitable site for this type of remedy because alongside the deep-water channel, 70 m. in width, is a flood-plain about one kilometre wide. It appears that this flood-plain is not covered except in exceptional circumstances, such as occurred after the record high Sobat flood of 1946 when both sides of the khor were flooded for several kilometres. The present grasses are largely of the intermediate type, and therefore considerable improvement could be expected from a scheme designed to increase the period and depth of flooding.

Some hydrological details of the Khor Adar are given in the special investigation concerning the Machar Marshes (pp. 975–8). In Fig. G 3 the design of an earth dam has been applied to Cross-Section No. 5, and its effects measured also on Cross-Section No. 6 (Fig. K 26). The slope of the khor is about 4·5 cm./km., so that the effect of damming to a depth of one metre would extend 22 km. up the channel. The earth bank should be designed to hold a water-level of R.L. 383·80, with dimensions as follows: minimum top width 4 m.; side slopes 3:1 and 2:1 on the upstream and downstream sides respectively; hydraulic gradient 7:1; bank cover above water-level 0·80 m. The total volume of earthwork is calculated to be 13,500 m^3., of which 8,500 m^3. would be required for the dam on the flood-plain and 5,000 m^3. for blocking the deep channel. We know that a discharge of 36 m^3/sec. has been measured at the mouth of the khor, and according to our calculations its maximum capacity as a carrying channel may be about 60 m^3/sec. Such high discharges will occur only rarely and it would not be economic to build a permanent spillway to pass them. We propose that the capacity of the control regulator should be 15 m^3/sec., and any flow in excess of that should be escaped from the channel over a grassed spillway on the left bank of the khor extending for a distance of 150 m. upstream of the dam. The earth obtained from excavating this spillway in the alluvial bank would be used in the dam itself. It would not be necessary to position the regulator in the deep channel, and it would be economical to build it on the flood-plain as shown on the diagram. Some excavation would be necessary to form a channel from the natural one to the regulator, and again the earth excavated would be used in the dam. The type of control proposed is of simple design. Four regulators of 2·5 m. × 2·0 m. would be necessary, and the flow would be regulated by inserting rolled steel joists in vertical grooves in the structure. The most suitable foundation would be of mass concrete with brick piers and abutments. A roadway across the top of the regulator would be provided by decking made of joists and jack-arches of concrete. Dry rubble pitching would be used to protect the approaches and exits. It would also be necessary to provide housing for the water control staff.

It is estimated that an area of at least 10 sq. km., or 2,380 feddans, would be flooded to an average depth of 0·25 m., varying from zero to approximately 1·0 m.

III. FULLER UTILIZATION OF INLAND PASTURE

A. BY PROVISION OF WATER SUPPLIES

(i) Baggara West Bank

We have described previously an area of 2,000 sq. km. west of the Nile between the latitudes of Gelhak and Renk, part of which, approximately 450 sq. km., carries a surplus of dry season pasture (see pp. 298, 550). This area of 450 sq. km. is at present partly grazed by Arab livestock as long as water is available in natural pools, some of which have been deepened by hand; but from January to June the remaining pasture could probably support an additional 8,000 Animal Units provided water was available.

Water Supplies

In this area of light rainfall (less than 640 mm.) hafirs must be sited at the foot of rocky outcrops or low hills, and it is unlikely that any sites could be found in addition to those already used; water would therefore have to be provided by deep-bore wells. A water-yard with twin-bore wells could supply sufficient water for 2,500 Animal Units per season on the average, so three such yards would accommodate approximately 8,000 Animal Units. Since the greatest length of the area is about 30 km., the distance from the farthest grazing to the water-point need not exceed 10 km. This distance is often covered in normal Baggara grazing practice and does not cause excessive hardship.

The disadvantage of water from deep-bore wells in this district is its high salinity (about 8,000 p.p.m.) and this might be harmful to livestock if consumed over a period of several months. The alternative would be a piped water supply from the river (a distance of not more than 45 km.) distributed to three points; it is doubtful if the cost of this would exceed that of three twin-bore water-yards, since in the latter case much of the cost would be incurred in the original drilling.

Layout

If we assume that deep-bore wells are to be used in connection with this form of remedy, it would be necessary to divide the whole unit into three sub-units each having a central water-yard. Each sub-unit would have a perimeter fire-line and be divided internally into 6 equal parts by fire-lines; each part would supply one month's grazing for all livestock within the sub-unit. Fencing would not be required; wide fire-lines should be sufficient to demarcate clearly the sub-units and their smaller divisions and would also act as lanes leading to the water-yard, thus minimizing the damage by trampling to grassland close to the yard.

Personnel

One veterinary head stockman and two stockmen, with one field dispensary, would be sufficient to perform the combined task of animal disease control and supervision of grazing procedure. The part-time services of a Grassland Inspector would also be required to advise on grassland management. Although houses for veterinary personnel and a dispensary would only be required during the dry season, it would be advisable to erect permanent buildings, partly to avoid the necessity for continual maintenance and partly to provide reasonable living conditions where amenities are few.

(ii) Machar Marshes

The potentialities of this area have been discussed in the previous chapter and further details are given in Volume III (p. 971). Much of the marsh produces swamp pasture and the remainder is intermediate land with a few scattered areas of higher ground. It would be unwise to put the general stock-carrying capacity of the grassland at more than 30 Animal Units per square kilometre (1 Animal Unit to 8 feddans), which is equivalent to that of the best regrowth pasture on the Eastern Plain. Taking an area of 800 sq. km. along the western fringe of the marshes (40 km. north-south $\times$ 20 km. east-west), and assuming only half to be useful grazing, we arrive at a maximum stock-carrying capacity of 12,000 Animal Units. This area of 800 sq. km., carrying 12,000 Animal Units, is treated as one unit.

There are plenty of suitable sites for hafirs, and we have already stated that a line of four, each of 9,500 m^3 capacity and at 15 km. intervals, between Khor Wol and the western fringe of swamp would be sufficient to water any number up to 26,000 Animal Units in transit to and from the Machar Marshes. In addition, as a safeguard against a shortage of accessible drinking-water in the Machar area, three hafirs would be required for every 6,000 Animal Units spending the dry season in this area, i.e. 6 additional hafirs, making a total of 10 for the unit. Apart from maintenance of the hafirs, the only recurrent expenditure required would be during the dry season, when it would be necessary for a supervisor to be present at each water-point to ensure that stock-owners drew water for their herds from troughs (of their own making) well away from the edges of the hafirs. No additional veterinary or pasture work would be required.

During the rainy season the hafirs would fill; by November or December the coarse grass of the plain would be burnt and some regrowth produced. In January or February natural water supplies away from the Nile would be very low and the general movement of livestock would begin. Those going to the Machar Marshes would cross the burnt plain, grazing on the limited regrowth and watering at the hafirs along the route—a journey of two or three days. When the swamp had been reached livestock would be able to graze the wetter parts, while the dried-out grasses would be burnt off to produce regrowth. The principal water supplies would be the natural lakes, pools and drainage-channels in the marshes, but there would be a reserve in the 6 hafirs which we have recommended. During the period April–May the average rainfall is 115 mm. at Malakal and 42 mm. at Renk and this is enough to bring on the new season's grass. By the middle of June there should therefore be sufficient grass and surface water near the permanent villages to allow stock-owners to bring their animals back from the swamp grazing.

We are confident that adequate water supplies could be provided, but our knowledge of the extent and quality of the grassland is very limited. As with some other proposals, a definite scheme must be preceded by detailed investigation.

B. BY BUSH CLEARANCE AND PROVISION OF WATER SUPPLIES

All aspects of bush clearance have already been described in general terms (see pp. 556–7) and we have concluded that clearance by hand labour, supplemented by the limited use of herbicides and perhaps bulldozers, would be the best method under present conditions. Although details cannot be supplied we must at least refer to the subject of hand labour. The area to be cleared, lying west of the Er Rua'at-Abu Rukba road, would be approximately 1,800 sq. km. or 428,400 feddans, on which some of the bush is almost impenetrable and some fairly open. Even if an unlimited labour force were available, the task would inevitably be a slow one and would take a period of perhaps ten years. As labourers are scarce and unskilled, every advantage should be taken of natural conditions. For instance, by preventing fire in a large stand of *Acacia mellifera* over a period of four or five years, the whole area could be cleared almost completely in one operation by burning. Alternatively, some open areas of small bush could be cleared by pulling the bushes out, exposing the roots and cutting them. The larger trees could be destroyed by ring-barking and applying diesel oil round the base of the tree. This would require at least six man-days' work per feddan, the operation being similar to clearing thick regeneration on land in East Africa. At this rate, allowing that 25% of the area could be cleared simply by burning, it would take a permanent labour force of 500 men about 10 years to clear the remainder.

As soon as each area of the more open bush was cleared the indigenous grasses would re-establish themselves, but to prevent rankness these would have to be systematically burned, grazed, or cut. Areas from which very thick bush was cleared would require to be sown with either the best indigenous grasses or proved species of imported grasses. This means that seed would have to be supplied for sowing (by hand or by machine or from the air) either by purchase or from a special local seed-production unit. It is expected that the new grassland would have a stock-carrying capacity of one Animal Unit to ten feddans for the 7-month season December to June inclusive. This is double the present stocking rate at the Saba-Asuda well-field (see pp. 1052–3) where there is a fair percentage of open bush.

WATER SUPPLIES

It is most unlikely that sites could be found for surface storage tanks, and water would have to be provided at yards having deep-bore wells. One yard, supplying 2,500 Animal Units, would be required for every 105 sq. km. The disadvantage of water from deep-bore wells in this area is likely to be its high salinity; its potability over a season could only be determined by trial. The provision of a piped water supply from the river is here out of the question because of the great distance involved—approximately 100 km.

LAYOUT

One unit would be composed of six sub-units each measuring 105 sq. km., each having a twin-bore water-yard, and each carrying 2,500 Animal Units. Each sub-unit would be contained by a fire-line round the perimeter and divided into six equal parts by fire-lines; each part should supply one month's grazing for all livestock within the sub-unit.

PERSONNEL

Routine staff for each water-yard would be needed. In addition, veterinary and pasture supervision would be performed by one head stockman and two stockmen for each unit. The whole scheme would require three months' supervision by a Grassland Inspector to advise on stocking rate, pasture, maintenance, etc.

IV. GRAVITY IRRIGATED PASTURE SCHEMES

In the previous chapter (see p. 564) we have recorded our conclusion that irrigated pasture could only be produced economically in the form of an irrigated ley grown in rotation with arable crops. However, we must consider in detail a scheme for irrigating pasture by itself, because in some areas it may not prove possible to grow pasture in rotation with other crops.

We have seen that irrigation can be carried out in all Zones of the Jonglei Area, though in the Northern Zone pumps would have to be employed. Whereas gravity irrigation schemes for pasture alone may be uneconomic, pump irrigation schemes, in which the capital and running costs are much greater, almost certainly would be, and we consider here only those areas where gravity irrigation could be applied, namely in the Aliab Valley—from the river—and on the Eastern Plain—from the Jonglei Canal. Our object is to produce permanent pastures and not short-term leys, which are part of a rotational arable farming system, so the design and layout of the pasture scheme is in no way governed by the demand of an arable crop. In the Flood Region, where rainfall averages 900 mm. in six or seven months, surface flooding may be severe, so it is obviously desirable that drainage should be provided in addition to irrigation, the latter being applied only in the dry season. With adequate drainage it would be possible to introduce a wide range of grasses and legumes, as well as forage mixtures during the rains.

The purpose of a pasture irrigation scheme would be to replace the riverain swamp pasture lost under the Project, and the pasture would be needed only in the dry season. It would not therefore be necessary to establish permanent settlements for the people, though certain areas should be set aside for their cattle-camps and the provision of water supplies would be essential. In addition permanent buildings would be required for staff and labourers and for storing implements.

DESCRIPTION OF SCHEME

The inhabitants of the area would move to the scheme at the beginning of January and their cattle would graze the irrigated pasture from that date until mid-May or early June. Throughout this period it would be essential to have a continuous supply of herbage. It would be best to supplement the grazing of irrigated pasture with hay made from the pasture at the end of the rainy season (in October or November).

As we are unable to say at this stage exactly how long permanent pastures grown in this way would remain productive, we must assume a period of about eight or ten years, after which they would have to be broken up and resown. This operation might well be started in the dry season (after February) and continued until the early part of the rainy season, so that the pasture in that year would be unproductive, except perhaps for a cut of hay in October. Re-establishing new pastures in this way would therefore have to be carried out rotationally. Approximately one-tenth of the area would be unproductive each year and would not require irrigation.

It might prove desirable to grow the grasses and legumes in rows on ridges and to sow pasture seeds under a quick-growing cover crop which, besides giving the young seedlings protection during the rains, could be harvested for fodder later. It would be necessary to avoid heavy grazing of the pasture during the first season since it would have had only seven or eight months' growth by January. Immediately after the grazing period, about the middle of May or early June, the land should be cultivated with a deep-penetrating inter-row cultivator to loosen the soil and to free the roots from entanglement. If no suitable perennial legumes could be found, the pasture might be entirely graminaceous and it would then be desirable to sow the seeds of an annual legume, such as velvet bean, cowpea, *Dolichos lablab*, etc., between the rows so that a grass-legume mixture could be cut for hay. The sowing could be done at the same time as the land was cultivated by attaching a seed box to the cultivator. The rainy season would be a period of uninterrupted growth for the pasture until approximately October, when the grass-legume mixture would be harvested and made into hay. Just before the start of irrigation in December, cultivating between the rows and applying a nitrogenous fertilizer would ensure that the pasture would be in first-class condition by the time the stock arrived and that its growth would be luxuriant throughout the grazing period. Grazing would continue until the early rains, when the cattle would move away from the scheme. Inter-row cultivation and sowing of the annual legume would then follow as in the previous year. This annual cycle of management would be repeated in the following eight years until the land was again broken up and fresh pasture established.

Assuming the unit to which the ten-year rotation would apply to be 100 feddans, the following operations would be necessary each year:

(i) Breaking up 10 feddans of pasture land in the dry season by ploughing with a one-way disc such as a Massey Harris ' 506 ', followed by cross-discing in the early rains with a machine such as a Massey-Harris ' 26 ', and then drilling in pasture seed.

(ii) Cultivating 90 feddans of pasture with an inter-row cultivator combined with seeding the legume-forage crop in the early rains.

(iii) Cutting the grass and legume mixture from 90 feddans by tractor-drawn mower, followed by collecting with a pick-up baler to bale the hay.

(iv) Cultivating and fertilizing 90 feddans of pasture land with an inter-row cultivator before the beginning of irrigation in December.

The rotational grazing and watering schedule eventually adopted might well be similar to the one tested at the Malakal Experimental Station, which has already been described (see p. 567).

Production

In a unit of 100 feddans, in which only 90 feddans would be under pasture, the stock-carrying capacity would be 20,250 Animal Unit days, estimated at the stock-carrying rate of 1·5 Animal Units per feddan for 150 days in the dry season. In addition 90 feddans of grass-legume mixture would be cut and made into hay. Its carrying capacity is estimated as follows. There should be 90,000 kg. dry weight of fodder calculated at the rate of 1,250 kg.p.f. and allowing 20% for wastage. Assuming that this hay would contain 5% of digestible crude protein(2), and assuming the average daily requirement per Animal Unit to be 0·25 kg. (see p. 571), then the carrying capacity would be 18,000 Animal Unit days. Altogether therefore we estimate that one unit would supply 38,250 Animal Unit days grazing, or carry 255 Animal Units over a dry season of 150 days.

Engineering Works

The engineering requirements of an irrigation scheme similar to the one described above may be summarized as follows:

(i) Water-Duty

The water-duty for pasture irrigated in the dry season has been estimated to be 860 m^3.p.f. per month (pp. 623–4), and 90% of the area would be irrigated, making a gross duty of 775 m^3.p.f. per month.

(ii) Drainage

A suitable drainage system would be required so that a wider range of grasses, legumes and forage mixtures could be introduced.

(iii) Domestic Water Supplies

Some facilities would be needed at cattle-camps for watering the large numbers of animals involved.

(iv) Buildings

These would have to be built on a scale sufficient to house the staff and equipment normally employed on the scheme.

We shall describe later how an irrigated crop production scheme might be applied to the Eastern Plain west of the Jonglei Canal (see pp.647–8); this agricultural scheme has been fully designed and is the basis for the estimates of quantities and costs of most of the gravity irrigation schemes considered for the purpose of remedial measures. The requirements for pasture, listed above, are different from those for normal crops and would call for the following differences in engineering works from those of the basic scheme.

Canalization

The capacity of the distribution system to serve the same gross area should be increased in the ratio of the respective over-all water-duties; in the basic case 633 m^3.p.f. per month, and in this case 775 m^3.p.f. per month (ratio 1 : 1·225). This factor should only be applied in those canals where the volume of excavation is based on hydraulic requirements; that is to say to the main canal and that part of the major canal alongside the Jonglei Canal. The excavation of the remaining part of the major canals, the minor canals, watercourses, and field channels, would be determined by the amount of spoil required to make banks for those channels and for raised roadways alongside them, and would be more than 25% in excess of the requirements for waterway. The excavation for these latter channels need not therefore be increased, though the capacities of the regulators on them should be.

DRAINAGE

The drainage system designed for the basic irrigation scheme would be made large enough to dispose of surface run-off in addition to irrigation, whereas in the present system there would be no irrigation of the pasture during the rains. We can therefore reduce the capacity of (and thus the engineering works for) the drainage system in the ratio of the run-off computed for the two sets of conditions, or by a half (see p. 627).

DOMESTIC WATER SUPPLIES

In an irrigation scheme, watering cattle may not appear to present any problem whatever, but further consideration will show that large herds of animals cannot be allowed simply to drink from the canals or watercourses because they would damage the banks extensively. For this reason all paddocks should be fenced and cattle should be watered at their cattle-camps. Probably the best method would be to supply water from an irrigation channel to a large filter well from which the water would be pumped into a tank and then distributed to drinking troughs.

BUILDINGS

In this form of pasture scheme it is assumed that there would be no reduction in the standards or quantities of buildings required for the staff from those needed on a normal agricultural scheme. While the management of pasture might be carried out with fewer staff, and therefore demand fewer houses, offices, stores, etc., than are needed in a normal agricultural scheme, we consider that any reduction in this way would be offset by the increased use of the land, as 90% of it would be cropped as against 67%.

2. AGRICULTURAL ALTERNATIVES

V. IRRIGATED CROP PRODUCTION SCHEMES (COTTON-SORGHUM-LEGUME SCHEMES)

AGRICULTURAL CONSIDERATIONS

The system of irrigated farming developed in the Gezira Scheme, which has as its basis a rotation of the type cotton/dura-lubia-fallow, has already been tried and proved successful in the Semi-Arid Region of the Jonglei Area. There seems to be no doubt that it could be extended farther south without great modification, provided that good drainage could be assured and varieties of cotton resistant to blackarm, essential where more humid conditions obtain, could be found.

Improvements and modifications to suit the different conditions are obviously possible. However, we consider it best to accept this well-tried system of farming as the basis of our recommendations. The system has been successfully applied in the Abdel Magid and White Nile Alternative Livelihood Schemes to provide a livelihood for those people displaced by the Jebel Aulia Reservoir. It is agronomically sound, and from the economic point of view the present division of profits assures the central authority sufficient income to cover the running costs of the scheme and to provide amortization of its capital costs. As far as the tenants are concerned, the schemes give a very fair standard of living and one to which the inhabitants of the Jonglei Area, whose traditional economy will be so drastically altered by the effects of the Equatorial Nile Project, should certainly be entitled.

The White Nile Alternative Livelihood Schemes have also provided fodder for livestock displaced by the Jebel Aulia Reservoir. It is significant that it frequently happens that one member of a family group is delegated to become a tenant primarily in order to supply the livestock with fodder when grazing is short. This practice is discouraged by the authorities[3] because of the complications, and sometimes damage to crops, which are the result of such conflicting interests. Yet, in our opinion, the practice must be accepted as inevitable in a mixed community which has strong traditions of a pastoral way of life and in which the wealth of the majority lies in animal stock. It is for this reason that the basis of our estimates, the output of digestible crude protein, seems to us more realistic than any other.

DESCRIPTION OF SCHEMES

The layout and cropping system which we recommend are based on techniques applied in the Abdel Magid Scheme. This scheme is described in some detail in *Agriculture in the Sudan*[4] and it is not necessary to repeat the description here.

OUTPUT IN TERMS OF DIGESTIBLE CRUDE PROTEIN PER HOLDING

The Abdel Magid type of holding covers 18 feddans allocated as follows:

Cotton	5 feddans
' Free choice '	1 feddan
Sorghum	3 feddans
Lubia	3 feddans
Fallow	6 feddans

Such a holding would therefore produce the following quantity of digestible crude protein, assuming yields as per Table 285 (p. 611) and the use of cotton seed as fodder, a practice absent on the Abdel Magid Scheme but in our case considered desirable:

TABLE 297

OUTPUT OF DIGESTIBLE CRUDE PROTEIN PER HOLDING ON COTTON-SORGHUM-LUBIA SCHEMES

Fodder	D.C.P.	Area feddans	Yield kg.	Total Output kg.	Handling Losses %	Fodder Available kg.	Available D.C.P. kg.
Sorghum Stover ...	1·5	3	2,500	7,500	30	5,250	79
Cotton Seed ...	13·5	5	420	2,100	20	1,680	227
Lubia	6·9	3	1,500	4,500	—	4,500	310
Total	—	—	—	—	—	—	616

On the basis of daily requirements of 0·25 kg. of digestible crude protein per Animal Unit, a holding of this type should provide fodder for 2,464 Animal Unit days or for 16·4 Animal Units for 150 days—the period when natural grazing is not available.

ENGINEERING WORKS

Irrigation schemes will, for obvious reasons, constitute a large part of our selected remedial measures. On the agricultural side schemes of this kind would be similar in all parts of the Jonglei Area, and the general description given above should suffice wherever the remedy might be applied. The irrigation and engineering aspects, however, differ as between gravity and pumped irrigation and each must be related to particular areas. In what follows we describe, in sufficient detail for estimates of the costs to be made later, a typical gravity irrigation scheme west of the Jonglei Canal. The detail is necessary to show exactly how such a scheme could be applied to a particular area. As far as pump schemes are concerned the description is not so complete because they would not differ greatly from those which are already well established on the banks of the White Nile, but we discuss the question of suitable sites and also methods of adapting sites which are naturally unsuitable for pump stations.

A. GRAVITY IRRIGATION SCHEME

IRRIGATION FROM THE JONGLEI CANAL

One of the most obvious remedial measures for the loss of riverain grazing in the Central Zone is an irrigation scheme, supplied by gravity flow from the Jonglei Canal, to irrigate pasture or agricultural crops such as sorghum and cotton. The agricultural scheme described above specifies a rotation of the type cotton-sorghum-legume. Except in the case of rice, which we are not considering here, the type of crop grown would make little difference to the engineering works required, which would begin with the main off-take and be carried down to the water-courses and lateral field-channels. The question of water-duty in general has been fully dealt with previously (see pp. 623–7). Recent knowledge tends to show that water-duties for different crops which cover the ground to the same extent do not vary greatly. In the dry season, from December to May, the temperature and humidity in the Central Zone are comparable with those in the Gezira, so the design of an irrigation scheme for a crop to be watered in the dry season, or part of it, should be made to the same water-duty as in the Gezira. This applies to the cotton crop in the above rotation, which would have to be watered until December.

With regard to the method of irrigation, since the major ground-slopes and the type of soil of the Eastern Plain are so similar to those in the Gezira, we assume that the method employed there could be successfully applied to the Eastern Plain. With these brief preliminary remarks we will now proceed to the design of a basic irrigation and drainage scheme from the Jonglei Canal for continuous day and night watering, assuming that two-thirds of the area of 100,000 feddans would be cropped.

Headworks

The water-level in the Jonglei Canal, as designed by Dr. Amin and Mr. Bambridge, will be at or below ground level for the whole of the Canal's length so that, as it stands, irrigation by gravity flow will not be possible. We begin therefore by stipulating that the Jonglei Canal *must be redesigned so that gravity flow is possible*. It is obviously uneconomic to install expensive pumping machinery with its high annual running costs when, by suitably designing the Canal in the first place, adequate command over the ground could be achieved without it. We further stipulate that one canal should be designed specifically for irrigation of the Eastern Plain between the Canal and the Bahr el Jebel (see p. 771). There would be several advantages in doing this. In the first place the cost of any barrages across a canal whose capacity is 27·5 m/d would be much greater than that of a control regulator on a canal for irrigation purposes only, whose capacity need only be 5 or 10 m/d. In the second place, owing to the high intensity of rainfall, which might occur when irrigation water was being supplied to cover a period of drought, it must be possible to cut the flow in the main canal extremely rapidly. For this reason each unit of irrigation should not be larger than, say, 100,000 feddans, and each main canal should take off from what we have called the ' Jonglei irrigation canal ', with its own headworks and control regulator (see p. 772). With such an arrangement the flow into the main canal could be switched at short notice back into the Jonglei irrigation canal and passed to the White Nile at the Sobat mouth. Thirdly, since it is essential that the Jonglei Canal should also be used for navigation, it would be extremely costly to build a number of barrages complete with locks, necessary for through navigation. By separating the functions of irrigation and navigation, each canal could be designed most suitably for its particular purpose. We therefore assume that there will be one canal designed to give command for gravity irrigation, another adapted to the needs of navigation, and a third, if necessary, to pass the remainder of the flow from Mongalla to the White Nile and to provide additional capacity for flood-escape discharges if they are found to be necessary. This will be dealt with fully under the ' Revised Operation ' (see Chapter 11, p. 709). Although the size of the irrigation canal could only be specified at a later stage when the total area of remedial measures based on gravity irrigation from the canal is known, we have assumed that a discharge of 5 m/d in the Jonglei irrigation canal will be a close enough approximation for the purposes of an estimate. We must note here that at the site of the off-take the water-level in such a canal must be 0·80 m. above ground level.

Water-Duty

We now proceed directly with the design of the irrigation and drainage scheme which we recommend. The water-duty, for design purposes, must be the maximum the crop requires during the irrigation season which is given above, namely 950 m^3.p.f. per month in December. Two definitions in connection with water-duty need to be given for those not familiar with Sudan Irrigation Department nomenclature:

Gross Factor: The water supplied in cubic metres per day per feddan ($m^3/f/d$) of gross area.

Crop Factor: The water supplied in cubic metres per day per feddan of the cropped area.

In the scheme under consideration a crop factor of 34 $m^3/f/d$ is taken for design; this amounts to 22·5 $m^3/f/d$ of gross area since only two-thirds would be cropped, and the following over-all factors would be applied for the design of canal sections and structures:

Minor Canals	$F = 22{\cdot}5\ m^3/f/d$
Major Canals	$F = 21{\cdot}0\ m^3/f/d$
Main (Branch) Canals	$F = 20{\cdot}0\ m^3/f/d$

This is in accordance with the latest Sudan Irrigation Department practice.

Drainage Factor

It is obvious that the drains in an irrigation scheme in the Central Zone must be designed for a larger run-off than in the lighter rainfall area of the Gezira. We have already explained why we have adopted the empirical formula below for calculating the run-off in this area:

$$Q = 0{\cdot}325 \left(\frac{\text{areas in feddans}}{1{,}000}\right)^{0{\cdot}8} m^3/\text{sec.}$$

Site and Layout of Canalization

A suitable site for the scheme would be west of the 'Direct' Line of the Jonglei Canal, between km. 30 and km. 70. The Egyptian Irrigation Department in Malakal have been able to supply a contoured map of this area. The major slope is approximately 10 cm/km. in a direction inclined 30° west of the 'Direct' Line, an important fact when considering irrigation from the Canal. For this reason it would not be easy to command areas east of the Canal. Since the Canal itself will intensify flooding from 'creeping flow' to the east of it and protect the plain to the west, the latter area would obviously be more suitable for a controlled irrigation scheme. Some 11 km. to the west of the Canal the contours show a drainage depression, which later becomes Khor Ding, running to the Bahr el Zeraf. This depression would therefore be suitable for disposing of drainage run-off.

A suggested layout of canalization for an area of 100,000 feddans is illustrated in Fig. G 1; this consists of three identical major distributory systems, the southernmost being supplied direct from the headworks at km. 30 and the other two being fed by a main (or 'branch' by Sudan Irrigation Department nomenclature) canal paralleling the Jonglei Canal to km. 41. The northernmost major system continues parallel to the Canal to km. 52 before turning away to feed minor canals. As shown in the diagram, the three major canals are aligned at 60° to the Jonglei Canal, and the minor canals at right angles to the majors. Further distribution would be made by watercourses serving 130 feddans each and field-channels feeding 10 feddans, both being on the normal rectangular pattern. They are not shown on the drawing. This layout is standard Sudan Irrigation Department practice for continuous watering systems; the low slope of the watercourses, approximately 8 cm/km., would reduce the area supplied by them to 130 feddans from the more normal area of 180 feddans.

The canal structures as shown also conform to Sudan Irrigation Department practice. Major head and the upper intermediate major regulators are of the undershot gate type operated by rack-and-worm gear. The lowest intermediate major regulator is also a movable weir. Minor canals take off through well-head regulators, and levels are held in their lower reaches by simple pipe-and-door regulators. Watercourses would be fed through standard 15 in. field outlet pipes and valves. Portable 10 in. and 8 in. pipes would serve to control levels in the watercourses and distribute the water to the field-channels. One canal bridge would be required over the northernmost major canal.

Drainage Layout

As shown in the diagram, the drainage system is entirely complementary to the canalization. Minor drains run down the non-watering side of the minor canals and discharge into major drains paralleling the major canals. The major drains unite to form a main drain which runs northwards and is carried a short distance away from the scheme down the depression which becomes Khor Ding. As designed, the area is protected on its western flank from the possibility of overland rain-flooding by a bank running from the tail of the southernmost major canal to the beginning of the main drain, and thereafter by the left bank of that drain. The structures for the drainage system would consist of inlets and bridges, an inlet being provided from the lowest corner of each 130-feddan plot into the minor drain, and from each minor drain into the major one. As shown, bridges are sited opposite to regulators on all canals, and in addition over drains above their junctions with majors, and over major drains where necessary for communications.

Design

The watering system would be designed to the following commands:

Minor Canals	maximum 0·50 m; minimum 0·30 m.
Major Canals	0·50 m. upstream of minor off-takes.
Main (or Branch) Canal	0·70 m. at the tail of each reach.

This gives 30 cm. head on regulators.

main (or branch) canal

As shown in Fig. G 1, this is 11·2 km. in length and runs alongside the Jonglei Canal from km. 30 to km. 41·2. It waters 69,420 feddans which, at a factor $F = 20\ m^3/f/d$, requires a discharge of 1·38 millions of cubic metres per day (16·1 cumecs). The design of the section to be excavated, based on the hydraulic capacity of the channel, would provide ample spoil for a road on the bank. With a water slope of 8 cm/km., the dimensions of a suitable channel would be:

Bed width: 12·0 m. Water depth: 1·9 m.

Side slopes: 2 : 1 $\frac{1}{n}$ (Manning's) = 45.

The total excavation required would be 211,000 m^3.

MAJOR CANALS

As shown, the total length of major canals is 59·5 km., of which 11·2 km. lie alongside the Jonglei Canal. Each major canal waters 34·710 feddans which, at a factor F = 21, would require a discharge of 0·729 millions of cubic metres per day (8·45 cumecs). With a slope of 8 cm/km., a suitable channel would be as follows:

Bed width: 6·5 m. Water depth: 1·7 m.
Side slope: 2 : 1 $\frac{1}{n}$ (Manning's) = 45.

However, for reasons given below, the criterion of waterway would apply only to the reach alongside the Jonglei Canal. The average excavation here would be 10·9 m^3. per metre run.

Owing to the heavy rains in this region it would be essential to make use of one bank of the Canal for a roadway, and for this purpose we specify a bank of 4 m. wide at the top, 0·75 m. cover above water-level, and 2: 1 side slopes. Assuming bulking and consolidation to be equal, we should need 8·0 m^3. per metre for one bank. The other bank would have to be 2·0 m. wide at the top and 0·75 m. above water-level, giving a cube of excavation of 5·6 m^3. per metre. The total earthwork on this basis would be 780,000 m^3. A saving in excavation could be made in the case of the two northern major canals by using spoil from the major drains. The amount of this saving is estimated to be 358,000 m^3., leaving net excavation at 422,000 m^3. The section to be excavated for banks would be 25% in excess of that required for waterway at the head of the major canals, where little saving could be made by using drain spoil. Lower down the canals, where more drain spoil would be available, the requirements for waterway would be less. On the whole we can say that the criterion for excavation in the major canals would be the amount of earth required for banks.

MINOR CANALS

The total length of minor canals, as shown, is 248 km. of watering channels and 23 km. of carrier channels alongside the majors. Most minor canals would water 4,920 feddans each, which, at a factor F = 22·5 m^3/f/d, would require a discharge of 0·097 millions of cubic metres per day (1·12 cumecs). A water slope of 5 cm/km. could be obtained in the carrier channels for which a suitable section would be: bed width 3 m.; water depth 1 m. The average command would be 0·35 m., the excavation amounting to 2·8 m^3. per metre, and the total excavation in the carrier channel to 70,000 m^3. In the watering reaches of the minor canals the criterion for design would be the amount of earth required for banks, and a volume of 3·26 m^3. per metre run would be required for each bank, making a total figure of 1,620,000 m^3.

As in the case of the major canal banks, considerable saving could be made by utilizing drain spoil and this would amount to 535,000 m^3., leaving net excavation required at 1,085,000 m^3.

BERM ROADS

The banks designed for the minor canals, with 2: 1 side slopes and a top width of 2·3 m., would give cover for 7: 1 hydraulic gradient from 0·20 m. above full supply level. If, instead, we limited the top width to 1·0 m. and used the remainder of the spoil to form a roadway 4 m. wide and 0·40 m. high, it would still give the requisite cover over the hydraulic gradient. Since raised roads would be an essential feature of any scheme in this area, and since this would not involve any additional excavation, we recommend that the narrower bank, with a wide external berm road, should be the type adopted.

WATERCOURSES AND FIELD-CHANNELS

These would be standard Sudan Irrigation 'Abu XX' and 'Abu VI' sizes, requiring excavations of 1·25 m^3. per metre run for banks and 0·36 m^3. per metre run for waterway. The total lengths of 'Abu XX' and 'Abu VI' would be 1,470 km. and 2,730 km. respectively. The volume of earthwork required in excavating these channels would be:

Watercourses: 1,840,000 m^3.
Field-Channels: 693,000 m^3.

DOMESTIC WATER SUPPLY CHANNELS

During the period when irrigation was not needed it would be desirable to supply water for domestic purposes by joining up the reaches of carrier canals, thereby avoiding the need to use the major canals which would become heavily infested with water weeds. By suitable grouping of the houses and settlements three-quarters of the minor canals could also be dried out when not required for irrigation. A total length of 25 km. of a section 1·25 m^3. per metre would be adequate, giving an addition of only 31,000 m^3. to the excavation.

CANAL STRUCTURES

Canal regulations would conform to standard Sudan Irrigation Department practice throughout, with the following differences in levels between the upstream and downstream sides of the regulators:

Major Canal Head Regulators ...	... 0·30 m.
Major Canal Intermediate Regulators	... 0·15 m.
Minor Canal Head Regulators ...	... 0·20 m.
Minor Canal Intermediate Regulators	... 0·20 m.

One bridge with masonry abutments and a reinforced concrete deck would be built across the northernmost canal. Below is a full list of the canal structures needed in the scheme:

MAIN CANAL STRUCTURE

1 No. Rack and Worm Regulator, 2 gates × 3·0 m.

MAJOR CANAL STRUCTURES

3 No. Rack and Worm Regulators, 1 gate × 3·0 m.
3 No. Rack and Worm Regulators, 1 gate × 2·5 m.
3 No. Rack and Worm Regulators, 1 gate × 2·0 m.
3 No. Movable Weir Series II, 2·0 m.
1 No. Bridge, Span 10 m., Height 2·5 m.

MINOR CANAL STRUCTURES

24 No. Well-head Regulators with pipes ...	1·24 m. diam.
3 No. Well-head Regulators with pipes ...	1·01 m. ,,
3 No. Well-head Regulators with pipes ...	0·91 m. ,,
21 No. Pipe Regulators	1·24 m. ,,
24 No. Pipe Regulators	0·91 m. ,,
24 No. Pipe Regulators	0·76 m. ,,
3 No. Pipe Regulators	0·50 m. ,,

WATERCOURSES AND FIELD-CHANNEL STRUCTURES

801 No. sets of Field Outlet Pipes ...	15″ diam.
2,403 No. Concrete Field Pipes	10″ ,,
5,607 No. Concrete Field Pipes	8″ ,,

DRAINS

The formula for estimating run-off has been explained above and it has been shown in our design that the drainage system is completely complementary to the irrigation canals.

Using this formula we have calculated discharges at various points in the systems and details of the drainage system, which are given in the following table:

HYDRAULIC DETAILS OF THE DRAINAGE SYSTEM

Position in System	Area Drained feddans	Discharge m^3/sec.	Ground Slope cm/km.	Water Depth m.	Bed Width m.	Excavation m^3/m.
Minor Drains:—						
Top	130	0·065	8	0·30	1·0	1·0
Middle	2,200	0·61	8	0·58	2·0	2·7
Outfall	4,400	1·02	8	0·90	2·0	4·6
Major Drains:—						
Top	4,700	1·12	8	0·92	2·0	5·0
Middle	17,500	3·20	8	1·30	4·0	10·5
Outfall	35,000	5·80	8	1·50	6·0	16·0
Main Drain:—						
Below Junction of Majors A and B	70,000	9·70	10	1·8	7·0	22·0
Below Junction of Major C...	104,000	13·30	10	2·0	9·0	29·5

NOTES: Manning's $\frac{1}{n}$ = 40, side slopes 2:1, water-level 0·20 m. below ground level.

The lengths and quantities of earthwork in the drains would be as follows:

Minor Drains: 250 km., 650,000 m^3.
Major Drains: 56 km., 593,000 m^3.
Main Drain: 21 km., 537,000 m^3.

As mentioned above, considerable saving could be effected in excavation for canal banks by utilizing spoil excavated from the drains.

DIVERSION BANK

This would be part of the drainage system because it would protect the irrigated area from rain-flooding from farther south. A bank 1·0 m. high, with 1·0 m. top width and 2 : 1 side slopes, should be adequate, requiring a total of 39,000 m^3. in 13 km.

ESCAPES

No escapes need be provided because, as has been explained, the area irrigated from one main (or branch) canal should be kept down to 100,000 feddans and, if the proposal for a separate Jonglei irrigation canal were adopted, it would provide automatically for escape at the headworks.

DRAIN STRUCTURES

Drain-crossings. We have designed 4 standard drain-crossings consisting of masonry abutments and concrete slab decks, and the details of the numbers of each type needed are given below:

Drain-Crossings Type	Number Required	Number of 2·0 m. Spans	Height of Abutments m.
A	105	1	1·0
B	18	2	1·5
C	19	3	1·7
D	2	4	2·0

Inlet structures are required from each 10 feddans into minor drains, and from minor to major drains. The former are built in mass concrete and the latter in dry rubble pitching:

Minor Drain Inlets ... 80 No.
Drain-to-Drain Inlets ... 29 No.

BUILDINGS

A precise plan of the buildings required for the scheme has not been made. Instead, for the purpose of estimating costs, we have adopted the arrangement of buildings required in the 100,000-feddan North-Western Gezira Extension which has just been completed. It allows for one Irrigation Sub-Division and four Gezira Board Agricultural Stations. The layout we suggest would probably be better arranged with three agricultural stations, but an area of 34,000 feddans is large for one station, and during the rainy season it is certain that subsidiary rest-houses, etc., would be needed.

The numbers and allocations of houses are given below:

NUMBERS AND ALLOCATIONS OF BUILDINGS IN THE N.W. EXTENSION OF THE GEZIRA

Type of Buildings	Number of Buildings				Totals
	Irrigation	Agriculture	Posts and Telegraphs	Medical Service	
P.W.D. Class 7	—	4	—	—	4
S.I.D. Class 5a	1	9	—	—	10
S.I.D. Class 4a	3	—	—	1	4
S.I.D. Class 3a	2	5	—	—	7
S.I.D. Class 2a	2	4	4	4	14
S.I.D. Class 1a	8	10	1	1	20
S.I.D. Class 1	33	80	2	5	120
S.I.D. Office	1	—	—	—	1
S.I.D. Stores	1	1	—	1	3
Garages	2	13	—	1	16
Stables	4	13	—	—	17
Latrines	6	8	—	—	14
Filter Wells	5	17	—	—	22
Telephone Kiosks	8	—	—	—	8
Agricultural Offices	—	4	—	—	4
Agricultural Stores	—	8	—	—	8
Dispensaries	—	—	—	4	4
Totals	76	176	7	17	276

B. PUMP IRRIGATION SCHEMES

In the previous section we have described in detail the suggested layout of a gravity irrigation scheme in the Central Zone. Apart from being necessary for estimating the cost in detail, the description has served to show exactly how such a scheme could be applied to a particular area, i.e. the most suitable area for an irrigation scheme.

Since pump irrigation schemes would not differ greatly in most respects from those already in existence on the banks of the White Nile[5], there is no need to describe a pump scheme in such detail. We must, however, draw attention to, and discuss, the points of difference between existing schemes and those which may have to be applied in the Jonglei Area.

Pump Sites

The pump schemes which have been constructed to date have been able to make use of pump sites which are naturally suitable[6]. Though there are still a fair number of pump sites available in the Jonglei Area, even in the Northern Zone, by the time the Project is constructed considerable development may have taken place, so that the remaining naturally suitable pump sites may be few and far between. In those circumstances it would be necessary to utilize other less favourable sites, and we here discuss ways and means of doing so.

SOUTHERN ZONE

The river in this Zone winds its way from side to side of its valley, which averages 7·5 km. in width. In many places it splits up into a number of smaller channels, so that a deep-water channel can in most cases be found a few kilometres from the sides of the valley.

Where the topography is suitable for pump irrigation schemes—that is, on the high ground to the east and north of Kursomba—the river is either close by, as it is east of the Aliab Valley, or, as in the case of the Mongalla–Gemmeiza reach, a short distance away. In this latter instance it would be necessary to dig a low-level channel across the *toich*, so for the purpose of a study of average conditions we will assume that Cross-Section Z at Kursomba (Fig. A 12) is typical. From our summary of the hydrology and topography of the Mongalla–Gemmeiza *toich* (Tables 388 and 389, p. 841) we see that the average *toich* level at this section (No. 9) is R.L. 430·50, and the water-level in the river at the lowest discharge under the Project, 57 m/d, is, by interpolation, R.L. 431·25.

It is clear from these figures that the excavation for the low-level inlet channel would be determined by the size of bank necessary to guide water to the pump site, after cutting through the alluvial bank. In order to avoid too high levels the low-level channel would have to take off from the river at the next cross-section downstream and lead south-eastwards to the pump site. High river level at this point will be R.L. 431·38 and the average command 1·38 m. A suitable bank would be, on the average, 2 m. high with 3·5 m. top width and 2 : 1 sides, its cross-section being 15 sq. m. The length diagonally from Cross-Section No. 10 is 4·5 km., and the total earthwork would amount to approximately 67,500 m^3.

CENTRAL ZONE

The data for the Central Zone are scanty, but considering the one available cross-section (at Peake's Track, Fig. A 15) it seems reasonable to assume that under the Project conditions will be similar to those in the Southern Zone, and similar arrangements for adapting pump sites would have to be made.

NORTHERN ZONE

The question of pump sites will probably be most important in the Northern Zone. Here they may be of the following types:

(a) Natural sites where the deep river channel or deep side-channel is close to the high ground.

(b) Sites where the pump station is close to the high ground, supplied by a low-level inlet channel across the *toich*, which averages 2 km. in width in this Zone.

(c) Sites where the pump station is at the river, supplying water to a main feeder canal, on high ground, leading some distance to the area to be irrigated. An examination of the flood-plain between Malakal and Melut on the 1/100,000 air survey maps indicates that 10 km. should be the limiting length of such a canal.

(d) In some cases the ground inland of the pump station may, for a distance of about one kilometre or more, be at a lower level than the area to be irrigated. In such a case a high-level aqueduct or rising main would have to be provided if the difficulty could not be overcome by one of the methods described above.

Drainage

The second point of difference would be in the capacity of the drainage system. We have already explained the basis on which the engineering works would be designed so as to dispose of rain-flooding in this area where the rainfall is much heavier than in the Gezira (pp. 627–8). This would result in somewhat higher costs.

For the purpose of the application and costs of this form of remedy, we have to make a distinction. The remedies are shown later in the summary of unit costs and in the charts as V B(i) and V B(ii), the distinction being in the amount and type of drainage necessary, which alters the unit costs, in the Semi-Arid Region, and in the Southern Zone and the remainder of the Northern Zone.

VI. DRAINAGE SCHEMES

AGRICULTURAL CONSIDERATIONS

We have had no opportunity to test the effectiveness of a drainage system—consisting only of a network of field-drains—in the removal of surface water and the prevention of waterlogging. Some crops require adequate aeration of the soil, and it might be necessary to supplement ordinary drainage with ridges similar to those constructed with a Killifer ditcher (see p. 602). It is as well to remember, however, that capital expenditure on drainage schemes must be kept as low as possible because the other principal risk in this area—periodical drought—still remains. Moreover, experiments on ridged land have shown a substantial reduction (about 50%) in the yield of most crops; and if this disadvantage is to be removed, a new system of farming adapted to ridged land must be evolved. For these reasons we do not recommend the introduction of drainage schemes in areas where Killifer ridges would be necessary, i.e., on the lower levels of intermediate land in the Flood Region (land dominated by *Hyparrhenia rufa*).

Our recommendations are confined to ridging with animal or tractor-drawn ridging ploughs, the water being led along the furrows into field-drains. This method seems especially suitable for the higher type of intermediate land where ground-slopes are adequate.

The type of drainage scheme described below, like other remedial measures, is primarily designed to accommodate as many cattle as possible, the owners being rewarded for their additional labours in cultivating by the proceeds of the crops. It is for this reason that our selection includes groundnuts as a principal crop, since groundnuts produce not only oil but also concentrated fodder cake and leguminous hay.

Organization

It seems to us that such a scheme could best be managed on the basis of partnership between some central authority or board and the cultivators. The central authority would provide the equipment necessary to cultivate the individual holdings and also the following services:

(i) Layout, installation, and maintenance of an adequate drainage system.
(ii) Agricultural advice and supervision, including a small research station.
(iii) Provision for the extraction of oil: it is assumed that groundnuts would be delivered and the cake collected by the cultivators, so that it would not be necessary to supply transport to and from the factory.
(iv) Marketing of the oil.
(v) Provision of domestic water supplies.
(vi) Storage facilities—a necessary precaution since crops may fail from drought.

Crop Husbandry

We consider that a suitable rotation would be as follows:

1. Cereals and other food crops.
2. Groundnuts.
3. and 4. Fallow.

It would be desirable to include more than one cereal in the rotation in order to keep *Striga hermonthica* under control. Besides sorghum, maize and bulrush millet might prove suitable. Groundnuts would provide the legume phase in this rotation, a procedure necessary to increase the nitrogen content of the soil and also to control *Striga*. Groundnuts should also act as a good weed-clearing crop. We consider that to maintain fertility and to check the incidence of weeds, disease, and parasites, it should be sufficient to keep half the area under fallow.

In the Jonglei Area there are indications that long periods of fallow may be more beneficial than short ones. The introduction of a long fallow need not alter the rotation basically. Only a longer period of cultivation would be needed, involving the alternation each year of cereals with groundnuts, followed by an equally long period of rest.

We have estimated yields on the assumption that no special methods would be used to control pests, diseases, and *Striga*; whether improvement in yields could be made by using scientific methods remains to be seen. In any case the costs of a drainage scheme should be more than repaid by increased yields. We do not recommend mechanization as it would require a large capital outlay, but it seems probable that on a centralized scheme of this kind animal-drawn implements would not only meet the requirements of the cultivator but would also not prove difficult to introduce. In addition an adequate supply of implements and hand tools must be made available. It would be necessary for the land to be ploughed and ridged every year. Apart from this, all other operations should be carried out by hand implements in the initial stages of the scheme, but later on, with more information available, it might be possible to substitute animal-drawn implements.

Individual Holdings and Output

A gross area of 16 feddans would be a suitable size for one family holding (of five persons) and would then consist of:

Cereals	3½ feddans.
Other food crops	½ "
Groundnuts	4 "
Fallow	8 "

The area under food crops should provide sufficient calories and proteins (when supplemented by animal products) to give a standard of diet equivalent to that recommended in the Gezira.

Since our calculations are based on the output of crude protein for livestock, it is necessary to consider such a holding and its value in terms of the Animal Units it can support:

TABLE 298

DIGESTIBLE CRUDE PROTEIN PRODUCED FROM A 16-FEDDAN HOLDING ON A DRAINAGE SCHEME

	D.C.P.	Area feddans	Yield kg.p.f.	Output of Holding kg.	Handling Losses %	Fodder available kg.	D.C.P. Available kg.
Cereal Stover ...	1·5	3·5	1,600	5,600	30	3,920	59
Groundnuts Stover	3·5	4·0	500	2,000	40	1,200	42
Groundnuts Cake	42·0	4·0	145	580	10	520	218
Total							319

The number of Animal Units which one holding would support can be calculated as follows:

the output of digestible crude protein is divided by the daily requirements per Animal Unit and by 150—the number of days when grazing is not available:

$$\frac{319}{0{\cdot}25 \times 150} = 8{\cdot}5$$

i.e. each holding would be able to support approximately 8·5 Animal Units per year.

Minimum Size of the Unit

It must be noted that a scheme of this type should be large enough to supply an oil mill economically and to justify the costs of installation. An intake of a mill of this kind should not be less than 5 tons per day. Assuming that it would have 300 working days per year, 1,500 tons of groundnuts would be required. To ensure such an output 3,950 feddans should be under groundnuts, making the gross area of each scheme 15,000 feddans.

ENGINEERING WORKS

In the description of the agricultural aspects of a drainage scheme such as that given above, it is stated that suitable sites are on the higher parts of intermediate land where ground-slopes are adequate. In some areas all that would be required to effect a considerable improvement in agriculture would be the installation of artificial drainage without irrigation. One such area is to be found on the west bank of the White Nile between Tonga and Malakal, in the so-called 'Raqaba Depression', where cultivation of millet is usually unsuccessful under normal rainfall owing to extensive flooding. The reason for this flooding is clear from an examination of the cross-sections at Fanyikang and Wau (Fig. A 22). From these it will be seen that there is a very shallow dish-shaped depression raised two or three metres above normal high river. Conditions are therefore ideal for the installation of artificial drainage.

A. FANYIKANG

An area of 10,000 feddans north of Fanyikang was surveyed by the Team, and contours at 0·20 m. intervals drawn on a plan from the spot levels (Fig. G 2). From our backwater computations for the White Nile (Table 217, p. 451) we see that the level of the river at Fanyikang (19 km. from the Sobat mouth) will normally reach a maximum of 385·17. The peak of the Sobat flood at Malakal in November occurs three months after the peak of the rainy season at Malakal in August. The river in August will normally be some 0·60 m. lower than the maximum, and drainage of the area thereby further facilitated. Since the lowest point of the natural depression in the dished plateau is 385·70 at 5 km. from the river, it is clear that the whole area could be drained even at highest river level.

Layout of Drainage Scheme

For ease of construction, maintenance, and agricultural administration, a rectangular layout of the area has been chosen, as illustrated in Fig. G 2. It will be seen that the smallest unit would be an area of 10 feddans (150 m. × 280 m.). This would be ridged so that drainage could be controlled by small banks into field-drains, corresponding to laterals in an irrigation system, which would discharge into field collector drains and thence to minor, major, and main drains. The layout to suit the contours is shown overprinted on the contour plan. Basically this consists of minor drains running at right angles to the river, leading to a major drain parallel to the river. This is modified at the western end owing to the existence of a natural depression in the middle of the western half of the scheme. The major drains meet in this depression whence the main drain leads to the river, cutting through an alluvial ridge on the way.

Drainage (or Run-Off) Factor

The general considerations which have led to the adoption of certain drainage factors have been given above (pp. 627–8). The maximum monthly rainfall in the area may be as high as 250 or 300 mm. but, since there would not be any irrigation, not all of this precipitation need be drained. In designing the channels the run-off has been calculated from the formula:

$$Q = 0{\cdot}162 \left(\frac{\text{Area drained in feddans}}{1{,}000}\right)^{0{\cdot}8}$$

which can be compared with the formula used in the Gezira (where drainage is complementary to irrigation), which is:

$$Q = 0{\cdot}174 \left(\frac{\text{Area drained in feddans}}{1{,}000}\right)^{0{\cdot}67}$$

The curve derived from the equation given above has been plotted on logarithmic paper, from which the run-off for different areas has been read and tabulated (Table 299 below).

Drain Design

The water-levels in all drains have been fixed at a minimum of 0·20 m. below ground level. In general it has been found possible to adopt the following scale of water slopes for different classes of drains:

Main drains:	12 cm/km.
Major drains:	15 cm/km.
Minor drains:	25 cm/km.

The cross-sections of the drain channels have been designed according to Manning's Formula with $^1/_n = 30$, which allows for considerable weed growth.

Major drain sections change where they are joined by minor drains, but sections of the latter are enlarged gradually by arranging that the slope of the bed is greater than the water slope. Field collector drains and field-drains have been given sections of 0·5 and 0·15 sq. m. respectively. In the case of main, major, and minor drains the spoil can be spread on both sides of the channels to a width sufficient for raised roads.

BANKING

In order to prevent run-off outside the area from entering it, a boundary bank at the edge of the cultivation would be necessary. A bank 1·0 m. high, 1·0 top width, and sides at 2:1 should be adequate.

STRUCTURES

Two types of structure would be required; inlets from smaller to larger drains, and culverts for roadways. In general, water-levels in minor drains at their outfalls would be higher than in the major drains. Extensive use has been made of standard steel pipes as used by the Sudan Irrigation Department, which serve the double purpose of inlets and road-crossings at the junctions of all drains. Field collector drains discharge into minor drains through 10 in. pipes.

DOMESTIC WATER SUPPLIES

It is assumed that the tenants of such a scheme would live on the alluvial ridge near the river and therefore no allowance need be made for drinking-water supplies in the dry season, except for the administrative staff.

B. EASTERN PLAIN

We have also considered in detail the layout of a drainage scheme of 100,000 feddans on the Eastern Plain. West of the Jonglei Canal the land would be protected from overland flooding, or creeping flow, by the Canal itself and, as explained previously, tributary channels leading to the Bahr el Zeraf would be conveniently situated for disposing of the run-off from the ground in this area.

The layout of this drainage scheme would follow the pattern of the drainage schemes which are complementary to irrigation (pp. 649–50). In this case, however, the run-off would have to be calculated according to the formula adopted for drainage without irrigation (p. 627). Field collector drains and field-drains would also have to be included. The watercourses and laterals would perform the functions of drains, when the need arose, in the case of schemes in which drainage was complementary to irrigation.

Domestic water supplies for cultivators on a large scheme on the Eastern Plain would require additional engineering works. The form of supply could be either small channels from the Jonglei Canal, or hafirs, or open wells dug to a depth of about 120 feet. In such a drainage scheme it would be desirable to arrange that a number of hafirs be filled by water collected by the drains themselves.

TABLE 299

RUN-OFF FROM GIVEN AREAS

Area feddans	Discharge m^3/sec.	Area feddans	Discharge m^3/sec.
100	0·025	1,500	0·23
200	0·043	2,000	0·29
300	0·060	3,000	0·40
400	0·077	4,000	0·50
600	0·107	6,000	0·70
800	0·136	8,000	0·88
1,000	0·162	10,000	1·04

TABLE 300

SIZES OF PIPE BRIDGES REQUIRED AT OUTLETS

Drain	Water-Level U.S.	Water-Level D.S.	Head if fully submerged m.	Discharge m^3/sec.	Best pipe drain diam. m.	Actual head required m.	Discharge at full head m^3/sec.
	Reduced Levels Datum 380 m.						
E. Major	6·35	5·58	0·77	0·70	0·76	0·20	1·50
W. Major	6·00	5·58	0·42	0·38	0·50	0·30	0·46
Minor at C ...	6·86	6·50	0·36	0·174	0·35	0·24	0·20
Minor at D ...	6·96	6·72	0·24	0·174	0·35	0·24	0·17
Minor at E ...	6·90	6·79	0·11	0·260	0·50	0·11	0·26
Minor at F (N.) ...	7·14	6·98	0·16	0·174	0·50	0·05	0·28
Minor at F (S.) ...	6·98	6·98	—	0·150	No structure required		
Minor at G ...	6·64	6·15	0·49	0·174	0·35	0·24	0·214
Minor at H (W.) ...	6·60	6·52	0·08	0·107	0·35	0·08	0·107
Minor at H (N.) ...	6·52	6·52	—	0·107	No structure required		

VII. *HARIQ* SCHEMES

AGRICULTURAL CONSIDERATIONS

We have already discussed, in general terms, the possibilities of *hariq* farming in the Transitional Belt between the Flood and Semi-Arid Regions (Vol. I, p. 204). The possibilities of improving crop output in this way are very considerable. However, from the description of the effects of the Equatorial Nile Project it will be seen that, in areas where *hariq* farming can be practised, the losses due to the Project could easily be remedied by purely pastoral measures. It is only in the northern Shilluk area that *hariq* schemes might be needed to make good local losses.

Our policy is to avoid resettlement on a large scale, but if it proves essential and is accepted as a general principle, then the development of agricultural production based on the extension of *hariq* farming could provide a livelihood for people affected by the Project in other parts of the Jonglei Area.

At present the two main crops grown by *hariq* methods are sorghum and cotton, but as we base our recommendations on stock-carrying capacity we have substituted groundnuts for cotton in schemes of this type. In fact we envisage a crop rotation similar to that proposed for the drainage scheme, but with the extended fallow period necessary for the regeneration of *hariq* grasses. Because of the unavoidable risks involved in *hariq* farming and also the additional hazard of drought in this area, we consider that the yields of crops will be generally lower than in drainage schemes. In calculating the stock-carrying capacity on *hariq* schemes we have reduced by 25% the yields on the drainage schemes. On the other hand the *hariq* system makes possible a greater area under crops for each holding. We have assumed the size of each holding to be twice that on drainage schemes.

DESCRIPTION OF SCHEMES

The following rotation would be suitable for a *hariq* scheme:

Groundnuts—sorghum and other food crops—4 years fallow.

This fallow period should be sufficient for the recovery of the grass, provided fire protection was efficient. Though weeding after sowing might be required, the more laborious forms of land preparation prior to planting should not be necessary except in areas where burning was badly mismanaged. Moreover, with a rotation of this type, there should be no undue trouble from *Striga hermonthica.*

With 7½ feddans of sorghum and ½ feddan of other food crops (cucurbits, beans, etc.), plus 8 feddans under groundnuts and 32 feddans under recovery fallow, each holding would cover 48 feddans. A suitable unit would be 60 such holdings, covering 2,880 feddans. The total area would be divided into 6 blocks protected by fire-lines. One block would be burnt off for sowing each year and subsequently divided into 60 plots, each belonging to one family unit. Groundnuts would be grown on this block in the first season and sorghum in the second, so that 2 out of 6 blocks would be under crop each year. The remaining 4 blocks would be under fallow and would have to be protected by fire-lines.

A suitable size of *hariq* block, sufficient for 60 plots of 8 feddans each, would therefore be 1,500 m. × 1,500 m. This allows just over 11% for bad patches, boundary paths, roads, etc., within the protected area. Since four such blocks would have to be surrounded by fire-lines every year, and assuming that (as might happen in the worst cases) each block would be separate, the total length of fire-lines required would be 1,500 m. × 4 × 4 or 24,000 m., i.e., 400 m. per family unit. The labour requirements for the clearing of fire-lines under the conditions of the *hariq* belt in the Jonglei Area are 30 labour days per 1,000 m.[7]. Consequently each family unit would have to provide about 12 labour days each season for the clearance of fire-lines, not an excessive demand. We therefore consider that in *hariq* schemes of this type, involving permanent settlement in the cultivation area, it would not be necessary to provide mechanical or chemical assistance for this task. The central authority would have to provide domestic water supplies, which are lacking in this area during the dry season. It would also have to provide oil mills (or ginneries if cotton were the main crop), as the production of groundnuts and the local consumption of groundnut cake are primary objectives.

The central authority would also have to provide over-year storage facilities because, where there are no means of alleviating moisture deficiencies and so much depends on difficult *hariq* operations, year to year variations in crop output would be unavoidable. Finally, the central authority would be responsible for giving agricultural advice, all the technical supervision necessary in this system of farming, and the marketing of produce, in this case oil.

We consider therefore that schemes of this type should be based on a partnership between a central authority (e.g., board) and the participating cultivators. Their shares in the revenue could be considered later in the light of practical experience.

Stock-Carrying Capacity of *Hariq* Holdings

The holding described above should produce the following quantities of digestible crude protein on the basis of which we calculate the stock-carrying capacities:

TABLE 301

DIGESTIBLE CRUDE PROTEIN PRODUCED BY A 48-FEDDAN *HARIQ* HOLDING

Fodder	D.C.P. %	Area feddans	Yield kg.p.f.	Output of holding kg.	Handling losses %	Fodder available kg.	Available D.C.P. kg.
Cereal stover ...	1·5	7·5	1,200	9,000	30	6,300	95
Groundnuts stover	3·5	8·0	375	3,000	40	1,800	63
Groundnuts cake...	42·0	8·0	110	880	10	790	332
Total							490

The number of Animal Units which one holding of this type would support can be assessed as follows:

the output of digestible crude protein is divided by the daily requirements per Animal Unit and by 150—the number of days when grazing is not available:

$$\frac{490}{0{\cdot}25 \times 150} = 13{\cdot}0$$

TABLE 302

CARRYING CAPACITY OF *HARIQ* HOLDING OF 48 FEDDANS
WITH COTTON SUBSTITUTED FOR GROUNDNUTS
OUTPUT OF DIGESTIBLE CRUDE PROTEIN PER HOLDING

	D.C.P. %	Area feddans	Yield kg.p.f.	Output of holding kg.	Handling losses %	Fodder available kg.	D.C.P. kg.
Sorghum stover ...	1·5	7·5	1,200	9,000	30	6,300	95
Cotton seed ...	13·5	8·0	120	960	10	860	116
Total							211

Stock-carrying capacity:

$$\frac{211}{0{\cdot}25 \times 150} = 5{\cdot}6$$

We have considered cotton as an alternative to groundnuts, but have based our calculations in the summary of unit costs on the latter, because groundnuts provide more digestible crude protein for fodder and will therefore support more animals.

Minimum Size of the Unit

As schemes of this type require oil mills (or ginneries, if cotton is adopted instead of groundnuts), they must be organized on a sufficient scale to assure the steady supply of the crop in sufficient quantity for a processing plant. As we have already shown (see p. 655), 1,500 tons of groundnuts would be required annually to assure the economic running of an oil mill. On the basis of the yield of 300 kg.p.f., 5,000 feddans should be under groundnuts to ensure sufficient output, making the gross area of the *hariq* scheme 30,000 feddans.

ENGINEERING WORKS

The engineering works required in connection with *hariq* schemes only concern housing for the staff and water supplies.

Buildings

Adequate buildings must be provided to accommodate supervisory staff, and the expenditure required has been included in our estimates of the Unit Costs.

Water Supplies

The provision of water supplies is more difficult to achieve at small cost. We have suggested that hafirs should be used, because that is the method now adopted in the area where *hariq* schemes could be applied as remedies, namely in the northern part of the Shilluk district. Their cost contributes 60% of the whole cost of this remedial measure. It is difficult to see what better method could be employed. One alternative, deep-bore water-yards, suffers the disadvantage of high maintenance costs, estimated to be 25% of the capital cost (see p. 675). The preliminary investigation of sub-soil water supplies has shown that in this area the water may be expected to be of high salinity and therefore unsuitable for drinking. Shallow open wells would be cheaper to maintain, but large numbers of animals could not be watered easily if water had to be drawn by hand; it is clear that a large number of such wells would be needed, and again it is suspected that the supplies would be saline. The only other possible method would be to pump water from the river and to distribute it by pipe-line to the places where it was needed. This would clearly be uneconomic in view of the large areas of *hariq* land required, of which two-thirds would lie fallow.

3. COMBINED REMEDIES

VIII. RICE AND PASTURE GRAVITY IRRIGATION SCHEMES

AGRICULTURAL CONSIDERATIONS

In a previous chapter we have shown that pasture could be produced under irrigation in the Jonglei Area (see p. 564), but in addition to the capital cost irrigated pasture would require a continual subsidy for maintenance. In a combined rice and pasture scheme capital costs would be greater, but the annual return from the sale of rice should be sufficient to cover the running costs of the whole scheme including pasture and, at present prices, possibly pay interest on the capital invested.

Such a scheme could be operated in those areas which can be irrigated in the Northern Zone. It could also be applied with advantage in the Flood Region, where drainage is a particular problem and where cash crops, other than rice, would require special drainage facilities to overcome waterlogging. Furthermore it would be agronomically sound to alternate rice with pasture leys, and an arrangement whereby rice could be irrigated in the wet season and pasture in the dry season would make the best and most economical use of land and water.

It is not intended that the scheme should consist of a number of permanent peasant holdings, though such an organization might be possible. It would be better for the scheme to be an alternative to riverain pasture in the dry season, to which the people could migrate annually, rather than one which would be occupied by them permanently. Rice could then be produced by cultivating with machinery at less cost and more efficiently than by the hand methods employed by peasant farmers. Some of the people would be employed as labourers on the scheme, but not as participating cultivators.

Description of Scheme

The design of a rice and pasture scheme would be as follows. The object of the scheme would be to produce enough pasture for the number of livestock displaced from riverain pasture in the dry season. The minimum area of rice is that which would finance the production of pasture. It is proposed to apply a ten-year rotation as follows:

Dry Season	Rains Season
1. Breaking up of pasture; preparation for rice	Rice crop
2. — — — — — — —	Rice crop
3. — — — — — — —	Rice crop
4. — — — — — — —	Rice crop
5. Establishment of pasture ley	—
6. Grazing of pasture ley	—
7. Grazing of pasture ley	—
8. Grazing of pasture ley	—
9. Grazing of pasture ley	—
10. Grazing of pasture ley	—

It can be seen that in each decade a unit of land, which is one-tenth of the whole, would carry four rice crops and five pasture crops for grazing in the dry season. On each unit in the first year, hay-making and grazing would be carried out on the land but no irrigation water applied. From March onwards the land would be cultivated, and sowing would start in May. Rice would be harvested between September and January, depending on the variety and date of planting. These processes, from May onwards, would be repeated in the three succeeding years, that is the second, third, and fourth years.

In the fourth year a quick-maturing variety of rice would be grown so that pasture could be established soon after the rains. As soon as the rice crop was harvested, grass would be sown by drill directly into the stubble. During the dry season of the fifth year, irrigation would be as light as possible to prevent excessive waterlogging in the succeeding rainy season, and it is likely that one or two light waterings following the sowing would be sufficient.

The pasture would be allowed to grow as usual during the rainy season of the fifth year, and as soon as the land was sufficiently dry to allow operations this growth would be cut for hay (October–November). The pasture would remain ungrazed until the dry season of the sixth year, unless it was in danger of being smothered by the regrowth of rice. By the end of December the seasonal migration would have begun and the livestock requiring to be accommodated on irrigated pasture would have arrived. They would remain on irrigated pasture from the beginning of January until the middle of May or later, by which time there would be sufficient grass and surface water inland to allow their return to the permanent villages. For the next five years (from the sixth to the tenth inclusive) the land would be grazed in the dry season. From mid-May of the tenth year until March of the eleventh year the grass would not be irrigated but made into hay or grazed lightly.

The ten-year cycle would then begin again.

Crop Husbandry

As we have already stated, mechanization can best be applied to cereal production on a large scale, and it has been proved (as for instance in America, Canada, and Australia) that this method is more efficient and economical than manual labour with or without the help of draught animals.

Since rice would be grown on these schemes as a cash crop to pay for the cost of irrigating pasture, it should be produced in the most economical way. This could only be achieved by employing the highest standard of husbandry, which would be difficult to enforce on numerous peasant holdings. We therefore consider that rice production ought to be fully mechanized but, as already stated (see p. 597), tillage operations must be kept to the necessary minimum. These should suffice:

(i) Two discings with a wide one-way disc of the Massey Harris '26' type.
(ii) Drilling, possibly combined with fertilizer placement.
(iii) Application of fertilizer before or after drilling.
(iv) One hand-weeding of the most weed-infested fields only.
(v) Harvesting with combine-harvester.

In addition the application of selective herbicides, insecticides, and possibly crop desiccators, to achieve uniform maturity, might prove economic. To save transport costs, hulling should be done on the spot. Another operation which would only be required once in ten years (i.e. one plot in ten, every year), in order to break up the pasture, would be heavy discing with either a one-way disc similar to a Massey Harris '509' or an even heavier implement.

Pasture Husbandry

As already stated (see pp. 567–9), rotational grazing would not only be desirable to achieve the greatest output from the pasture but would be essential because the watering schedule would have to be followed. The length of the grazing period in each plot could only be determined by experience after a pasture had been established. In order to maintain the health and vitality of the ley throughout the five-year period, two annual treatments would be required, one at the end of the rainy season and one at the end of the last grazing season period. The type of treatment would depend on whether the pasture were a sward, requiring harrowing, or established rows, requiring inter-row cultivation (see p. 568). We do not consider that artificial fertilizers need be applied. Because of the comparatively heavy application of fertilizer to the rice crop, there should be sufficient residue in the soil to assist the establishment of the pasture. Thereafter, because animal products are largely consumed in the locality and because of the absence of any organized sewage destruction, most of the nutriment withdrawn from the soil would return directly, in the form of human and animal excreta.

For the purpose of this scheme a unit would be an area of 100 feddans, divided into plots of 10 feddans, each plot carrying one stage in the 10-year rotation. The perimeter of each unit would be permanently fenced. Temporary and movable fences would divide the pasture plots from the others in the station. Electric fences should be quite sufficient to keep the cattle on the grazing plots. An alternative would be to plant hedges around all plots, but these would be difficult to establish and their effectiveness is doubtful. For various reasons given above (pp. 568–9), the cattle would return at night to permanent camp areas close to, but outside, their irrigated pastures, where water-points would be situated.

Hay-making

The irrigated pasture would be vacated at the end of May and its growth would therefore continue unchecked throughout the rainy season. By January, after seven months' growth, the grass would be old and coarse. In order that the grass might be in a young, nutritive state when grazing began it would be necessary to remove this growth; so the grass should be cut in late October or early November, about six to eight weeks before the grazing period. If this cut were made into hay it would make a substantial contribution to the animal fodder for use in the succeeding dry season. This hay would be stacked and fed in the plot from which it was cut. The operations needed would be:

(i) One cutting by tractor-drawn mower.

(ii) Harvesting by pick-up baler (harvesting and stacking by hand would be a lengthy process requiring adequate labour at a time of year when labour is not normally available).

(iii) Carting and stacking of bales.

Yield of Fodder per Unit per Annum

From a 100-feddan unit the following dry season feeding stuffs would be available annually:

50 feddans irrigated pasture

50 feddans hay (cut from the above after the previous rains)

10 feddans hay (cut from the pasture plot prior to sowing with rice)

40 feddans by-products from the previous season's rice crop.

The yields in terms of digestible crude protein are tabulated below:

	D.C.P. %	Area feddans	Yield kg.p.f.	Output per unit kg.	Handling losses %	Fodder available kg.	Available D.C.P. kg.
Hay[1]	3·5	60	1,250	75,000	20	60,000	2,100
Rice Straw[2] ...	0·5	40	1,000	40,000	30	28,000	140
Bran[3]	7·5	40	75	3,000	20	2,400	180
Husks[4]	0·5	40	150	6,000	20	4,800	24
Total							2,444

(1) See p. 645.
(2) See Table 285, p. 611.
(3) See Table 285, p. 611.
(4) See Table 285, p. 611.

We have already calculated that the daily requirement of one Animal Unit (average bullock) in the Jonglei Area is 0·25 kg. digestible crude protein (see p. 571). Therefore the above is sufficient for 9,776 Animal Unit days.

The irrigated pasture is expected to have a stock-carrying capacity of 1·5 Animal Units per feddan per season of 150 days. Thus 50 feddans of pasture should provide 11,250 Animal Unit days grazing. This does not include the value of (*a*) the plot being converted from pasture to rice, after the hay cut in November, or (*b*) the new growth of grass in the plot in which pasture is being established. But their value is not easily determined and is deliberately excluded from the estimate of stock-carrying capacity.

The total output of animal fodder per annum from a 100-feddan unit is therefore grazing for 21,026 Animal Unit days (9,776 plus 11,250). This would support 140 Animal Units throughout the 150-day dry season.

The possibility of growing fodder crops on an irrigation scheme in the Flood Region has been discussed in a previous chapter (p. 569), where it was decided that their introduction in this connection would not be desirable.

Irrigation and Drainage on the Eastern Plain

In another section of this part of the report we have described in detail the application to the Eastern Plain of an irrigation scheme producing agricultural crops such as cotton, sorghum and a legume (pp. 647–52). There is no need to repeat here such a full description of a typical rice and pasture scheme, but we must describe the differences in irrigation methods between the two types and assess what effects these differences would have on the engineering works required.

Water-Duty

It will be remembered that in the basic design the crop water-duty was assumed to be 950 m³.p.f. per calendar month. This is the maximum requirement of the usual agricultural crops in a month in which there is no rainfall. We have also assumed that watering would be continuous by day and night and that two-thirds of the whole would be cropped. The over-all water-duty would therefore be 633 m³.p.f. per month. From experience in Malakal it is estimated that the maximum water-duty of a rice crop in a dry month is 1,500 m³.p.f. Also it is clear from the statements made previously on the agricultural and pasture management aspects of the scheme that 40% of the area would be under rice. Although in the design of the scheme it is intended that most of the irrigation of rice would take place during the rains, the crop would need irrigation in November and possibly December, when rainfall would be negligible, so the irrigation canals must be designed to the maximum requirements of water mentioned above. However, as only 40% of the area would carry rice, the over-all water-duty would be 600 m³.p.f. per calendar month. On the whole therefore the irrigation works required for a rice and pasture scheme as described above would be almost the same as those needed for other normal crops, even though there would be adjustments in detail, as for instance altering the layout to suit 100-feddan, and not 130-feddan, units. The above general principle could be applied in detail provided that only 40% of the area irrigated by any channel was cropped with rice. In the rice and pasture scheme which we have designed the unit specified consists of an area of 100 feddans divided into 10-feddan plots. Therefore all main, major and minor canals, and the regulators on them, would be the same size as in a scheme designed to irrigate the more usual types of crops. Even the watercourses, which serve units of 100 feddans, need not be any larger, since only 40% of the area served by them would be under rice and in any case their size is determined by the volume of earth required to make banks and not by hydraulic considerations. When considering the next smallest irrigation unit, an area of 10 feddans irrigated by one field-channel, we must examine the matter more carefully. Each field-channel would be required to irrigate 10 feddans of rice or 100% of the area it served. Since the size of a field-channel, too, is based on the requirement of earth for banks, it is possible that the standard size used for normal irrigation would not need enlargement to irrigate rice if other things were equal. However, the method of irrigating the field would be different. Instead of distributing water through smaller channels and thence to ridges and furrows, the watercourses would discharge directly on to flat fields, which are essential for mechanized rice production. The normal spacing of field-channels in combination with ridges and furrows is 153 m. Experience on the pump scheme at Malakal has shown that the limit of penetration of water from a field-channel over a flat field of rice is 75 m., and therefore the number of field-channels in this scheme would have to be doubled to ensure adequate distribution of water. Alternatively we could alter the dimensions of the 10-feddan plot from 150 m. × 280 m. to say 100 m. × 420 m., and in this way each field-channel would water land up to 50 m. on each side of it. This alternative layout would be better for tractor operations, since there would be longer straight runs and less land wasted in turning space at each end. But for the purpose of estimating the engineering works required we will assume that the field-channels would be doubled in number. With this one proviso we may say that the engineering works required to irrigate a rice and pasture scheme of the type we envisage would be the same as those on the more normal type of scheme, the design of which we have described in detail.

Drainage

As we have explained in the general considerations of remedial measures, there are two aspects of drainage which must not be confused; the engineering one which is concerned with the disposal of surface water, and the agricultural one which is concerned with the extraction of moisture from the soil itself so that conditions are suitable for plant growth. It has already been stated that rice is particularly suitable as a crop in the Flood Region because it does not need aeration of the soil it grows in. In an irrigation scheme for rice therefore, drainage in the agricultural sense is not necessary, but a moment's consideration of the probable effect of a storm of 200 mm. of rain on an area which may have had irrigation applied just previously at the intensity of 1,500 m³.p.f. is sufficient to indicate the need for drainage in the engineering sense. In the absence of any practical experience of irrigation and drainage on this scale in the area concerned, we propose to adopt the same formula as previously in calculating the expected run-off from rainfall in addition to irrigation (see p. 627). This seems reasonable as the over-all irrigation water-duty is the same in both schemes during the rains. We may conclude that, for the purpose of this estimate, the same drainage works would be required in the scheme under consideration.

Irrigation in the Aliab Valley

So far we have considered only the possibility of irrigation by gravity flow on the Eastern Plain, according to the standard layout of canals and watercourses as practised elsewhere in the Sudan. In our general description of the engineering possibilities of remedial measures we noted that gravity irrigation would be possible in the Aliab Valley, and that the ' contour ' method of irrigation as practised in Australia might well be applied in the Southern Sudan. We consider therefore that the design of a ' contour ' irrigation scheme in the Aliab Valley would show how such a method could be applied in the Jonglei Area, and enable us to estimate in detail the engineering works required for it and their cost.

The Problem of Flood Protection

The Egyptian proposals for the Equatorial Nile Project include the construction of a bank on the west side of the Bahr el Jebel from Tombe to the barrage downstream of the Atem Head. Since, as we have pointed out, the engineering details of this banking are not explained, we must assume either that the bank would be designed to withstand the highest levels likely to arise during a period of flood-escape, for clearly a bank that is large enough to retain only normal discharges would be destroyed by higher floods and would need rebuilding, or that any additional flow above the normal would be spilled through regulators into the Aliab Valley or, another possibility, be carried through it in a suitably large channel. From the example of the distribution of flow between the Bahr el Jebel and the Jonglei Canal for a discharge of 150 m/din the 80 m/d Canal stage (see p. 459) it appears that the first suggestion is what is intended, though, from what details we have been able to obtain, we have shown that the idea has not been considered fully. Under normal conditions in the 55 m/d Canal stage, the Aliab Valley will be banked off so that the river will not spill into it, and consequently the grazing and fishing interests there will be affected. Since the Project itself will provide the banking essential to protect the area from the river, it is clearly desirable to investigate the possibilities of irrigating the area under controlled gravity flow from the river. We must, however, emphasize that any remedial scheme situated on what are now flood-plains of the river, and therefore on ground below the level of the river, will be liable to destruction by flooding during a period of escaping flood-waters unless adequate provision is made to carry the higher discharges in safety past the areas concerned.

Preliminary consideration was given by the Team to various methods of irrigating pasture in the Aliab Valley. In one scheme water would have been ponded by building banks across the valley and thereby dividing it into a number of basins. This was not taken further because the hydrological requirements of the grasses could not be met satisfactorily. Another scheme considered for pasture required that one flush of irrigation water should be applied in the dry season after the natural coarse grasses, which would appear under the altered hydrological conditions, had been burnt off. This method was suggested by the observations on shallow-flooded *toich* grasses which do not flourish after burning until the early rains begin to fall. Since such a scheme would in any case require an extensive layout of channels, we consider that it would be preferable as a remedial measure to use those channels for irrigating pastures or other crops in the normal way. What follows, then, is a description of an irrigation scheme suitable for any cropping, including a combined rice and pasture scheme as described for the Eastern Plain.

Contour Irrigation

Preliminary figures for levelling the ground, so that the Australian ' Border Check ' method of irrigation could be applied, show that the enormous volume of 19,000,000 m³. of earth or 630 m³.p.f. would have to be moved to provide the sloping plane surface essential in the ' Border Check ' method. We therefore conclude that the ' contour ' method, also common in Australia, would be the only satisfactory system which would overcome the unevenness of the ground and be suitable for the comparatively steep major slopes of 1·0 m/km.

An examination of the contour plan and cross-sections of the Aliab Valley suggests that an area of about 30,000 feddans in that part of the valley which has been surveyed is suitable for this method of irrigation. It lies between the Bahr el Jebel and the River Aliab (Khor Ker) and north of the present Aliab head near Gukthon (Fig. H 1). A suitable design would be as follows.

Design of the Scheme

Two feeder channels, taking off from the Bahr el Jebel through twin regulators at the present Aliab head, would follow the high ground down the valley; one on the alluvial ridge of the Bahr el Jebel on the east side of the valley, and the other on the alluvial ridge of the River Aliab on the west side of it. These channels would be of constant section throughout, so that they could be used to escape water when necessary to the tail of the scheme. This would not necessarily be a wasteful method because the same excavation would be needed in any case to provide earth for a bank, as will be seen later. From these feeder channels watercourses would run across the valley from the high ground towards the central drainage line and carry the supply of water to the bays into which the whole area would be divided by contour banks. The watercourses would be spaced at 200 m. intervals. The banks or levées would be wide in relation to their height; about 6 m. wide at the bottom and about 0·5 m. high in the middle. They would be constructed on contours at intervals corresponding to 0·10 m. difference in height between them. As the average slope down the contours is 1·0 m/km. (see Fig. H 1), there would be 10 contour banks in one kilometre at intervals of approximately 100 m. The bays, or areas enclosed by banks and watercourses, would average about 5 feddans each. The method of irrigating would be to open water on to the topmost bays first. When they were flooded, excess water would be drained on to the next lower bays, and at the same time the supply of water in the watercourse would be switched from the top to the next lower bays, and so on. Drainage would be provided in the same watercourses, as well as from bay to bay as described above. There is a natural drainage line in the centre of the valley (see Fig. H 1) into which the watercourses would discharge when they were being used as drains. Some improvement of the natural drainage line by excavation might be necessary.

The details of the design would be as follows:

MAJOR CANALS

To irrigate an area of 30,000 feddans (127 sq. km.) there would be two major canals designed to serve 15,000 feddans each. We assume as before that the maximum water-duty in a dry month would be 950 m^3.p.f. If two-thirds of the area were under crops the water-duty in the major canals would be 20 $m^3/f/d$, which is the standard practice of the Sudan Irrigation Department for a continuous watering system. The total discharge would be 600,000 m^3. per day, and each major canal would supply water at the rate of 300,000 m^3. per day (3·5 cumecs). Suitable dimensions of a major canal would be:

Bed width 4·0 m. Water depth 1·35 m.

Side slopes 2 : 1 Water slope 11·5 cm/km.

If the average command in the major canals were 0·30 m., the average excavation would be 6·4 m^3. per metre run. One bank only would be required for each canal, as the other bank on the east side of the valley would consist of the river protection bank, and on the west side of the alluvial bank of the River Aliab. For a roadway 4 m. wide on top of a bank designed to 0·75 m. cover above water-level, the excavation necessary would also be 6·4 m^3. per metre run. Hence the canals could economically be excavated to the same capacity throughout their length. The total length of major canals would be 73 km., and the volume of earth work 460,000 m^3.

WATERCOURSES

These would be designed to a command of 0·20 m. at the outlets to the bays, which is estimated to be sufficient for the water to travel 200 m. from each watercourse. The total length of watercourses would be 635 km. (area in square kilometres multiplied by 5) and the volume of each required to provide two banks to each watercourse, 0·5 m. high and 1·0 m. wide at the top, would be 1,270,000 m^3. or 2 m^3. per metre run.

CONTOUR BANKS

From the major canals to the natural drainage line the range of level would be 5 m., and, since the contour banks would be constructed at intervals of 0·10 m. difference in level, there would be 50 banks. Their average length would be 18 km. The section of the contour banks would be 6 m. wide at the bottom and 0·5 m. high in the middle, an area of 1·5 m^3. Hence the total volume of earth in the contour banks would be 1,350,000 m^3.

DRAINAGE

Improvements to the natural drainage line have been assessed at 5 m³. of excavation per metre run, or 175,000 m³. all told in a length of 35 km.

SUMMARY OF EARTHWORKS

Major Canals	460,000 m³.
Watercourses	1,270,000 m³.
Contour Banks	1,350,000 m³.
Drains	175,000 m³.
Total	3,255,000 m³.

STRUCTURES

The headworks would have to be simple but substantial regulators. They would consist of twin regulators each feeding one major canal, and we can compare the standard of their construction with the major canal regulators in the 100,000-feddan irrigation scheme in the Eastern Plain (see p. 651), but their size and cost would be scaled down in proportion to the areas they were designed to serve. The intermediate regulators on the feeder canals would all be of one size, and simple pipe regulators protected with dry rubble pitching would be sufficient. Each regulator would consist of three 1·24 m. diameter pipes with doors. Sixteen regulators would be required all told. The watercourses, serving about 125 feddans each, would take off from the feeder canals directly through field outlet pipes, of which 300 sets would be required. In the watercourses 10 in. pipes would be required, and through their banks 8 in. pipes, one of each for each contour bay, totalling 7,500 of each kind.

4. FISHERIES REMEDIES

Estimates of the order of losses in fisheries and mention of the difficulties which may arise have been made (see p. 524). Remedies to meet these losses fall under two main headings:

(i) The development of commercial fisheries in those areas where the potentialities remain even when the Project has been completed.

(ii) The provision of fish farms in those areas where the actual stock of fish is substantially reduced.

IX. THE DEVELOPMENT OF COMMERCIAL FISHERIES

The former method involves the training of personnel in the technique of netting fish, and also the preparation of fish in the form of sun-drying, canning, and in some cases smoking. Preliminary tests carried out by the Jonglei Investigation Team have been described in previous reports (Jonglei Investigation Team, *Progress Report* 1948–49, and H. Sandon, ' Problems of Fisheries in the Area affected by the Equatorial Nile Project ', *S.N. & R.*, Vol. XXXII, 1951).

Since then, the Fisheries Section (under the Game Department) has carried out further experiments. It seems clear that development—especially in the southern reaches of the Northern Zone—will best take the form of centralized co-operative schemes, a procedure necessary to ensure sound marketing systems and the provision of apparatus at an economic price. The amount of training and supervision will depend largely on the stage of development reached by the time the Project is in full operation. It must be remembered also that it will be necessary to assess the effects of the Project on such commercial fisheries as have developed in the interim. We cannot enter into further detail here. We have already recommended the line of investigation and experiment we consider necessary (see p. 524). We can only recommend that, included in the costs of remedial measures, a sum be set aside to subsidize the initiation of commercial fisheries in those areas where indigenous fishing techniques are no longer effective, and to cover any substantial losses in the output of commercial fisheries by then in existence.

X. FISH FARMING

Fish farming—the cultivation of fish in natural ponds and lakes and in artificial pools—is increasing in Africa, particularly in the Belgian Congo and some of the East African territories. Many projects, though still in the early stages of development, are promising, and we can safely assume that it would be both practicable and economic to apply this method as a remedial measure. There may be opportunities to make use of natural lagoons and depressions by the addition of simple and comparatively inexpensive works, especially in the Southern Zone.

Under future conditions many lagoons could be banked to give full control. The alternative, which is universally applicable, is the creation of artificial ponds by excavating and banking. Here we assume that 1·5 m. of water is the minimum depth required; a depth we consider adequate in the Southern Sudan where temperatures, particularly important during the growing period, are generally lower than in the Northern Sudan, and where relative humidity is high.

In considering the relative advantages of these two forms of fish-ponds, it is clear that (in the Southern Zone) the first—natural lagoons—could be successfully utilized since there would be an adequate head of water in the timely season and opportunities to drain in the untimely season. In our opinion, however, this form of land and water utilization has disadvantages. In the first place the slope is such that to obtain adequate water at the upper limits would require a very great depth and hence very high and expensive banking at the lower ends. Secondly, the draining period would coincide with the rains when relative humidity is normally high and the curing and storing of fish is always difficult. Finally, such a method, giving only poor control, cannot aim at more than the production of fish under more or less natural conditions, with yields which, in relation to capital costs, are likely to be uneconomic. In the Central Zone some depressions will be above the future maximum and for that reason could only be irrigated by pump. Others are below minimum and could only be drained by pump. In other words, the range is not great enough to give both supply and drainage by gravity.

Therefore, though we admit the possibility of utilizing such depressions, the object being to produce fish under conditions not dissimilar to the natural ones, we have based our estimates on the second form, the provision of properly constructed fish farms. We shall deal with the question of local application of such remedies later, but we must mention at once that we consider that such schemes could not be applied as a direct substitute for the present unspecialized form of fisheries. The capital expenditure involved would only be justified if the strictest form of control and management were applied with the object of providing the largest possible yields. It is worth mentioning also that in order to provide an exact substitute for this item in the present subsistence economy of the people it would be necessary to site the fish farms in a well-distributed pattern throughout the area; as will be obvious, the siting would have to coincide with the movements of the people under future conditions. This would not only be very difficult but would necessitate a large number of small fish farms, and the smaller the farm the greater the over-all costs of the remedy. Alternatively, the farms could be run more suitably on a purely commercial basis by a specialized section of the communities involved.

We therefore consider that the most suitable remedy is fish farming, adequately managed and controlled, run in conjunction with other irrigation schemes along the Jonglei Canal or along the main river, and operated by a small specialist proportion of the population.

Yields from Fish Farms and Requirements in Feddans

In Africa fish farming is as yet in the experimental stage only. The productivity of fish-ponds varies considerably with fertility and farm management. As a basis for our calculations we take the following figures:

Without treatment ... ... ½ metric ton per feddan.
With treatment... ... ... ¾ to 1 metric ton per feddan.
With treatment and feeding ... 1 to 2 metric tons per feddan.

The objective must, of course, be the production of the highest possible yield per feddan in relation to the costs of treatment and feeding. For the purposes of our calculations we take one metric ton (of wet fish) per feddan as being the standard yield. It follows that, in round figures, 300 feddans of fish would be required in the Southern Zone and 2,800 feddans in the Central Zone (see Chapter 4, p. 524).

Generally speaking the larger the farm the smaller the relative costs per feddan, both in construction (especially in an area where long distances and heavy transport costs are involved) and in maintenance. For the purpose of estimates we have taken 200 feddans as a minimum.

Before giving a summary of our estimate of unit costs, brief mention must be made of the possibilities of growing fish in combination with rice or rice-pasture schemes (see p. 660). In many territories experiments in this form of production are being carried out, and the results are encouraging. Under normal conditions in the Jonglei Area fish nearly always enter irrigated rice schemes sited on the flood-plain; a fact which was amply demonstrated in the experimental *toich* schemes opposite Malakal, though unfortunately no attempt was made to record the yields. In the comparatively short period of the rice growth (maximum six months, depending on the variety) only small natural yields can be expected. If the rice fields are stocked with suitable fish, worth-while yields may be expected, again depending on the period during which the crop is under water, but ranging from perhaps 50 kg.p.f. where the fish rely on natural feeds, to as much as 1,000 kg.p.f. where they are fed. In some cases it might be possible to grow fish during a period of wet fallow in rotation with rice and pasture grasses, or to grow them in combination with rice and pasture where the type of ground required considerable depth and duration of flooding (e.g., *Echinochloa*, etc.). In fact this combined operation would only be possible in low *toich* schemes irrigated by gravity—a method which we have discarded as uneconomic—and does not appear to be suitable for the type of rice-pasture rotation which we have recommended. The possibilities should not, however, be forgotten.

The design of the fish farm described below is not based on any reliable experimental work and is included merely to indicate the order of the costs.

Estimate of the Engineering Works Required

As we have no practical experience of the engineering designs of fish farms what follows may, or may not, be practicable. We have given the problem some thought and it is hoped the results will not be found unreasonable. The first requirement for a fish farm is that the depth of the pond should be between five and six feet (in the Jonglei Area). We have assumed that the optimum depth is 1·5 m. Ideally the units should be as small as possible, and we have made a preliminary design based on 5-feddan units. It is obvious that the volume of excavation in an area of 200 feddans divided into 5-feddan units by earth banks would be considerable. Using Carryall Scrapers, or Euclid Loaders with Dump Trucks, it would be possible to balance cut against earth required for banks, but the method would be costly, and only a small reduction in the level of water above ground could be made (0·3 m.).

For these reasons we have decided that the basic units must be larger and the whole depth of the pond must be above ground level. On the flat plains of the Central Zone, where fish farms will be needed most, it is impossible to obtain a range in level of water of 1·5 m. by gravity alone. In the irrigation scheme designed by us for the purpose of estimating costs, the usual command for a major canal is 0·5 m. and the drains are designed to a water surface of 0·2 m. below ground. This is a range of 0·7 m., and the remainder to make up 1·5 m. must be obtained by pumping in or out. The latter requires deep excavation, so we have adopted the former.

Layout of a 200-Feddan Fish Farm

A square area of 200 feddans divided into four quadrants is assumed to lie between a major canal and a drain. The external banks and the internal dividing banks would hold a level of 1·5 m. above ground. Pipe regulators would be required (a) to supply water from the canal (as far as gravity flow would permit), (b) to connect one bay with another, (c) so that each pond could be drained independently, and (d) to serve as overflow pipes to dispose of rain-storms. Pumping units would be required to lift water from the canal to the maximum height above ground, and to replace water lost by evaporation.

BANK DESIGN

The outer banks would be designed to hold a head of 1·75 m. (0·25 m. above normal head) with a hydraulic gradient of 7 : 1. The top of the bank would be 4 m. wide, and 0·75 m. cover above normal water-level. There would also be a counterberm, 3 m. wide and 1·0 m. high, on the outer toe; the excavation for the latter would be outside the bank and would form a perimeter drain. The internal cross-banks would be designed to the same standard, but without the counterberm. The length of a side of the square would be 917 m. and the total volume of excavation 126,000 m^3. We assume that half of it could be dug by elevating grader, and the remainder by drag-line excavator.

STRUCTURES

Simple pipe regulators, using 0·5 m. diameter pipes fitted with doors and some dry rubble pitching, seem most suitable. They would supply water by gravity from the canal, distribute it between the four ponds, allow each pond to be drained independently, and provide overflow escapes for rain-water.

The total weight of steelwork for pipes and doors would be 22 tons, to which we have added 10% to allow for fish screens.

PUMPS

The total capacity of the ponds would be 1·26 million m^3., of which 0·42 million m^3. could be supplied by gravity flow (including absorption over the area). It is assumed that the remainder, 0·84 million m^3., would be supplied in a month. Filling would be carried out during the rains, when evaporation is less than rainfall. Theoretically, pumping 12 hours per day against an average lift of 0·5 m. would require 102 h.p. Allowing 75% efficiency and 50% standing unit, a total of 204 h.p. would be needed. This could most conveniently be supplied by 3 units of, say, 70 h.p. each.

QUANTITIES

The following is a summary of the quantities required:

Excavation for Banks	126,000 m³.
0·5 m. diam. Pipes and Doors	22 tons
Dry Rubble Pitching	240 m³.
Pumping Installation	210 h.p.

There are numerous lagoons and depressions near to the river in the Northern Zone which will be accessible under the Project. It might be possible to supply water to them by gravity flow, in which case today there is sufficient variation in level between high and low river so that both supply and drainage could be effected by gravity flow. The present range of 2·3 m. would be reduced to approximately 1·0 m. under the Project, and pumps would have to be used for one purpose or the other. However, since the cost of the pumps would be the largest item, and since these lagoons would be most likely to be found in small units of, say, 10 feddans, it is not likely that the cost per feddan would be appreciably less.

5 OTHER POSSIBLE REMEDIES AND ALTERNATIVES

XI. UTILIZATION OF INLAND WATERCOURSES

In the survey of the Jonglei Area we have described the type of inland watercourse which is common in certain parts of the Flood Region; wide, shallow, heavily grassed, of small slope, and carrying a small discharge. We have also shown that where these watercourses are connected to a river, the flow in them may travel in both directions; towards the river in the wet season, and away from it in the dry season. They are generally bound by alluvial banks which are classed as high land in this flat area. Today they are of immense value during the rains for local drainage, as is demonstrated by the common occurrence of cultivations and habitations on their banks, and in the dry season for pasture and water supplies in their beds. They are to be found mainly in the northern part of the Eastern Plain, on the Zeraf Island, on the Western Plain (in Western Nuer District), and in the southern part of the Northern Zone.

Early in the investigation the possibility of making some use of these watercourses as a remedial measure was considered, and the design for a scheme to improve pasture was worked out on the detailed survey of the Khor Adar. As this was too large a scheme for an immediate experiment, and because there were objections to it on other grounds outside the scope of this report, attention was diverted to another area, Khor Tiak in the Western Nuer District, where an earth dam was constructed by hand labour in May 1951. The bank, 430 m. long, was designed on hydraulic principles, and involved 5,114 m³. of earthwork. Spillways covered by natural grasses were left at each end of the bank.

In the following February, after normal rainfall, water was ponded in the khor for a distance of 15 km. In April 1952 there was still water in it for a distance of 8 km. In such a short time it is impossible to assess the effects of the experiment, but according to a report from the District Commissioner, Western Nuer District, its first effects at least are favourable.

It was feared that damming the watercourse might have an adverse effect on drainage and lead to flooding of habitations and high land cultivations, but the same authority stated that there was no evidence that this had happened.

At a late stage in the investigation more convincing evidence was available that these inland watercourses could be used for several purposes, which we mention very briefly here:

(i) IMPROVEMENTS IN KHOR-BED PASTURES

The improvements here may be in different ways. By conserving rainfall by damming the watercourses, the pasture in them would be preserved until later in the dry season and more reliance could be placed on this source of grazing. Alternatively the type of pasture could be improved, depending on the configuration of the channel. In general, where there is a preponderance of intermediate land grasses, a marked improvement could be achieved by increasing the period and depth of flooding. Where the existing pastures consist mostly of shallow-flooded and deep-flooded *toich* grasses, the improvements expected might be less marked, and in some cases there might be an increase in those types of grasses, such as *Vossia cuspidata*, which are unsuitable for grazing. Difficulties of this sort might be overcome by careful regulation. Further, depending on levels, the area of pasture could be increased. Another way to improve pasture would be to control the release of water from one dam to the next in a series along the length of a watercourse. The reader should realize that, in order to assess the extent of the benefits to pasture of this type of remedy, more experiments must be made, accompanied by scientific observations on the distribution of grasses and the changes over a period of several years. Although, as will be seen later, for the purposes of an estimate an average or typical watercourse has been taken, yet the detailed application of this type of remedy requires careful field surveys of the individual watercourses themselves.

(ii) Improvements in Drainage

In an extremely flat region these watercourses provide the only natural form of drainage. Owing to the alluvial nature of the formation of their banks, it would be possible, as a study of the cross-sections will show, to drain considerable areas of land outside their banks by introducing artificial drainage-channels. In this way it would be possible to increase both the cultivable area and the run-off into the watercourses. It is unfortunate that these aspects were not fully appreciated in time to make a thorough survey of a suitable site, from which the engineering works of a local drainage scheme could be estimated.

(iii) Fish-Ponds

Although we have not been able to examine this aspect in great detail, it is obvious that any scheme which provides a series of ponds in a watercourse could be used for the provision of fisheries. If the ponds were stocked, the only engineering work required in addition to an earth bank would be some simple form of regulator so that the ponds could be emptied when required for catching the fish. Alternatively the inhabitants of the area could catch the fish by local methods or by netting. If the fisheries were dependent on the natural migration of fish, then some simple form of fish-pass would be necessary. The stocking of artificial ponds of this kind has been successfully carried out in Uganda.

(iv) Domestic Water Supplies

Under the Equatorial Nile Project, the watercourses which are connected to the Bahr el Jebel and the Bahr el Zeraf in the Flood Region will be deprived of spill from the river except in very small and limited quantities. It will then be of greater importance to conserve rainfall in them to provide drinking-water for men and animals in the following dry season.

From these brief notes it will be seen that, by utilizing these inland watercourses in various ways, the effects of the losses in animal husbandry, crop production, and fisheries under the Project might be considerably alleviated. There are several reasons why we cannot apply this highly promising type of remedy on a large scale, but we include it in this list of selected remedies because it will be found to have limited application in some cases and because, in a backward area, we consider that a number of small schemes such as this, simple enough for the people to understand, must be applied, complementary to the large-scale remedial measures which we have described elsewhere.

Before this type of remedy could be applied on a large scale more data are required than we have at present. We need the results of experiments over a period of years, with scientific observations not only on pasture grasses but also on fish and the development of fish farms. We also require comprehensive ground surveys so that the extent of the watercourses in length and area can be measured. The application of the method must be preceded by detailed surveys in which ground levels are determined; hydrological surveys are needed to gauge the discharges and to measure the effects of local rainfall in the watercourses.

We give below some practical examples of small earth dams on watercourses, designed on a few typical cross-sections of watercourses taken during the course of our surveys.

Khor Nyin Yar on Zeraf Island

The longitudinal slope of the bed of this khor is about 2 cm/km. On the right bank there is high ground for habitations and cultivation; on the left the land is low and flat. Six kilometres downstream of the Ful Lita–Buffalo Cape road-crossing the khor is constricted to a comparatively narrow channel. At this point an earth dam 650 m. long and 5,000 m^3. in volume would pond water to an arbitrary level of 9·60 m. (see Fig. G 4). At this level more than 10 km. (the limit of the survey) of the watercourse would be inundated to an average width of one kilometre, or an area of at least 10 sq. km. The crest of the proposed bank would be 0·75 m. above standing water-level. When the water was flowing, it is assumed that the level would rise a further 0·25 m. and that the water would pass round both ends of the bank over naturally grassed spillways.

As designed in the diagram, the minimum top width of the bank has been taken as 6 m., which is the smallest width suitable for building by Carryall Scrapers.

Khor Fullus at Ful Turuk

The cross-section here shows that with water held at an arbitrary level of 9·00 (Fig. D 29), a width of 2·3 km. could be flooded. We have assumed that the longitudinal slope of the flood-plain of the khor is of the same order as the major slope in the area, 10 cm/km.; and on this assumption we estimate that the area flooded by this bank would be 15 sq. km. With a minimum top width of 6 m., the volume of earthwork in the dam would be 21,000 m^3.

KHOR VEVENO NEAR MANYABOL

In the Egyptian Ministry of Public Works publication *The Veveno-Pibor Scheme*, 1932, there are many cross-sections of the Veveno channel. We have selected Section No. 23 (Plate 17) near Manyabol, 124 km. from Pibor Post, as an example for the purpose of designing an earth dam. The longitudinal slope of the watercourse is about 12·5 cm/km; with a dam length of 3·25 km., a level of standing water 418·30 could be held. The bank would be at R.L. 419·05, 0·75 m. above standing water-level. The width of the bank would vary between a minimum of 6 m. and a maximum of 12 m. in the middle of the channel where hydraulic principles would require it. The volume of earth in the dam in this case would be 46,000 m^3. The usual naturally grassed spillways would be allowed at both ends of the bank. It is estimated that the area flooded would be 16 sq. km.

KHOR TIAK DAM AT CHOTYIL (Fig. G 5)

This dam has already been constructed by the Team and a description has been given in the text (see p. 669). We estimate that an area of about 3 sq. km. is flooded when the water is at spillway level, and the volume of earthwork is 5,114 m^3.

LUWENG DAM NEAR PALOICH

At the request of the Upper Nile Province Development Committee, we designed an earth dam for the watercourse at Luweng, combined with a hafir. The dam was constructed with earth from the hafir in February 1953, and the opportunity was taken of using Carryall Scrapers on this type of work. The volume of earthwork in the dam is 7,300 m^3., and it has been found in practice that the minimum top width for mechanical construction should be 6 m.

The details of the design for different watercourses are summarized in Table 303. We have added a column showing the physical characteristics of the average of the five watercourses.

KHOR ADAR

We have included above (p. 641) a description of a scheme for damming the Khor Adar because it is the one watercourse which was surveyed in detail (see Vol. III, p. 975). The survey covered the deep water channel and flood-plain, but did not extend far outside the alluvial banks which mark the limits of the flood-plain (see Figs. K 25–K 27). The channel and its flood-plain form one of the largest possible examples of inland watercourses, and may be said to be unique; for that reason we have not included it in the table of typical channels.

The importance of this method of conserving rainfall and of providing improved pasture and facilities for drainage and fisheries cannot be overstressed. Quite apart from its value as a possible remedial measure in connection with the Equatorial Nile Project, it had obvious promise in connection with more immediate problems of economic development. We recommend that it receive the fullest attention of the newly formed Southern Development Investigation Team.

TABLE 303

SUMMARY OF DESIGNS OF EARTH DAMS IN INLAND WATERCOURSES

Item	WATERCOURSE					
	Nyin Yar	Fullus	Veveno	Tiak	Luweng	Average
Average slope: cm/km. ...	2	10	12·5	6	8	7·7
Crest length: m.	650	2,300	3,250	430	450	1,416
Volume of dam: m^3.	5,000	21,000	46,000	5,100	7,300	17,000
Area flooded at standing water-level: sq. km.	10	15	16	3	3	10
Volume per sq. km.: m^3. ...	500	1,400	2,900	1,700	2,400	1,700

XII. IMPROVEMENT OF PASTURE MANAGEMENT

Some ways in which pasture management could be improved have been mentioned in the general assessment of potentialities (p. 550), but improvement of pasture cannot be recommended as a remedy by itself for the following reasons. The potentialities of indigenous grasses and the local application of improved methods of management have not been fully investigated. There are no enclosures and the area of land is vast in comparison with the human and animal population; the peoples are semi-nomadic and are reasonably satisfied with their traditional systems of management. Finally, it is not possible to forecast the improvement likely to be achieved by improved methods of management in measurable terms of additional Animal Units.

XIII. CONSERVATION OF FODDER

We have stated (p. 317) that there is a surplus of rains season grass, particularly in the Flood Region, which could feed a large number of livestock in the dry season if it could be conserved. All the information in our possession has been recorded in the previous section (pp. 551-3), but we have insufficient knowledge of fodder conservation under local conditions to be able to recommend this as a remedial measure. The principal difficulties are high humidity, and widespread flooding during the rainy season, which slows down such operations as cutting and carting. However, on irrigation schemes producing pasture or fodder crops, supervisory staff would be present and machinery available: only in such schemes can fodder conservation be considered as part of a remedial measure.

XIV. IMPROVEMENT OF NATURAL PASTURE BY DRAINAGE

Natural dry season pasture in the Jonglei Area, apart from riverain pasture, has a comparatively low carrying capacity. It might be possible to improve this form of pasture by drainage. This would apply on intermediate land which does not normally produce robust grass regrowth in the dry season, and is therefore of value only in the early rains season. For reasons given previously (see p. 554) the grassland, if drained, would produce grazing for about one Animal Unit Month per feddan, i.e. have a stock-carrying capacity of one Animal Unit for five feddans for a five-month season. Because of the very slight land-slope over the whole area, only land close to a khor or a main river could be drained. Such land is limited in extent; its estimated improved carrying capacity is so low that a large area would be required to support a small number of livestock (21 sq. km. for 1,000 A.U.), and water supplies would have to be provided. For these reasons we do not recommend the application of this form of remedial measure.

XV. EXTENSION AND INTRODUCTION OF SUPERIOR GRASSES AND LEGUMES

This method has not yet been attempted in the Sudan except under irrigation. Because of irregular rainfall and the consequent danger from drought and flooding, and because of lack of information, we cannot recommend this measure under natural conditions. Under irrigation some introduced grasses and legumes have shown promise and we recommend their use in conjunction with pasture or fodder crops under irrigation (see pp. 565-6).

XVI. IMPROVEMENT OF LIVESTOCK

As previously stated, too little is known about the potentialities of indigenous stock and the possibilities of their improvement to enable us to recommend the improvement of livestock as a remedial measure (see pp. 570-1).

XVII. INCREASE OF OUTPUT ON PEASANT HOLDINGS BY THE INTRODUCTION OF ANIMAL-DRAWN IMPLEMENTS

In Chapter 7 of this Volume (see pp. 594-6) we have discussed in detail the possibilities of introducing animal-drawn implements to increase crop production in the Jonglei Area. From the technical point of view this is one of the simpler and cheaper remedial measures. To estimate how effective and practicable it would be, the following assumptions must be made:

(i) That in the Flood Region, where the problem is most serious, the number of Animal Units per average household is 7 (based on the ratio Animal Units : humans = 1·33 : 1, the average number of people per household being 5).

(ii) That the digestible crude protein requirements per year of this number of Animal Units are 262 kg. (based on daily requirements = 0·25 per Animal Unit, and the number of days when grazing is not available = 150).

(iii) That output of fodder crop per feddan in terms of digestible crude protein = 100 kg. (on the basis of velvet beans with net yield 1,000 kg.p.f. (dry weight) and digestible crude protein content of 10%).

On the basis of the above assumptions it is evident that in order to supply the livestock with fodder crops the area under cultivation would have to be increased by over $2\frac{1}{2}$ feddans per household. As far as the Flood Region is concerned, this means nearly doubling the area cropped. However, the work of Biggs already quoted (see p. 594) makes it clear that an increase of this scale could be achieved by introducing ploughs and other animal-drawn implements.

Yet there are many obstacles, which could doubtless be overcome in time but which lead us to exclude this type of remedial measure from the list of selected remedies. These have already been discussed and may be summarized as follows:

(i) Animal-drawn implements introduced to increase the area cropped would not lighten the work of the cultivator. Their introduction would probably place an even greater demand on his stamina.
(ii) The heavy clay soils predominating in this area are difficult to till, even with animal-drawn implements, and would require large teams of oxen, demanding skill in handling which the local cultivators would take a long time to acquire.
(iii) Before the crop acreage could be enlarged, improved methods of bush clearance would have to be found and applied in many parts of this area.
(iv) The considerable distances between homesteads and cultivations, unavoidable where shifting cultivation is the rule and where better-drained sites are scattered, present difficulties in transport of heavier implements and waste of time.
(v) The conservatism of the local peasant, and especially the attitude of Nilotics towards their cattle, is an obvious difficulty.

Consequently we consider the introduction of animal-drawn implements as practicable only on centralized and closely supervised schemes, such as a drainage scheme of the kind already considered. We hesitate to recommend their introduction to scattered peasant holdings as an immediately practicable remedial measure.

XVIII. MECHANIZED CROP PRODUCTION SCHEMES

In our recommendations we have limited the full mechanization of crop production to rice, a cereal crop lending itself easily to this form of cultivation. In Chapter 7 (pp. 596-600) we have shown that, with the difficult environmental conditions in this area and its distance from the markets and supply centres, agricultural mechanization is likely to be a difficult problem. The only district where it could be introduced on a large scale without the simultaneous introduction of drainage or, even more often, drainage and irrigation, is in the Transitional Belt between the Semi-Arid and Flood Regions, i.e. in the Paloich area and parts of Dunjol country. Yet in this part of the Jonglei Area the losses under the Project are comparatively small and can easily be met by pastoral remedies or *hariq* cultivation schemes. However, if our recommendations concerning the other parts of this area prove impracticable from either the technical or the economic point of view—and at the same time the principle of wholesale resettlement, irrespective of tribal boundaries, is accepted—then the possibility of remedying the losses by the introduction of mechanized crop production schemes in this district should be further considered.

XIX. FODDER PRODUCTION SCHEMES

From the technical point of view *toich* grazing could be replaced by rain-grown fodder crops conserved for consumption in the dry season. We have carried out a series of experiments in this connection and have found that a considerable range of fodder crops can be grown successfully on better-drained land. Yet their conservation presents a special problem in this warm and humid climate. Moreover the main objection to the introduction of such schemes is economic. With the present low quality of livestock, fodder production would require large annual subsidies. However, when more information is available, it might be worth while comparing the economics of fodder crop production with the economics of irrigated pastures.

XX. *TOICH* BANKING SCHEMES

In Chapter 7 (p. 605) the possibilities of flood control by banking off areas of irrigated *toich* were examined in detail. We have, however, rejected this type of remedial measure on the basis of cost. The Engineering Section of the Team has estimated the capital cost of banking at £E44.000 $^{m}/_{m}$ per feddan. The figure for pump schemes has been estimated to be £E 42,380 $^{m}/_{m}$ per feddan. Therefore, considering the risks and difficulties involved in the cultivation even of banked-off *toich*, the choice is obvious. Risks connected with flood-escape discharges should also be taken into account.

XXI. OTHER TYPES OF DRAINAGE SCHEMES

In our recommendations described above we consider a drainage scheme designed to produce food crops (mainly cereals) and groundnuts. The latter would serve as a cash crop, necessary from the point of view of the economics of such a scheme, and as a crop which would supply both leguminous hay and a concentrate (groundnut cake) for feeding domestic stock during the dry season. On the basis of our present knowledge of crop yields and prices this appears to be the best solution. However, it is obvious that land where drainage has been improved as a measure for remedying pastoral losses under the Project could be utilized in a number of ways, e.g., it might be preferred in future to reduce the number of livestock and concentrate on cash crops such as rain-grown cotton or some other oil-producing crop which could then replace groundnuts. It might, on the other hand, be found better to grow a special fodder crop in addition to the cash and food crops. At present, however, the combination of cereals and groundnuts appears most practical for a scheme designed as a remedial measure, the main objective of which is to preserve the livestock in the area affected by the Project.

We have given (pp. 582-7) the range of new varieties and crops which appear promising for production on better-drained land in this area. The choice is wide and the future system of farming on artificially drained land must depend on knowledge acquired by the continuation of agronomic experiments, and on future economic conditions both inside and outside the Sudan, as well as on the basic choice of the method of remedying losses in pasture.

XXII. OTHER TYPES OF IRRIGATION SCHEMES

We have recommended above two types of irrigation schemes, one based on the rotation of rice with pasture and another on a rotation containing cotton, sorghum and a forage legume (*Dolichos lablab*). The former is recommended on the basis of the most extensive of our experiments; the latter system of farming is well tried in the central Sudan. Besides these, a number of other crops could be grown on irrigation schemes, especially if drainage were improved (see Chapter 7, pp. 582-7). Rice, which does not require the provision of special drainage, could be grown in combination with catch crops or crops irrigated during the dry season. Our remarks concerning alternative drainage schemes also apply here.

XXIII. SUGAR SCHEMES

In Chapter 7 of this volume (p. 587) we have pointed out that sugar-cane is one of the crops which could almost certainly be introduced into the southern part of the Jonglei Area, provided it could be irrigated during the rainless months. We have also shown that gravity irrigation during the dry season would be possible in the Aliab Valley and from the Jonglei Canal (see pp. 619-20).

At present the Sudan imports approximately 75,000 tons of sugar per annum, so that the production of sugar-cane is of obvious economic importance quite apart from its value as a remedial measure. We have considered the possibilities of the introduction of a sugar-producing scheme as a source of alternative livelihood for the peoples whose livestock will be affected by the Project. Such a scheme could best be run as a large plantation of cane, combined with a milling and refining factory. At any rate in the early stages it would be impossible, technically and economically, to base such a scheme on decentralized peasant holdings. The introduction of the plantation system would mean the reduction in status of independent cattle-owners or peasant cultivators to that of mere wage-earning labourers. This is one reason why we do not include a sugar-producing scheme in the list of remedies.

We have also examined the possibilities of sugar production from the financial point of view. Information concerning capital and running costs of production has been kindly provided by the Director of Agriculture. On the basis of this information we have estimated that the capital required would be approximately £E78 per ton of annual sugar output. We have also estimated that the running cost would be approximately £E29 per ton of sugar ex sacks at a factory in the southern part of the Jonglei Area. Both these estimates were made on the assumption that the first crop and two ratoons occupying the land for four years (including replanting) would produce 90 tons of cane or 9 tons of sugar per feddan. The value of unsacked sugar at a factory in the southern part of the Jongeli Area was estimated at £E37 per ton (on the basis of the wholesale price of sacked sugar less royalties—i.e., £E50—at Khartoum). Therefore the profit per ton which could reasonably be expected would be about £E8, or only about 10% on capital invested; this would leave scarcely any margin for amortization of capital (as distinct from depreciation), a consideration not included in our estimate of current costs of production. Consequently, until transport costs are reduced and the difference in the value of sugar between the Northern Sudan (the main potential market) and the Southern Sudan (the production area) is sufficiently reduced, it would be unwise on financial grounds, to recommend this type of scheme, and hence we do not include it in our primary recommendations.

6. NOTE ON THE PROVISION OF DOMESTIC WATER SUPPLIES

SURFACE CONSERVATION HAFIRS

High rainfall, impermeable soil, wide shallow watercourses, and drainage depressions are all features of the Jonglei Area which facilitate the provision of domestic and stock water supplies by surface run-off conservation methods. It will be seen below that each hafir would be capable of supplying the needs of from 250 to 750 head of cattle, depending on location; the higher figure applying to the region of Bor, where evaporation in the dry season is about 1·0 m. per year, and the lower one to the Kosti area, where evaporation is about 2·6 m. per year. The size of the hafir on which these figures are based is the average size of those already dug in the Northern Zone: 9,500 m^3. capacity and 5·6 m. deep. It is estimated that such a hafir will support cattle as follows:

District	Dry Season	Number of Animal Units Supported
Bor	November 1–March 31	750
Malakal	October 15–May 15	500
Renk	October 1–June 15	340
Kosti	September 1–June 30	250

(For further details, see Volume I, pp. 34-5.)

DEEP-BORE WATER-YARDS

As a result of our drilling programme it can safely be said that water can be found almost all over the Jonglei Area at shallow depths, and that with suitable methods outputs of 1,000 gallons per hour can be obtained. It has also been shown that the belt of saline water found near Kosti extends approximately to the line of the White Nile–Sobat. South of that line potable water has been found. We do not know whether cattle can tolerate the higher salinities found in the north of the area, but there are some reasons for believing that they can.

The average static level of water after it had been struck was 135 ft., but the average depth to which bores had to be taken before water was found was 150 ft. To be on the safe side we shall assume that the average depth of bores for productive water-yards must be 175 ft.

On the basis of experience in Kordofan and Darfur, details of which have been kindly supplied by the Director of Works, normally 2,500 head of cattle can be watered from one yard at the rate of 10 gallons per head per day. At rush periods as many as 5,000 head may be watered using 33,000 gallons, or at the rate of 6·6 gallons per head per day.

7. SPECIAL STIPULATIONS

STIPULATIONS CONCERNING ENGINEERING WORKS OF THE PROJECT

In examining the effects of the Project as proposed by Dr. Amin and Mr. Bambridge we have commented on various engineering aspects of it which are not wholly satisfactory from the point of view of the Sudan.

Therefore, in addition to the application of certain selected remedies described above, there are also several stipulations concerning the engineering works of the Project which will have to be observed. For the sake of clarity these are summarized in what follows. Direct reference should be made to the description of the Project at the beginning of this volume (pp. 399 et seq).

LAKE VICTORIA

Our investigations show that if regulation had been applied over the past 48 years, the range of levels from 9·80 m. to 12·80 m. on Entebbe gauge would have been adequate for over-year storage. Our proposals for operating Lake Victoria in conjunction with Lake Albert are given later, together with our suggestions for the Revised Operation of the Project (Part III of this volume).

LAKE KIOGA

We agree with the proposal to build a regulating barrage at Lake Kioga outlet to eliminate the time-lag of changes of discharge between Lakes Victoria and Albert. It is noted that this part of the Project has yet to be investigated, and we request that detailed proposals based on full surveys should be prepared as soon as possible.

Lake Albert

In our view a range of levels in Lake Albert from 10·00 m. to 18·50 m. on Butiaba gauge is quite inadequate to protect the Sudan against severe flooding. Our own recommendations for the regulation of Lake Albert are given together with our proposals for the Revised Operation of the Project, and we estimate that the special maximum permissible level should be 25·00 m. on Butiaba gauge.

Site of Lake Albert Dam

We agree with the point of view expressed that for engineering reasons Nimule would be preferable to Mutir for the site of the Lake Albert Dam. Our opinion is based largely on the ease with which the torrents, which join the river between Lake Albert and Mongalla, could be controlled if the dam were to be built at Nimule. However, provided that the torrents could be controlled in other ways, building the dam at Mutir would have no adverse effect in the Sudan.

Torrents Balancing Reservoir

We recommend early investigation to determine the possibility of a balancing reservoir in the valley north of Nimule. Our own view is that if the Lake Albert Dam is to be built at Mutir, then the torrents could be controlled by a low dam at Nimule combined with a smaller balancing reservoir north of it.

Sudd Diversion Channel and Banking South of the Atem Head

It will be remembered that in the Project the ' *Sudd* Diversion Channel ' consists of two parts: the Atem Inlet Channel and the Jonglei Canal. Our first comment concerns the Atem Inlet Channel. While agreeing that the present proposals for banking the west side of the Bahr el Jebel from Tombe to the Bahr el Jebel barrage at the Atem Head, together with the banked and remodelled Atem, may be satisfactory for normal operation of the Project, we draw attention to the fact that no definite proposals based on ground surveys have yet been put forward, and that the Sudan will have to be informed of the details of such a scheme before agreeing to the Project as it stands. Furthermore it appears that totally inadequate provision has been made to carry flood-escape discharges in safety past the Aliab Valley and Bor District between Tombe and the Bahr el Jebel barrage at the Atem Head. If, as is suggested, the discharge of the river at Mongalla is to rise to 150 m/d, then it will be necessary.to provide additional channel capacity either in the river or in a canal in the Aliab Valley. The importance of this requirement can be judged from the size such a channel would have to be. We estimate that its capacity should be about 60 m/d and its length 105 km., i.e. it should be comparable in capacity with the Jonglei Canal itself and three-eighths of its length.

Provided that adequate provision is made to deal with flood-escape discharges south of the barrage, we agree with the proposal to site the barrage on the Bahr el Jebel downstream of the Atem Head in the 55 m/d Canal stage, and that its function of dividing the flow of the river between the Bahr el Jebel north of it and the Atem Inlet Channel can be performed satisfactorily. However, we must comment that in the intermediate constructional stages no such barrage is proposed at any site. We consider that it will be essential to build a barrage at Jonglei at least for the 27·5 m/d Canal stage. Our own suggestions are given together with our proposals for the Revised Operation of the Project (see Chapter 11).

At this juncture it is necessary to comment on the question of flood-escape discharges north of the barrage. It is clearly the intention to dispose of flood-waters in the Central Zone at the rate of 120 m/d for long periods and at even higher rates for shorter periods. In view of the possibility that a period of from 20 to 30 years will elapse during which the present swamps will be dried out and the discharge in the Bahr el Jebel north of the barrage will not exceed 35 m/d, such a proposal is quite unacceptable to the Sudan. Our view, that all the additional flood-escape discharges should be carried to the north in the *Sudd* Diversion Channel, is put forward together with our proposals for the Revised Operation of the Project.

Alignment of the Jonglei Canal

Following our comments on the Atem Inlet Channel, we now pass to the second part of the *Sudd* Diversion Channel, the Jonglei Canal. On the question of the alignment of the Canal we are in complete agreement with the proposal put forward in the Project as a result of our predecessors' recommendation that the Jonglei Canal should be dug on the ' Direct '

Line from Jonglei to the White Nile at the Sobat mouth[8]. We repeat here the most important reasons for the superiority of the ' Direct ' Line when compared with Line VII; if the ' Direct ' Line is followed:

(i) Conditions in the Bahr el Zeraf below Khor Famyr will not be disturbed to anything like the same extent.

(ii) The White Nile will be much less affected between Lake No and the Sobat mouth owing to reduced backwater effects.

(iii) Cross-drainage problems will be very greatly reduced.

(iv) No grazing will be lost because the Canal intercepts backflow; on the contrary, the ' Direct ' Line will open up new grazing which formerly suffered from lack of water.

(v) The ' Direct ' Line is well placed for irrigating artificial pastures, in great contrast to Line VII.

(vi) As a line of communication, the ' Direct ' Line is shorter both for water traffic and by land.

(vii) The ' Direct ' Line crosses a region where mosquitoes flourish only in the rains, in contrast with Line VII which is never far from swamp.

Further surveys and investigations, carried out since the publication of the *First Interim Report*, have confirmed the reasons for this preference.

Our investigations have added more emphasis to the fourth and fifth reasons given above. There is no doubt that of all the effects of the Project on local interests the effect on grazing is of paramount importance. Therefore because the ' Direct ' Line will not intercept backflow and because it will open up new areas where artificial pastures can be irrigated it is infinitely preferable to Line VII.

Design of the Jonglei Canal

On the question of the design of the Jonglei Canal, we must stipulate that there must be one canal designed specifically for irrigation of remedial schemes which will be sited to the west of the ' Direct ' Line. We suggest that a canal with a capacity of 5 m/d will be adequate for this purpose. It is essential that the remedial measures should be irrigated by gravity flow from this canal.

Our suggestions for the maximum capacity of the Jonglei Canal (or canals) are given together with our proposals for the Revised Operation of the Project. We wish to draw attention to the fact that it will be impossible to operate the Project as designed by Dr. Amin and Mr. Bambridge because they propose that in the untimely season the discharge in the Canal should be no more than 17 m/d. We have shown that a discharge of at least 40 m/d will be necessary if irrigation is to be maintained in one canal and weed growth prevented in the other. Furthermore if the two canals are inter-connected with cross-cuts, as proposed by these authors, it will be impossible to run them at different levels and discharges. The General Manager of the Sudan Railways has agreed that a water depth of 2·5 m. will be sufficient for navigation for a limited period of not more than 72 days, provided that thereby substantial quantities of water can be saved and made available for irrigation. However, the authors of the Project propose that the reduced flow in the untimely season should continue for 172 days every year, which is too long a period to satisfy the conditions on which this agreement is given.

We also stipulate that the Jonglei Canal must be large enough to carry the special maximum discharge necessary to escape flood-waters in safety from Jonglei on the Bahr el Jebel to the White Nile. We estimate that a capacity of 65 m/d should be sufficient for this purpose. We repeat that there must be no question of disposing of flood-waters by releasing them into the Bahr el Jebel north of the barrage.

RESETTLEMENT OF POPULATIONS

We have already stated that in considering remedial measures we have taken it as a general principle that resettlement of populations should as far as possible be avoided, even though resettlement and the exploitation of certain more favourable areas may seem economically desirable. In most cases the remedies indicated fall within the present territory of the people concerned. There are, however, one or two cases in which resettlement will be unavoidable. For example Remedy No. VA (Gravity Irrigated Crop Production Schemes along the line of the Canal) is necessary to meet losses in Sector No. 6 (see Chapter 10, p. 696). In such cases we have not taken into consideration the costs of resettlement, which would involve not only subsidies for the rebuilding of housing and the clearing of land but also additional money to cover the costs of designing suitable villages, with all the public amenities essential for a more sedentary way of life. These are details of application which cannot be dealt with until the exact nature of the remedy and the site has been determined, but we draw attention to the point since it must be considered in connection with the costs of remedial measures as a whole.

NOTES AND REFERENCES

(1) Panchang, G. M., ' Use of frequency method for estimating rainfall intensities of rare occurrence with reference to data of the Tapti Basin ', *Irrigation and Power*, April 1952.

(2) Seed hay (rye, grass and clover) has a digestible crude protein content of 7·5%, and *Setaria incrassata* young hay of 3·44%.

(3) Thomson, J. R., *Pump Scheme Management on the White Nile*, Agricultural Publications Committee, Khartoum, 1950, pp. 71–3.

(4) Tothill, J. D. (Ed.), *Agriculture in the Sudan*, O.U.P., 1948, pp. 71–3.

(5) ibid, Chapter XXI.

(6) ibid, p. 616.

(7) Todd, L. S., private communication.

(8) Jonglei Investigation Team, *First Interim Report*, 1946, p. 41.

SUMMARY OF UNIT COSTS

Details of unit costs are reserved for the files of the Sudan Government. Summaries of the unit costs of Remedies I to X are given below.

SUMMARY OF UNIT COSTS

(in money)

Remedy Number	Description	Cost per Animal Unit		
		Capital £ m/m	Running £ m/m	Total Capital £ m/m
	1. PASTURE REMEDIES			
I	IMPROVED INTERMEDIATE LAND PASTURE			
	Conservation of Rainfall by Contour Banking	18·000	1·170	64·800
II	IMPROVED KHOR-BED PASTURE			
	Khor Adar	18·000	0·450	36·000
III	FULLER UTILIZATION OF INLAND PASTURE			
	A. By Provision of Water Supplies			
	(i) Baggara West Bank	3·429	0·870	38·200
	(ii) Machar Marshes	2·958	0·237	12·400
	B. By Bush Clearance and Provision of Water Supplies	43·313	0·896	79·200
IV	GRAVITY IRRIGATED PASTURE SCHEMES	14·186	1·662	80·700
	2. AGRICULTURAL ALTERNATIVES			
V	IRRIGATED CROP PRODUCTION SCHEMES (COTTON–SORGHUM–LEGUME SCHEMES)			
	A. Gravity Irrigation Schemes			
	Irrigation from the Jonglei Canal	28·734	—	28·700
	B. Pump Irrigation Schemes			
	(i) Semi-Arid Region...	46·515	—	46·500
	(ii) Southern Zone and Remainder of Northern Zone	52·000	—	52·000
VI	DRAINAGE SCHEMES			
	A. Fanyikang...	18·616	—	18·600
	B. Eastern Plain	22·983	—	23·000
VII	*HARIQ* SCHEMES	15·873	—	15·900
	3. COMBINED REMEDIES			
VIII	RICE AND PASTURE GRAVITY IRRIGATION SCHEMES	29·027	—	29·000
	4. FISHERIES REMEDIES			
IX	THE DEVELOPMENT OF COMMERCIAL FISHERIES	—	—	—
X	FISH FARMS (per ton of Wet Fish)	270·000	—	270·000

NOTE: The costs are given above in terms of losses, i.e., in Animal Units and in metric tons of fish.

SUMMARY OF DETAILS OF UNIT COSTS

Remedy Number	Description	Cost	
		Per Feddan £ m/m	Per Animal Unit £ m/m
I	IMPROVED INTERMEDIATE LAND PASTURE		
	Capital Costs		
	Pasture Management Costs	0·056	0·510
	Engineering Works	1·915	17·500
	Totals	1·971	18·010
	Running Costs		
	Pasture Management Costs	0·024	0·222
	Engineering Works	0·105	0·947
	Totals	0·129	1·169
	Costs per Animal Unit are based on the assumption that 10,000 Animal Units will be accommodated on 91,392 feddans.		

Remedy Number	Description	Cost	
		Per Feddan £ m/m	Per Animal Unit £ m/m
II	IMPROVED KHOR-BED PASTURE		
	Capital Costs		
	Pasture Management Costs	Nil	Nil
	Engineering Works	3·782	18·000
	Totals	3·782	18·000
	Running Costs		
	Pasture Management Costs	Nil	Nil
	Engineering Works	0·100	0·450
	Totals	0·100	0·450
	Costs per Animal Unit are based on the assumption that 500 Animal Units will be accommodated on 2,380 feddans.		
III	FULLER UTILIZATION OF INLAND PASTURE		
	Capital Costs		
	A. Provision of Water Supplies		
	(i) Baggara West Bank	0·256	3·429
	(ii) Machar Marshes	0·186	2·958
	B. Bush Clearance and Provision of Water Supplies ...	4·313	43·313
	Running Costs		
	A. Provision of Water Supplies		
	(i) Baggara West Bank	0·065	0·870
	(ii) Machar Marshes	0·015	0·237
	B. Bush Clearance and Provision of Water Supplies ...	0·089	0·896
	Costs per Animal Unit are based on the following assumptions: A. (i) 8,000 Animal Units will be accommodated on 107,100 feddans. A.(ii) 12,000 Animal Units will be accommodated on 190,400 feddans. B. 15,000 Animal Units will be accommodated on 149,900 feddans.		
IV	GRAVITY IRRIGATED PASTURE SCHEMES		
	Capital Costs		
	Pasture Management Costs	16·974	6·656
	Engineering Works	19·200	7·530
	Totals	36·174	14·186
	Running Costs		
	Pasture Management Costs	3·740	1·467
	Engineering Works	0·500	0·195
	Totals	4·240	1·662
	Costs per Animal Unit are based on the assumption that the carrying capacity of irrigated pasture will be 2·55 Animal Units per feddan (gross).		
V	IRRIGATED CROP PRODUCTION SCHEMES		
	Capital Costs		
	A. Gravity Irrigation Schemes: Irrigation from the Jonglei Canal		
	Agricultural Costs	7·380	8·100
	Engineering Works	18·800	20·634
	Totals	26·180	28·734
	B. Pump Irrigation Schemes		
	(i) Semi-Arid Region		
	Agricultural Costs	7·380	8·100
	Engineering Works	35·000	38·415
	Totals	42·380	46·515
	(ii) Southern Zone and Remainder of Northern Zone		
	Agricultural Costs	7·380	8·100
	Engineering Works	40·000	43·900
	Totals	47·380	52·000
	Running Costs are not considered because they will be met by the sale of agricultural produce. Costs per Animal Unit are based on the assumption that a holding of 18 feddans gross will accommodate 16·4 Animal Units.		

Remedy Number	Description	Cost	
		Per Feddan £ m/m	Per Animal Unit £ m/m
VI	DRAINAGE SCHEMES		
	Capital Costs		
	A. Fanyikang		
	Agricultural Costs	2·610	4·913
	Engineering Works	7·280	13·703
	Totals	9·890	18·616
	B. Eastern Plain		
	Agricultural Costs	2·610	4·913
	Engineering Works	9·600	18·070
	Totals	12·210	22·983
	Running Costs are not considered because they will be met by revenue from the sale of oil. Costs per Animal Unit are based on the assumption that a holding of 16 feddans gross will accommodate 8·5 Animal Units.		
VII	*HARIQ* SCHEMES		
	Capital Costs		
	Agricultural Costs	0·785	2·898
	Engineering Works	3·514	12·975
	Totals	4·299	15·873
	Running Costs are not considered because they will be met by the sale of produce from the scheme. Costs per Animal Unit are based on the assumption that a holding of 48 feddans gross will accommodate 13 Animal Units.		
VIII	RICE AND PASTURE GRAVITY IRRIGATION SCHEMES		
	Capital Costs		
	Agricultural and Pasture Costs	21·138	15·100
	Engineering Works	19·500	13·927
	Totals	40·638	29·027
	Running Costs are not considered because they will be met from revenue from the sale of rice. Costs per Animal Unit are based on the assumption that the carrying capacity of the combined rice and pasture scheme will be 1·4 Animal Units per feddan (gross).		
IX	THE DEVELOPMENT OF COMMERCIAL FISHERIES		
	It has not been possible to estimate unit costs for the development of commercial fisheries. A subsidy is considered in the final account.		
X	FISH FARMS		Per Ton Wet Fish
	Capital Costs		
	Fish Farm Management	20·000	20·000
	Engineering Works	250·000	250·000
	Totals	270·000	270·000
	Running Costs are not considered because it is expected that they will be met from revenue from the sale of fish. Costs per ton of wet fish are based on the assumption that on the average the yield will be one ton per feddan.		

SUMMARY OF UNIT COSTS

(in Water)

Water requirements per annum for schemes requiring irrigation

Remedy Number	Description	Feddans per Animal Unit	m^3. per Feddan	m^3. per Animal Unit
IV	GRAVITY IRRIGATED PASTURE SCHEMES	0·392	4,644	1,820
V	IRRIGATED CROP PRODUCTION SCHEMES			
	(i) Semi-Arid Region	1·100	3,739	4,113
	(ii) Southern Flood Region	1·100	2,766	3,043
	Northern Flood Region...	1·100	2,580	2,838
VIII	RICE AND PASTURE GRAVITY IRRIGATION SCHEMES	0·714	4,180	2,984

SCHEDULE A

IRRIGATED PASTURE

Water-Duties and Requirements

1. Basic water-duty: 860 m^3.p.f. per month
2. Area under crop: 0·9 feddan
3. Period of irrigation: December–May = 6 months

Total water required per feddan gross area:
$860 \times 0{\cdot}9 \times 6 = 4{,}644$ m^3.p.f. gross area

SCHEDULE B

IRRIGATED CROP PRODUCTION SCHEMES

(Cotton-Sorghum-Legume Schemes)

Water-Duties and Requirements

	SOUTHERN FLOOD REGION (Water requirements based on Bor rainfall)					NORTHERN FLOOD REGION (Water requirements based on Malakal rainfall)					SEMI-ARID REGION (Water requirements based on Kosti rainfall)				
	Water requirements—m^3.p.f.					Water requirements—m^3.p.f.					Water requirements—m^3.p.f.				
	Cotton	Sorghum	Legume	Free	Fallow	Cotton	Sorghum	Legume	Free	Fallow	Cotton	Sorghum	Legume	Free	Fallow
January	950	—	—	950	—	950	—	—	950	—	950	—	—	950	—
February	—	—	—	950	—	—	—	—	950	—	950	—	—	950	—
March	—	—	—	950	—	—	—	—	950	—	950	—	—	950	—
April	—	—	—	620	—	—	—	—	950	—	—	—	—	950	—
May	—	—	—	440	—	—	—	—	580	—	—	—	—	950	—
June	440	440	—	440	—	390	—	—	390	—	—	—	—	950	—
July...	360	360	360	360	—	250	250	250	250	—	—	—	—	720	—
August	410	410	410	410	—	210	210	210	210	—	650	650	650	650	—
September... ...	490	490	490	490	—	450	450	450	450	—	860	860	860	860	—
October	550	—	550	550	—	580	580	580	580	—	950	950	950	950	—
November... ...	950	—	950	950	—	950	—	950	950	—	950	—	950	950	—
December	950	—	950	950	—	950	—	950	950	—	950	—	950	950	—
Total ...	5,100	1,700	3,710	8,060	—	4,730	1,490	3,390	8,160	—	7,210	2,460	4,360	10,780	—
Proportion of area occupied by crop	$\frac{5}{18}$	$\frac{3}{18}$	$\frac{3}{18}$	$\frac{1}{18}$	$\frac{6}{18}$	$\frac{5}{18}$	$\frac{3}{18}$	$\frac{3}{18}$	$\frac{1}{18}$	$\frac{6}{18}$	$\frac{5}{18}$	$\frac{3}{18}$	$\frac{3}{18}$	$\frac{1}{18}$	$\frac{6}{18}$
Water requirement per feddan gross area—in m^3. ...	1,417	283	618	448	—	1,314	248	565	453	—	2,003	410	727	599	—
Total water requirement per annum	2,766 m^3.p.f. gross area					2,580 m^3.p.f. gross area					3,739 m^3.p.f. gross area				

SCHEDULE C

RICE AND PASTURE SCHEMES

Water-Duties and Requirements

	Rice	Pasture	Fallow
January	—	860	—
February	—	860	—
March	—	860	—
April	—	860	—
May	—	860	—
June	4,000 (average assuming maturation period = 150 days)	—	—
July		—	—
August		—	—
September		—	—
October		—	—
November		—	—
December	—	860	—
Total	4,000	5,160	—
Proportion of the area occupied by crop ...	$\frac{4}{10}$	$\frac{5}{10}$	$\frac{1}{10}$
Water requirement per feddan gross area—in m^3.	1,600	2,580	—
Total water requirement per feddan gross area per annum		4,180 m^3.p.f. gross area	

19

CHAPTER 10. APPLICATION AND COSTS OF DIRECT REMEDIES

Our terms of reference include the submission of a ' reasonable forecast of the costs of remedial measures in terms of money and water ', and the text of the preceding chapter, including an appendix giving a summary of unit costs, has been prepared as a basis for our calculations. We must now record our ideas concerning the application of different forms of remedy in the various parts of the Jonglei Area. For this purpose we divide the Jonglei Area into a number of sectors. This division is based on various factors: tribal boundaries; the boundaries of the three main Zones; the boundaries of areas where different forms of remedy seem promising; and a variety of practical considerations. The sectors are as follows:

SOUTHERN ZONE

Sector No. 1. Bari and Mandari country.

Sector No. 2. The territory occupied by the Bor Agok Dinka, about one-fifth of the Bor Athoich, and about five-sixths of the Aliab Dinka.

CENTRAL ZONE

Sector No. 3. The territory occupied by the remainder of the Athoich Dinka, the Twi, Nyareweng, and Ghol Dinka and the Gaweir and Thiang Nuer living east of the Bahr el Zeraf.

Sector No. 4. The country of the Gaweir, Thiang and Lak Nuer living in the southern part of the Zeraf Island.

Sector No. 5. The territory occupied by the remainder of the Aliab Dinka, the Chich Dinka, and small groups of other Western Dinka tribes—Atwot, Agar, Luaich, etc.—who utilize the riverain swamp pastures between Tombe and a point north of Shambe.

Sector No. 6. The territory of the Nuong, Dok, Jagey and part of the Western Jikaing Nuer who utilize the riverain swamp pastures between a point north of Shambe and Buffalo Cape.

NORTHERN ZONE

Sector No. 7. The territory of the Ruweng (Kwil) Dinka living north of Lake No and the remainder of the Western Jikaing Nuer who use the riverain swamp pastures along the Bahr el Jebel and Bahr el Ghazal; the country of the remainder of the Lak Nuer living in the northern part of the Zeraf Island whose dry season pastures are mainly along the Bahr el Jebel and Lake No and the White Nile between Lake No and the mouth of the Bahr el Zeraf; the territory of the Ruweng (Paweng), Rut, Thoi, and Luaich Dinka. Very few of these people will be directly affected by the Project in the 55 m/d Canal stage, but they are treated as a group.

Sector No. 8. Shilluk country.

Sector No. 9. Dunjol and Paloich Dinka country.

Sector No. 10. The territory of the Abialang Dinka, and a few Ta'aisha and other people of Arab origin included in Renk District.

Sector No. 11. The territory occupied by the Baggara inhabitants of Kosti District—mainly Sobaha, Nizzi, and Ta'aisha—who live on the east bank of the White Nile between Geigar and Jebelein.

Sector No. 12. The territory occupied by the Baggara inhabitants of Kosti District on the west bank, mainly Seleim and Ahamda, with a number of small sections from other Baggara groups who move seasonally to the river in this area.

(Reference should be made to Map 6 on which tribal boundaries are marked.)

1. PASTURE REMEDIES AND AGRICULTURAL ALTERNATIVES

The occupants of all these sectors, their economy and seasonal utilization of the flood-plains of the White Nile system, have been described previously and details need not be repeated here.

In Table 304 we record in summarized form the number of Animal Units belonging to the various tribes and tribal segments, the number of Animal Units dependent on riverain swamp pasture naturally irrigated by spill from the main channels of the river, and our estimate of the number of Animal Units likely to be displaced as a result of the Equatorial Nile Project.

In the charts which follow, we present—again in summarized form—the types of direct remedy which we consider could be most suitably and economically applied in each sector. In most cases there are several possibilities, and in many a combination of several remedies is possible. The particular remedy or combination of remedies we ourselves believe to be the most promising is underlined in each case. We must, however, emphasize once more that all our suggestions are tentative and that, apart from obvious difficulties in introducing new means of livelihood to a conservative people bound by the traditions of a migratory pastoral life, all remedies proposed require further investigation and trial. We must therefore stress once more that the suggestions we have to make are principally intended to form the basis upon which a ' reasonable forecast of the costs of remedial measures in terms of money and water ' can be made. All losses and suggested remedies apply to the 55 m/d Canal stage of the Project. (Reference should be made to the list of remedies on p. 638 and to the summary of unit costs on pp. 683–7.)

TABLE 304

LOSSES IN RIVERAIN SWAMP PASTURE EXPRESSED IN TERMS OF ANIMAL UNITS (1)

Sector Number	Tribe	Proportion of Tribe	Total Human Population	Total Animal Units	Total Animal Units Using Riverain Pasture	Total Losses in Animal Units	Percentage Loss
1	Bari	—	—	16,300	16,300	—	—
	Mandari	—	—	21,100	18,900	—	—
		—	52,300	37,400	35,200	Nil	Nil
2	Bor Agok	—	—	45,300	45,300	—	—
	Bor Athoich	1/5	—	7,900	7,900	—	—
	Aliab	5/6	—	50,000	50,000	—	—
		—	49,300	103,200	103,200	46,900	45·3
TOTAL SOUTHERN ZONE		—	101,600	140,600	138,400	46,900	33·9
3	Bor Athoich	4/5	—	31,300	31,300	—	—
	Twi	—	—	76,800	75,800	—	—
	Nyareweng	—	—	25,600	24,500	—	—
	Ghol	—	—	17,400	14,300	—	—
	Gaweir (Mainland) ...	—	—	37,500	32,300	—	—
	Thiang (Mainland) ...	—	—	1,000	1,000	—	—
		—	117,100	189,600	179,200	85,100	47·5
4	Zeraf Island:						
	Gaweir	—	—	12,500	12,500	—	—
	Thiang	—	—	14,400	14,400	—	—
	Lak (Southern) ...	—	—	30,100	30,100	—	—
		—	41,000	57,000	57,000	13,000	22·8
5	Chich	—	—	54,400	38,000	—	—
	Aliab	1/6	—	11,900	11,900	—	—
	Others (Lakes District)	—	—	(2)	12,000	—	—
		—	48,200	66,300+	61,900	41,000	66·2
6	Nuong...	—	—	26,300	26,300	—	—
	Dok and Aak ...	—	—	49,000	49,000	—	—
	Jagey	—	—	37,800	37,800	—	—
	W. Jikaing	1/3	—	12,200	12,200	—	—
		—	61,400	125,300	125,300	50,800	40·5
TOTAL CENTRAL ZONE		—	267,700	438,200+	423,400	189,900	44·9
7	W. Jikaing	2/3	—	24,300	24,300	—	—
	Ruweng (Kwil) ...	—	—	13,000	13,000	—	—
	Lak	—	—	18,000	18,000	3,800	—
	Ruweng (Paweng) ...	—	—	12,400	12,400	—	—
	Rut	—	—	2,400	2,400	—	—
	Thoi	—	—	3,900	3,900	—	—
	Luaich...	—	—	5,200	5,200	1,000	—
		—	60,400	79,200	79,200	4,800	6·1
8	Shilluk	—	120,000	55,000	55,000	28,100	51·1
9	Dunjol	—	—	7,200	7,200	—	—
	Paloich	—	—	11,000	11,000	—	—
		—	17,600	18,200	18,200	6,000	33·0
10	Abialang	—	—	6,900	6,900	—	—
	Ta'aisha	—	—	2,200	2,200	—	—
		—	10,600	9,100	9,100	Nil	Nil
11	Baggara (East Bank):						
	Sobaha	—	—	} 16,600	} 16,600	} 2,500	—
	Nizzi	—	—				
	Ta'aisha	—	—				
		—	7,600	16,600	16,600	2,500	15·1
12	Baggara (West Bank):						
	Ahamda	—	—	27,500	27,500	—	—
	Seleim	—	—	29,200	29,200	—	—
	Others	—	—	5,500+(2)	5,500	—	—
		—	14,700	62,200+	62,200	10,000	16·1
TOTAL NORTHERN ZONE (to Jebelein)		—	230,900	240,300+	240,300	51,400(3)	21·4
TOTAL JONGLEI AREA		—	600,200	819,100+	802,100	288,200	35·9

(1) Figures taken to nearest hundred.
(2) Total of Animal Units is considerable, but is not entered because only scattered sections use the river-front grazing.
(3) Gross loss.

SECTOR No. 1 (BARI AND MANDARI)

No effects on dry season pasture facilities are expected in this sector. It should be noted that although there will be an actual loss of riverain swamp pasture for 4,600 Animal Units in February, this loss will be partly balanced by a surplus of grazing for 1,600 Animal Units in January and a surplus for 4,000 Animal Units in March and in April. Since the total animal population belonging to the inhabitants of this area is not entirely dependent on swamp pastures produced by river spill, the deficit does not seem to us significant. There will, however, be a considerable loss in potential (at present not utilized), amounting to grazing for 77,000 Animal Units per month.

SECTOR No. 2 (BOR AGOK, BOR ATHOICH, AND ALIAB DINKA IN SOUTHERN ZONE)

Pasture Remedies				Agricultural Alternatives				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	£E	Water mill. m³.
I	46,900	3,039,120	—	—	—	—	—	—	—	—	—	3,039,120	—
IV	46,900	3,784,830	85	—	—	—	—	—	—	—	—	3,784,830	85
—	—	—	—	—	—	—	—	VIII	46,900	1,360,100	140	1,360,100	140
I	25,000	1,620,000	—	—	—	—	—	VIII	21,900	635,100	65	2,255,100	65

It is estimated that the total loss in this sector will be riverain swamp pasture for 46,900 Animal Units. There are three possible remedies, each of which could accommodate the total animal population displaced. Practical considerations make the application of any single remedy inadvisable. If only Remedy No. IV (Gravity Irrigated Pasture Scheme) or No. VIII (Rice-Pasture Scheme) were applied, the Bor Dinka on the east bank would have to move seasonally to the west bank into the Aliab Valley (as at present); it would be better to accommodate their herds east of the river on intermediate land pasture (on the Eastern Plain) made more reliable than at present by contour banking (Remedy No. 1). Similarly, if this latter remedy were applied alone, the Aliab Dinka would have to cross the Nile and move through the territory of the Bor Dinka on to the Eastern Plain. The disadvantages are obvious; apart from the actual distance to be covered, political friction would undoubtedly arise. Remedy No. IV has many advantages since, when compared with a rice-pasture scheme (Remedy VIII), less organization and mechanization would be necessary. Both methods would be practicable and both types of scheme could be irrigated by gravity. Yet the production of pasture by irrigation would require perpetual subsidy, whereas rice-pasture schemes should pay for themselves. Remedy No. IV is therefore not recommended. This being so, a combination of Remedies Nos. I and VIII is indicated. Another important point is the need for flood protection. It must be remembered that any remedial measure sited on ground which is below normal river level would be destroyed by flooding during a period of escape unless adequate measures were taken to carry the higher discharges in safety past the areas concerned. This applies to the Aliab Valley. A full discussion of this question has been given previously (pp. 435–6). The authors of the Equatorial Nile Project have shown that it is their intention to provide adequately for these higher discharges, but from the details which we have been able to extract it seems that their proposals are not entirely suitable. In recommending remedial schemes in the Aliab Valley we must therefore stipulate that the Project be designed and constructed in such a way that flood-escape discharges are transmitted through this area without endangering any schemes introduced along this reach of the river.

SECTOR No. 3 (BOR ATHOICH, TWI, NYAREWENG, AND GHOL DINKA, GAWEIR AND THIANG NUER)

Pasture Remedies				Agricultural Alternatives				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m^3.	Remedy Number	Animal Units	£E	Water mill. m^3.	Remedy Number	Animal Units	£E	Water mill. m^3.	£E	Water mill. m^3.
I	85,100	5,514,480	—	—	—	—	—	—	—	—	—	5,514,480	—
IV	85,100	6,867,570	155	—	—	—	—	—	—	—	—	6,867,570	155
—	—	—	—	V A	85,100	2,442,370	259*	—	—	—	—	2,442,370	259*
—	—	—	—	—	—	—	—	VIII	85,100	2,467,900	254	2,467,900	254
I	40,000	2,592,000	—	—	—	—	—	VIII	45,100	1,307,900	135	3,899,900	135

* Water-duties for the southern part of the Flood Region.

It is estimated that the total loss in this sector will be riverain swamp pasture for 85,100 Animal Units. Remedies Nos. I (Improved Intermediate Land Pasture: Eastern Plain), IV (Gravity Irrigated Pasture Scheme), V A (Irrigated Crop Production Scheme), and VIII (Rice-Pasture Scheme) could each accommodate the total number of displaced animals. Remedy No. IV does not seem to us desirable because, as elsewhere, it would require perpetual subsidy; Remedy No. VIII would be more satisfactory. An irrigated crop production scheme (Remedy No. V A) would also be possible in this area. However, as no long staple cotton has been tried in this area, it would be necessary to find suitable blackarm-resistant varieties; yields from such varieties cannot be predicted. Drainage for cotton would also be important and, since rainfall is a variable factor, periodic drought might be very harmful. Further investigation is therefore essential before any remedy of this type can be recommended. Livestock belonging to the people of this sector could also be conveniently accommodated in the Eastern Plain, and it seems to us that a combination of Remedies Nos. I and VIII would give the most practicable and reliable solution.

SECTOR No. 4 (GAWEIR, THIANG, AND LAK NUER—SOUTHERN ZERAF ISLAND)

Pasture Remedies				Agricultural Alternatives				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	£E	Water mill. m³.
IV	13,000	1,049,100	24	—	—	—	—	—	—	—	—	1,049,100	24
—	—	—	—	V A	13,000	373,100	40*	—	—	—	—	373,100	40*
—	—	—	—	—	—	—	—	VIII	13,000	377,000	39	377,000	39

* Water-duties for the southern part of the Flood Region.

It is estimated that the total loss in this sector will be riverain swamp pasture for 13,000 Animal Units. Apart from minor remedies in the form of utilization of inland watercourses (Remedy No. XI), remedial measures could only be applied along the ' Direct ' Line where irrigated pasture schemes (Remedy No. IV) or rice-pasture schemes (Remedy No. VIII) could be supplied with water by gravity from the Jonglei Canal. It should be noted that in the case of both these latter remedies, animals would have to be brought across the Bahr el Zeraf and driven to the vicinity of the Canal every dry season, a distance of anything up to 50 miles. This is not a major disadvantage because, under present conditions, many people in this and other areas have to migrate equal or greater distances. An agricultural alternative in the form of an irrigated crop production scheme (by gravity from the Canal: Remedy No. V A) would be possible, but would involve complete resettlement of the people concerned; since we do not recommend resettlement where it is possible to avoid it, and since the costs of this type of remedy are not appreciably less than a rice and pasture scheme, we consider that the latter (Remedy No. VIII) would provide the most satisfactory solution.

SECTOR No. 5 (ALIAB, CHICH, AND OTHER WESTERN DINKA)

Pasture Remedies				Agricultural Alternatives				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	£E	Water mill. m³.
IV	41,000	3,308,700	75	—	—	—	—	—	—	—	—	3,308,700	75
—	—	—	—	—	—	—	—	VIII	41,000	1,189,000	122	1,189,000	122

It is estimated that the total loss in this sector will be riverain swamp pasture for 41,000 Animal Units, about two-thirds of the present animal population. As in the case of the Aliab Dinka (Sector No. 2), Remedies Nos. IV (Gravity Irrigated Pasture Scheme) and VIII (Rice-Pasture Scheme) could be provided in the Aliab Valley. For the reasons already given (see Sector No. 2), we consider that Remedy No. VIII would be the most practicable and economic.

SECTOR No. 6 (NUONG, DOK, JAGEY, AND WESTERN JIKAING NUER)

Pasture Remedies				Agricultural Alternatives				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m^3.	Remedy Number	Animal Units	£E	Water mill. m^3.	Remedy Number	Animal Units	£E	Water mill. m^3.	£E	Water mill. m^3.
I	50,800	3,291,840	—	—	—	—	—	—	—	—	—	3,291,840	—
IV	50,800	4,099,560	92	—	—	—	—	—	—	—	—	4,099,560	92
—	—	—	—	—	—	—	—	VIII	50,800	1,473,200	152	1,473,200	152
—	—	—	—	VA	50,800	1,457,960	155*	—	—	—	—	1,457,960	155*

* Water-duties for the southern part of the Flood Region.

It is estimated that the loss in this area will be riverain swamp pasture for 50,800 Animal Units. An obvious possibility is the provision of improved intermediate land pasture in the Western Plain (by Remedy No. I as in the Eastern Plain), particularly along the Bilnyang system. It must be remembered, however, that approximately 49,000 Animal Units will in any case be using this part of the area. There seems little doubt that, apart from spill from the Bahr el Jebel which will no longer occur, there will be adequate water available from other sources (e.g. the Lau, Na'am, Gel, etc.) and the remedy seems the most suitable, but we hesitate to recommend it without further detailed surveys. Minor remedies in the form of khor banking might prove successful (Remedy No. XI), but large-scale remedies to accommodate all, or a substantial proportion of, the livestock could only be found with certainty along the line of the Jonglei Canal. Here, as in some other areas, irrigated pasture schemes (Remedy No. IV), rice-pasture schemes (Remedy No. VIII), or irrigated crop production schemes (Remedy No. VA) could be applied, but would involve resettlement in each case because an annual dry season migration, involving the crossing of the Bahr el Jebel and the Bahr el Zeraf, would be impracticable. Such pasture schemes (IV and VIII) aim at the provision of grazing during the dry season and, in the latter case (VIII), the provision of a cash crop in the form of rice to cover maintenance costs of the pasture which would otherwise require annual subsidies. An additional area of land would therefore be required to allow for the normal cultivation of rain-grown crops and for grazing during the rainy season. Under present circumstances the land through which the Jonglei Canal will run is inundated to a greater or lesser extent by rain precipitation, local run-off, and water draining in from the east. When the Canal has been constructed, overland flooding from the east should be much reduced and will not affect the area lying west of the Canal. The land there should be better drained and more suitable for habitation, rain-grown crops, and grazing during the rainy season. However, the extent of these advantages can only be estimated after further detailed surveys. Bearing all these considerations in mind, and with the recommendation that further investigation into the possibilities of Remedy No. I be carried out, we consider that (in the absence of more definite information) an irrigated crop production scheme (Remedy No. VA), supplying as it does a complete alternative livelihood scheme throughout the year, would be the most suitable, even though it would involve resettlement of a substantial proportion of the population.

SECTOR No. 7 (RUWENG [KWIL] DINKA, WESTERN JIKAING AND LAK NUER, RUWENG [PAWENG], RUT, THOI, AND LUAICH DINKA)

Pasture Remedies				Agricultural Alternatives				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m^3.	Remedy Number	Animal Units	£E	Water mill. m^3.	Remedy Number	Animal Units	£E	Water mill. m^3.	£E	Water mill. m^3.
IV	4,800	387,360	9	—	—	—	—	—	—	—	—	387,360	9
—	—	—	—	V A	4,800	137,760	14*	—	—	—	—	137,760	14*
—	—	—	—	—	—	—	—	VIII	4,800	139,200	14	139,200	14

* Water-duties for the northern part of the Flood Region.

It is estimated that the loss in this sector will be riverain swamp pasture for 4,800 Animal Units, a very small proportion of the total livestock (79,200 A.U.). There will be a loss of riverain swamp grazing along the Khor Fullus (Luaich Dinka) for 1,000 Animal Units—and for 3,800 Animal Units in the northern parts of Lak Nuer country. Remedies Nos. IV (Irrigated Pasture), VIII (Rice-Pasture Scheme) and V A (Irrigated Crop Production) could be applied along the line of the Jonglei Canal. In the case of the first two remedies, it would be necessary for the Lak Nuer to move their herds in the dry season from the Zeraf Island to the Canal, a distance of about 60 miles. The Luaich Dinka would only have to move a few miles since their permanent settlements are close to the proposed 'Direct' Line of the Canal. The third remedy, irrigated crop production, would involve resettlement, a measure we seek to avoid. Bearing these considerations in mind, we think that rice-pasture schemes (Remedy No. VIII) would prove the most satisfactory. The Luaich Dinka would not have to move far; the Lak Nuer could be conveniently accommodated in the same way as the majority of that tribe in Sector No. 4.

SECTOR No. 8 (SHILLUK)

Pasture Remedies				Agricultural Alternatives				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	£E	Water mill. m³.
—	—	—	—	V B(ii)	28,100	1,461,200	80*	—	—	—	—	1,461,200	80*
—	—	—	—	VI A	18,000	334,800	—	—	—	—	—	495,390	—
—	—	—	—	VII	10,100	160,590							
—	—	—	—	V B(ii)	9,000	468,000	26*						
—	—	—	—	VI A	9,000	167,400	—	—	—	—	—	795,990	26*
—	—	—	—	VII	10,100	160,590	—						

* Water-duties for the northern part of the Flood Region.

It is estimated that the loss in this sector will be riverain swamp pasture for 28,100 Animal Units. The people concerned, the Shilluk, have a mixed economy, with less emphasis on animal stock than the tribes farther south. Nevertheless this loss amounts to more than 50% of their total livestock and must be considered a serious one. Alternative dry season pasture could only be supplied by pumped irrigation—the most expensive and least economic remedy of all. Therefore, in this sector, only agricultural alternatives seem possible, i.e. a pump irrigation scheme for the production of crops (Remedy No. V B(ii)), drainage schemes (Remedy No. VI A), or *hariq* schemes (Remedy No. VII). The first of these could be applied anywhere in this area and appears to be the most certain and reliable remedy, though costs would be comparatively high. In the southern parts of the area (south of approximately Kodok) the limiting factor to rain-grown crop production is lack of drainage; cultivations in the hinterland (*wak* cultivations) are often destroyed by rain-floods. In the northern part of the sector there are plentiful *hariq* grasses, and *hariq* schemes could be introduced. Both these remedies have the great advantage that no irrigation is required, and they are relatively inexpensive to initiate and run. But they have one major disadvantage; rainfall is a variable and unreliable factor. This disadvantage is at present balanced by the people's possession of animal stock which—as in so many parts of the Jonglei Area—is used as an insurance against poor grain crops; it is this asset which will in part be lost. For these reasons we consider that a combination of all three remedies would provide the most satisfactory solution.

SECTOR No. 9 (DUNJOL AND PALOICH DINKA)

Pasture Remedies				Agricultural Alternatives				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m^3.	Remedy Number	Animal Units	£E	Water mill. m^3.	Remedy Number	Animal Units	£E	Water mill. m^3.	£E	Water mill. m^3.
II	6,000	216,000	—	—	—	—	—	—	—	—	—	216,000	—
—	—	—	—	VII	6,000	95,400	—	—	—	—	—	95,400	—
III A(ii)	6,000	74,400	—	—	—	—	—	—	—	—	—	74,400	—

It is estimated that the losses in this sector will be riverain swamp pasture for 6,000 Animal Units. As the total present livestock amounts to 18,200 Animal Units, the percentage of loss is high, but the people concerned place greater reliance on crop husbandry, a form of economic activity which is fast developing in the form of *hariq* cultivations. There are three obviously promising remedies. The Khor Adar could be banked to produce considerable quantities of khor-bed pasture, probably sufficient to accommodate all displaced animal stock (Remedy No. II). *Hariq* schemes, already successfully introduced, could be expanded and developed as an alternative (Remedy No. VII). Finally, there are great possibilities of opening up grazing areas in the Machar Marshes (Remedy No. III A (ii)). As mentioned previously the people have shown a marked prejudice against the use of these marshes, but we consider that the principal reason is the lack of dry season water supplies between their permanent settlements and the edge of the marshes. This difficulty could easily be overcome by providing hafirs along definite routes. Although more detailed information is required concerning the type, quantity, and reliability of the pasture in these swamps before definite recommendations can be made, the latter form of remedy appears to us the most promising, and there seems little doubt that the Machar Marshes could accommodate the relatively small number of cattle involved.

SECTOR No. 10 (ABIALANG DINKA AND TA'AISHA OF RENK AREA)

Although there will be a loss of riverain swamp pasture along the White Nile in this sector, there will still be sufficient for the present number of domestic animals. There will be a loss of potential, but the present requirements of the people will still be met; no remedies will be necessary in the 55 m/d Canal stage.

SECTOR No. 11 (EAST BANK BAGGARA OF KOSTI DISTRICT)

Pasture Remedies				Agricultural Alternatives				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m^3.	Remedy Number	Animal Units	£E	Water mill. m^3.	Remedy Number	Animal Units	£E	Water mill. m^3.	£E	Water mill. m^3.
—	—	—	—	V B(i)	2,500	116,250	10*	—	—	—	—	116,250	10*

* Water-duties for the Semi-Arid Region.

It is estimated that the loss in this sector will be riverain swamp pasture for 2,500 Animal Units (over the 5-month season, February to June). Investigation has so far revealed no possibility of providing alternative pastures inland. Agricultural alternatives are therefore necessary, and the most suitable remedy would be a pump irrigated crop production scheme (Remedy No. V B (i)). Schemes of this kind are already rapidly expanding in this area and are clearly a natural line of development. The number of people affected will be small and no real difficulties should arise.

SECTOR No. 12 (WEST BANK BAGGARA OF KOSTI DISTRICT)

Pasture Remedies				Agricultural Alternatives				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m^3.	Remedy Number	Animal Units	£E	Water mill. m^3.	Remedy Number	Animal Units	£E	Water mill. m^3.	£E	Water mill. m^3.
III A(i)	8,000	305,600	—	—	—	—	—	—	—	—	—	464,000	—
III B	2,000	158,400											
—	—	—	—	V B(i)	10,000	465,000	41*	—	—	—	—	465,000	41*
III A(i)	8,000	305,600	—	V B(i)	2,000	93,000	8*	—	—	—	—	398,600	8*

* Water-duties for the Semi-Arid Region.

It is estimated that the loss in this sector will be riverain swamp pasture for 10,000 Animal Units. Unlike Sector No. 11 on the opposite bank of the river, there are possibilities of providing alternative grazing inland by the provision of water-points (Remedy No. III A (i)) or of increasing the grazing by bush clearance and providing suitable water-points (Remedy No. III B). It might be possible to accommodate all displaced livestock by these means, but the effectiveness of bush clearance in particular is by no means certain and costs would certainly be high. For this reason we believe that the most satisfactory solution would be to apply Remedy No. V B (i) (a Pump Irrigated Crop Production Scheme) to accommodate 2,000 Animal Units, and Remedy No. III A (i) in favourable areas to accommodate the rest.

2. REMEDIES FOR LOSSES IN FISH

Predicted losses in fish have been recorded in Table 273 (see p. 524). Remedy No. IX, the development of commercial fisheries, would apply only to the Northern Zone. The costs cannot, at this stage, be assessed with any accuracy, but in our final estimate of the costs of remedial measures we have stipulated a subsidy of £E.278,000, based on what figures and indications are available. Requirements in the Southern Zone amount to 237 metric tons and in the Central Zone to 2,725 metric tons. As the most suitable remedy, fish-farming (Remedy No. X), could only be applied economically in units of 200 feddans or more, the losses in round figures are given as 300 and 2,800 metric tons respectively.

An exact division according to the requirements of each sector cannot be given, but estimated percentage losses are given as a guide:

Sector No.	Total Loss of Fish metric tons	Percentage of Total Loss		Remedy No.	Cost	
		%	metric tons		£E	mill. m^3.
2	300	100	300	X	81,000	1·7
3	2,800	18	504	X	756,000	16·2
4		44	1,232			
5		23	644			
6		15	420			
7–12	—	—	—	IX	278,000 (subsidy for development of fisheries in Northern Zone)	—
	3,100	—	—	—	£E.1,115,000	17·9

The water requirements have been calculated on the assumption that the ponds would be filled in February and kept full until the end of December. Since they would be emptied again in January, the net annual water requirement would be that required to offset evaporation. Assuming that Bor is a representative station, the evaporation from the open water surface from February to December is 1,375 mm. (Table 22, p. 60), and the water-duty would therefore be 5,775 m^3.p.f. per year.

3. COMMUNICATIONS

In our general consideration of the engineering aspects of remedial measures we stated that 6 pairs of cable-ferries would be needed at crossing-points at 40 km. intervals along the line of the Jonglei Canal. In addition 6 bridges would be required to cross the irrigation canal.

The cost of a suitable cable-ferry (to carry 50 head of cattle) has been estimated by the General Manager of the Sudan Railway to be £E.4,500 complete delivered at Jonglei at 1953 prices.

We have estimated that the cost of a bridge to cross a canal of 5 m/d capacity would be £E.5,000.

Hence the cost of 12 ferries and 6 bridges to provide cross-communications would be £E.84,000.

No other remedies will be needed for communications.

TABLE 305

REMEDIAL MEASURES: SUMMARY OF COSTS IN MONEY AND WATER

Sector	Most Expensive			Least Expensive			Suggested		
	Remedy	£E	mill. m³.	Remedy	£E	mill. m³.	Remedy	£E	mill. m³.
1	—	—	—	—	—	—	—	—	—
2	IV	3,784,830	85	VIII	1,360,100	140	I and VIII	2,255,100	65
3	IV	6,867,570	155	V A	2,442,370	259	I and VIII	3,899,900	135
4	IV	1,049,100	24	V A	373,100	40	VIII	377,000	39
5	IV	3,308,700	75	VIII	1,189,000	122	VIII	1,189,000	122
6	IV	4,099,560	92	V A	1,457,960	155	V A	1,457,960	155
7	IV	387,360	9	V A	137,760	14	VIII	139,200	14
8	V B(ii)	1,461,200	80	VI A and VII	495,390	—	V B(i) VI A VII	795,990	26
9	II	216,000	—	III A(ii)	74,400	—	III A(ii)	74,400	—
10	—	—	—	—	—	—	—	—	—
11	V B(i)	116,250	10	V B(i)	116,250	10	V B(i)	116,250	10
12	III A(i) III B	465,000	41	III A(i) V B(i)	398,600	8	III A(i) V B(i)	398,600	8
Pastoral and Agricultural Remedies ...	—	21,755,570	571	—	8,044,930	748	—	10,703,400	574
Fisheries Remedies	—	1,115,000	18	—	1,115,000	18	—	1,115,000	18
Communications	—	84,000	—	—	84,000	—	—	84,000	—
Grand Total	—	22,954,570	589	—	9,243,930	766	—	11,902,400	592

PART III

REVISED OPERATION OF THE PROJECT

INTRODUCTION

Our work so far has been based upon the assumption that the Equatorial Nile Project will be implemented exactly as it is proposed. It seems to us that there are other and better ways of solving the whole problem of the Project's effects. For this purpose we attempt below to re-design the operation of the Project with one aim in mind—to provide the maximum amount of water for irrigation north of the Jonglei Area while still preserving as far as possible the present actual and potential resources of its inhabitants. We refer to this as the Revised Operation. This involves one fundamental principle, that the Nile system must be regarded as a single unit and the exploitation of its waters must be designed for the maximum benefit of all the people who are in one way or another dependent upon them. Naturally there is often a conflict of interests, but we believe that a compromise, advantageous to all, is possible.

CHAPTER 11. THE REVISED OPERATION OF THE PROJECT

1. CONTROL OF LAKES VICTORIA AND ALBERT

The Equatorial Nile Project is composed basically of two major parts and one minor one. The first major part is concerned with regulation of the Great Lakes so that the long-term mean annual outflow will pass Mongalla every year. The minor part, control of the torrents which join the Bahr el Jebel between Lake Albert and Mongalla, is connected with this first major part. The second major part concerns the method of transmitting the annual flow through the *Sudd* region with as little loss as possible. The Team's investigations have shown that aspects other than the engineering or hydrological ones must be taken into account, particularly in this second part, and this revised method of operating the Project is an attempt to do so. We begin our description of the Revised Operation where the flow of water begins, at Lakes Victoria and Albert, and discuss various methods of regulation, bearing in mind the requirements farther downstream in the Southern Sudan. We then describe the torrents and suggest methods of controlling them. The next section explains the sort of river régime which will be more suitable for local interests, in particular riverain pasture and fisheries, as well as serving the interests of irrigation in the Northern Sudan and Egypt. Detailed proposals are made for the Revised Operation under normal conditions, and during a period of flood-escape.

The object of our study of the control of Lakes Victoria and Albert is to devise ways and means of operating them so that the ideal of Century Storage will be attained as far as possible, and to determine the maximum storage capacities needed in the two lakes so that the Sudan will be adequately safeguarded against the danger of flooding. This latter objective is considered in conjunction with the maximum safe discharges at Mongalla, discussed in a later section (pp. 770–1). During a period of high floods we will need to know what is the maximum storage capacity available in the lakes and what is the maximum rate at which water can be escaped safely from them. Here we are on fairly sure ground; capacities can be measured and related to levels at the lakes, and the rate of escape can be determined by such things as the size of the Jonglei Canal and the carrying capacity of the river at various points. However, in order to know whether our methods of control will be satisfactory or not it would be desirable to know the maximum possible rate of inflow to the lakes. This is more problematic. We might use, for instance, a statistical method to compute the one per cent chance flood, or attempt to estimate the maximum run-off from a formula relating rainfall intensity with the catchment area, or we might examine past records and make provision for the worst floods that have occurred and allow a factor of safety in addition to that.

The statistical method falls down partly because 48 years do not constitute enough cases for a satisfactory analysis, and also because the distribution is 'skewed' to such an extent that the maximum recorded discharges seem to bear no relation to the mean or normal discharges, as will be seen from the following table:

Annual Flow at Mongalla milliards	Occurrence Number of Times
60–55	1
55–50	0
50–45	1
45–40	0
40–35	4
35–30	8
30–25	14
25–20	14
20–15	6
15–10	0
10– 5	0
5– 0	0

(See Table 309, p. 715)

The second method, based on rainfall and catchment area, which is widely favoured in the United Kingdom, could not be applied easily because of the great extent and varied character of the catchment and because of the lack of sufficient data on rainfall over it. Furthermore because of the great size of Lake Victoria the effect of rainfall on it is reflected in its discharges for the ensuing two or three years, and because of delays in Lakes Kioga and Albert several months elapse before the effects are felt lower down the river.

For these reasons we have adopted the third course. We have applied our suggested methods of operation to the records of the past 48 years from 1905 to 1952, from which we determine the storage capacities needed in the two lakes. In this connection it must be mentioned that we are lucky in having the very high flood of 1916–17–18 included in the records as an example of what may be expected. It must also be realized that floods similar to that probably occurred three times in the 40-year period between 1878 and 1918[1], and in the course of time we may confidently expect an even greater flood. Moreover the reader should note that the highest recorded flood was followed almost immediately (1921–22) by the lowest recorded annual flows. It is abundantly clear therefore that the storage capacities determined by this method are the very least possible to safeguard the Sudan, and that they must be covered by some additional factors of safety.

We are also aware of the criticism that, in principle, applying methods of regulating to one particular set of hydrological data is considerably inferior to applying them (to see their effects) to a large number of sets of hydrological and meteorological data, such as those used by Dr. Hurst in determining the constant in the formula for the capacity needed for Century Storage.

Finally we must caution the reader with the obvious remark that because the annual flows of a river have been as recorded in the past 48 years, that in itself is no guarantee that they will be the same in the next 48 years.

BASIC DATA

PERIOD CONSIDERED

When examining the effects of certain methods of controlling the Great Lakes we used, in the first place, the records which were available at the time covering the period from 1905 to 1942. At a very late stage in the investigation more records, extending the period up to 1952, were received from the Inspector General of Irrigation, Southern Nile. It will be found therefore that some methods of control given below have not been examined after 1942. All the most important methods have been applied to the full period of 48 years, and the other methods have been applied to the important periods of extreme high and low levels such as the period from 1916 to 1918 and 1922.

The starting date was determined by the availability of records covering all the key gauging points between Lake Victoria and Mongalla. Discharges at the Ripon Falls have been computed from 1896 to 1942 (*The Nile Basin*, Vol. IV, 2nd and 3rd Supps.). Discharges of the Victoria Nile below Lake Kioga have been recorded from 1912 to 1944, but for other years they can be estimated with reasonable accuracy from the Ripon Falls discharges. The records for Lake Albert exit and Mongalla, dating from 1904 and 1905, are given in the same volume of *The Nile Basin*.

LAKE VICTORIA

The basic data for Lake Victoria consist of natural inflows and outflows. They have been computed by months for the period 1905 to 1942 from the Entebbe gauge-readings (*The Nile Basin*, Vol. III and Supplements) and from the Ripon Falls discharges (Volume IV, 2nd and 3rd Supplements). The records for the later period from 1943 to 1952, obtained from the Egyptian Irrigation Department direct, include those for Entebbe gauge and discharges at Namasagali. The records are complete and the computations are straightforward. It has been assumed that the surface area of Lake Victoria is 67,000 sq. km. at all levels between 9·80 m. and 12·80 m. on Entebbe gauge. Though the computations have been made on a monthly basis, for obvious reasons we publish only the annual figures in Table 306 (p. 712).

LAKE ALBERT

CONTENTS

The determination of the basic data for Lake Albert is more involved. The surface area of the lake increases with height above datum. We have prepared a table of contents from a curve given in an appendix to Amin and Bambridge's *Modified Jonglei Canal and Over-year Storage Schemes* (Table 307). The datum is taken as 10·00 m. on Butiaba gauge and the contents above datum are given up to a level of 35·00 m.

'OTHER SOURCES' INFLOW

Since in any method of controlling the lakes the flow of the Victoria Nile will be regulated at Ripon Falls and at Lake Kioga (see below), it is necessary to distinguish between the flow into Lake Albert from the Victoria Nile, and the flow from all 'other sources'. In our computations we have assumed that the Victoria Nile inflow is the same as the discharge of the

Victoria Nile below Lake Kioga because records of discharges taken in 1941 and 1942 at Masindi Port, Kamdini, and Fajao indicate that the losses between Lakes Kioga and Albert are negligible. A graphical comparison of the discharges below Lake Kioga with those at Ripon Falls showed that, although there were considerable variations, a fair average value of the losses between the two sites was 10%. For the periods from 1905 to 1911, 1938 to 1939, and 1944 to 1952, we have assumed that the Victoria Nile inflow was 90% of the Ripon Falls discharge. By subtracting these figures from the total inflow to Lake Albert we have obtained the inflow from sources other than the Victoria Nile, which is designated ' other sources ' inflow. Although the monthly quantities have been computed, we again publish only the annual totals (Table 308). In all the computations for Lake Albert which follow later we have assumed that the controlled inflow of the Victoria Nile is 90% of the regulated outflow at Ripon Falls.

TORRENTS INFLOW

The approximate discharges of the torrents between Lake Albert and Mongalla from 1907 are published in *The Nile Basin*, Vol. IV, 2nd and 3rd Supps. To obtain the figures for 1905 and 1906 we subtracted the discharges of Lake Albert at its exit, less 5%, from the recorded discharges at Mongalla. We assume that the torrents can be controlled completely by methods which are discussed later (p. 757 et seq.), and in most examples of the control of Lake Albert that their flow can be virtually impounded in Lake Albert. In such cases the flow of the torrents as at Mongalla, increased by 5%, has been added to the ' other sources ' inflow and the Victoria Nile controlled inflow to make up the total inflow into Lake Albert.

WORKING ASSUMPTIONS

In presenting examples of methods of control of the lakes we must make certain assumptions concerning the practical ways of applying the regulation. These are summarized as follows:

(i) The lag through Lake Kioga will be eliminated by a regulator near Masindi Port, though storage will not be available in Lake Kioga above the natural maximum of 13·50 m. on Masindi Port gauge.

(ii) The main dam for Lake Albert will be at Mutir, and the lag between Mutir and Nimule can be eliminated, and navigation assured, by a low dam at Nimule.

CONTROL OF THE TORRENTS

In some of the examples which have been applied to past records we have assumed that the torrents could have been controlled; in others we have shown what would have happened if they had not been controlled at all.

In the former computations we have assumed that the control was complete. If there had been a low dam at Nimule it would have been virtually possible to do this when the torrents' discharge did not exceed the range of control. The river from Nimule to Rejaf is swift-flowing and the lag between these points is probably not more than one day. By regulating at Nimule and simultaneously at Mutir according to the gauge-reading at Rejaf, it should have been possible to control the torrents almost entirely. The highest monthly average flows were 99 m/d in September 1916, and 84·5 m/d in October 1917. Otherwise the torrents' discharges seldom exceeded 50 or 60 m/d. It will be seen later that the controlled monthly discharge in September and October proposed by us would have been about 97 m/d in those years. Thus if the outflow from Lake Albert had been reduced to zero in those months the torrents would have provided all that was necessary. We have calculated in a previous report (*Progress Report* 1948–49, Jonglei Investigation Team) that the maximum momentary discharge in September 1916 was probably as high as 200 m/d, and 124 m/d in the last 10-day period in September. Though a recurrence of the former discharge might make conditions temporarily unpleasant downstream of Rejaf, the peak would be rapidly damped by the flood-plains of the Southern Zone, and over a 10-day period a discharge of 124 m/d would not cause any severe damage. So we consider it reasonable to assume that the torrents can be controlled completely. Even in the two exceptional cases mentioned, all but about 25% of the torrents' flow could have been controlled and virtually impounded in Lake Albert. It should not be forgotten that peak flows such as these two exceptional ones cannot be controlled altogether unless there is, in addition to a low dam at Nimule, another dam and balancing reservoir at Bedden, the capacity of which we have found from a previous study should be of the order of one-third of a milliard.

MONGALLA DISCHARGES

In order to round off the presentation of basic data we have included a table of the actual discharges at Mongalla for the period from 1905 to 1952, taken from Volume IV of *The Nile Basin* and its supplements, and from the provisional data supplied by the Inspector General of Irrigation, Southern Nile (Table 309).

TABLE 306

LAKE VICTORIA

In milliards per year

Year	Natural Inflow	Natural Outflow	In Order of Magnitude		
			Year	Inflow	Difference from Mean of 20·92
1905	19·08	24·44	1917	64·58	43·66
1906	56·12	32·00	1926	61·55	40·63
1907	6·56	27·33			
1908	15·51	22·21	1937	59·33	38·41
1909	3·90	20·65	1930	57·71	36·79
			1947	57·42	36·50
1910	12·47	18·50	1906	56·12	35·20
1911	− 5·18	15·59	1916	55·04	34·12
1912	20·09	14·73	1951	51·98	31·06
1913	28·26	16·87			
1914	24·76	16·72	1923	38·78	17·86
			1942	34·05	13·13
1915	23·57	18·88	1931	33·99	13·07
1916	55·04	24·22	1952	31·54	10·62
1917	64·58	33·09	1941	31·51	10·59
1918	− 17·65	29·25	1936	30·89	9·97
1919	8·82	21·55			
			1940	28·55	7·63
1920	6·20	18·26	1913	28·26	7·34
1921	− 6·57	15·54	1932	26·59	5·67
1922	4·88	12·25	1914	24·76	3·84
1923	38·78	13·99	1925	23·79	2·87
1924	7·31	16·02	1915	23·57	2·65
			1912	20·09	− 0·83
1925	23·79	15·08			
1926	61·55	22·02	1928	19·67	− 1·25
1927	− 4·85	23·96	1905	19·08	− 1·84
1928	19·67	19·67	1945	18·80	− 2·12
1929	0·44	16·52	1946	17·38	− 3·54
			1935	15·75	− 5·17
1930	57·71	22·20	1908	15·51	− 5·41
1931	33·99	24·61	1948	14·99	− 5·93
1932	26·59	25·92	1910	12·47	− 8·45
1933	11·46	24·86	1933	11·46	− 9·46
1934	5·57	19·64	1938	10·15	− 10·77
1935	15·75	19·10	1919	8·82	− 12·10
1936	30·89	22·85	1950	7·74	− 13·18
1937	59·33	27·17	1924	7·31	− 13·61
1938	10·15	25·56	1944	6·71	− 14·21
1939	5·24	21·99	1907	6·56	− 14·36
			1920	6·20	− 14·72
1940	28·55	21·85	1934	5·57	− 15·35
1941	31·51	21·46	1939	5·24	− 15·68
1942	34·05	27·35	1922	4·88	− 16·04
1943	− 13·52	21·32	1909	3·90	− 17·02
1944	6·71	16·76	1929	0·44	− 20·48
1945	18·80	16·79	1927	− 4·85	− 25·77
1946	17·38	15·37	1911	− 5·18	− 26·10
1947	57·42	23·25	1921	− 6·57	− 27·49
1948	14·99	23·03	1949	− 6·85	− 27·77
1949	− 6·85	18·61	1943	− 13·52	− 34·74
			1918	− 17·65	− 38·57
1950	7·74	17·12	—	—	—
1951	51·98	17·81	—	—	—
1952	31·54	19·48	—	—	—
Total	1,004·11	1,003·44	Standard Deviation	20·82	
Averages	20·92	20·91	Median ...	18·09	

TABLE 307

LAKE ALBERT
RESERVOIR CONTENTS
In milliards related to Butiaba Gauge in metres

Gauge	0·00	0·10	0·20	0·30	0·40	0·50	0·60	0·70	0·80	0·90
10	0·0	0·5	1·1	1·6	2·1	2·7	3·2	3·8	4·3	4·8
11	5·4	5·9	6·5	7·0	7·6	8·1	8·7	9·2	9·8	10·3
12	10·9	11·4	12·0	12·6	13·1	13·7	14·2	14·8	15·4	15·9
13	16·5	17·1	17·6	18·2	18·8	19·4	20·0	20·5	21·1	21·7
14	22·3	22·8	23·4	24·0	24·6	25·2	25·8	26·4	27·0	27·6
15	28·1	28·7	29·3	30·0	30·6	31·2	31·8	32·4	33·0	33·6
16	34·2	34·8	35·4	36·0	36·6	37·2	37·9	38·5	39·1	39·7
17	40·3	40·9	41·6	42·2	42·8	43·5	44·1	44·7	45·3	46·0
18	46·6	47·2	47·9	48·5	49·2	49·8	50·4	51·1	51·7	52·4
19	53·0	53·7	54·3	55·0	55·6	56·3	57·0	57·6	58·2	58·9
20	59·5	60·2	60·9	61·5	62·2	62·9	63·5	64·2	64·8	65·5
21	66·2	66·8	67·5	68·2	68·9	69·5	70·2	70·9	71·5	72·2
22	72·9	73·5	74·2	74·9	75·6	76·2	76·9	77·6	78·3	78·9
23	79·6	80·3	81·0	81·7	82·3	83·0	83·7	84·4	85·1	85·7
24	86·4	87·1	87·8	88·5	89·2	89·9	90·5	91·2	91·9	92·6
25	93·3	94·0	94·7	95·4	96·1	96·8	97·5	98·1	98·8	99·5
26	100·2	100·9	101·6	102·3	103·0	103·7	104·4	105·1	105·8	106·5
27	107·2	107·9	108·6	109·3	110·0	110·7	111·4	112·1	112·9	113·6
28	114·3	115·0	115·7	116·4	117·1	117·8	118·5	119·2	120·0	120·7
29	121·4	122·1	122·8	123·5	124·2	125·0	125·7	126·4	127·1	127·8
30	128·4	129·3	130·0	130·7	131·4	132·2	132·9	133·6	134·3	135·1
31	135·8	136·5	137·2	138·0	138·7	139·4	140·2	140·9	141·6	142·4
32	143·1	143·8	144·6	145·3	146·0	146·8	147·5	148·2	149·0	149·7
33	150·4	151·2	151·9	152·7	153·4	154·2	154·9	155·6	156·8	157·1
34	157·9	158·6	159·4	160·1	160·9	161·6	162·4	163·1	163·8	164·6
35	165·3	—	—	—	—	—	—	—	—	—

TABLE 308

LAKE ALBERT

In milliards per year

Year	Total Natural Inflow	Victoria Nile Inflow	Other Sources Inflow	Torrents at Lake Albert Virtual Inflow	In Order of Magnitude	
					Year	Inflow
1905	30·10	21·99	8·11	6·65	1917	56·77
1906	35·68	28·08	7·60	7·17		
1907	28·62	25·75	2·87	4·82	1918	37·25
1908	26·91	20·13	6·78	4·94	1906	35·68
1909	28·44	18·96	9·48	5·27	1942	34·25
					1916	33·45
1910	24·73	16·82	7·91	5·55	1947	30·37
1911	19·52	14·03	5·49	4·60	1905	30·10
1912	18·85	12·35	6·50	5·83		
1913	20·68	13·67	7·01	3·94	1952	29·96
1914	22·37	14·22	8·15	6·07	1932	29·51
					1907	28·62
1915	23·78	15·45	8·33	5·25	1909	28·44
1916	33·45	19·27	14·18	12·41	1931	28·13
1917	56·77	30·07	26·70	11·35	1948	27·98
1918	37·25	25·72	11·53	1·72	1937	27·28
1919	23·85	19·20	4·65	4·10	1908	26·91
					1933	26·87
1920	22·07	17·31	4·76	4·13	1938	26·13
1921	13·70	14·11	− 0·41	2·68		
1922	12·35	11·28	1·07	3·45	1926	24·86
1923	18·40	12·58	5·82	6·00	1910	24·73
1924	18·28	15·07	3·21	2·85	1919	23·85
					1930	23·82
1925	15·04	12·76	2·28	3·20	1915	23·78
1926	24·86	17·83	7·03	6·65	1927	23·66
1927	23·66	21·40	2·26	1·81	1949	23·56
1928	20·15	17·47	2·68	6·73	1914	22·37
1929	17·28	15·58	1·70	3·53	1936	22·26
					1920	22·07
1930	23·82	18·60	5·22	3·00	1941	20·81
1931	28·13	21·58	6·55	4·92	1913	20·68
1932	29·51	23·82	5·69	5·85	1939	20·66
1933	26·87	23·61	3·26	3·22	1943	20·60
1934	19·72	19·08	0·64	4·58	1928	20·15
1935	17·87	17·27	0·60	4·91	1934	19·72
1936	22·26	20·15	2·11	3·93	1911	19·52
1937	27·28	20·85	6·43	5·25	1912	18·85
1938	26·13	23·69	2·44	4·92	1923	18·40
1939	20·66	20·41	0·25	2·46	1924	18·28
					1946	18·27
1940	17·84	18·26	− 0·42	3·48	1935	17·87
1941	20·81	18·63	2·18	4·91	1940	17·84
1942	34·25	29·92	4·33	4·53	1929	17·28
1943	20·60	19·08	1·52	3·75	1951	15·39
1944	14·85	15·05	− 0·20	3·54	1945	15·24
					1925	15·04
1945	15·24	15·12	0·12	4·64		
1946	18·27	13·85	4·42	7·13	1944	14·85
1947	30·37	21·01	9·36	4·48	1921	13·70
1948	27·98	20·33	7·65	4·88	1950	13·66
1949	23·56	20·84	2·72	4·18	1922	12·35
1950	13·66	12·75	0·91	5·13		
1951	15·39	10·95	4·44	2·69		
1952	29·96	20·09	9·87	4·23		
Total	1,141·82	896·04	245·78	231·31	Standard Deviation	7·7
Average	23·79	18·67	5·12	4·82	Median ...	23·41

TABLE 309

MONGALLA DISCHARGES

In milliards per year

Year	Mongalla Discharges	Averages at 5-year Intervals	In Order of Magnitude	
			Year	Discharge
1905	36·2	—	1917	55·8
1906	38·9	—		
1907	35·9	—	1918	47·1
1908	29·8	—		
1909	31·9	34·54	1906	38·9
			1916	37·9
1910	30·4	—	1905	36·2
1911	25·2	—	1907	35·9
1912	23·4	—	1932	32·6
1913	23·0	—		
1914	25·5	30·02	1942	32·1
		—	1948	31·92
1915	27·9	—	1909	31·9
1916	37·9	—	1919	31·2
1917	55·8	—	1933	30·6
1918	47·1	—	1910	30·4
1919	31·2	33·34	1938	30·2
1920	25·8	—	1908	29·8
1921	16·6	—	1931	29·0
1922	15·3	—	1952	28·65
1923	19·3	—	1943	28·46
1924	20·4	29·88	1937	28·1
			1947	27·91
1925	18·9	—	1915	27·9
1926	24·9	—		
1927	26·0	—	1949	26·68
1928	26·6	—	1928	26·6
1929	21·3	28·61	1934	26·3
			1927	26·0
1930	22·7	—	1920	25·8
1931	29·0	—	1914	25·5
1932	32·6	—	1911	25·2
1933	30·6	—		
1934	26·3	28·55	1926	24·9
			1939	24·9
1935	23·5	—	1935	23·5
1936	23·4	—	1912	23·4
1937	28·1	—	1936	23·4
1938	30·2	—	1913	23·0
1939	24·9	28·18		
1940	22·2	—	1941	22·9
1941	22·9	—	1930	22·7
1942	32·1	—	1950	22·35
1943	28·46	—	1946	22·22
1944	20·71	27·82	1940	22·2
			1929	21·3
1945	18·72	—	1944	20·71
1946	22·22	—	1924	20·4
1947	27·91	—		
1948	31·92	—	1923	19·3
1949	26·68	27·56	1951	18·98
			1925	18·9
1950	22·35	—	1945	18·72
1951	18·98	—	1921	16·6
1952	28·65	27·30	1922	15·3
Total	1,310·30		Standard Deviation	7·4
Average	27·3		Median	26·15

KEY TO METHODS OF CONTROLLING LAKES VICTORIA AND ALBERT

METHODS OF CONTROLLING LAKES VICTORIA AND ALBERT

Regulation A - 1: Lake Victoria normal outflow 20 milliards per year.

The principle and object of Century Storage is to deliver as near as possible the long-term mean outflow every year. Therefore it seems logical to examine first what would have happened if the lakes had been operated ideally for this purpose. It is also a useful exercise which accentuates certain important points about the regulation of the lakes.

Table 310 (p. 719) sets out the natural inflow, controlled outflow, cumulative storage, and Entebbe gauge-readings at the end of every year, from 1905 to 1952. The regulated outflow has been taken as 20·08 milliards per year or 55 m/d. For the period considered, the mean natural inflow was 20·92 milliards per year or 57·3 m/d. The result of regulating the outflow to 55 m/d would be that by the end of the period Lake Victoria would have accumulated a reserve of storage of 39·67 milliards more than at the beginning of regulation. This is the first important point. What value should be adopted for the long-term mean? It varies year by year, and any attempt to regulate Lake Victoria to discharge the long-term mean must take the variation of the mean into account. In fact the future value is unknown.

The second point which is of some importance is the starting level. The future range of levels in Lake Victoria will be from 9·80 m. to 12·80 m. on Entebbe gauge, the mean level being 11·30 m. The recorded range in the past has varied from a minimum of 9·81 m. to a maximum of 11·40 m., with a mean of 10·57 m.

The level at the end of 1904 was 10·78 m. or some 20 cm. above the mean. There is also good reason for believing that the discharges from the lake, and thus the lake levels, were high at the turn of the century (Table 6, *Third Interim Report* of the Jonglei Investigation Team). Furthermore the Owen Falls Dam is nearing completion and it is intended to accumulate storage in Lake Victoria before the remainder of the Equatorial Nile Project is completed. It therefore seems reasonable to assume a starting level of 11·50 m. on Entebbe gauge in our investigations.

Starting at this figure, and with the lake outflow regulated to 55 m/d, the level would have exceeded 12·00 m. on the following occasions:

Year	Entebbe Gauge on 31.12 metres	Maximum level during the year metres
1906	12·02	12·29 in June
1917	12·45	12·45 in December
1918	11·89	12·46 in June
1937	12·18	12·30 in June
1938	12·03	12·32 in June
1941	12·10	12·14 in June
1942	12·31	12·73 in June
1947	12·11	12·31 in May
1948	12·03	12·23 in June
1952	12·09	12·50 in June

This illustrates two further points. First, the maximum gauge-reading usually occurs at the end of June. Thus a rainy season at Lake Victoria is ending just as that in the Sudan is beginning. Secondly, since the mean natural outflow for the period is 57·3 m/d whereas the regulated outflow adopted is 55 m/d, the last years of the period are characterized by high levels.

If the larger figure for the outflow had been adopted the lake levels would have been 0·41 m. (27·4 milliards) less in 1937, 0·47 m. (31·5 milliards) less in 1942 and 0·60 m. (40 milliards) less in 1952, and the maximum levels would have been as follows:

Year	Entebbe Gauge on 31.12 metres	Maximum level during the year metres
1906	12·00	12·27 in June
1917	12·29	12·29 in December
1918	11·72	12·30 in June
1937	11·77	11·90 in June
1938	11·61	11·91 in June
1941	11·64	11·69 in June
1942	11·84	12·27 in June
1947	11·58	11·79 in June
1948	11·48	11·69 in June
1952	11·49	11·91 in June

This emphasizes the importance of determining what figure shall be adopted as the long-term mean.

Regulations A - 2, A - 3 and A - 4: Lake Albert normal outflow 23·46, 28·35 and 23·50 milliards per year, the second figure including control of the torrents.

Turning now to the tables for Lake Albert (Tables 311 to 313, pp. 720–2) regulated in combination with Regulation A - 1 above, we start by filling in the column for the controlled Victoria Nile inflow, which is 90% of the Ripon Falls outflow, as explained earlier. In Table 311 we have added to this column the 'other sources' inflow. The total inflow averages 23·20 milliards per year for the full period, but the outflow, 23·47 milliards, was equal to the average inflow for the period 1905–42 for which the original computation was made. It is also equal to the mean for the 31-year period 1912–42. Though the table has been extended to cover 48 years, we have left the outflow unaltered because it illustrates that an outflow equal to the 38-year mean inflow cannot be continued for 48 years without the level in Lake Albert falling not only below the starting level but also below the datum of 10·00 m. on Butiaba gauge. We have assumed that at the end of a rainy season in December 1904 the level in Lake Albert would have been 13·00 m. on Butiaba gauge.

There are two points about this regulation. First, the maximum level in Lake Albert would have been 21·82 m. on Butiaba gauge at the end of 1918. (The year was examined by months as well.) Secondly, the level in Lake Albert would not have fallen below 13·00 m. for the period 1905 to 1942, but would never have been above it after that.

From 1905 to 1918, for 14 years, the level in Lake Albert would have risen steadily, whereas from 1919 to 1946, for 28 years, the level would have fallen. In other words the mean natural inflow in the first part of the period was greater than the mean outflow which we have adopted, and in the second part less. It is possible that this illustrates the occurrence of a climatic cycle, the years before 1918 being considerably wetter than any since then. In the *Third Interim Report* (p. 49) it was concluded, from the available evidence, that floods comparable with the highest recorded in 1917–18 occurred three times within the 40-year period previous to 1918. Nothing on the same scale has occurred on the Bahr el Jebel since then, which may also indicate that we are now passing through a comparatively dry climatic period. The same type of regulation has also been examined for Lake Albert on the assumption that the torrents were completely controlled, and the results are given in Table 312 (p. 721). The computation is done by assuming that the torrents virtually form part of Lake Albert inflow, as explained above. The outflow adopted is 28·35 milliards per year at Lake Albert or 27·0 milliards at Mongalla.

The points to note are that the level in Lake Albert would have risen to 24·33 m. on Butiaba gauge at the end of 1918 and would have fallen to 9·25 m. in 1951.

For further comparison we have included a table for Lake Albert, assuming that it alone was under control and the Victoria Nile inflow was uncontrolled. In this case (Table 313, p. 722) the maximum level in Lake Albert would have been 25·22 m. on Butiaba gauge with a mean outflow for the period of 23·50 milliards per year, the mean for the period 1912-42.

Summarizing our investigations so far we may note:

Lake Victoria

That even with its outflow regulated to a steady 55 m/d, 2·3 m/d less than the actual inflow for the period, and starting at a level of 11·50 m. on Entebbe gauge, the level in Lake Victoria would not have exceeded the proposed maximum level of 12·80 m. on Entebbe gauge during the period considered.

Lake Albert

That with its outflow regulated to the mean for the period 1905–42 the level in Lake Albert would have reached 21·82 m. on Butiaba gauge with Lake Victoria regulated as above, 24·33 m. with control on Lake Victoria, including complete control of the torrents, and 25·22 m. with no control on Lake Victoria and not including the torrents.

TABLE 310

LAKE VICTORIA
REGULATION A - 1
CONTROLLED OUTFLOW 55 M/D, OR 20 MILLIARDS PER YEAR
Discharges in milliards per year. Gauges in metres.

Year	Natural Inflow	Controlled Outflow	Stored or Released	Cumulative Storage	ENTEBBE GAUGE	
					Difference from 11·50	Reading
					Assumed Start	11·50
1905	19·08	20·08	− 1·00	− 1·00	− 0·01	11·49
1906	56·12	20·08	36·04	35·04	0·52	12·02
1907	6·56	20·08	− 13·52	21·52	0·32	11·82
1908	15·51	20·13	− 4·62	16·90	0·25	11·75
1909	3·90	20·08	− 16·18	0·72	0·01	11·51
1910	12·47	20·08	− 7·61	− 6·89	− 0·10	11·40
1911	− 5·18	20·08	− 25·26	− 32·15	− 0·48	11·02
1912	20·09	20·13	− 0·04	− 32·19	− 0·48	11·02
1913	28·26	20·08	8·18	− 24·01	− 0·36	11·14
1914	24·76	20·08	4·68	− 19·33	− 0·29	11·21
1915	23·57	20·08	3·49	− 15·84	− 0·24	11·26
1916	55·04	20·13	34·91	19·07	0·28	11·78
1917	64·58	20·08	44·50	63·57	0·95	12·45
1918	− 17·65	20·08	− 37·73	25·84	0·39	11·89
1919	8·82	20·08	− 11·26	14·58	0·22	11·72
1920	6·20	20·13	− 13·93	0·65	0·01	11·51
1921	− 6·57	20·08	− 26·65	− 26·00	− 0·39	11·11
1922	4·88	20·08	− 15·20	− 41·20	− 0·61	10·89
1923	38·78	20·08	18·70	− 22·50	− 0·34	11·16
1924	7·31	20·13	− 12·82	− 35·32	− 0·53	10·97
1925	23·79	20·08	3·71	− 31·61	− 0·47	11·03
1926	61·55	20·08	41·47	9·86	0·15	11·65
1927	− 4·85	20·08	− 24·93	− 15·07	− 0·22	11·28
1928	19·67	20·13	− 0·46	− 15·53	− 0·23	11·27
1929	0·44	20·08	− 19·64	− 35·17	− 0·52	10·98
1930	57·71	20·08	37·63	2·46	0·04	11·54
1931	33·99	20·08	13·91	16·37	0·24	11·74
1932	26·59	20·13	6·46	22·83	0·34	11·84
1933	11·46	20·08	− 8·62	14·21	0·21	11·71
1934	5·57	20·08	− 14·51	− 0·30	0·00	11·50
1935	15·75	20·08	− 4·33	− 4·63	− 0·07	11·43
1936	30·89	20·13	10·76	6·13	0·10	11·60
1937	59·33	20·08	39·25	45·38	0·68	12·18
1938	10·15	20·08	− 9·93	35·45	0·53	12·03
1939	5·24	20·08	− 14·84	20·61	0·31	11·81
1940	28·55	20·13	8·42	29·03	0·44	11·94
1941	31·51	20·08	11·43	40·46	0·60	12·10
1942	34·05	20·08	13·97	54·43	0·81	12·31
1943	− 13·52	20·08	− 33·60	20·83	0·31	11·81
1944	6·71	20·13	− 13·42	7·41	0·11	11·61
1945	18·80	20·08	− 1·28	6·13	0·09	11·59
1946	17·38	20·08	− 2·70	3·43	0·05	11·55
1947	57·42	20·08	37·34	40·77	0·61	12·11
1948	14·99	20·13	− 5·14	35·63	0·53	12·03
1949	− 6·85	20·08	− 26·93	8·70	0·13	11·63
1950	7·74	20·08	− 12·34	− 3·44	− 0·05	11·45
1951	51·98	20·08	31·90	28·26	0·42	11·92
1952	31·54	20·13	11·41	39·67	0·59	12·09
Total(1)	1,004·11	964·44	39·67	—	—	—
Averages	20·92	20·09	—	—	—	—
Total(2)	1,004·11	960·00	44·11	—	—	12·16

(1) Total as above. (2) Total ignoring leap years, and assuming outflow is 20 milliards per year.

21

TABLE 311

LAKE ALBERT

REGULATION A - 2

VICTORIA NILE INFLOW 49·5 M/D, OR 18 MILLIARDS PER YEAR

LAKE ALBERT OUTFLOW 64·28 M/D, OR 23·46 MILLIARDS PER YEAR

Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Other Sources Inflow	Total Inflow	Controlled Outflow	Contents above 10·00	Butiaba Gauge
				Assumed Start	16·50	13·00
1905	18·07	8·11	26·18	23·46	19·22	13·47
1906	18·07	7·60	25·67	23·46	21·43	13·86
1907	18·07	2·87	20·94	23·46	18·91	13·42
1908	18·12	6·78	24·90	23·52	20·29	13·66
1909	18·07	9·48	27·55	23·46	24·38	14·36
1910	18·07	7·91	25·98	23·46	26·90	14·79
1911	18·07	5·49	23·56	23·46	27·00	14·80
1912	18·12	6·50	24·62	23·52	28·10	15·00
1913	18·07	7·01	25·08	23·46	29·72	15·26
1914	18·07	8·15	26·22	23·46	32·48	15·72
1915	18·07	8·33	26·40	23·46	35·42	16·20
1916	18·12	14·18	32·30	23·52	44·20	17·62
1917	18·07	26·70	44·77	23·46	65·51	20·90
1918	18·07	11·53	29·60	23·46	71·65	21·82
1919	18·07	4·65	22·72	23·46	70·91	21·71
1920	18·12	4·76	22·88	23·52	70·27	21·61
1921	18·07	− 0·41	17·66	23·46	64·47	20·75
1922	18·07	1·07	19·14	23·46	60·15	20·09
1923	18·07	5·82	23·89	23·46	60·58	20·15
1924	18·12	3·21	21·33	23·52	58·39	19·82
1925	18·07	2·28	20·35	23·46	55·28	19·35
1926	18·07	7·03	25·10	23·46	56·92	19·60
1927	18·07	2·26	20·33	23·46	53·79	19·12
1928	18·12	2·68	20·80	23·52	51·07	18·70
1929	18·07	1·70	19·77	23·46	47·38	18·12
1930	18·07	5·22	23·29	23·46	47·21	18·10
1931	18·07	6·55	24·62	23·46	48·37	18·28
1932	18·12	5·69	23·81	23·52	48·66	18·32
1933	18·07	3·26	21·33	23·46	46·53	17·99
1934	18·07	0·64	18·71	23·46	41·78	17·23
1935	18·07	0·60	18·67	23·46	36·99	16·46
1936	18·12	2·11	20·23	23·52	33·70	15·92
1937	18·07	6·43	24·50	23·46	34·74	16·10
1938	18·07	2·44	20·51	23·46	31·79	15·61
1939	18·07	0·25	18·32	23·46	26·65	14·75
1940	18·12	− 0·42	17·70	23·52	20·83	13·75
1941	18·07	2·18	20·25	23·46	17·62	13·20
1942	18·07	4·33	22·40	23·46	16·56	13·01
1943	18·07	1·52	19·59	23·46	12·69	12·32
1944	18·12	− 0·20	17·92	23·52	7·09	11·31
1945	18·07	0·12	18·19	23·46	1·82	10·34
1946	18·07	4·42	22·49	23·46	0·85	10·16
1947	18·07	9·36	27·43	23·46	4·82	10·90
1948	18·12	7·65	25·77	23·52	7·07	11·31
1949	18·07	2·72	20·79	23·46	4·40	10·82
1950	18·07	0·91	18·98	23·46	− 0·08	10·00
1951	18·07	4·44	22·51	23·46	− 1·03	9·80
1952	18·12	9·87	27·99	23·52	3·44	10·64
Total	867·96	245·78	1,113·74	1,126·80	− 13·06	10·64
Averages	18·08	5·12	23·20	23·47	—	—

TABLE 312

LAKE ALBERT

REGULATION A - 3

VICTORIA NILE INFLOW 49·5 M/D, OR 18 MILLIARDS PER YEAR

LAKE ALBERT, INCLUDING TORRENTS, OUTFLOW 28·35 MILLIARDS PER YEAR

Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Other Sources plus Torrents Inflow	Total Inflow	Controlled Outflow	Cumulative Storage	Butiaba Gauge
				Assumed Start	16·50	13·00
1905	18·07	14·76	32·83	28·35	20·98	13·78
1906	18·07	14·77	32·84	28·35	25·47	14·55
1907	18·07	7·69	25·76	28·35	22·83	14·00
1908	18·12	11·72	29·84	28·43	24·29	14·35
1909	18·07	14·75	32·82	28·35	28·76	15·10
1910	18·07	13·46	31·53	28·35	31·94	15·64
1911	18·07	10·09	28·16	28·35	31·75	15·60
1912	18·12	12·33	30·45	28·43	33·77	15·94
1913	18·07	10·95	39·02	28·35	34·44	16·05
1914	18·07	14·22	32·29	28·35	38·38	16·69
1915	18·07	13·58	31·65	28·35	41·68	15·59
1916	18·12	26·59	44·71	28·43	57·96	19·76
1917	18·07	38·05	56·12	28·35	85·73	23·90
1918	18·07	13·25	31·32	28·35	88·70	24·33
1919	18·07	8·75	26·82	28·35	87·17	24·11
1920	18·12	8·89	27·01	28·43	85·75	23·90
1921	18·07	2·27	20·34	28·35	77·74	22·72
1922	18·07	4·52	22·59	28·35	71·89	21·85
1923	18·07	11·82	29·89	28·35	73·52	22·10
1924	18·12	6·06	24·18	28·43	69·27	21·46
1925	18·07	5·48	23·55	28·35	64·47	20·75
1926	18·07	13·68	31·75	28·35	67·87	21·25
1927	18·07	4·07	22·14	28·35	61·66	20·32
1928	18·12	9·41	27·53	28·43	60·76	20·18
1929	18·07	5·23	23·30	28·35	55·71	19·42
1930	18·07	8·22	26·29	28·35	53·65	19·10
1931	18·07	11·47	29·54	28·35	54·84	19·28
1932	18·12	11·54	29·66	28·43	56·07	19·47
1933	18·07	6·48	24·55	28·35	52·27	18·89
1934	18·07	5·22	23·29	28·35	47·21	18·10
1935	18·07	5·51	23·58	28·35	42·44	17·34
1936	18·12	6·04	24·16	28·43	38·17	16·65
1937	18·07	11·68	29·75	28·35	39·57	16·88
1938	18·07	7·36	25·43	28·35	36·65	16·40
1939	18·07	2·71	20·78	28·35	29·08	15·16
1940	18·12	3·06	21·18	28·43	21·83	13·95
1941	18·07	7·09	25·16	28·35	18·64	13·37
1942	18·07	8·86	26·93	28·35	17·22	13·12
1943	18·07	5·27	23·34	28·35	12·21	12·24
1944	18·12	3·34	21·46	28·43	5·24	10·98
1945	18·07	4·76	22·83	28·35	− 0·28	9·95
1946	18·07	11·55	29·62	28·35	0·99	10·19
1947	18·07	13·84	31·91	28·35	4·55	10·85
1948	18·12	12·53	30·65	28·43	6·77	11·25
1949	18·07	6·90	24·97	28·35	3·39	10·63
1950	18·07	6·04	24·11	28·35	− 0·85	9·85
1951	18·07	7·13	25·20	28·35	− 4·00	9·25
1952	18·12	14·10	32·22	28·43	− 0·21	9·95
Total(¹)	867·96	477·09	1,345·05	1,361·76	− 16·71	9·95
Averages	18·08	9·94	28·02	28·37	—	—
Total(²)	864·00	477·09	1,341·09	1,360·80	− 19·71	9·39

(¹) Total as above. (²) Ignoring leap years, and assuming Victoria Nile inflow is 18 milliards per year.

TABLE 313

LAKE ALBERT
REGULATION A - 4
CONTROLLED OUTFLOW 23·50 MILLIARDS PER YEAR
Discharges in milliards per year. Gauges in metres.

Year	Natural Inflow	Regulated Outflow	Stored or Released	Contents above 10·00	Butiaba Gauge
			Assumed Start	16·50	13·00
1905	30·10	23·50	6·60	23·10	14·15
1906	35·68	23·50	12·18	35·28	16·18
1907	28·62	23·50	5·12	40·40	17·02
1908	26·91	23·56	3·35	43·75	17·55
1909	28·44	23·50	4·94	48·69	18·33
1910	24·73	23·50	1·23	49·92	18·52
1911	19·52	23·50	− 3·98	45·94	17·90
1912	18·85	23·56	− 4·71	41·23	17·15
1913	20·68	23·50	− 2·82	38·41	16·69
1914	22·37	23·50	− 1·13	37·28	16·51
1915	23·78	23·50	0·28	37·56	16·55
1916	33·45	23·56	9·89	47·45	18·13
1917	56·77	23·50	33·27	80·72	23·16
1918	37·25	23·50	13·75	94·47	25·17
1919	23·85	23·50	0·35	94·82	25·22
1920	22·07	23·56	− 1·49	93·33	25·01
1921	13·70	23·50	− 9·80	83·53	23·58
1922	12·35	23·50	− 11·15	72·38	21·93
1923	18·40	23·50	− 5·10	67·28	21·16
1924	18·28	23·56	− 5·28	62·00	20·37
1925	15·04	23·50	− 8·46	53·54	19·08
1926	24·86	23·50	1·36	54·90	19·29
1927	23·66	23·50	0·16	55·06	19·32
1928	20·15	23·56	− 3·41	51·65	18·79
1929	17·28	23·50	− 6·22	45·43	17·82
1930	23·82	23·50	0·32	45·75	17·87
1931	28·13	23·50	4·63	50·38	18·59
1932	29·51	23·56	5·95	56·33	19·51
1933	26·87	23·50	3·37	59·70	20·05
1934	19·72	23·50	− 3·78	55·92	19·45
1935	17·87	23·50	− 5·63	50·29	18·73
1936	22·26	23·56	− 1·30	48·99	18·38
1937	27·28	23·50	3·78	52·77	18·97
1938	26·13	23·50	2·63	55·40	19·37
1939	20·66	23·50	− 2·84	52·56	18·93
1940	17·84	23·56	− 5·72	46·84	18·04
1941	20·81	23·50	− 2·69	44·15	17·61
1942	34·25	23·50	10·75	54·90	19·29
1943	20·60	23·50	− 2·90	52·00	18·84
1944	14·85	23·56	− 8·71	43·29	17·47
1945	15·24	23·50	− 8·26	35·03	16·14
1946	18·27	23·50	− 5·23	29·80	15·27
1947	30·37	23·50	6·87	36·67	16·41
1948	27·98	23·56	4·42	41·09	17·13
1949	23·56	23·50	0·06	41·15	17·14
1950	13·66	23·50	− 9·84	31·31	15·53
1951	15·39	23·50	− 8·11	23·20	14·16
1952	29·96	23·56	6·40	29·60	15·24
Total	1,141·82	1,128·72	—	—	15·24
Averages	23·79	23·52	—	—	—

Regulation B - 1: Lake Victoria normal outflow 20 milliards per year, and subject to the following:

(1) Entebbe gauge greater than 12·00 m. and lake level rising, outflow 100 m/d.

(2) Entebbe gauge greater than 12·50 m. and lake level falling, outflow 100 m/d.

(3) Supplementing Lake Albert when the level falls below 12·00 m. on Butiaba gauge.

So far we have considered ideal methods of controlling the two lakes together, but the ideal can seldom be achieved in practice, and, referring to the tables for Lake Albert in the previous example, one may pointedly ask what would have happened if the period of high levels ending in 1918 had been followed by another period of high inflows instead of by the period of phenomenally low ones which occurred in the early 1920's.

It is natural that the Uganda authorities should require safeguards so that the maximum and minimum proposed levels in Lake Victoria are not passed, and so that there will always be sufficient flow of water for the hydro-electric power station at Owen Falls. The following suggestions have been put forward:

(i) The normal outflow from Lake Victoria should be 20 milliards per year, or 55 m/d, and it has been agreed that the range of levels in the lake will be from 9·80 to 12·80 m. on Entebbe gauge.

(ii) When the level in the lake is rising and exceeds 12·00 m., the outflow should be increased to 100 m/d.

(iii) When the level in the lake is falling, the criterion for an outflow of 100 m/d should be 12·50 m. on Entebbe gauge.

(iv) Whenever the level falls below 10·15 m., the outflow should be reduced to 44 m/d, the minimum required to develop the full power at Owen Falls.

One possible point of controversy about these stipulations is whether it is advisable to increase the outflow to 100 m/d. The level in Lake Victoria will always depend largely on the uncontrollable incidence of rainfall and evaporation. In this connection the extreme variability of inflow is to be noted. In Table 306 (p. 712) it will be seen that the standard deviation of the natural inflow from the normal is equal to the normal itself. Over a long period we have shown that the level will also depend on the value adopted for the long-term mean outflow, and that it will be essential to adjust this to suit the variable inflow from time to time. Regulating the outflow as proposed here at both ends of the scale is one way of adjusting the mean outflow to suit the contents of the reservoir, but it has the serious drawback, as will be seen later, of further aggravating conditions in Lake Albert during a period of high inflows similar to 1916–18. Lake Victoria has approximately 11 times the capacity of Lake Albert for equal changes in level. By increasing the flow from 55 m/d to 100 m/d, the level in Lake Victoria could be lowered by 2 cm. per month, or 24·5 cm. a year. During the period considered the following changes in lake level occurred under natural conditions, that is, under the effect of rainfall and evaporation, and with the outflow varying according to lake level up to a maximum of 104 m/d in 1906 and 100 m/d in 1917:

Year	Months	cm.		Rate of Change cm./month	
		Rise	Fall	Average	Maximum
1906	March–May	66	—	22	34
1906–07	June 1906–March 1907	—	53	6	10
1916–17	Jan. 1916–June 1917	98	—	5½	28
1917–19	July 1917–Dec. 1918	—	75	4	24
1925–27	Nov. 1925–Dec. 1927	106	—	5½	29
1927	June–Dec.	—	68	10	15
1928	March–June	43	—	11	28
1929–30	Dec. 1929–June 1930	77	—	11	24
1942	Jan.–June	57	—	10	21
1942	July–Dec.	—	47	8	13
1946–47	March 1946–May 1947	103	—	7¾	32
1951–52	Oct. 1951–Dec. 1952	64	—	16	28

In Table 314 we show what would have happened if Lake Victoria had been regulated in accordance with these rules. We have also taken into account the need to supplement Lake Albert at low levels, as will be seen later. As might be expected, escapage is necessary only in the first half of the period, whereas Lake Albert would have been drawing on supplies from Lake Victoria for most of the latter half.

The level in Lake Victoria would have reached the following maximum values:

Year	Entebbe Gauge on Dec. 31. metres	Maximum Level during the year	metres
1906	11·98	In May	12·26
1907	11·76	In May	12·12
1917	12·30	In November	12·33
1918	11·69	In May	12·28

By comparing this with the previous table, we see that the maximum levels would have been 3, 12, and 18 cm. lower in 1906, 1917 and 1918 than in Regulation A - 1.

The most important point to note is that at the end of 1952 the level in Lake Victoria would have been 1·02 m. lower than at the beginning of 1905. This represents a loss of 68 milliards, as opposed to a gain of 44 milliards in the previous example, a net loss of 112 milliards, due to the high rate of escape of 100 m/d followed by the need to supplement Lake Albert outflow in the later years of the period. Lake Albert, too, is emptied by the introduction of a flood-escape régime. At this juncture we draw attention to the obvious fact that it is impossible both to deliver the long-term mean outflow from the lake and to escape at a very high rate the inflow which determines that mean. It is also relevant to note that the total inflow in March, April, May and June 1917 was 48·5 milliards, while the outflow at the rate of 100 m/d could only total 12·2 milliards. Before we discuss this further we will describe the method of operating Lake Albert in conjunction with the above.

Regulation B - 2: Lake Albert normal outflow 28·35 milliards per year (27·00 milliards per year at Mongalla).

In the above discussion we have queried the advisability of increasing the outflow from Lake Victoria to 100 m/d at high levels. We must also consider its effect on levels in Lake Albert. As mentioned previously the contents held in one metre in Lake Victoria, 67 milliards, are contained in 10 or 11 metres on Lake Albert according to the height above datum. In other words a reduction of 24·5 cm. per year in Lake Victoria results in an increase of 2·45 m. per year in Lake Albert. Before considering flood escape measures for Lake Albert, we have computed the effect of the change in the method of regulating Lake Victoria on Lake Albert, assuming that the outflow from the latter is still kept at 28·35 milliards a year (Table 315, p. 727), which includes control of the torrents. The level would have risen to 26·00 m. in Lake Albert instead of 24·33 m., a difference of 1·67 m., or 11·52 milliards.

Regulation B - 3: Lake Albert normal outflow 28·35 milliards per year (27·00 milliards per year at Mongalla). Escaping high inflows at the rates of 39·68 and 42·04 milliards per year in the first and subsequent years. (Corresponding figures at Mongalla are 37·72 milliards and 40 milliards respectively.)

We now come to the method of controlling Lake Albert in combination with Lake Victoria as in Regulation B - 1, including escaping high inflows, or, as it may be called, a flood-escape régime. The following rules have been devised:

(i) The object of the regulation of Lake Albert will be to provide normally a discharge of 27 milliards per year at Mongalla (28·35 milliards at Lake Albert exit), distributed by months according to a provisional programme designed as far as possible to pass additional quantities of water, for irrigation in the Northern Sudan and Egypt, with the minimum dislocation of grazing and other means of livelihood in the Southern Sudan (see Table 317, p. 729).

(ii) It is assumed that the torrents will be controlled completely by means of low dams at Nimule and at Bedden.

(iii) Normally the range of levels in Lake Albert will lie between 11·50 m. and 15·00 m. on Butiaba gauge.

(iv) When the level in Lake Albert exceeds 15·00 m. on Butiaba gauge, then the outflow from the lake will be increased to 39·68 milliards and 42·04 milliards per year at the lake exit (37·5 and 40 milliards per year at Mongalla) in the first and subsequent years. This flood-escape régime will not be started until the grazing season is practically over, i.e. on May 1st at Mongalla, and not later than 1st September in any year.

(v) The flood-escape régime will be continued until the level in Lake Albert falls to 14·00 m. on Butiaba gauge.

(vi) When the level in Lake Albert falls below 12·00 m., supplementary supplies will be released from Lake Victoria at the rate of 100 m/d at Owen Falls and will be continued until the level exceeds 14·00 m. again, provided the level in Lake Victoria is above 10·15 m. on Entebbe gauge.

The result of applying these rules is given in Table 316 (p. 728) and may be summarized as follows.

The flood-escape régime would have been started (a) in May 1910 and would have continued for about a year, (b) in September 1916 and would have continued until the end of January 1921, a period of 4 years and 5 months. During these two periods a total of 75 milliards of water above the normal outflow of 28·35 milliards per year would have been escaped, and the result of this can be appreciated from the following:

(i) 75 milliards is about 5·5% of the total outflow for 48 years, and the effect of its abstraction is to reduce the mean outflow by 1·56 milliards, to 26·79 milliards per year at the lake exit, or to 25·45 milliards per year at Mongalla.

(ii) In round figures (i.e. ignoring leap years, etc.) Lake Victoria would have lost 112 milliards in 48 years, while Lake Albert would have gained 26 milliards and 75 milliards would have been escaped (a total of 101 milliards, which is 90% of 112 milliards).

(iii) It would have been necessary to supplement the flow from Lake Albert on 10 occasions after 1920, instead of possibly once. In Regulation A - 2, Lake Albert level would not have fallen below its starting level between 1905 and 1942.

(iv) A precarious situation would have arisen at the end of 1950 when the level in Lake Victoria would have fallen to 10·00 m. on Entebbe gauge, while the level in Lake Albert would have stood at 11·90 m. on Butiaba gauge. Although difficulties would have been avoided by the exceptionally high inflow in 1951 of 52 milliards, this precarious position is somewhat different from the previous examples in which the Entebbe gauge would have been 11·45 m. while the level in Lake Albert would have been 10·03 m.

(v) It was found in the examination of regulation on a monthly basis, which is not given here, that a rather curious procedure would have been necessary in 1921, when the termination of a flood-escape régime in January would have been followed by supplementary supplies from Lake Victoria into Lake Albert in January of the following year.

(vi) As will be seen later, the maximum discharge which could be passed safely through the Southern Sudan without re-flooding land in the Central Zone, which will be dried out for a period of from 10 to 30 years, is 38·7 milliards at Mongalla (p. 737). Discharges of 40·6 milliards per year at Mongalla would involve the dissipation of an additional 1·25 milliards per year in the Bahr el Jebel north of Jonglei, and would probably cause serious damage by flooding to new settlements and agricultural activities which will almost certainly become established near the river.

The six items given above summarize the disadvantages of a flood-escape régime operated in accordance with the rules given at the beginning of this section. What are its advantages? There are two. First, the maximum level in Lake Victoria would have been 0·18 m. lower in 1918 than without it, and secondly the maximum level in Lake Albert would have been 20·29 m. instead of 24·33 m. on Butiaba gauge at the end of 1918, or approximately 4 m. lower.

The conclusions are obvious. If the range in Lake Albert could be extended to say 25·00 m. on Butiaba gauge, then both lakes could be regulated so as to deliver their long-term mean outflows. All inflows into both lakes could have been accommodated in them, including control of the torrents, without the necessity of introducing high rates of flood-escape. This period includes the phenomenally high inflows of the years 1916–17–18. Should inflows higher than those previously recorded occur in the future, the discharge at Mongalla could be increased up to 38·7 milliards per year, with effects in the Sudan which are estimated later. But it should be noted that there would be no need to introduce such a flood-escape régime except in the very remote chance of a repetition of successive inflows as high as those of 1916–17–18.

It is, of course, obvious that the more water that is escaped, the lower will be the maximum level in Lake Albert, but there is a practical limit to the maximum rate of escape, which we estimate at 38·7 milliards per year at Mongalla (see p. 737). The total inflow in the second half of 1917 was 40·00 milliards, and even on the assumption that the maximum rate of escape could be applied at once, which is very improbable, some 20 milliards would have had to be stored in one half-year above the normal working level of the lake. If the latter is a gauge-reading of 15·00 m., which corresponds to a capacity of 28 milliards above datum, then the level would rise to 18·20 m. on Butiaba gauge, which corresponds to a capacity of 48 milliards, although the actual starting level would have been higher because of high inflows in 1916.

A further point to note is that if water is escaped, then the normal outflow—the long-term mean—must be reduced. This in turn means that in years of abnormally high inflow more water than ever must be stored or escaped, and so on in a vicious circle.

TABLE 314

LAKE VICTORIA
REGULATION B - 1
NORMAL OUTFLOW 20 MILLIARDS/YEAR
ENTEBBE GAUGE > 12·0 AND RISING, 100 M/D; > 12·50 AND FALLING, 100 M/D
ENTEBBE GAUGE < 10·15, 44 M/D

Discharges in milliards per year. Gauges in metres.

Year	Natural Inflow	Controlled Outflow	Stored or Released	Cumulative Storage	Entebbe Gauge	
					Difference from 11·50	Reading
					Assumed Start	11·50
1905	19·08	20·00	− 0·92	− 0·92	− 0·01	11·49
1906	56·12	22·76	33·36	32·44	0·48	11·98
1907	6·56	21·36	− 14·80	17·64	0·26	11·76
1908	15·51	20·00	− 4·49	13·15	0·20	11·70
1909	3·90	20·00	− 16·10	− 2·95	− 0·04	11·46
1910	12·47	20·00	− 7·53	− 10·48	− 0·16	11·34
1911	− 5·18	20·00	− 25·18	− 35·66	− 0·53	10·97
1912	20·09	20·00	0·09	− 35·57	− 0·53	10·97
1913	28·26	20·00	8·26	− 27·31	− 0·41	11·09
1914	24·76	20·00	4·76	− 22·55	− 0·34	11·16
1915	23·57	20·00	3·57	− 18·98	− 0·28	11·22
1916	55·04	20·00	35·04	16·06	0·24	11·74
1917	64·58	26·92	37·66	53·72	0·80	12·30 (1)
1918	− 17·65	22·76	40·41	13·31	0·20	11·70
1919	8·82	20·00	− 11·18	2·13	0·02	11·52
1920	6·20	20·00	− 13·80	− 11·67	− 0·17	11·33
1921	− 6·57	20·00	− 26·57	− 38·24	− 0·57	10·93
1922	4·88	36·50	− 31·62	− 69·86	− 1·03	10·47
1923	38·78	20·00	18·78	− 51·08	− 0·75	10·75
1924	7·31	20·00	− 12·69	− 63·77	− 0·94	10·54
1925	23·79	20·00	3·79	− 59·98	− 0·89	10·61
1926	61·55	20·00	41·55	− 18·43	− 0·27	11·23
1927	− 4·85	20·00	− 24·85	− 43·28	− 0·65	10·85
1928	19·67	36·50	− 16·83	− 60·11	− 0·72	10·78
1929	0·44	20·00	− 19·56	− 79·67	− 1·17	10·33
1930	57·71	20·00	37·71	− 41·96	− 0·49	11·01
1931	33·99	20·00	13·99	− 27·97	− 0·33	11·17
1932	26·59	20·00	6·59	− 21·38	− 0·25	11·25
1933	11·46	20·00	− 8·54	− 29·92	− 0·35	11·15
1934	5·57	20·00	− 14·43	− 44·35	− 0·52	10·98
1935	15·75	36·50	− 20·75	− 65·10	− 0·97	10·53
1936	30·89	28·18	2·71	− 62·39	− 0·93	10·57
1937	59·33	20·00	39·33	− 23·06	− 0·35	11·15
1938	10·15	20·00	− 9·85	− 32·91	− 0·49	11·01
1939	5·24	20·00	− 14·76	− 47·67	− 0·71	10·79
1940	28·55	36·50	− 7·95	− 55·62	− 0·83	10·67
1941	31·51	28·18	3·33	− 52·29	− 0·78	10·72
1942	34·05	20·00	14·05	− 38·24	− 0·57	10·93
1943	− 13·52	20·00	− 33·52	− 71·76	− 1·07	10·43
1944	6·71	20·00	− 13·29	− 85·05	− 1·27	10·23
1945	18·80	29·59	− 10·79	− 95·84	− 1·42	10·08
1946	17·38	16·00	1·38	− 94·46	− 1·41	10·09
1947	57·42	16·00	41·42	− 53·04	− 0·79	10·71
1948	14·99	28·18	− 13·19	− 66·23	− 0·99	10·51
1949	− 6·85	19·33	− 26·18	− 92·41	− 1·38	10·12
1950	7·74	16·00	− 8·26	− 100·67	− 1·50	10·00
1951	51·98	28·18	23·80	− 76·87	− 1·15	10·35
1952	31·54	22·90	8·64	− 68·23	− 1·02	10·48
Total	1,004·11	1,072·34	− 68·23	—	− 1·02	10·48
Averages	20·92	22·34	—	—	—	—

(1) Maximum level 12·33 m. at the end of November 1917

TABLE 315

LAKE ALBERT
REGULATION B - 2
LAKE ALBERT INFLOW INCLUDING CONTROL OF THE TORRENTS
LAKE ALBERT OUTFLOW 28·35 MILLIARDS PER YEAR
Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Other Sources plus Torrents Inflow	Total Inflow	Controlled Outflow	Cumulative Storage	Butiaba Gauge
				Assumed Start	16·50	13·00
1905	18·00	14·76	32·76	28·35	20·91	13·77
1906	20·48	14·77	35·25	28·35	27·81	14·94
1907	19·22	7·69	26·91	28·35	26·37	14·70
1908	18·00	11·72	29·72	28·35	27·74	14·93
1909	18·00	14·75	32·75	28·35	32·14	15·67
1910	18·00	13·46	31·46	28·35	35·25	16·18
1911	18·00	10·09	28·09	28·35	34·99	16·14
1912	18·00	12·33	30·33	28·35	36·97	16·36
1913	18·00	10·95	28·95	28·35	37·57	16·55
1914	18·00	14·22	32·22	28·35	41·44	17·18
1915	18·00	13·58	31·58	28·35	44·67	17·70
1916	18·00	26·59	44·59	28·35	60·91	20·20
1917	24·22	38·05	62·27	28·35	94·83	25·22
1918	20·49	13·25	33·74	28·35	100·22	26·00
1919	18·00	8·75	26·75	28·35	98·62	25·77

TABLE 316

LAKE ALBERT
REGULATION B - 3
(For method see text)
Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Other Sources and Torrents Inflow	Total Inflow	Controlled Outflow	Cumulative Storage	Butiaba Gauge
				Assumed Start	13·67	12·50
1905	18·00	14·76	32·76	28·35	18·08	13·28
1906	20·48	14·77	35·25	28·35	24·98	14·45
1907	19·22	7·69	26·91	28·35	23·54	14·22
1908	18·00	11·72	29·72	28·35	24·91	14·44
1909	18·00	14·75	32·75	28·35	29·31	15·20
1910	18·00	13·46	31·46	39·68	21·09	13·80
1911	18·00	10·09	28·09	28·35	20·83	13·75
1912	18·00	12·33	30·33	28·35	22·81	14·10
1913	18·00	10·95	28·95	28·35	23·41	14·20
1914	18·00	14·22	32·22	28·35	27·28	14·95
1915	18·00	13·58	31·58	28·35	30·51	15·40
1916	18·00	26·59	44·59	35·17	39·93	16·94
1917	24·22	38·05	62·27	40·76	61·44	20·29
1918	20·49	13·25	33·74	42·04	53·14	19·02
1919	18·00	8·75	26·75	42·04	37·85	16·60
1920	18·00	8·89	26·89	42·04	22·70	14·08
1921	18·00	2·27	20·27	32·04	10·93	12·01
1922	32·85	4·52	37·37	28·35	19·95	13·60
1923	18·00	11·82	29·82	28·35	21·42	13·85
1924	18·00	6·06	24·06	28·35	17·13	13·11
1925	18·00	5·48	23·48	28·35	12·26	12·25
1926	18·00	13·68	31·68	28·35	15·59	12·84
1927	18·00	4·07	22·07	28·35	9·31	11·72
1928	32·85	9·41	42·26	28·35	23·22	14·16
1929	18·00	5·23	23·23	28·35	18·10	13·28
1930	18·00	8·22	26·22	28·35	15·97	12·90
1931	18·00	11·47	29·47	28·35	17·09	13·10
1932	18·00	11·54	29·54	28·35	18·28	13·31
1933	18·00	6·48	24·48	28·35	14·41	12·63
1934	18·00	5·22	23·22	28·35	9·28	11·71
1935	32·85	5·51	38·36	28·35	19·29	13·51
1936	25·37	6·04	31·41	28·35	22·35	14·02
1937	18·00	11·68	29·68	28·35	23·68	14·24
1938	18·00	7·36	25·36	28·35	20·69	13·73
1939	18·00	2·71	20·71	28·35	13·05	12·39
1940	32·85	3·06	35·91	28·35	20·61	13·72
1941	25·37	7·09	32·46	28·35	24·72	14·42
1942	18·00	8·86	26·86	28·35	23·23	14·17
1943	18·00	5·27	23·27	28·35	18·15	13·29
1944	18·00	3·34	21·34	28·35	11·14	12·05
1945	26·63	4·76	31·39	28·35	14·18	12·59
1946	14·40	11·55	25·95	28·35	11·78	12·16
1947	14·40	13·84	28·24	28·35	11·67	12·15
1948	25·37	12·53	37·90	28·35	21·22	13·81
1949	17·41	6·90	24·31	28·35	17·18	13·11
1950	14·40	6·04	20·44	28·35	9·27	11·71
1951	25·37	7·13	32·50	28·35	13·42	12·45
1952	20·61	14·10	34·71	28·35	19·78	13·57
Total	965·14	477·09	1,442·23	1,436·12	6·11	13·57
Averages	20·11	9·94	30·05	29·92	—	—

TABLE 317

DISCHARGES AT MONGALLA

TYPICAL DISTRIBUTION OF FLOW AT MONGALLA BY MONTHS, USED IN THE EXAMPLE OF REGULATION B - 3

Month	Normal Regulation			
	Mongalla		Lake Albert	
	m/d	milliards	m/d	milliards
January	64	1·97	66·5	2·06
February	64	1·79	66·5	1·88
March	64	1·97	66·5	2·06
April	64	1·92	66·5	2·02
May	64	1·97	66·5	2·06
June	75	2·25	79·0	2·37
July	80	2·47	83·9	2·60
August	85	2·67	88·7	2·75
September	90	2·70	94·7	2·84
October	85	2·62	88·7	2·75
November	80	2·40	83·9	2·53
December	75	2·32	79·0	2·43
Year	74·0	27·0	77·7	28·35

Month	Flood-Escape Regime 1st Year				Flood-Escape Regime 2nd Year			
	Mongalla		Lake Albert		Mongalla		Lake Albert	
	m/d	milliards	m/d	milliards	m/d	milliards	m/d	milliards
January ...	90	2·79	95	2·94	100	3·12	105	3·28
February ...	80	2·24	84	2·36	90	2·52	95	2·65
March ...	80	2·48	84	2·61	90	2·79	95	2·94
April	80	2·40	84	2·52	90	2·70	95	2·84
May	85	2·64	89	2·78	100	3·12	105	3·28
June	100	3·09	105	3·25	120	3·60	126	3·79
July	120	3·72	126	3·91	120	3·72	126	3·92
August ...	120	3·72	126	3·91	120	3·72	126	3·92
September ...	120	3·60	126	3·79	120	3·60	126	3·79
October ...	120	3·72	126	3·91	120	3·72	126	3·92
November ...	120	3·60	126	3·79	120	3·60	126	3·79
December ...	120	3·72	126	3·91	120	3·72	126	3·92
Year	103	37·72	109	39·68	110	39·93	115	42·04

Regulation C - 1: Lake Victoria normal outflow 20 milliards per year ± 1/10th of the contents above or below the level of 11·50 m. on Entebbe gauge, and according to :

Entebbe gauge	> 12·00 m.	—	Discharge 100 m/d[2]
,, ,,	< 10·15 m.	—	,, 44 m/d.

Regulation C - 2: Lake Albert normal outflow 28·35 milliards per year (27 milliards at Mongalla) ± 1/10th contents above or below 13·5 m. on Butiaba gauge.

Regulations D - 1 and D - 2: Lakes Victoria and Albert as in Regulation C - 1, but with the addition of supplements from Lake Victoria when Lake Albert level falls to 11·50 m. on Butiaba gauge.

The results of these methods of operating the lakes are given in Tables 318 to 320 (pp. 731–3). We will comment on them briefly because they represent steps in the development of methods given later and provide examples for purposes of comparison.

We have pointed out how essential it is to alter the mean outflow in accordance with the mean inflow. One method of doing this would be to revise the mean every 10 years or so, but the disadvantage of this would be that the longer the period of records, already nearly 50 years, the smaller the variation in the long-term mean from year to year, whereas the inflow appears to vary in definite cycles of high and low periods. In an attempt to overcome this difficulty, to dispose of surplus storage, and to cut down the outflow in the case of a deficiency of storage, we propose to add to or subtract from the long-term mean annual outflow already determined, one-tenth of the contents above or below the arbitrary mean levels of 11·50 m. on Entebbe gauge and 13·50 m. on Butiaba gauge, at the end of the previous year. In addition we have adopted the rule for regulating Lake Victoria at Entebbe gauges of 12·00 and 10·15 m.

In Lake Victoria, without supplementing Lake Albert, the level in the lake would have exceeded 12·00 m. on Entebbe gauge in 1906, 1907, 1917, 1918, 1937 and 1938, reaching a maximum of 12·38 m. in June 1917. The mean regulated outflow for the period would have been 56·56 m/d, or 20·66 milliards per year, and at the end of 1942[3], the beginning of a period of low years, the level in the lake would have been 11·99 m.

In Lake Albert, without supplements from Lake Victoria, the contents would have ranged from plus 67·47 milliards above the starting level to minus 18·76 milliards below it, or approximately from 11·50 to 25·15 m. on Butiaba gauge. We assume in this case that the starting level would have been 13·50 m. The mean regulated outflow for the period would have been 80·09 m/d or 29·25 milliards per year. The maximum outflow would have been 35·1 milliards in 1919, and the minimum 26·47 milliards in 1937. In these computations the outflows were altered annually, according to the lakes' levels at the end of the previous year. Ideally to suit grazing needs in the Sudan, the increase in flow should take effect on 1st May every year, but this would have introduced an unnecessary complication into the computation.

The only other relevant comment concerns both this method of operation, Regulation C - 1, and the next, Regulations D - 1 and D - 2. It is clear from Table 319 that the range of levels in Lake Albert could have been reduced to 67 milliards (22·40 m.) by eliminating the negative values, or in other words by starting at 11·50 m. on Butiaba gauge, and by supplementing Lake Albert outflow from Lake Victoria whenever the level in the former fell to the starting level. The result of doing this is shown in Table 320, which is a continuation of Tables 318 and 319, starting in 1925. The supplementary supplies from Lake Victoria were continued until the level in Lake Albert again reached 13·00 m.

In the case of Regulation D - 1 the level in Lake Victoria would have exceeded 12·00 m. only in 1906, 1907, 1917 and 1918. Lake Albert would have drawn on storage in Lake Victoria on no less than 12 occasions. The finishing level in Lake Victoria would have been 11·31 m. on Entebbe gauge, and in Lake Albert at its starting level of 11·50 m. on Butiaba gauge.

TABLE 318

LAKE VICTORIA
REGULATION C - 1

NORMAL OUTFLOW 20·08 MILLIARDS/YEAR (55 M/D), MINIMUM 16·00 MILLIARDS/YEAR,
REGULATED OUTFLOW 20·08 MILLIARDS ± 1/10TH CONTENTS ABOVE OR BELOW 11·50 METRES
SUBJECT TO OUTFLOW 100 M/D ENTEBBE GAUGE > 12·00 METRES

Discharges in milliards per year. Gauges in metres

Year	Natural Inflow	Regulated Outflow	Stored or Released	Cumulative Storage	Entebbe Gauge	
					Difference from 11·50	Reading
					Assumed Start	11·50
1905	19·08	20·08	− 1·00	− 1·00	− 0·01	11·49
1906	56·12	28·36	27·76	26·76	0·40	11·90
1907	6·56	25·13	− 18·57	8·19	0·12	11·62
1908	15·51	20·90	− 5·39	2·80	0·04	11·54
1909	3·90	20·36	− 16·46	− 13·66	− 0·20	11·30
1910	12·47	18·71	− 6·24	− 19·90	− 0·30	11·20
1911	− 5·18	18·09	− 23·27	− 43·17	− 0·64	10·86
1912	20·09	16·00	4·09	− 39·08	− 0·58	10·92
1913	28·26	16·12	12·14	− 26·94	− 0·40	11·10
1914	24·76	17·39	7·37	− 19·57	− 0·29	11·21
1915	23·57	18·12	5·45	− 14·12	− 0·21	11·29
1916	55·04	18·67	36·37	22·25	0·33	11·83
1917	64·58	31·82	32·76	55·01	0·82	12·32[1]
1918	− 17·65	31·91	− 49·56	5·45	0·08	11·58
1919	8·82	20·63	− 11·81	− 6·36	− 0·10	11·40
1920	6·20	19·44	− 13·24	− 19·60	− 0·29	11·21
1921	− 6·57	18·12	− 24·69	− 44·29	− 0·66	10·84
1922	4·88	16·00	− 11·12	− 55·41	− 0·82	10·68
1923	38·78	16·00	22·78	− 32·63	− 0·49	11·01
1924	7·31	16·82	− 9·51	− 42·14	− 0·63	10·87
1925	23·79	16·00	7·79	− 34·35	− 0·51	10·99
1926	61·55	16·64	44·91	10·56	0·17	11·67
1927	− 4·85	21·14	− 25·99	− 15·43	− 0·23	11·27
1928	19·67	18·54	1·13	− 14·30	− 0·21	11·29
1929	0·44	18·65	− 18·21	− 32·51	− 0·49	11·01
1930	57·71	16·83	40·88	8·37	0·13	11·63
1931	33·99	20·92	13·07	21·44	0·32	11·82
1932	26·59	22·22	4·37	25·81	0·39	11·89
1933	11·46	22·66	− 11·20	14·61	0·22	11·72
1934	5·57	21·54	− 15·97	− 1·36	− 0·02	11·48
1935	15·75	19·94	− 4·19	− 5·55	− 0·08	11·42
1936	30·89	19·51	11·38	5·83	0·08	11·58
1937	59·33	25·93	33·40	39·23	0·58	12·08
1938	10·15	30·23	− 20·08	19·15	0·29	11·79
1939	5·24	22·00	− 16·76	2·39	0·04	11·54
1940	28·55	20·32	8·23	10·62	0·16	11·66
1941	31·51	21·14	10·37	20·99	0·31	11·81
1942	34·05	22·18	11·87	32·86	0·49	11·99
Totals	817·92	785·06	32·86	32·86	0·49	11·99
Averages	21·52	20·66	—	—	—	—

[1] Maximum level 12·38 m. in June 1917

TABLE 319

LAKE ALBERT

REGULATION C - 2

LAKE ALBERT OUTFLOW 28·35 MILLIARDS/YEAR ± 1/10TH CONTENTS DIFFERENCE FROM MEAN

Discharges in milliards per year

Year	Victoria Nile Controlled Inflow	Other Sources Inflow	Torrents Virtual Inflow	Total Inflow	Regulated Outflow	Cumulative Storage
1905	18·07	8·11	6·65	32·83	28·35	4·48
1906	25·52	7·60	7·17	40·29	28·80	15·97
1907	22·62	2·87	4·82	30·31	29·95	16·33
1908	18·81	6·78	4·94	30·53	29·98	16·88
1909	18·32	9·48	5·27	33·07	30·04	19·91
1910	16·84	7·91	5·55	30·30	30·34	19·87
1911	16·28	5·49	4·60	26·37	30·34	15·90
1912	14·40	6·50	5·83	26·73	29·94	12·69
1913	14·51	7·01	3·94	25·46	29·62	8·53
1914	15·65	8·15	6·07	29·87	29·20	9·20
1915	16·31	8·33	5·25	29·89	29·27	9·82
1916	16·80	14·18	12·41	43·39	29·33	23·88
1917	28·64	26·70	11·35	66·69	30·74	59·83
1918	28·72	11·53	1·72	41·97	34·33	67·47
1919	18·57	4·65	4·10	27·32	35·10	59·69
1920	17·50	4·76	4·13	26·39	34·32	51·76
1921	16·31	− 0·41	2·68	18·58	33·53	36·81
1922	14·40	1·07	3·45	18·92	32·03	23·70
1923	14·40	5·82	6·00	26·22	30·72	19·20
1924	15·14	3·21	2·85	21·20	30·27	10·13
1925	14·40	2·28	3·20	19·88	29·36	0·65
1926	14·98	7·03	6·65	28·66	28·42	0·89
1927	19·03	2·26	1·81	23·10	29·44	− 5·45
1928	16·69	2·68	6·73	26·10	27·80	− 7·15
1929	16·78	1·70	3·53	22·01	27·63	− 12·77
1930	15·15	5·22	3·00	23·37	27·07	− 16·47
1931	18·83	6·55	4·92	30·30	26·70	− 12·87
1932	20·00	5·69	5·85	31·54	27·06	− 8·39
1933	20·39	3·26	3·22	26·87	27·51	− 9·03
1934	19·39	0·64	4·58	24·61	27·45	− 11·87
1935	17·95	0·60	4·91	23·46	27·16	− 15·57
1936	17·56	2·11	3·93	23·60	26·79	− 18·76
1937	23·34	6·43	5·25	35·02	26·47	− 10·21
1938	27·21	2·44	4·92	34·57	27·33	− 2·97
1939	19·80	0·25	2·46	22·51	28·00	− 8·46
1940	18·29	− 0·42	3·48	21·35	27·50	− 14·61
1941	19·03	2·18	4·91	26·12	26·89	− 15·38
1942	19·96	4·33	4·53	28·82	26·81	− 13·37
Totals	706·59	204·97	186·66	1,098·22	1,111·59	− 13·37
Averages	18·59	5·39	4·91	28·90	29·25	—
Range of Storage ...	67·47 − 18·76		Range of Levels	25·15 11·50	25·55 12·00	25·95 12·50
Total in milliards ...	86·23		metres ...	13·65	13·55	13·45

TABLE 320

LAKE VICTORIA

REGULATION D - 1

Discharges in milliards per year. Gauges in metres.

Year	Natural Inflow	Regulated Outflow	Stored or Released	Cumulative Storage	Entebbe Gauge	
					Difference from 11·50	Reading
Brought Forward ...	366·53	408·67	— 42·14	— 42·14	— 0·63	10·87
1925	23·79	16·00	7·79	— 34·35	— 0·51	10·99
1926	61·55	29·80	31·75	— 2·60	— 0·04	11·46
1927	— 4·85	19·82	— 24·67	— 27·27	— 0·41	11·09
1928	19·67	17·33	2·34	— 24·93	— 0·37	11·13
1929	0·44	33·28	— 32·84	— 57·77	— 0·86	10·64
1930	57·71	16·00	41·71	— 16·06	— 0·24	11·26
1931	33·99	29·00	4·99	— 11·07	— 0·16	11·34
1932	26·59	18·97	7·62	— 3·45	— 0·05	11·45
1933	11·46	19·73	— 8·27	— 11·72	— 0·17	11·33
1934	5·57	36·50	— 30·93	— 42·65	— 0·63	10·87
1935	15·75	16·00	— 0·25	— 42·90	— 0·64	10·86
1936	30·89	28·18	2·71	— 40·19	— 0·60	10·90
1937	59·33	16·00	43·33	3·14	0·05	11·55
1938	10·15	36·50	— 26·35	— 23·21	— 0·35	11·15
1939	5·24	17·68	— 12·44	— 35·65	— 0·53	10·97
1940	28·55	36·50	— 7·95	— 43·60	— 0·65	10·85
1941	31·51	16·00	15·51	— 28·09	— 0·42	11·08
1942	34·05	28·18	5·87	— 22·22	— 0·33	11·17
Total	817·92	840·14	— 22·22	— 22·22	— 0·33	11·17
Average	21·51	22·11	—	—	—	—

LAKE ALBERT

REGULATION D - 2

Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Torrents and Other Sources	Total Inflow	Controlled Outflow	Cumulative Storage above 11·50	Butiaba Gauge
Brought Forward ...	367·81	258·52	626·33	616·20	10·13	13·31
1925	14·40	5·48	19·88	29·36	0·65	11·62
1926	26·82	13·68	40·50	28·42	12·73	13·75
1927	17·84	4·07	21·91	29·62	5·02	12·40
1928	15·60	9·41	25·01	28·85	1·18	11·70
1929	29·95	5·23	35·18	28·47	7·89	12·90
1930	14·40	8·22	22·62	29·14	1·37	11·75
1931	26·13	11·47	37·60	28·45	10·52	13·43
1932	17·07	11·54	28·61	29·41	9·72	13·24
1933	17·76	6·48	24·24	29·33	4·63	12·34
1934	32·85	5·22	38·07	28·83	13·87	13·95
1935	14·40	5·51	19·91	29·75	4·03	12·23
1936	25·37	6·04	31·41	28·76	6·68	12·70
1937	14·40	11·68	26·08	29·02	3·74	12·22
1938	32·85	7·36	40·21	28·72	15·23	14·19
1939	15·91	2·71	18·62	29·87	3·98	12·22
1940	32·85	3·06	35·91	28·75	11·14	13·48
1941	14·40	7·09	21·49	29·46	3·17	12·13
1942	25·37	8·86	34·23	28·67	8·73	13·06
Total	756·18	391·63	1,147·81	1,139·08	8·73	13·06
Averages	19·90	10·31	30·21	29·98	—	—

Regulations E - 1 and E - 2: Lakes Victoria and Albert, regulated according to their contents.

In the previous examples we have shown the effects of applying both theoretical and practical methods of regulation, and have pointed out their advantages and disadvantages. In this example we attempt to combine the best features of both methods. As before we must devise some rules for regulation, which are as follows:

LAKE VICTORIA

(i) The normal annual outflow from Lake Victoria will be 20 milliards per year (55 m/d) plus or minus one-tenth of the contents of the reservoir above or below the gauge-reading of 11·50 m. on Entebbe gauge at the end of the previous calendar year, or according to the following scale:

Entebbe Gauge m.	Contents below 11·50 m. mds.	Annual Outflow mds.	Entebbe Gauge m.	Contents above 11·50 m. mds.	Annual Outflow mds.
10·90	40	16·0	11·50	0	20·0
11·00	33	16·7	11·60	7	20·7
11·10	27	17·3	11·70	13	21·3
11·20	20	18·0	11·80	20	22·0
11·30	13	18·7	11·90	27	22·7
11·40	7	19·3	12·00	33	23·3

(ii) Whenever the level on Entebbe gauge exceeds 12·00 m., the outflow will be increased to 100 m/d, and will continue at that rate until the lake level again falls below 12·00 m.[4]

(iii) Whenever the level on Entebbe gauge falls below 10·15 m., the outflow will be reduced to 44 m/d, and will continue at that rate until the lake level again rises above 10·15 m.

(iv) Supplementary supplies of water will be passed to Lake Albert whenever the level on Butiaba gauge falls below 12·00 m., provided that the level on Entebbe gauge stands above 10·15 m.

(v) These supplements will be discharged from Owen Falls at the rate of 100 m/d, the maximum possible rate, which will continue until the level on Butiaba gauge exceeds 14·00 m.

LAKE ALBERT

(vi) Assuming that the torrents can be controlled completely with low dams at Nimule and Bedden, the object of regulation of Lake Albert will be to discharge 28·35 milliards per year (27·0 milliards per year at Mongalla).

(vii) The normal range of levels in Lake Albert will be from 11·50 to 14·00 m. on Butiaba gauge.

(viii) When at the end of the previous year (or at the end of April of the current year when the lake level is normally at its lowest) the level exceeds 14·00 m. on Butiaba gauge, then the annual outflow will be increased by approximately one-tenth of the contents above 11·50 m. at the beginning of May, or of June at the latest, according to the following scale:

Butiaba Gauge m.	Annual Outflow at Lake Albert Exit mds.
11·5	28·35
14·0	29·0
15·0	30·0
16·0	31·0
17·0	31·5
18·0	32·0
19·0	33·0
20·0	33·5
21·0	34·0
22·0	35·0
23·0	35·5
24·0	36·5
25·0	36·5 (p. 737)
etc.	

(ix) When the level on Butiaba gauge falls below 12·00 m., the inflow of the Victoria Nile will be increased to 90 m/d (100 m/d at Owen Falls). It will continue at this rate until the level in Lake Albert again reaches 14·00 m. on Butiaba gauge.

(x) (ix) above will apply only when the level in Lake Victoria exceeds 10·15 m. on Entebbe gauge.

(xi) When the level in Lake Albert is below 14·00 m. on Butiaba gauge at the end of the previous year (or at the end of April), and at the same time the level in Lake Victoria is below 11·50 m. on Entebbe gauge, then the annual outflow from Lake Albert will be reduced by the same amount as the annual outflow from Lake Victoria, or one-tenth of the difference in contents from 11·50 m. on the gauge, less transmission losses between the two lakes which are assumed to be 10%, according to the following scale:

LEVEL IN LAKE ALBERT LESS THAN 14·00 m. ON BUTIABA GAUGE

Entebbe Gauge m.	Lake Albert Regulated Annual Outflow mds.
10·90	24·75
11.00	25·38
11·10	25·92
11·20	26·55
11·30	27·18
11·40	27·72
11·50	28·35

(xii) In all cases the outflow from Lake Albert will be distributed throughout the year so as to cause the least dislocation of grazing in the Sudan, according to Tables 323 to 328 (pp. 739–41). The results of applying these rules of regulation to the 38-year period from 1905 to 1942 are given in Tables 329 and 330 (pp. 742–3).

The level in Lake Victoria would have exceeded 12·00 m. on Entebbe gauge in 1906, 1907, 1917 and 1918 only, reaching a maximum 12·40 m. in November 1917. The mean annual outflow for the period would have been 21·22 milliards, and the level of the lake would have been 11·66 m. on Entebbe gauge at the end of the period.

The maximum level in Lake Albert would have been 23·63 m. on Butiaba gauge, reached in July 1918. The mean regulated outflow would have been 29·06 milliards per year, an increase of 0·71 milliards per year over the long-term mean of 28·35 milliards per year. Thus in 38 years a total of 27·00 milliards would have been discharged in excess of the long-term mean.

In the 38 years outflows occurred as follows:

ANNUAL OUTFLOWS

Outflow mds.	Occurrence	Outflow mds.	Occurrence	Outflow mds.	Occurrence
27·18	1	24·75	1	31·0	1
27·72	3	25·38	1	31·5	1
28·35	9	25·92	3	32·0	1
29·00	9	26·55	1	33·5	1
30·00	3			35·2	2
				35·5	1
Total Average Outflows ...	25	Total Low Outflows ...	6	Total High Outflows ...	7

The level in the lake would have been 13·80 m. on Butiaba gauge at the end of the period and at the beginning of a low period.

Lake Albert would have drawn on Lake Victoria storage in five years, 1928, 1935, 1936, 1940, 1941.

Regulation E - 3: Lakes Victoria and Albert operated as in Regulations E - 1 and E - 2 but with the sliding scale of outflows from Lake Albert raised so that the maximum rate of outflow (36·5 milliards per year, p. 737) is reached when the level reaches 20·00 m. on Butiaba gauge.

With the previous method of operation the level in Lake Albert would have risen to a maximum of 23·63 m. on Butiaba gauge, and if this method were to be accepted it would be necessary to get the agreement of the Uganda authorities to a maximum level in the lake of about 25·00 m. We suggest that this is to be recommended, since the regulation could then be a fair compromise between the opposing requirements to keep the level in Lake Albert as low as possible and to conserve as much as possible of the inflows in high years for use in low years, and at the same time cause as little damage as possible to livelihood in the Sudan.

However, before such a proposal could be accepted we must examine all ways and means of reducing the level in Lake Albert, and the first modification to the proposed Regulations E - 1 and E - 2 which occurs to us is to revise the sliding scale of outflow so that the maximum rate of outflow is reached at a lower level. For this purpose we suggest the following revised scale of outflows:

REVISED SLIDING SCALE OF ANNUAL OUTFLOWS FROM LAKE ALBERT

Butiaba Gauge m.	Lake Albert Annual Outflow mds.
11·5	28·35
14·0	29·0
15·0	30·0
16·0	31·0
17·0	32·0
18·0	33·0
19·0	34·0
20·0	36·5
21·0	36·5
etc.	

It will be noted that this approximates to the previous rule of the mean outflow plus one-tenth of the contents above 11·50 m. on Butiaba gauge for the lower levels, but increases at higher levels to the fraction of 1/6·3 of the contents at a gauge-reading of 20·00 m.

Without altering the rules for regulating Lake Victoria, we have examined this suggestion as far as the peak year, 1918, in Table 331 (p. 744). Owing to the high rate of inflow in 1917, due to escaping water from Lake Victoria, the level in Lake Albert jumps from 17·02 m. at the end of 1916 to 22·33 m. in 1917, so that the maximum rate of outflow is reached in 1918, 1919, and 1920.

The maximum level in Lake Albert would have been 23·43 m. at the end of July 1918, a mere 20 cm. less than in the previous example, or no appreciable difference. Since this high level is largely due to escaping water from Lake Victoria, it would seem reasonable to take that factor further into account in Lake Albert regulation; this is done in the next example.

Regulation E - 4: Lakes Victoria and Albert operated as in Regulations E - 1 and E - 2, modified so that, whenever the level in Lake Victoria exceeds 12·00 m. on Entebbe gauge and the outflow is increased to 100 m/d, the outflow from Lake Albert is increased to the maximum of 36·5 milliards a year, provided that the latter is not started before 1st May in any year or later than 1st September.

We have examined what would have happened in 1917 and 1918 with this regulation. This is a particularly instructive example as will be seen from Table 331 for Regulation E - 4. In spite of applying the maximum rate of outflow from Lake Albert as soon as water is being escaped from Lake Victoria, the level in the former would have risen to a maximum of 22·72 m. in July 1918.

We are thus forced to the conclusion that if the torrents are to be controlled, and if there is to be a fair compromise between conserving and escaping water in Lakes Victoria and Albert, the level in Lake Albert would have risen to 23·63 or 23·43 m. in 1918, and even if the maximum acceptable rate of escape had been applied as soon as water was being escaped from Lake Victoria, the level in Lake Albert would have risen to 22·72 m. in July 1918.

We have suggested that it is necessary first to examine methods of operation when applied to past records, and that the working arrangements should be based on the results of such an examination. In addition some provision must be made to allow for higher floods than have occurred in the past.

There can be one other ' factor of safety '. We have assumed here (and will discuss later) that the maximum rate of outflow from Lake Albert which will not cause a violent upheaval in the Central Zone of the Jonglei Area is 36·5 milliards per year at the lake exit, or 34·67 milliards per year at Mongalla. Normally the rate of escape should not exceed this figure which assumes a maximum capacity of 55 m/d in the Jonglei Canal, but if it becomes vitally necessary to escape more water from Lake Albert, as a last resort, either the régime in the Central Zone can be changed, or velocities in the Jonglei Canals increased above 1·0 m./sec., so that as much as 40·6 milliards (38·7 milliards at Mongalla) can be escaped.

Regulation F - 1: Lake Victoria outflow regulated as in Regulation E - 1. Lake Albert outflow regulated to 23·5 milliards per year plus approximately one-tenth of the contents above 11·50 m. on Butiaba gauge to the following scale, leaving the torrents uncontrolled:

Butiaba Gauge m.	Lake Albert Annual Outflow mds.
11·5	23·5
14·0	24·0
15·0	25·0
16·0	26·0
17·0	26·5
18·0	27·0
19·0	28·0
20·0	28·5
21·0	29·0
22·0	30·0
23·0	30·5
24·0	31·0
25·0	31·0

It is perhaps instructive to examine conditions in Lake Albert on the assumption that no attempt is made to control the torrents. The effect in the Sudan will be examined later, but for the moment we will assume that Lake Albert is operated as in Regulation E - 2 above, and that the torrents run uncontrolled into the Sudan. Since in a normal year at present the flow from the lake varies only slightly throughout the year, it is reasonable to arrange that the controlled outflow from the lake is constant all the year round, but altered from year to year according to the regulation based on the lake's contents at the end of each year.

The results are shown in Table 332 (p. 745), where it will be seen that the maximum level at the end of 1918 would have been 21·85 m.

Regulation F - 2: As in Regulation F - 1 but with the sliding scale of outflows from Lake Albert revised so that the maximum is reached at a level of 20·00 m. on Butiaba gauge, according to the following scale, and leaving the torrents uncontrolled:

Butiaba Gauge m.	Lake Albert Annual Outflow mds.
11·5	23·5
14·0	24·0
15·0	25·0
16·0	26·0
17·0	27·0
18·0	28·0
19·0	29·0
20·0	30·0
21·0	31·0
etc.	

The maximum level in Lake Albert would have been 21·65 m. in September 1918 (Table 332).

TABLE 321

MONTHLY AND ANNUAL TOTAL DISCHARGES IN MILLIARDS FROM LAKE VICTORIA AS DETERMINED BY ENTEBBE GAUGE AT END OF PREVIOUS YEAR

Entebbe Gauge ...	10·20	11·00	11·10	11·20	11·30	11·40	11·50
January	1·36	1·42	1·47	1·53	1·59	1·64	1·70
February ...	1·23	1·28	1·33	1·37	1·43	1·48	1·53
March	1·36	1·42	1·47	1·53	1·59	1·64	1·70
April	1·31	1·37	1·42	1·48	1·53	1·59	1·65
May	1·36	1·42	1·47	1·53	1·59	1·64	1·70
June	1·32	1·37	1·42	1·48	1·54	1·58	1·64
July	1·36	1·42	1·47	1·53	1·59	1·64	1·70
August	1·36	1·42	1·47	1·53	1·59	1·64	1·70
September ...	1·31	1·37	1·42	1·48	1·53	1·59	1·64
October	1·36	1·42	1·47	1·53	1·59	1·64	1·70
November ...	1·31	1·37	1·42	1·48	1·54	1·58	1·64
December ...	1·36	1·42	1·47	1·53	1·59	1·64	1·70
Year	16·00	16·70	17·30	18·00	18·70	19·30	20·00

Entebbe Gauge ...	11·60	11·70	11·80	11·90	12·00	>12·00
January	1·76	1·81	1·87	1·93	1·98	3·10
February ...	1·58	1·63	1·69	1·74	1·79	2·80
March	1·76	1·81	1·87	1·93	1·98	3·10
April	1·70	1·75	1·81	1·87	1·92	3·00
May	1·76	1·81	1·87	1·93	1·98	3·10
June	1·70	1·75	1·80	1·86	1·91	3·00
July	1·76	1·81	1·87	1·93	1·98	3·10
August	1·76	1·81	1·87	1·93	1·98	3·10
September ...	1·70	1·75	1·81	1·86	1·91	3·00
October	1·76	1·81	1·87	1·93	1·98	3·10
November ...	1·70	1·75	1·80	1·86	1·91	3·00
December ...	1·76	1·81	1·87	1·93	1·98	3·10
Year	20·70	21·30	22·00	22·70	23·30	36·50

TABLE 322

MONTHLY AND ANNUAL TOTAL DISCHARGES IN MILLIARDS INTO LAKE ALBERT AS DETERMINED BY ENTEBBE GAUGE AT END OF PREVIOUS YEAR

Entebbe Gauge ...	10·90	11·00	11·10	11·20	11·30	11·40	11·50
January	1·22	1·28	1·32	1·38	1·43	1·47	1·53
February ...	1·10	1·15	1·19	1·24	1·30	1·34	1·38
March	1·22	1·28	1·33	1·37	1·43	1·47	1·53
April	1·19	1·23	1·28	1·33	1·38	1·43	1·48
May	1·23	1·28	1·32	1·38	1·43	1·48	1·52
June	1·18	1·23	1·28	1·33	1·38	1·43	1·48
July	1·22	1·28	1·32	1·37	1·43	1·47	1·53
August	1·22	1·28	1·33	1·38	1·43	1·48	1·53
September ...	1·18	1·23	1·28	1·33	1·38	1·43	1·48
October	1·22	1·28	1·32	1·38	1·43	1·47	1·53
November ...	1·19	1·23	1·28	1·33	1·38	1·43	1·48
December ...	1·23	1·28	1·32	1·38	1·43	1·47	1·53
Year	14·40	15·03	15·57	16·20	16·83	17·37	18·00

Entebbe Gauge ...	11·60	11·70	11·80	11·90	12·00	>12·00
January	1·58	1·63	1·68	1·73	1·78	2·79
February ...	1·43	1·47	1·52	1·57	1·61	2·52
March	1·59	1·63	1·68	1·74	1·78	2·79
April	1·53	1·57	1·63	1·68	1·72	2·70
May	1·58	1·63	1·68	1·73	1·78	2·79
June	1·53	1·58	1·63	1·68	1·72	2·70
July	1·58	1·63	1·68	1·74	1·78	2·79
August	1·58	1·63	1·68	1·73	1·78	2·79
September ...	1·53	1·57	1·63	1·68	1·73	2·70
October	1·59	1·63	1·68	1·74	1·78	2·79
November ...	1·53	1·57	1·63	1·68	1·72	2·70
December ...	1·58	1·63	1·68	1·73	1·78	2·79
Year	18·63	19·17	19·80	20·43	20·96	32·85

TABLE 323

DISCHARGES AT LAKE ALBERT EXIT

Annual Outflows less than 28·35 milliards per year

Entebbe Gauge (m.)	10·90	11·00	11·10	11·20	11·30	11·40	11·50
Lake Victoria Outflow (milliards)	16·00	16·70	17·30	18·00	18·70	19·30	20·00
As at Lake Albert (milliards)	14·40	15·03	15·57	16·20	16·83	17·37	18·00
Reduction at Lake Albert (milliards)	3·60	2·97	2·43	1·80	1·17	0·63	—
Lake Albert Outflow (milliards)	24·75	25·38	25·92	26·55	27·18	27·72	28·35
Month	milliards						
January	1·78	1·82	1·86	1·93	1·98	2·02	2·06
February	1·59	1·64	1·69	1·73	1·78	1·82	1·88
March	1·78	1·82	1·86	1·93	1·90	2·02	2·06
April	1·70	1·76	1·82	1·85	1·92	1·96	2·02
May	1·78	1·82	1·87	1·93	1·98	2·02	2·06
June	2·05	2·12	2·16	2·21	2·25	2·30	2·37
July	2·28	2·35	2·39	2·44	2·50	2·55	2·60
August	2·45	2·50	2·55	2·60	2·66	2·70	2·75
September	2·53	2·60	2·63	2·68	2·73	2·78	2·84
October	2·45	2·50	2·54	2·60	2·66	2·70	2·75
November	2·22	2·27	2·32	2·37	2·41	2·47	2·53
December	2·14	2·18	2·23	2·28	2·33	2·38	2·43
	millions of cubic metres/day						
January	57·5	58·6	60·0	62·2	63·9	65·1	66·5
February	57·5	58·6	60·0	62·2	63·9	65·1	66·5
March	57·5	58·6	60·0	62·2	63·9	65·1	66·5
April	57·5	58·6	60·0	62·2	63·9	65·1	66·5
May	57·5	58·6	60·0	62·2	63·9	65·1	66·5
June	68·5	70·6	72·0	73·7	75·0	76·6	79·0
July	74·0	75·6	77·4	79·0	80·5	82·4	84·5
August	79·0	80·6	82·0	83·8	85·7	87·1	88·7
September	84·4	86·7	87·7	89·4	91·0	92·8	94·7
October	79·0	80·6	82·0	83·8	85·7	87·1	88·7
November	74·0	75·6	77·4	79·0	80·5	82·4	84·5
December	68·5	70·6	72·0	73·7	75·0	76·6	79·0

TABLE 324

DISCHARGES AT LAKE ALBERT EXIT

Annual and Monthly Outflows

Annual Outflow (milliards)	28·35	29·00	30·00	31·00	31·50	32·00	33·00
Month	milliards						
January	2·06	2·13	2·20	2·29	2·34	2·38	2·46
February	1·88	1·92	2·00	2·09	2·13	2·16	2·23
March	2·06	2·13	2·20	2·29	2·34	2·38	2·46
April	2·02	2·05	2·15	2·23	2·27	2·32	2·40
May	2·06	2·13	2·20	2·29	2·34	2·38	2·46
June	2·37	2·42	2·49	2·58	2·62	2·66	2·73
July	2·60	2·65	2·73	2·82	2·86	2·90	3·00
August	2·75	2·81	2·88	2·98	3·02	3·06	3·16
September	2·84	2·89	2·97	3·05	3·09	3·14	3·22
October	2·75	2·81	2·88	2·98	3·02	3·06	3·16
November	2·53	2·58	2·69	2·75	2·78	2·82	2·90
December	2·43	2·48	2·61	2·65	2·69	2·74	2·82
	millions of cubic metres/day						
January	66·5	68·7	71·0	73·9	75·5	76·8	79·4
February	66·5	68·7	71·0	73·9	75·5	76·8	79·4
March	66·5	68·7	71·0	73·9	75·5	76·8	79·4
April	66·5	68·7	71·0	73·9	75·5	76·8	79·4
May	66·5	68·7	71·0	73·9	75·5	76·8	79·4
June	79·0	80·7	83·0	86·0	87·4	88·7	91·0
July	83·9	85·5	88·0	91·0	92·2	93·5	96·7
August	88·7	90·6	92·9	96·0	97·3	98·6	102·0
September	94·7	96·4	99·0	101·8	103·0	104·8	107·3
October	88·7	90·6	92·9	96·0	97·3	98·6	102·0
November	83·9	85·5	88·0	91·0	92·2	93·5	96·7
December	79·0	80·7	83·0	86·0	87·4	88·7	91·0

TABLE 325

DISCHARGES AT LAKE ALBERT EXIT

Annual and Monthly Outflows

Annual Outflow (milliards)... ...	33·5	34·0	35·0	35·5	36·0	36·5	40·64
Month	milliards						
January	2·50	2·55	2·63	2·68	2·73	2·77	3·12
February	2·27	2·31	2·39	2·42	2·46	2·50	2·82
March	2·50	2·55	2·63	2·68	2·73	2·77	3·12
April	2·44	2·47	2·65	2·59	2·63	2·67	3·02
May	2·50	2·55	2·63	2·68	2·73	2·77	3·12
June	2·80	2·83	2·90	2·94	2·99	3·02	3·34
July...	3·03	3·07	3·16	3·21	3·24	3·28	3·65
August	3·19	3·24	3·33	3·37	3·41	3·45	3·81
September ...	3·26	3·30	3·37	3·41	3·45	3·50	3·84
October	3·19	3·24	3·34	3·37	3·42	3·45	3·81
November ...	2·95	2·99	3·06	3·10	3·14	3·18	3·53
December ...	2·87	2·90	3·00	3·05	3·08	3·14	3·45
	millions of cubic metres/day						
January	80·6	82·2	84·9	86·5	88·0	89·4	100·8
February	80·6	82·2	84·9	86·5	88·0	89·4	100·8
March	80·6	82·2	84·9	86·5	88·0	89·4	100·8
April	80·6	82·2	84·9	86·5	88·0	89·4	100·8
May	80·6	82·2	84·9	86·5	88·0	89·4	100·8
June	93·3	94·5	96·6	98·0	99·7	100·7	111·3
July...	97·8	99·0	102·0	103·5	104·5	106·8	117·6
August	103·0	104·5	107·4	108·8	110·0	111·2	122·9
September ...	108·8	110·0	112·3	113·8	115·0	116·8	128·1
October	103·0	104·5	107·4	108·8	110·0	111·2	122·9
November ...	97·8	99·0	102·0	103·5	104·5	106·8	117·6
December ...	93·3	94·5	96·6	98·0	99·7	100·7	111·3

TABLE 326

MONGALLA DISCHARGES

CORRESPONDING TO CONTROLLED LAKE ALBERT DISCHARGES

Discharges less than 27·0 milliards per year

Lake Albert Outflow (milliards) ... Mongalla Discharge (milliards) ...	24·75 23·51	25·38 24·11	25·92 24·62	26·55 25·22	27·18 25·82	27·72 26·33	28·35 27·00
Month	milliards						
January	1·69	1·73	1·77	1·83	1·88	1·92	1·97
February	1·51	1·56	1·61	1·64	1·69	1·73	1·79
March	1·69	1·73	1·77	1·83	1·88	1·92	1·97
April	1·62	1·67	1·72	1·76	1·81	1·86	1·92
May	1·69	1·73	1·77	1·83	1·88	1·92	1·97
June	1·95	2·01	2·05	2·10	2·14	2·19	2·25
July...	2·17	2·23	2·27	2·32	2·38	2·41	2·47
August	2·33	2·38	2·42	2·47	2·53	2·57	2·67
September ...	2·40	2·46	2·50	2·55	2·59	2·64	2·70
October	2·33	2·38	2·42	2·47	2·53	2·57	2·62
November ...	2·10	2·16	2·20	2·25	2·29	2·34	2·40
December ...	2·03	2·07	2·12	2·17	2·22	2·26	2·32
	millions cubic metres/day						
January	54·4	56·1	57·5	59·15	60·8	62·2	64
February	54·4	56·1	57·5	59·15	60·8	62·2	64
March	54·4	56·1	57·5	59·15	60·8	62·2	64
April	54·4	56·1	57·5	59·15	60·8	62·2	64
May	54·4	56·1	57·5	59·15	60·8	62·2	64
June	65·4	67·1	68·5	70·15	71·8	73·2	75
July...	70·4	72·1	73·5	75·15	76·8	78·2	80
August	75·4	77·1	78·5	80·15	81·8	83·2	85
September ...	80·4	82·1	83·5	85·15	86·8	88·2	90
October	75·4	77·1	78·5	80·15	81·8	83·2	85
November ...	70·4	72·1	73·5	75·15	76·8	78·2	80
December ...	65·4	67·1	68·5	70·15	71·8	73·2	75

TABLE 327

MONGALLA DISCHARGES

CORRESPONDING TO CONTROLLED LAKE ALBERT DISCHARGES

Discharges above 27·0 milliards per year

Lake Albert Outflow (milliards) ... Mongalla Discharge (milliards) ...	28·35 27·0	29·00 27·55	30·00 28·50	31·00 29·45	31·50 29·93	32·00 30·40	33·00 31·35
Month	milliards						
January	1·97	2·02	2·10	2·18	2·22	2·26	2·34
February	1·79	1·82	1·90	1·98	2·02	2·05	2·12
March	1·97	2·02	2·10	2·18	2·22	2·26	2·34
April	1·92	1·95	2·04	2·12	2·16	2·20	2·28
May	1·97	2·02	2·10	2·18	2·22	2·26	2·34
June	2·25	2·30	2·37	2·45	2·49	2·53	2·60
July...	2·47	2·52	2·60	2·68	2·72	2·76	2·84
August	2·67	2·67	2·75	2·83	2·87	2·91	3·00
September	2·70	2·75	2·82	2·90	2·94	2·98	3·06
October	2·62	2·67	2·75	2·83	2·87	2·91	3·00
November	2·40	2·45	2·52	2·60	2·64	2·68	2·75
December	2·32	2·36	2·45	2·52	2·56	2·60	2·68
	millions of cubic metres/day						
January	64	65·5	68	70·7	72	73·3	75·9
February	64	65·5	68	70·7	72	73·3	75·9
March	64	65·5	68	70·7	72	73·3	75·9
April	64	65·5	68	70·7	72	73·3	75·9
May	64	65·5	68	70·7	72	73·3	75·9
June	75	76·5	79	81·7	83	84·3	86·9
July...	80	81·5	84	86·7	88	89·3	91·9
August	85	86·5	89	91·7	93	94·3	96·9
September	90	91·5	94	96·7	98	99·3	101·9
October	85	86·5	89	91·7	93	94·3	96·9
November	80	81·5	84	86·7	88	89·3	91·9
December	75	76·5	79	81·7	83	84·3	86·9

TABLE 328

MONGALLA DISCHARGES

CORRESPONDING TO CONTROLLED LAKE ALBERT DISCHARGES

Discharges above 27·0 milliards per year

Lake Albert Outflow (milliards) ... Mongalla Discharge (milliards) ...	33·50 31·83	34·00 32·30	35·00 33·25	35·50 33·73	36·00 34·20	36·50 34·67	40·64 38·70
Month	milliards						
January	2·38	2·42	2·50	2·55	2·59	2·63	2·98
February	2·16	2·20	2·27	2·30	2·34	2·37	2·69
March	2·38	2·42	2·50	2·55	2·59	2·63	2·98
April	2·32	2·35	2·43	2·46	2·50	2·54	2·88
May	2·38	2·42	2·50	2·55	2·58	2·63	2·98
June	2·65	2·69	2·76	2·79	2·84	2·87	3·18
July...	2·88	2·92	3·00	3·05	3·08	3·12	3·47
August	3·03	3·07	3·16	3·20	3·24	3·28	3·63
September	3·10	3·14	3·20	3·24	3·28	3·32	3·66
October	3·03	3·07	3·17	3·20	3·25	3·28	3·63
November	2·80	2·84	2·91	2·94	2·98	3·02	3·36
December	2·72	2·76	2·85	2·90	2·93	2·98	3·29
	millions of cubic metres/day						
January	77·2	78·5	81·1	82·4	83·7	85·0	96
February	77·2	78·5	81·1	82·4	83·7	85·0	96
March	77·2	78·5	81·1	82·4	83·7	85·0	96
April	77·2	78·5	81·1	82·4	83·7	85·0	96
May	77·2	78·5	81·1	82·4	83·7	85·0	96
June	88·2	89·5	92·1	93·4	94·7	96·0	106
July...	93·2	94·5	97·1	98·4	99·7	101·0	112
August	98·2	99·5	102·1	103·4	104·7	106·0	117
September	103·2	104·5	107·1	108·4	109·7	111·0	122
October	98·2	99·5	102·1	103·4	104·7	106·0	117
November	93·2	94·5	97·1	98·4	99·7	101·0	112
December	88·2	89·5	92·1	93·4	94·7	96·0	106

TABLE 329

LAKE VICTORIA
REGULATION E - 1

Discharges in milliards per year. Gauges in metres.

Year	Natural Inflow	Controlled Outflow	Stored or Released	Cumulative Storage	Entebbe Gauge	
					Difference from 11·50	Reading
					Assumed Start 11·50	
1905	19·08	20·00	− 0·92	− 0·92	− 0·01	11·49
1906	56·12	28·32	27·80	26·88	0·40	11·90
1907	6·56	25·01	− 18·45	8·43	0·12	11·62
1908	15·51	20·70	− 5·19	3·24	0·05	11·55
1909	3·90	20·00	− 16·10	− 12·86	− 0·19	11·31
1910	12·47	18·70	− 6·23	− 19·09	− 0·28	11·22
1911	− 5·18	18·00	− 23·18	− 42·27	− 0·63	10·87
1912	20·09	16·00	4·09	− 38·18	− 0·57	10·93
1913	28·26	16·00	12·26	− 25·92	− 0·39	11·11
1914	24·76	17·30	7·46	− 18·46	− 0·28	11·22
1915	23·57	18·00	5·57	− 12·89	− 0·19	11·31
1916	55·04	18·70	36·34	23·45	0·35	11·85
1917	64·58	31·74	32·84	56·29	0·84	12·34 (1)
1918	− 17·65	30·96	− 48·61	7·68	0·12	11·62
1919	8·82	20·70	− 11·88	− 4·20	− 0·04	11·46
1920	6·20	19·30	− 13·10	− 17·30	− 0·26	11·29
1921	− 6·57	18·00	− 24·57	− 41·87	− 0·62	10·88
1922	4·88	16·00	− 11·12	− 52·99	− 0·79	10·71
1923	38·78	16·00	22·78	− 30·21	− 0·45	11·05
1924	7·31	16·70	− 9·39	− 39·60	− 0·59	10·91
1925	23·79	16·00	7·79	− 31·81	− 0·47	11·03
1926	61·55	16·70	44·85	13·04	0·19	11·69
1927	− 4·85	20·70	− 25·55	− 12·51	− 0·19	11·31
1928	19·67	33·62	− 13·95	− 26·46	− 0·40	11·10
1929	0·44	17·30	− 16·86	− 43·22	− 0·65	10·85
1930	57·71	16·00	41·71	1·61	− 0·02	11·48
1931	33·99	19·30	14·69	13·08	0·20	11·70
1932	26·59	21·30	5·29	18·37	0·28	11·78
1933	11·46	21·30	− 9·84	8·53	0·13	11·63
1934	5·57	20·70	− 15·13	− 6·60	− 0·10	11·40
1935	15·75	32·26	− 16·51	− 23·11	− 0·34	11·16
1936	30·89	22·03	8·86	− 14·25	− 0·21	11·29
1937	59·33	18·00	41·33	27·08	0·40	11·90
1938	10·15	22·70	− 12·55	14·53	0·22	11·72
1939	5·24	21·30	− 16·06	− 1·53	− 0·02	11·48
1940	28·55	26·51	2·04	0·51	0·01	11·51
1941	31·51	35·29	− 3·78	− 3·27	− 0·05	11·45
1942	34·05	19·30	19·75	11·48	0·16	11·66
Totals	817·92	806·44	11·48	11·48	0·16	11·66
Average	21·52	21·22	—	—	—	—

(1) Maximum level 12·40 m. at the end of June 1917

TABLE 330

LAKE ALBERT

REGULATION E - 2

Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Other Sources Inflow	Torrents Virtual Inflow	Total Inflow	Regulated Outflow	Cumulative Storage	Butiaba Gauge
					Assumed Start	8·11	11·50
1905	18·00	8·11	6·65	32·76	28·35	12·52	12·30
1906	25·49	7·60	7·17	40·26	28·35	24·43	14·38
1907	22·51	2·87	4·82	30·20	29·00	25·63	14·58
1908	18·63	6·78	4·94	30·35	29·00	26·98	14·80
1909	18·00	9·48	5·27	32·75	29·00	30·73	15·43
1910	16·83	7·91	5·55	30·29	30·00	31·02	15·48
1911	16·20	5·49	4·60	26·29	30·00	27·31	14·86
1912	14·40	6·50	5·83	26·73	29·00	25·04	14·47
1913	14·40	7·01	3·94	25·35	29·00	21·39	13·85
1914	15·57	8·15	6·07	29·79	25·92	25·26	14·51
1915	16·20	8·33	5·25	29·78	29·00	26·04	14·65
1916	16·83	14·18	12·41	43·42	29·00	40·46	17·02
1917	28·57	26·70	11·35	66·62	31·50	75·58	22·40
1918	27·87	11·53	1·72	41·12	35·00	81·70	23·30(1)
1919	18·63	4·65	4·10	27·38	35·50	73·58	22·10
1920	17·37	4·76	4·13	26·26	35·00	64·84	20·80
1921	16·20	− 0·41	2·68	18·47	33·50	49·81	18·50
1922	14·40	1·07	3·45	18·92	32·00	36·73	16·42
1923	14·40	5·82	6·00	26·22	31·00	31·95	15·63
1924	15·03	3·21	2·85	21·09	30·00	23·04	14·13
1925	14·40	2·28	3·20	19·88	29·00	13·92	12·54
1926	15·03	7·03	6·65	28·71	25·38	17·25	13·13
1927	18·63	2·26	1·81	22·70	28·35	11·60	12·13
1928	30·27	2·68	6·73	39·68	27·18	24·10	14·30
1929	15·57	1·70	3·53	20·80	25·92	18·98	13·43
1930	14·40	5·22	3·00	22·62	24·75	16·85	13·06
1931	17·37	6·55	4·92	28·84	27·72	17·97	13·26
1932	19·17	5·69	5·85	30·71	28·35	20·33	13·73
1933	19·17	3·26	3·22	25·65	28·35	17·63	13·20
1934	18·63	0·64	4·58	23·85	28·35	13·13	12·40
1935	29·03	0·60	4·91	34·54	27·72	19·95	13·60
1936	19·83	2·11	3·93	25·87	25·92	19·90	13·59
1937	16·20	6·43	5·25	27·88	26·55	21·33	13·82
1938	20·43	2·44	4·92	27·79	28·35	20·67	13·72
1939	19·17	0·25	2·46	21·88	28·35	14·20	12·60
1940	23·86	− 0·42	3·48	26·92	27·72	13·40	12·46
1941	31·76	2·18	4·91	38·85	28·35	23·90	14·28
1942	17·37	4·33	4·53	26·23	29·00	21·13	13·80
Totals ...	725·82	204·97	186·66	1,117·45	1,104·43	—	—
Averages ...	19·10	5·39	4·91	29·41	29·06	—	—

(1) Maximum level 23·63 m. at the end of July 1918

TABLE 331

LAKE ALBERT

REGULATION E - 3

SLIDING SCALE REVISED. OUTFLOW 36·5 M/D AT 20·00 METRES ON BUTIABA GAUGE.

Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Other Sources plus Torrents Inflow	Total Inflow	Controlled Outflow	Cumulative Storage	Butiaba Gauge
				Assumed Start	8·11	11·50
1905	18·00	14·76	32·76	28·35	12·52	12·30
1906	25·49	14·77	40·26	28·35	24·43	14·37
1907	22·51	7·69	30·20	29·00	25·63	14·57
1908	18·63	11·72	30·35	29·00	26·98	14·80
1909	18·00	14·75	32·75	29·00	30·73	15·43
1910	16·83	13·46	30·29	30·00	31·02	15·48
1911	16·20	10·09	26·29	30·00	27·31	14·86
1912	14·40	12·33	26·73	29·00	25·04	14·42
1913	14·40	10·95	25·35	29·00	21·39	13·85
1914	15·57	14·22	29·79	25·92	25·26	14·51
1915	16·20	13·58	29·78	29·00	26·04	14·64
1916	16·83	26·59	43·42	29·00	40·46	17·02
1917	28·57	38·05	66·62	32·00	75·08	22·33
1918	27·87	13·25	41·12	36·50	79·70	23·01(1)
1919	18·63	8·75	27·38	36·50	70·58	21·65
Totals	288·13	224·96	513·09	450·62	70·58	—

REGULATION E - 4

FLOOD-ESCAPE DISCHARGE WHEN VICTORIA NILE OUTFLOW IS 100 M/D

Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Other Sources plus Torrents Inflow	Total Inflow	Controlled Outflow	Cumulative Storage	Butiaba Gauge
				Assumed Start	8·11	11·50
1905	18·00	14·76	32·76	28·35	12·52	12·30
1906	25·49	14·77	40·26	32·45	20·33	13·65
1907	22·51	7·69	30·20	29·68	20·85	13·75
1908	18·63	11·72	30·35	28·35	22·85	14·10
1909	18·00	14·75	32·75	29·00	26·60	14·73
1910	16·83	13·46	30·29	29·00	27·89	14·96
1911	16·20	10·09	26·29	29·00	25·18	14·50
1912	14·40	12·33	26·73	29·00	22·91	14·11
1913	14·40	10·95	25·35	29·00	19·26	13·48
1914	15·57	14·22	29·79	25·92	23·13	14·15
1915	16·20	13·58	29·78	29·00	23·91	14·28
1916	16·83	26·59	43·42	29·00	38·33	16·68
1917	28·57	38·05	66·62	34·69	70·26	21·61
1918	27·87	13·25	41·12	35·88	75·50	22·39(2)
1919	18·63	8·75	27·38	35·00	67·88	21·25
Totals	288·13	224·96	513·09	453·32	67·88	21·25

(1) Maximum level 23·43 m. in July 1918
(2) Maximum level 22·72 m. at the end of July 1918

TABLE 332

LAKE ALBERT

REGULATION F - 1

LAKE ALBERT REGULATED AS IN E - 2 BUT WITHOUT CONTROLLING THE TORRENTS

Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Other Sources Inflow	Total Inflow	Controlled Outflow	Cumulative Storage	Butiaba Gauge
				Assumed Start	8·11	11·50
1905	18·00	8·11	26·11	23·50	10·72	11·98
1906	25·49	7·60	33·09	23·50	20·31	13·67
1907	22·51	2·87	25·38	23·50	22·19	13·99
1908	18·63	6·78	25·41	23·50	24·10	14·31
1909	18·00	9·48	27·48	24·00	27·58	14·90
1910	16·83	7·91	24·74	24·00	28·32	15·03
1911	16·20	5·49	21·69	25·00	25·01	14·47
1912	14·40	6·50	20·90	24·00	21·91	13·94
1913	14·40	7·01	21·41	19·90	23·42	14·20
1914	15·57	8·15	23·72	24·00	23·14	14·15
1915	16·20	8·33	24·53	24·00	23·67	14·24
1916	16·83	14·18	31·01	24·00	30·68	15·42
1917	28·57	26·70	55·27	25·00	60·95	20·22
1918	27·87	11·53	39·40	28·50	71·85	21·85 (1)
1919	18·63	4·65	23·28	29·00	66·13	21·00
Totals	288·13	135·29	423·42	365·40	66·13	21·00

REGULATION F - 2

LAKE ALBERT REGULATED AS IN F - 1 BUT WITH THE SLIDING SCALE OF DISCHARGES REVISED TO REACH THE MAXIMUM RATE OF OUTFLOW AT A LOWER LEVEL

Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Other Sources Inflow	Total Inflow	Controlled Outflow	Cumulative Storage	Butiaba Gauge
				Assumed Start	8·11	11·50
1905	18·00	8·11	26·11	23·50	10·72	11·98
1906	25·49	7·60	33·09	23·50	20·31	13·67
1907	22·51	2·87	25·38	23·50	22·19	13·99
1908	18·63	6·78	25·41	23·50	24·10	14·31
1909	18·00	9·48	27·48	24·00	27·58	14·90
1910	16·83	7·91	24·74	24·00	28·32	15·03
1911	16·20	5·49	21·69	25·00	25·01	14·47
1912	14·40	6·50	20·90	24·00	21·91	13·94
1913	14·40	7·01	21·41	19·90	23·42	14·20
1914	15·57	8·15	23·72	24·00	23·14	14·15
1915	16·20	8·33	24·53	24·00	23·67	14·24
1916	16·83	14·18	31·01	24·00	30·68	15·42
1917	28·57	26·70	55·27	25·00	60·95	20·22
1918	27·87	11·53	39·40	30·00	70·35	21·62 (2)
1919	18·63	4·65	23·28	31·00	62·63	20·50
Totals	288·13	135·29	423·42	368·90	62·63	20·50

(1) Maximum level 21·85 m. at the end of 1918.

(2) Maximum level 21·65 m. at the end of September 1918.

Regulations G - 1 and G - 2, G - 3 and G - 4, and G - 5 and G - 6: Lakes Victoria and Albert.

The next three examples are given as comparisons. The method of regulation in all of them is exactly as described for Regulation E - 1, except in regard to the outflow from Lake Victoria.

In Regulation G - 1 the maximum rate of outflow, 100 m/d, is applied only when the level on Entebbe gauge exceeds 12·00 m. when the lake level is rising, and 12·50 m. when the lake level is falling. The maximum level would have been 12·46 m. in Lake Victoria, compared with 12·40 m. under Regulation E - 1, both on Entebbe gauge. Regulation G - 2 is similar to Regulation E - 2 for Lake Albert, but complementary to Regulation G - 1, and the maximum level would have been 22·50 m. on Butiaba gauge compared with 23·63 m. under Regulation E - 2 (Tables 333 and 334).

In Regulation G - 3 we give an example of an alternative method of operating Lake Victoria according to the sliding scale given below:

Entebbe Gauge m.	Lake Victoria Outflow m/d
10·15 and below	44
From 10·15 to 12·30	55
12·30 and above	60
12·35 and above	70
12·40 and above	80
12·45 and above	90
12·50 and above	100

It should be noted that the normal outflow adopted was 20 milliards per year. Regulation G - 4 is similarly for Lake Albert as in Regulation E - 2, complementary to Regulations G - 3. The maximum levels would have been 12·44 m. on Entebbe gauge and 22·31 m. on Butiaba gauge (Tables 335 and 336).

Since this is not directly comparable with Regulations G - 1 and G - 2 we have compiled further tables (Tables 337 and 338) showing Regulations G - 5 and G - 6 for which the rules were as for Regulation E - 1, except for the method of operating Lake Victoria at its highest levels. In this latter example the sliding scale as in Regulation G - 3 was applied only when the level on Entebbe gauge exceeded 12·30 m.

The maximum levels would have been 12·50 m. on Entebbe gauge and 22·43 m. on Butiaba gauge.

TABLE 333

LAKE VICTORIA
REGULATION G - 1
AS IN REGULATION E - 1, EXCEPT THAT LAKE VICTORIA OUTFLOW OF 100 M/D WAS APPLIED WHEN THE LEVEL ON ENTEBBE GAUGE EXCEEDED 12·00 WHEN RISING AND 12·50 WHEN FALLING

Discharges in milliards per year. Gauges in metres

Year	Natural Inflow	Regulated Outflow	Stored or Released	Cumulative Storage	Entebbe Gauge	
					Difference from 11·50	Reading
					Assumed Start 11·50	
1905	19·08	20·00	− 0·92	− 0·92	− 0·01	11·49
1906	56·12	22·76	33·36	32·44	0·48	11·98
1907	6·56	23·84	− 17·28	15·16	0·23	11·73
1908	15·51	21·30	− 5·79	9·37	0·14	11·64
1909	3·90	20·70	− 16·80	− 7·43	− 0·11	11·39
1910	12·47	18·70	− 6·23	− 13·66	− 0·20	11·30
1911	− 5·18	18·70	− 23·88	− 37·54	− 0·56	10·94
1912	20·09	16·00	4·09	− 33·45	− 0·50	11·00
1913	28·26	16·70	11·56	− 21·89	− 0·33	11·17
1914	24·76	17·30	7·46	− 14·43	− 0·21	11·29
1915	23·57	18·00	5·57	− 8·86	− 0·13	11·37
1916	55·04	18·70	36·34	27·48	0·41	11·91
1917	64·58	29·66	34·92	62·40	0·93	12·43 (1)
1918	− 17·65	27·77	− 45·42	16·98	0·25	11·75
1919	8·82	21·30	− 12·48	4·50	0·07	11·57
1920	6·20	20·00	− 13·80	− 9·30	− 0·14	11·36
1921	− 6·57	18·70	− 25·27	− 34·57	− 0·52	10·98
1922	4·88	16·00	− 11·12	− 45·69	− 0·68	10·82
1923	38·78	16·00	22·78	− 22·91	− 0·34	11·16
1924	7·31	17·30	− 9·99	− 32·90	− 0·49	11·01
1925	23·79	16·70	7·09	− 25·81	− 0·39	11·11
1926	61·55	17·30	44·25	18·44	0·28	11·78
1927	− 4·85	21·30	− 26·15	− 7·71	− 0·11	11·39
1928	19·67	18·70	0·97	− 6·74	− 0·10	11·40
1929	0·44	30·84	− 30·40	− 37·14	− 0·56	10·94
1930	57·71	22·74	34·97	− 2·17	− 0·03	11·47
1931	33·99	19·30	14·69	12·52	0·19	11·69
1932	26·59	20·70	5·89	18·41	0·27	11·77
1933	11·46	21·30	− 9·84	8·57	0·13	11·63
1934	5·57	20·70	− 15·13	− 6·56	− 0·10	11·40
1935	15·75	19·30	− 3·55	− 10·11	− 0·15	11·35
1936	30·89	34·99	− 4·10	− 14·21	− 0·21	11·29
1937	59·33	18·00	41·33	27·12	0·40	11·90
1938	10·15	22·70	− 12·55	14·57	0·22	11·72
1939	5·24	21·30	− 16·06	− 1·49	− 0·02	11·48
1940	28·55	22·18	6·37	4·88	0·07	11·57
1941	31·51	36·50	− 4·99	− 0·11	—	11·50
1942	34·05	20·00	14·05	13·94	0·21	11·71
1943	− 13·52	21·30	− 34·82	− 20·88	− 0·31	11·19
1944	6·71	18·93	− 12·22	− 33·10	− 0·49	11·01
1945	18·80	36·50	− 17·70	− 50·80	− 0·76	10·74
1946	17·38	16·00	1·38	− 49·42	− 0·74	10·76
1947	57·42	16·00	41·42	− 8·00	− 0·12	11·38
1948	14·99	18·70	− 3·71	− 11·71	− 0·17	11·33
1949	− 6·85	18·70	− 25·55	− 37·26	− 0·55	10·95
1950	7·74	16·00	− 8·26	− 45·52	− 0·68	10·82
1951	51·98	29·76	22·22	− 23·30	− 0·35	11·15
1952	31·54	17·30	14·24	− 9·06	− 0·13	11·37
Total	1,004·11	1,013·17	− 9·06	− 9·06	− 0·13	11·37
Average	20·92	21·11	—	—	—	—

(1) Maximum level 12·46 m. at the end of November 1917.

TABLE 334

LAKE ALBERT

REGULATION G - 2

Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Other Sources and Torrents Virtual Inflow	Total Inflow	Regulated Outflow	Cumulative Storage	Butiaba Gauge
				Assumed Start	8·11	11·50
1905	18·00	14·76	32·76	28·35	12·52	12·30
1906	20·48	14·77	35·25	28·35	19·42	13·51
1907	21·46	7·69	29·15	28·35	20·22	13·65
1908	19·17	11·72	30·89	28·35	22·76	14·09
1909	18·63	14·75	33·38	29·00	27·14	14·81
1910	16·83	13·46	30·29	29·00	28·43	15·05
1911	16·83	10·09	26·92	30·00	25·35	14·53
1912	14·40	12·33	26·73	29·00	23·08	14·12
1913	15·03	10·95	25·98	29·00	20·06	13·62
1914	15·57	14·22	29·79	28·35	21·50	13·87
1915	16·20	13·58	29·78	28·35	22·93	14·11
1916	16·83	26·59	43·42	29·00	37·35	16·52
1917	26·69	38·05	64·74	31·00	71·09	21·74
1918	24·99	13·25	38·24	34·00	75·33	22·37 (1)
1919	19·17	8·75	27·92	35·00	68·25	21·31
1920	18·00	8·89	26·89	34·00	61·14	20·24
1921	16·83	2·27	19·10	33·50	46·74	18·02
1922	14·40	4·52	18·92	32·00	33·66	15·92
1923	14·40	11·82	26·22	30·00	29·88	15·29
1924	15·57	6·06	21·63	30·00	21·51	13·97
1925	15·03	5·48	20·51	25·38	16·64	13·03
1926	15·57	13·68	29·25	25·92	19·97	13·60
1927	19·17	4·07	23·24	28·35	14·86	12·71
1928	16·83	9·41	26·24	27·18	13·92	12·55
1929	27·76	5·23	32·99	27·72	19·19	13·47
1930	20·47	8·22	28·69	24·75	23·13	14·15
1931	17·37	11·47	28·84	29·00	22·97	14·12
1932	18·63	11·54	30·17	29·00	24·14	14·32
1933	19·17	6·48	25·65	29·00	20·79	13·74
1934	18·63	5·22	23·85	28·35	16·29	12·96
1935	17·37	5·51	22·88	27·72	11·45	12·10
1936	31·49	6·04	37·53	27·18	21·80	13·92
1937	16·20	11·68	27·88	26·55	23·13	14·15
1938	20·43	7·36	27·79	29·00	21·92	13·95
1939	19·17	2·71	21·88	28·35	15·45	12·82
1940	19·96	3·06	23·02	27·72	10·75	11·98
1941	32·85	7·09	39·94	28·35	22·34	14·01
1942	18·00	8·86	26·86	29·00	20·20	13·64
1943	19·17	5·27	24·44	28·35	16·29	12·97
1944	17·04	3·34	20·38	25·92	10·75	11·98
1945	32·85	4·76	37·61	25·38	22·98	14·13
1946	14·40	11·55	25·95	29·00	19·93	13·60
1947	14·40	13·84	28·24	24·75	23·42	14·20
1948	16·83	12·53	29·36	29·00	23·78	14·16
1949	16·83	6·90	23·73	29·00	18·51	13·35
1950	14·40	6·04	20·44	24·75	14·20	12·59
1951	26·78	7·13	33·91	24·75	23·36	14·19
1952	15·57	14·10	29·67	29·00	24·03	14·30
Totals	911·85	477·09	1,388·94	1,373·02	24·03	14·30
Averages	19·00	9·94	28·94	28·60	—	—

(1) Maximum level 22·50 m. at the end of August 1918

TABLE 335

LAKE VICTORIA
REGULATION G - 3
NORMAL OUTFLOW 20 MILLIARDS/YEAR AND SLIDING SCALE BETWEEN LEVELS OF 12·30 AND 12·50 ON ENTEBBE GAUGE

Discharges in milliards per year. Gauges in metres.

Year	Natural Inflow	Regulated Outflow	Stored or Released	Cumulative Storage	ENTEBBE GAUGE	
					Difference from 11·50	Reading
					Assumed Start	11·50
1905	19·08	20·00	− 0·92	− 0·92	− 0·01	11·49
1906	56·12	20·00	36·12	35·20	0·53	12·03
1907	6·56	20·00	− 13·44	21·76	0·32	11·82
1908	15·51	20·00	− 4·49	17·27	0·26	11·76
1909	3·90	20·00	− 16·10	1·17	0·02	11·52
1910	12·47	20·00	− 7·53	− 6·36	− 0·09	11·41
1911	− 5·18	20·00	− 25·18	− 31·54	− 0·46	11·04
1912	20·09	20·00	0·09	− 31·45	− 0·46	11·04
1913	28·26	20·00	8·26	− 23·19	− 0·35	11·15
1914	24·76	20·00	4·76	− 18·43	− 0·28	11·22
1915	23·57	20·00	3·57	− 14·86	− 0·22	11·28
1916	55·04	20·00	35·04	20·18	0·30	11·80
1917	64·58	23·42	41·16	61·34	0·92	12·42[1]
1918	− 17·65	22·76	− 40·41	20·93	0·31	11·81
1919	8·82	20·00	− 11·18	9·75	0·15	11·65
1920	6·20	20·00	− 13·80	− 4·05	− 0·06	11·44
1921	− 6·57	20·00	− 26·57	− 30·62	− 0·46	11·04
1922	4·88	20·00	− 15·12	− 45·74	− 0·68	10·82
1923	38·78	20·00	18·78	− 26·96	− 0·40	11·10
1924	7·31	20·00	− 12·69	− 39·65	− 0·59	10·91
1925	23·79	20·00	3·79	− 35·86	− 0·53	10·97
1926	61·55	20·00	41·55	5·69	0·08	11·58
1927	− 4·85	20·00	− 24·85	− 19·16	− 0·29	11·21
1928	19·67	20·00	− 0·33	− 19·49	− 0·29	11·21
1929	0·44	20·00	− 19·56	− 39·05	− 0·58	10·92
1930	57·71	20·00	37·71	− 1·34	− 0·02	11·48
1931	33·99	20·00	13·99	12·65	0·19	11·69
1932	26·59	20·00	6·59	19·24	0·29	11·78
1933	11·46	20·00	− 8·54	10·70	0·16	11·66
1934	5·57	20·00	− 14·43	− 3·73	− 0·05	11·45
1935	15·75	35·10	− 19·35	− 23·08	− 0·34	11·16
1936	30·89	24·07	6·82	− 16·26	− 0·24	11·26
1937	59·33	20·00	39·33	23·07	0·34	11·84
1938	10·15	20·00	− 9·85	13·27	0·20	11·70
1939	5·24	20·00	− 14·76	− 1·54	− 0·02	11·48
1940	28·55	26·92	1·63	0·09	—	11·50
1941	31·51	33·74	− 2·23	− 2·14	− 0·03	11·47
1942	34·05	20·00	14·05	11·91	0·18	11·68
1943	− 13·52	20·00	− 33·52	− 21·61	− 0·32	11·18
1944	6·71	20·00	− 13·29	− 34·90	− 0·52	10·98
1945	18·80	35·10	− 16·30	− 51·20	− 0·76	10·74
1946	17·38	20·00	− 2·62	− 53·82	− 0·80	10·70
1947	57·42	20·00	37·42	− 16·40	− 0·24	11·26
1948	14·99	20·00	− 5·01	− 21·41	− 0·30	11·20
1949	− 6·85	20·00	− 26·85	− 48·26	− 0·72	10·78
1950	7·74	20·00	− 12·26	− 60·52	− 0·90	10·60
1951	51·98	20·00	31·98	− 28·54	− 0·42	11·08
1952	31·54	20·00	11·54	− 17·00	− 0·25	11·25
Total	1,004·11	1,021·11	—	− 17·00	− 0·25	11·25
Average	20·92	21·27	—	—	—	—

(1) Maximum level 12·44 m. at the end of November 1917

TABLE 336

LAKE ALBERT
REGULATION G - 4
Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Other Sources and Torrents Virtual Inflow	Total Inflow	Regulated Outflow	Cumulative Storage	Butiaba Gauge
				Assumed Start	8·11	11·50
1905	18·00	14·76	32·76	28·35	12·52	12·30
1906	18·00	14·77	32·77	27·72	17·57	13·19
1907	18·00	7·69	25·69	28·35	14·91	12·71
1908	18·00	11·72	29·72	28·35	16·28	12·96
1909	18·00	14·75	32·75	28·35	20·68	13·73
1910	18·00	13·46	31·46	28·35	23·79	14·27
1911	18·00	10·09	28·09	29·00	22·88	14·11
1912	18·00	12·33	30·33	29·00	24·21	14·33
1913	18·00	10·95	28·95	29·00	24·16	14·32
1914	18·00	14·22	32·22	29·00	27·38	14·87
1915	18·00	13·58	31·58	29·00	29·96	15·30
1916	18·00	26·59	44·59	30·00	44·55	17·67
1917	21·08	38·05	59·13	31·50	72·18	21·90
1918	20·48	13·25	33·73	34·00	71·91	21·87(1)
1919	18·00	8·75	26·75	34·00	64·66	20·77
1920	18·00	8·89	26·89	33·50	58·05	19·77
1921	18·00	2·27	20·27	33·00	45·32	17·80
1922	18·00	4·52	22·52	31·50	36·34	16·35
1923	18·00	11·82	29·82	31·00	35·16	16·16
1924	18·00	6·06	24·06	31·00	28·22	15·01
1925	18·00	5·48	23·48	30·00	21·70	13·91
1926	18·00	13·68	31·68	28·35	25·03	14·47
1927	18·00	4·07	22·07	29·00	18·10	13·28
1928	18·00	9·41	27·41	26·55	18·96	13·43
1929	18·00	5·23	23·23	26·55	15·64	12·85
1930	18·00	8·22	26·22	24·75	17·11	13·11
1931	18·00	11·47	29·47	27·72	18·86	13·41
1932	18·00	11·54	29·54	28·35	20·05	13·62
1933	18·00	6·48	24·48	28·35	16·18	12·93
1934	18·00	5·22	23·22	28·35	11·05	12·03
1935	31·59	5·51	37·10	27·72	20·43	13·69
1936	21·66	6·04	27·70	25·92	22·21	13·99
1937	18·00	11·68	29·68	26·55	25·34	14·52
1938	18·00	7·36	25·36	29·00	21·70	13·90
1939	18·00	2·71	20·71	28·35	14·06	12·57
1940	24·22	3·06	27·28	27·72	13·62	12·49
1941	30·37	7·09	37·46	28·35	22·73	14·09
1942	18·00	8·86	26·86	29·00	20·59	13·71
1943	18·00	5·27	23·27	28·35	15·51	12·83
1944	18·00	3·34	21·34	25·92	10·93	12·01
1945	31·59	4·76	36·35	24·75	22·53	14·04
1946	18·00	11·55	29·55	29·00	23·08	14·14
1947	18·00	13·84	31·84	29·00	25·92	14·62
1948	18·00	12·53	30·53	29·00	27·45	14·89
1949	18·00	6·90	24·90	29·00	23·35	14·19
1950	18·00	6·04	24·04	29·00	18·39	13·33
1951	18·00	7·13	25·13	24·75	18·77	13·40
1952	18·00	14·10	32·10	26·55	24·32	14·35
Total	918·99	477·09	1,396·08	1,379·87	24·32	14·35
Average	19·15	9·94	29·09	28·75	—	—

(1) Maximum level 22·31 m. in July 1918

TABLE 337

LAKE VICTORIA

REGULATION G - 5

AS IN REGULATION E - 1, EXCEPT FOR SLIDING SCALE FOR LAKE VICTORIA OUTFLOW

Discharges in milliards per year. Gauges in metres.

Year	Natural Inflow	Controlled Outflow	Stored or Released	Cumulative Storage	ENTEBBE GAUGE	
					Difference from 11·50	Reading
					Assumed Start 11·50	
1905	19·08	20·00	− 0·92	− 0·92	− 0·01	11·49
1906	56·12	19·30	36·82	35·90	0·54	12·04
1907	6·56	24·00	− 17·44	18·46	0·28	11·78
1908	15·51	21·30	− 5·79	12·67	0·19	11·69
1909	3·90	20·70	− 16·80	− 4·13	− 0·06	11·44
1910	12·47	19·30	− 6·83	− 10·96	− 0·16	11·34
1911	− 5·18	18·70	− 23·88	− 34·84	− 0·52	10·98
1912	20·09	16·00	4·09	− 30·75	− 0·46	11·04
1913	28·26	16·70	11·56	− 19·19	− 0·29	11·21
1914	24·76	18·00	6·76	− 12·43	− 0·18	11·32
1915	23·57	18·70	4·87	− 7·56	− 0·11	11·39
1916	55·04	18·70	36·34	28·78	0·43	11·93
1917	64·58	28·07	36·51	65·29	0·97	12·47[(1)]
1918	− 17·65	25·23	− 42·88	22·41	0·33	11·83
1919	8·82	22·00	− 13·18	9·23	0·14	11·64
Totals	315·93	306·70	9·23	—	0·14	11·64

(1) Maximum level 12·50 m. in June and November 1917

LAKE ALBERT

REGULATION G - 6

Discharges in milliards per year. Gauges in metres.

Year	Victoria Nile Controlled Inflow	Other Sources plus Torrents Inflow	Total Inflow	Controlled Outflow	Cumulative Storage	Butiaba Gauge
				Assumed Start	8·11	11·50
1905	18·00	14·76	32·76	28·35	12·52	12·30
1906	17·37	14·77	32·14	27·72	16·94	13·08
1907	21·60	7·69	29·29	28·35	17·88	13·24
1908	19·17	11·72	30·89	28·35	20·42	13·68
1909	18·63	14·75	33·38	28·35	25·45	14·54
1910	17·37	13·46	30·83	29·00	27·28	14·95
1911	16·83	10·09	26·92	29·00	25·20	14·50
1912	14·40	12·33	26·73	29·00	22·93	14·11
1913	15·03	10·95	25·98	29·00	19·91	13·60
1914	16·20	14·22	30·42	26·55	23·78	14·26
1915	16·83	13·58	30·41	29·00	25·19	14·50
1916	16·83	26·59	43·42	29·00	39·61	16·89
1917	25·24	38·05	63·29	31·87	71·03	21·73
1918	22·71	13·25	35·96	34·17	72·82	21·99[(1)]
1919	19·80	8·75	28·55	34·00	67·37	21·12
Totals	276·01	224·96	500·97	441·71	67·37	21·12

(1) Maximum level 22·43 m. in July 1918

Regulations H - 1: Lake Victoria; and H - 2: Lake Albert.

The reader may have noticed that in all the preceding examples we assumed that the normal outflow from Lake Victoria was basically 20 milliards per year. The outflow was varied in certain circumstances, usually according to levels prevailing in Lake Victoria itself. However, in Regulation D - 1 the outflow from Lake Victoria was increased to supplement Lake Albert at low levels so that the required range of levels in the latter could be reduced. As a further step it would be logical to reduce the outflow from Lake Victoria whenever possible; that is, when the sum of the resulting reduced Victoria Nile inflow with ' other sources ' and torrents inflows, together with perhaps a small change in the contents of Lake Albert, would be sufficient to meet the required annual outflow of 27·0 milliards at Mongalla. The results of this regulation are shown in Tables 338 and 339, for which the following rules were devised:

(i) The basis for regulation of both lakes is the annual discharge at Mongalla, which is fixed at 27·0 milliards per year or 28·35 milliards at Lake Albert exit.

(ii) The normal range of operating levels lies between 12·50 and 15·00 m. on Butiaba gauge.

(iii) When the level in Lake Albert rises above 15·00 m. the outflow will be increased according to the following sliding scale:

Butiaba Gauge m.	Lake Albert Annual Outflow mds.
14·00	28·35
15·00	29·00
16·00	30·00
17·00	31·50
18·00	33·00
19·00	36·50
20·00	40·00

(iv) The outflow from Lake Victoria will be regulated to suit the requirements in Lake Albert between the limits of 44 m/d and 100 m/d (16·0 to 36·5 milliards/year).

(v) When the level in Lake Victoria reaches 10·15 m. on Entebbe gauge, the outflow from the lake will be reduced to 44 m/d.

(vi) When the level in the lake is rising and exceeds 12·00 m. or falling and exceeds 12·50 m. on Entebbe gauge, the outflow will be increased to 100 m/d.

It will be seen that the application of this method gives the most satisfactory results of all. There is a wide range of adjustment of the outflow from Lake Victoria between 16·0 and 36·5 milliards, and consequently of the inflow into Lake Albert. The inflow of the Victoria Nile into Lake Albert comprises approximately two-thirds of the total inflow on the average, and it would have been possible, theoretically, to keep the level in Lake Albert very nearly constant in all years except from 1916 to 1920. The maximum levels would have been 12·59 m. on Entebbe gauge and 22·16 m. on Butiaba gauge. At the end of 48 years the contents in Lake Victoria would have decreased by 22 milliards, as opposed to increasing by 44 milliards under Regulation A - 1, while Lake Albert contents would have increased by 5 milliards as opposed to decreasing by 20 milliards, and 34 milliards would have been escaped in excess of the normal outflow (Tables 338 and 339).

TABLE 338

LAKE VICTORIA

REGULATION H - 1

REGULATION OF LAKE VICTORIA ACCORDING TO REQUIREMENTS IN LAKE ALBERT TO MAKE UP 27 MILLIARDS PER YEAR AT MONGALLA

Discharges in milliards per year. Gauges in metres.

Year	Natural Inflow	Controlled Outflow	Stored or Released	Cumulative Storage	ENTEBBE GAUGE	
					Difference from 11·50	Reading
					Assumed Start	11·50
1905	19·08	16·00	3·08	3·08	0·05	11·55
1906	56·12	19·42	36·70	39·78	0·60	12·10
1907	6·56	19·42	− 12·86	26·92	0·40	11·90
1908	15·51	18·70	− 3·19	23·73	0·35	11·85
1909	3·90	16·00	− 12·10	11·63	0·17	11·67
1910	12·47	16·70	− 4·23	7·40	0·11	11·61
1911	− 5·18	20·00	− 25·18	− 17·78	− 0·27	11·23
1912	20·09	18·00	2·09	− 15·69	− 0·23	11·27
1913	28·26	19·30	8·96	− 6·73	− 0·10	11·40
1914	24·76	16·00	8·76	2·03	0·03	11·53
1915	23·57	16·70	6·87	8·90	0·13	11·63
1916	55·04	24·59	30·45	39·35	0·59	12·09
1917	64·58	33·24	31·34	70·69	1·06	12·56[1]
1918	− 17·65	22·90	− 40·55	30·14	0·45	11·95
1919	8·82	16·00	− 7·18	22·96	0·34	11·84
1920	6·20	16·00	− 9·80	13·16	0·20	11·70
1921	− 6·57	16·00	− 22·57	− 9·41	− 0·14	11·36
1922	4·88	22·70	− 17·82	− 27·23	− 0·41	11·09
1923	38·78	18·70	20·08	− 7·15	− 0·11	11·39
1924	7·31	23·30	− 15·99	− 23·14	− 0·34	11·16
1925	23·79	25·41	− 1·62	− 24·76	− 0·37	11·13
1926	61·55	16·00	45·55	20·79	0·31	11·81
1927	− 4·85	27·00	− 31·85	− 11·06	− 0·16	11·34
1928	19·67	21·30	− 1·63	− 12·69	− 0·19	11·31
1929	0·44	25·69	− 25·25	− 37·94	− 0·57	10·93
1930	57·71	22·70	35·01	− 2·93	− 0·04	11·46
1931	33·99	18·70	15·29	12·36	0·18	11·68
1932	26·59	18·70	7·89	20·25	0·30	11·80
1933	11·46	24·30	− 12·84	7·41	0·11	11·61
1934	5·57	25·70	− 20·13	− 12·72	− 0·19	11·31
1935	15·57	25·70	− 9·95	− 22·67	− 0·34	11·16
1936	30·89	24·30	6·59	− 16·08	− 0·24	11·26
1937	59·33	18·70	40·63	24·55	0·37	11·87
1938	10·15	23·30	− 13·15	11·40	0·17	11·67
1939	5·24	28·49	− 23·25	− 11·85	− 0·18	11·32
1940	28·55	28·49	0·06	− 11·79	− 0·18	11·32
1941	31·51	23·30	8·21	− 3·58	− 0·05	11·45
1942	34·05	22·00	12·05	8·47	0·13	11·63
1943	− 13·52	25·70	− 39·22	− 30·75	− 0·46	11·04
1944	6·71	27·79	− 21·08	− 51·83	− 0·77	11·73
1945	18·80	25·70	− 6·90	− 58·73	− 0·87	10·63
1946	17·38	18·70	− 1·32	− 60·05	− 0·90	10·60
1947	57·42	16·00	41·42	− 18·63	− 0·28	11·22
1948	14·99	16·00	− 1·01	− 19·64	− 0·29	11·21
1949	− 6·85	23·30	− 30·15	− 49·79	− 0·74	10·76
1950	7·74	24·30	− 16·56	− 66·35	− 0·99	10·51
1951	51·98	23·30	28·68	− 37·67	− 0·56	10·94
1952	31·54	16·00	15·54	− 22·13	− 0·33	11·17
Total	1,004·11	1,026·24	—	− 22·13	− 0·33	11·17
Average	20·92	21·38	—	—	—	—

(1) Maximum level 12·59 m. in June 1917

TABLE 339

LAKE ALBERT

REGULATION H - 2

REGULATION ACCORDING TO REQUIREMENTS AT MONGALLA

Discharges in milliards per year. Gauges in metres

Year	Victoria Nile Controlled Inflow	Other Sources and Torrents Inflow	Total Inflow	Regulated Outflow	Cumulative Storage	Butiaba Gauge
				Assumed Start	13·67	12·50
1905	14·40	14·76	29·16	28·35	14·48	12·64
1906	17·48	14·77	32·25	28·35	18·38	13·33
1907	17·48	7·69	25·17	28·35	15·20	12·77
1908	16·83	11·72	28·55	28·35	15·40	12·81
1909	14·40	14·75	29·15	28·35	16·20	12·95
1910	15·03	13·46	28·49	28·35	16·34	12·97
1911	18·00	10·09	28·09	28·35	16·08	12·92
1912	16·20	12·33	28·53	28·35	16·26	12·96
1913	17·37	10·95	28·32	28·35	16·23	12·95
1914	14·40	14·22	28·62	28·35	16·50	13·00
1915	15·03	13·58	28·61	28·35	16·76	13·05
1916	22·13	26·59	48·72	28·35	37·13	16·48
1917	29·92	38·05	67·97	33·20	71·90	21·86
1918	20·61	13·25	33·86	38·86	66·90	21·11[1]
1919	14·40	8·75	23·15	40·00	50·05	18·54
1920	14·40	8·89	23·29	33·00	40·34	17·00
1921	14·40	2·27	16·67	31·50	25·51	14·55
1922	20·43	4·52	24·95	28·35	22·11	13·98
1923	16·83	11·82	28·65	28·35	22·41	14·03
1924	20·97	6·06	27·03	28·35	21·09	13·80
1925	22·87	5·48	28·35	28·35	21·09	13·80
1926	14·40	13·68	28·08	28·35	20·82	13·75
1927	24·28	4·07	28·35	28·35	20·82	13·75
1928	19·17	9·41	28·58	28·35	21·05	13·79
1929	23·12	5·23	28·35	28·35	21·05	13·79
1930	20·43	8·22	28·65	28·35	21·35	13·84
1931	16·83	11·47	28·30	28·35	21·30	13·84
1932	16·83	11·54	28·37	28·35	21·32	13·84
1933	21·87	6·48	28·35	28·35	21·32	13·84
1934	23·13	5·22	28·35	28·35	21·32	13·84
1935	23·13	5·51	28·64	28·35	21·61	13·89
1936	21·87	6·04	27·91	28·35	21·27	13·83
1937	16·83	11·68	28·51	28·35	21·33	13·84
1938	20·97	7·36	28·33	28·35	21·31	13·84
1939	25·64	2·71	28·35	28·35	21·31	13·84
1940	25·64	3·06	28·70	28·35	21·66	13·90
1941	20·97	7·09	28·06	28·35	21·37	13·85
1942	19·80	8·86	28·66	28·35	21·68	13·90
1943	23·13	5·27	28·40	28·35	21·73	13·91
1944	25·01	3·34	28·35	28·35	21·73	13·91
1945	23·13	4·76	27·89	28·35	21·27	13·83
1946	16·83	11·55	28·38	28·35	21·30	13·84
1947	14·40	13·84	28·24	28·35	21·19	13·81
1948	14·40	12·53	26·93	28·35	19·77	13·57
1949	20·97	6·90	27·87	28·35	19·29	13·48
1950	21·87	6·04	27·91	28·35	18·85	13·41
1951	20·97	7·13	28·10	28·35	18·60	13·37
1952	14·40	14·10	28·50	28·35	18·75	13·39
Total	923·60	477·09	1,400·69	1,395·61	—	—
Averages	19·24	9·94	29·18	29·06	—	—

(1) Maximum level 22·16 m. in July 1918

CONCLUSIONS

BASIC DATA

The basic data for this investigation are the records of levels and discharges concerning Lakes Victoria and Albert, the torrents, and the river at Mongalla, obtained from *The Nile Basin* (Vols. III and IV and Supplements) for the 48-year period from 1905 to 1952. We have assumed that Lake Victoria will be regulated by a dam at Owen Falls, and Lake Albert by a dam at Mutir. For Lake Kioga we have assumed that there will be a regulator near Masindi Port whose purpose will be to eliminate the time-lag between Lake Victoria and Lake Albert. No allowance is made for any possible storage in Lake Kioga itself. It is suggested that reasonable control of the torrents could be effected, and navigation assured, by a low dam at Nimule.

METHODS OF CONTROLLING LAKES VICTORIA AND ALBERT.

Nine methods of controlling Lake Victoria and sixteen methods of controlling Lake Albert in conjunction with it are examined in detailed tables, and the results are summarized in Table 340 (p. 756).

We suggest that probably the best method of regulating the two lakes together would be on the following lines:

(i) The basis for regulation of both lakes together should be the mean annual discharge at Mongalla, estimated from past records to be 27·0 milliards, equivalent to 28·35 milliards at Lake Albert exit.

(ii) The normal range of operating levels in Lake Albert should be between 12·50 m. and 15·00 m. on Butiaba gauge.

(iii) If the level in Lake Albert should rise above 15·00 m., the outflow should be increased according to sliding scale such as that given on page 752.

(iv) The outflow from Lake Victoria should be regulated to suit the requirements in Lake Albert between the limits of 44 m/d and 100 m/d. It has been agreed that the range of levels in Lake Victoria will be between 9·80 m. and 12·80 m. on Entebbe gauge.

(v) If the level in Lake Victoria should fall to 10·15 m. on Entebbe gauge, the outflow should be reduced to 44 m/d.

(vi) If the level in Lake Victoria should exceed 12·00 m. when rising, or 12·50 m. when falling, the outflow should be increased to 100 m/d. (This is one suggestion of several which have been made for dealing with high levels in Lake Victoria.)

If the lakes had been regulated to these simple rules, and if the flow at Mongalla throughout the year had been regulated to suit local interests as far as possible, during the 48-year period from 1905 to 1952 the level in Lake Victoria would have risen to 12·59 m. on Entebbe gauge and the level in Lake Albert to 22·16 m. on Butiaba gauge.

It must be concluded that the minimum storage necessary in Lake Albert for flood protection should be 80 milliards, which corresponds to a gauge-reading of 23·00 m. above datum level (10·00 m. on Butiaba gauge). As a guide to the maximum desirable level to be held in Lake Albert we may mention that the maximum level reached under any of the suggested methods of operation would have been 26·00 m. on Butiaba gauge. In order to provide a factor of safety to allow for a flood in the future greater in volume than the highest recorded in the past, common sense indicates that the maximum storage available in Lake Albert should be at least that corresponding to a gauge-reading of 25·00 m. on Butiaba gauge.

TABLE 340

CONTROL OF LAKES VICTORIA AND ALBERT
SUMMARY OF RESULTS OF DIFFERENT METHODS OF REGULATION

Regulation	Lake	Starting Level metres	Finishing Level metres	Finishing Year	Maximum Level Reached			Minimum Level		Change in Contents		Quantity Escaped milliards
					Gauge metres	Year	Month	Gauge metres	Year	Increase milliards	Decrease. milliards	
A – 1	Victoria	11·50	12·16	1952	12·73	1942	June	10·89	1922	44	—	—
A – 2	Albert	13·00	10·64	1952	21·82	1918	December	9·80	1951	—	13	—
A – 3	Albert	13·00	9·39	1952	24·33	1918	December	9·25	1951	—	20	—
A – 4	Albert	13·00	15·24	1952	25·22	1919	December	13·00	1905	13	—	—
B – 1	Victoria	11·50	10·48	1952	12·33	1917	November	10·00	1950	—	68	112
B – 2	Albert	13·00	25·77	1919	26·00	1918	December	—	—	82	—	—
B – 3	Albert	12·50	13·57	1952	20·29	1917	December	11·71	1934 and 1950	6	—	75
C – 1	Victoria	11·50	11·99	1942	12·38	1917	June	10·68	1922	33	—	25
C – 2	Albert	14·50	12·13	1942	25·15	1918	December	11·50	1936	—	13	34
D – 1	Victoria	11·50	11·17	1942	12·38	1917	June	10·64	1929	—	22	80
D – 2	Albert	11·50	13·06	1942	22·40	1918	December	11·62	1925	9	—	62
E – 1	Victoria	11·50	11·66	1942	12·40	1917	June	10·71	1922	11	—	46
E – 2	Albert	11·50	13·80	1942	23·63	1918	July	11·50	1905	13	—	27
E – 3	Albert	11·50	21·65	1919	23·43	1918	July	L. Albert Supplemented		62	—	25
E – 4	Albert	11·50	21·25	1919	22·72	1918	July	L. Albert Supplemented		60	—	28
F – 1	Albert	11·50	21·00	1919	21·85	1918	December	L. Albert Supplemented		58	—	13
F – 2	Albert	11·50	20·50	1919	21·65	1918	November	L. Albert Supplemented		55	—	16
G – 1	Victoria	11·50	11·37	1952	12·46	1917	November	10·74	1945	—	9	53
G – 2	Albert	11·50	14·30	1952	22·50	1918	August	11·98	1940 and 1944	16	—	12
G – 3	Victoria	11·50	11·25	1952	12·44	1917	November	10·60	1950	—	17	61
G – 4	Albert	11·50	14·35	1952	22·31	1918	July	12·01	1944	16	—	19
G – 5	Victoria	11·50	11·64	1919	12·50	1917	June & Nov.	—	—	9	—	7
G – 6	Albert	11·50	21·12	1919	22·43	1918	July	—	—	59	—	16
H – 1	Victoria	11·50	11·17	1952	12·59	1917	June	10·51	1950	—	22	66
H – 2	Albert	12·50	13·39	1952	22·16	1918	July	12·81	1908	5	—	34

NOTES: (1) In Regulations for Lake Albert from D – 2 to G – 6 inclusive, the starting level makes little or no difference because the outflow is regulated according to contents and a working level is soon established.
(2) Minimum gauges for G - 2, G - 4, and H - 2 do not include starting levels.
(3) Quantity escaped. The total outflow in excess of the averages of 20 milliards and 28·35 milliards per year in Lakes Victoria and Albert respectively.
(4) The gauges referred to are the Entebbe gauge on Lake Victoria and Butiaba gauge on Lake Albert.

2. CONTROL OF THE TORRENTS

In this section we discuss the problem of controlling the torrents which join the Bahr el Jebel between Lake Albert and Mongalla. This is, in effect, a continuation of the investigation which was started in the 1948–49 *Progress Report* of the Jonglei Investigation Team. The conclusions reached there may be summarized as follows. During a period of high flood such as occurred in September 1916 the discharge of the torrents may rise to a momentary maximum of 200 m/d, and average 124 m/d for 10 days or 100 m/d for a month. Since prolonged discharges of more than 120 m/d will lead to damage by flooding in the Central Zone of the Jonglei Area, the controlled discharge from Lake Albert Dam will have to be reduced to compensate for the torrents. Even so, if the dam is built at Mutir, a balancing reservoir of 1·5 milliards capacity will be needed between Mutir and Mongalla for temporary storage of the torrents until reductions in the controlled discharge can take effect. This is because the lag is indefinite between Mutir and Nimule, where the river consists of lagoons and fringing swamps about 200 sq. km. in area, and because the range of control at Mutir is limited by the need to maintain navigation between Mutir and Nimule. Most of these difficulties could be overcome by building the Lake Albert Dam (or a dam for a balancing reservoir) at Nimule, as the river is swift-flowing in a narrow channel north of Nimule, and navigation would be possible on the Lake Albert Reservoir. It would still be necessary to build a small balancing reservoir north of Nimule to control the highest spates of the torrents. Alternatively, allowance could be made in the following period for discharges exceeding 120 m/d at Mongalla, the maximum recorded monthly mean discharge of the torrents being 100 m/d. Possible dam sites for a balancing reservoir combined with the Lake Albert Dam at Mutir are at Nimule, Shukoli, Makedo, and Bedden, where capacities of the reservoirs might be 0·55 milliard at Nimule and 0·35 milliard at the other three sites.

Since that report was written, the Egyptian Irrigation Department have surveyed the valley from Rejaf to south of Makedo and have shown that a reservoir with a dam at Bedden could contain 2·3 milliards, but the dam would have to be about 5 km. long and 56 m. high. It has also become apparent that the Uganda authorities are unwilling to allow the Lake Albert Dam to be built at Nimule because the reservoir would inundate valuable agricultural land, although the engineering and hydrological advantages of the Nimule site are incomparably greater. To round off the investigation the Irrigation Section of the Team carried out surveys of the three major torrents—the Assua, the Kaia, and the Kit—to determine the possibilities of storage on the torrents themselves. We therefore describe these torrents and the dam site surveys in some detail, and conclude the section with a discussion on the suggestion made in the previous report on the possibilities of a low dam at Nimule, to control the torrents, combined with the Lake Albert Dam at Mutir.

When we come to the section of the report concerned with the regulation of the discharges to suit grazing in the Sudan, we show that control of the torrents is made much easier by operating the Project in phase, instead of out of phase, with the natural seasons.

When reading what follows the reader should refer to the map of the torrents joining the Bahr el Jebel (Fig. G 9).

THE ASSUA AND ITS MAIN TRIBUTARIES

The uppermost reaches of the Assua (spelt Aswa in Uganda) are on a group of hills, on the western border of the Karamoja District of Uganda, which seems to have no generic name. The river lies between latitudes 2° 30′ and 3° 00′ and longitudes 33° 30′ and 34° 00′. The hills rise to an altitude of 6,000 feet, above a plain whose general level is 4,000 feet. They are granite outcrops of the basement complex, of which there are many north and south of the southern mountains in the Sudan. Their slopes are steep and sparsely covered with trees with little undergrowth. From such hills large and sudden run-offs would be expected, so it is surprising to find no definite drainage-channels crossing the road from Moroto to Patonga which skirts the southern foothills. This is almost certainly due to a wide beach of permeable talus at the foot of the hills in which water is absorbed as soon as it reaches it.

However, the map of Uganda shows three streams issuing from the hills to form a river called at first the Kokokoi and then, after a short way, the Alito. The ground at the junction of these streams is black cotton soil. The origin of the sudden flows must be rainfall on this area. From the contours it appears that the slope of the clay plain is about 6·4 m/km.

At lat. 2° 20′, long. 33° 36′, the Alito enters the defined valley which characterizes the Assua for most of its way to its mouth north of Nimule. In the upper part of this reach there is a small flood-plain 100 m. wide, and terrific spates with a vertical range of 6 m. occur. Wooded hills flank both banks, rising with a certain abruptness from the flood-plain, but whose average slope appears to be of the order of 9 m/km., again scaled from the contours. They are broken by a large number of small valleys, some 500 m. in width, down which flow streams in *damboes* or grassy swamps. Some storage dams have been built on these streams, but they are of too small a capacity to affect the considerable discharges which must flow down after continuous heavy rain, once the ground is saturated.

At the gauging station at Paranga, the flood-plain and river are only 60 and 20 m. wide respectively. The bed is rocky instead of sandy as it is farther upstream, and the slope of the river appears to be about one metre per kilometre. Rocks and rapids occur irregularly from Paranga right to the mouth of the Assua on the Bahr el Jebel, about 20 km. north of Nimule. The rock is granitic as at the Fola Rapids below Nimule, and its strata are parallel to the river. At Awere, below Paranga, the channel is 60 m. wide with no flood-plain. At the second gauging site, the Gulu-Kitgum road-crossing (lat. 2° 57′, long. 30° 6′), and at Jebel Latwara (lat. 3° 20′, long. 32° 15′) the river is still the same and it can be assumed to be similar for the remainder of its course to the Sudan. At the Nimule–Juba road-crossing within the Sudan, after it has been joined by the Pager, Nimur, and Ateppi, the Assua is an impressive river some 100 m. wide, tumbling over rocky rapids in a deep gorge to the Nile.

The Agago

The first tributary of any importance joins the Assua between the two gauging sites, at lat. 2° 50′, long. 3° 10′. It drains the western slopes of the group of hills whose southern slopes give rise to the Alito. The former are less steep and more heavily wooded, and the run-off from them is not so rapid. At Patonga, where the smaller drainage-channels unite to form the Agago, the river rises slowly from April to June, runs full until August, and falls slowly from October until it dries up in February, except for pools.

The Pager

The next major tributary of the Assua is the Pager which runs in from the right bank, as all the tributaries do, at lat. 3° 9′, long. 32° 28′. The Pager supposedly drains a very large area of country in north-eastern Karamoja District to the east of the Nangeya range (see Fig. A 26). Here there is an ill-defined watershed between the Pager and Kidepo catchments. Most of the flow of the Pager, and certainly its spates, comes from the southern slopes of the Imatong Mountains, in channels such as the Aringa and Lonyang. These two streams were supplying all the flow of the Pager passing the gauging site at Kitgum in January 1952. A few streams, whose flash-flow is probably considerable, join the Pager downstream of the gauge. At Kitgum the river is only 10 m. wide at low stages, but in high spates extends over a width of 50 m. and cannot be crossed by the pierced Irish bridge built there.

The Nimur (or Namur)

The third significant tributary, the Nimur, joins the Assua inside the Sudan border at lat. 3° 40′, long. 32° 10′. Whitehouse, in his paper ‘ The Langia-Acholi Mountain Region of the Sudan ’ (*Geog. Jour.*, Vol. 77, 1931), listed the Nimur as one of the principal streams draining the Imatong-Acholi group, but did not consider it equal in importance to the Ateppi and Kinyeti. Its characteristics seem to be similar to those of the Koss; sudden high spates, flow beginning in April, running full from June to August, and drying up in October or November.

The Ateppi

The Ateppi is probably the most important of the Assua tributaries, both in total flow and in the size of its spates. Its catchment is entirely within the Sudan, and its mouth is a kilometre upstream of the Juba–Nimule road-bridge across the Assua at lat. 3° 43′, long. 32° 1′. It drains the eastern slopes of the Imatong-Acholi group. In its upper reaches it consists of a large number of *damboes* between tall mahogany forests. Lower down there are numerous rapids, and the stream increases in size to 30 m. at its junction with the Assua. The Egyptian Irrigation Department have recently built a gauge at Farajok, a good site in a straight reach upstream of a rock bar. Unfortunately there must be considerable run-off from the bare slopes of the valley downstream of the gauge, so that not all of the spates will be gauged.

GAUGES AND DISCHARGES

The Egyptian Irrigation Department have been gauging the Assua since 1923, and have recently started measurements on the Ateppi at Farajok, as mentioned above. The Uganda Hydrological Survey began to gauge the Assua at Paranga and at the Gulu-Kitgum road site and the Pager at Kitgum in 1950. The E.I.D. site on the Assua covers the whole catchment of some 31,000 sq. km., and the highest discharge recorded there between 1923 and 1942 was

36·8 m/d in May 1928. The flow of the Assua often increases suddenly and falls away again slowly, as for example in July and August 1938 when successive 10-day mean discharges were 2·5, 3·5, 25·4, 18·1, 17·5 and 13·7 millions of cubic metres per day.

From the discharges on 30th April 1951 at Paranga, 16·43 cumecs, and at the Gulu-Kitgum road, 49·76 cumecs, it will be seen that the Agago, the only tributary between the gauges, together with direct run-off from the sides of the valley, contributed as much as 33·43 cumecs. The Uganda Hydrological Survey intend to gauge this tributary as well.

The normal discharge of the Assua is given as 1·520 milliards per year which, on an area of 31,000 sq. km. where the rainfall averages 1,400 mm. per year, represents a run-off percentage of only 3·5%. Losses in the bed are known to be very heavy.

THE KIT

The River Kit joins the Bahr el Jebel at lat. 4° 43′, long. 31° 34′. The confluence is about 27 km. below the Bedden Rapids, the northernmost site on the main river for a balancing reservoir. The sources of the Kit are found on the western slopes of the Acholi Mountains, which are thickly forested with tall trees. The streams run into *damboes* at the foot of the hills, where they are perennial. Farther downstream at Magwe, where its channel is 10 m. wide and consists of a series of rapids, the river dries out to small pools. From Magwe the course of the river runs for 40 km. northwards before turning west to the Bahr el Jebel. From the contours the average slope appears to be about 7 m/km., decreasing towards the mouth to 1·5 m/km. Several smaller streams join the Kit on its right bank in this reach, and there must be considerable run-off from the sides of the valley. At its mouth the Kit is 100 m. wide, and protrudes a silt bank into the Nile. The area of catchment is approximately 3,500 sq. km. The normal run-off is estimated to be 0·257 milliards (7% of 1,050 mm. on 3,500 sq. km.), though it may well be half that amount.

THE KAIA

The Assua and the Kit are the main torrents on the right bank of the Bahr el Jebel. The Kaia is the principal one on the left bank south of Juba. The Luri and the Koda join the flood-plains of the Nile north of Juba and have been described in the survey of the area (Vol. I, p. 23). The Kaia is remarkable as being the first sizeable stream to cut through the high, steep-sided ridge which flanks the Bahr el Jebel on the west, north of Nimule. It does so in a striking trough fault some 50 m. deep about 15 km. west of its junction with the Bahr el Jebel, which is an obvious natural site for a dam. The farthest source of the Kaia is a small rocky hill rising out of the south-western plateau to a height of a few hundred feet, and the river runs in a well-defined valley with rocky sides and many small rapids for most of its length. For the last 20 km. before it cuts through to the Nile it follows the knife-edge ridge which forms the western wall of the Bahr el Jebel valley. Just upstream of the break-through it is joined by the Kijo, which, on a basis of catchment area, must be more important than the stream called the Kaia above the junction. The Kijo rises in the plateau east of Yei.

We have estimated the run-off of the Kaia, with its tributary the Kijo, to be 0·455 milliard in a normal year (7% of 1,300 mm. rainfall on a catchment of 5,000 sq. km.), though the percentage taken may be too high.

DAM SITE SURVEYS

As a preliminary to ground surveys we were able to fly over the courses of the Kit, the Ateppi, and the Kaia so as to note any outstanding features worth investigating further. Generally speaking the only outstandingly good site for a dam was found on the Kaia, which has been described above, where it cuts through the sharp ridge of hills on the west of the Bahr el Jebel valley. The valley of the Kit appeared to be suitable for a number of small dams; the Ateppi appeared to be much too steep, and as it ran in a narrow gorge cut into the plateau lying between the Bahr el Jebel and the mountains, there appeared to be no sites favourable for storage. Sites for small dams abounded on the Kaia, though they were not so plentiful on the Kijo, the more important of the two, but in any case the trough fault site could not be bettered.

The Assua-Ateppi Dam Site

Though the aerial reconnaissance was not promising, there was one possible site at the Assua-Ateppi confluence which is probably as good as any to be found. This site was within 1·5 km. of the Juba–Nimule road and was thus accessible to a survey party. The country farther upstream was so rough and broken that time did not allow a further reconnaissance on foot. It is also an advantage to site a dam near the mouth of a stream where all its flow can be impounded directly and where slopes are, naturally, the smallest.

A plan and cross-section of the site are given in Figures G 13 and G 16. The bed level of the Assua was R.L. 600 m., and at the site water could be impounded to a depth of 20 m. (R.L. 620 m.). With 2 m. free board the crest length is 960 m. The country is rocky and good foundations are almost as certain as at Nimule, 20 km. away.

The Kit Dam Site

The most promising site of many seen from the air for a dam on the Kit appeared to be at a point some 25 km. from its mouth. However, when a gauge was being built near its mouth, a fair site was found 2 km. from it. For the reasons given above, sites nearer the mouth of a river should be better than others farther upstream. Time was also a consideration, and there was no road to the upstream site; the intervening country was extremely rough and covered with trees and scrub. The site surveyed is where the Kit cuts through the watershed which separates its catchment from that of the minor torrents running west directly to the Bahr el Jebel. On the left bank the ground rises abruptly from the river, whereas on the right the rise is more gradual to a small isolated hill. The cross-section was extended over a small saddle to high ground beyond it.

The plan of the survey and cross-section of the site are given in Figures G 14 and G 17. A level of R.L. 472·50 m. can be held some 12 m. above the bed of the river.

The Kaia Dam Site

Seen from the air the site of the trough fault in the granitic ridge seemed ideal. Access was, however, difficult, and some time was spent in clearing and repairing an old gold-panners' track from the Juba-Yei road down to it. A plan of the survey and a cross-section at the dam site are given in Figures G 15 and G 18. The country was extremely broken, rocky, rough, and covered with trees and scrub, which made the going difficult. The Kaia upstream of the gap was found to have a steep slope of just over 4 m./km., and as the sides of its valley were fairly steep, the reservoir capacity was disappointingly small. As there were no bench-marks anywhere nearby, the survey was tied to an arbitrary datum. Water can be held to a level of 45·00 m. above the bed level in the gap, provided that two small, low gaps to the north of the left shoulder of the hill are also dammed.

METHOD OF SURVEY AND DATA OBTAINED

Precise surveys of the extent of the reservoirs were not possible in the time available, so an approximate method of assessing reservoir capacities was adopted. This is described by Mr. P. B. Mitchell in the *Journal of the Institution of Water Engineers*, August 1951, in a paper entitled ' Reservoir Site Investigation and Economics '. Briefly the method, known as the Lapworth method, consists of surveying two contours at different levels round the reservoir area, whose areas are then measured.

It is assumed that the area of water surface is proportional to an exponential function of the depth of water. The formula used is:

$$A = Kh^n \qquad \ldots \qquad \ldots \qquad (1)$$

where A is the area of the water surface, K a constant, h the depth of water, and n an index whose value depends on the slope of the valley. Integrating the above with respect to h, we derive the simple formula:

$$\text{Capacity } C = K \frac{h^m}{m} \qquad \ldots \qquad \ldots \qquad (2)$$

where $m = n + 1$.

The author gives the following values for m according to the type of country:

Type of Country	Value of m
Lake	1·0 to 1·5
Flood-Plain and Foothill	1·5 to 2·5
Hill	2·5 to 3·5
Gorge	3·5 to 4·5

Mitchell states that the error involved in using this method is usually within 5% and rarely greater than 10% or 15%.

By measuring the area of two contours and substituting in the formula (1) above, the values of the constants for the particular site can be determined.

The contours were, in every case, pegged out and surveyed with a compass traverse. Prominent points on the traverses were triangulated and the dead-reckoning misclosures adjusted to the triangulation. At all three sites this work was hampered by forest or bush. On the Assua-Ateppi and Kit surveys the higher of the two contours followed was the top water level to be impounded. On the Kaia the distance round the top contour would have been too great, so the higher of the two contours was taken at half full height. Cross-sections were taken at the actual dam sites. The details of the reservoirs and dams are given in Table 341 (p. 763). It will be noted that the value of the index m computed for all three values was approximately 2·5, the lower value of the range given for hilly country in Mitchell's paper.

To estimate the volume of concrete in gravity dams at the three sites, another approximate method, known as Sutherland's, was adopted, also from Mitchell's paper. In this method it is assumed that the site area of the dam (the area of the longitudinal section of the dam, or cross-section of the valley at the dam site) is an exponential function of the height as follows:

$$a = ch^{v} \quad .. \quad .. \quad (3)$$

where a is the site area, h the height above bed level, c a constant, and v a numerical index.

From this equation, a formula is derived by calculus for the volume of a concrete gravity dam, triangular in section, with a ratio of base width to height of 3 : 4. The formula is:

$$V = 0{\cdot}75\ ch^{v+1} \quad .. \quad .. \quad .. \quad (4)$$

when V is the volume of the concrete gravity dam, c a constant, h the height from 2 m. below bed level to 2 m. above top water-level, and v a numerical index.

Values for c and v in equation (4) are obtained from measurements of the site area at two different levels and substitution in equation (3).

As suggested by Mitchell, an allowance of 5% is added to the total volume for a roadway on the crest. He also gives the following values for v:

For concave V-shaped valley $v > 2$
For straight-sided V-shaped valley $v = 2$
For convex V-shaped valley $v < 2$

We summarize the results of the surveys in the table below in which the mean annual discharges of the three torrents is compared with the reservoir capacities found from the surveys:

	Assua-Ateppi	Kit	Kaia
Estimated Annual Flow in milliards	1·520	0·257	0·455
Reservoir Capacity in milliards	0·046	0·021	0·110
Capacity as % of Annual Flow	3·0%	8·2%	24·2%

In the previous investigation the ratio of the capacity of the balancing reservoir to the total normal flow of the torrents was 35%.

CONCLUSIONS

There is no doubt that, in principle, a series of storage dams on the three major tributaries would help to solve the problem of control of the torrents and would be of immense practical benefit to the district as a whole, but there would have to be many dams on each tributary. We now realize from our increased knowledge of the area that, apart from the Assua, a large part of the torrents' inflow north of Nimule, particularly in the case of high spates, consists of direct run-off from the sides of the valley in the hundreds of small streams connected directly with the Bahr el Jebel. The only way to impound most of this flow would be in a reservoir formed on the main river itself. The Egyptian Irrigation Department have shown that the required capacity could be obtained with a dam at Bedden. The expense of either numerous small dams or the lengthy dam at Bedden would be considerable, and in our view it could be avoided by adopting another method which we will now describe.

COMBINATION OF A LOW DAM AT NIMULE WITH THE LAKE ALBERT DAM AT MUTIR

In our 1948–49 *Progress Report* we showed that with the Lake Albert Dam at Mutir the torrents could be controlled completely by balancing reservoirs at Nimule and Rejaf of 0·55 and 0·35 milliards capacity respectively. We also showed that it would be a perfectly practical proposition with a height of impounded water of 5 m. at Nimule. The level downstream of Mutir Dam would be raised 2·50 m. when the Nimule reservoir was full, but since the purpose of filling the balancing reservoir would be to reduce the controlled flow during a period of extremely high natural inflows, this would not be a disadvantage.

The use of a low dam at Nimule would eliminate the previous difficulties due to the time-lag between Mutir and Nimule and to the need to maintain navigation.

Regarding the small reservoir specified at Rejaf, this could be dispensed with if the discharges at Mongalla could be allowed to exceed 120 m/d for short periods. It was shown in our earlier report that a peak momentary discharge of 60 m/d above the range of control would probably flow in north of Nimule from the torrents if conditions as severe as those which occurred in September 1916 were to occur again. Even then the mean monthly flow of the torrents was 100 m/d, so that with a range of control at Nimule of 120 m/d, any temporary excess over 120 m/d at Mongalla could have been offset by compensating reductions later in the month. Since there will not be a regulator actually at Mongalla it will be impossible to ensure that the discharge there will never exceed 120 m/d for short periods, but it would be quite easy to arrange reductions in flow from a dam at Nimule subsequently so that the average discharge over a 10-day period, or at most a month, would not exceed the prescribed figure. The lag from Nimule to Mongalla is about 2 days, but most of the torrents, including the Kit, run in south of Rejaf, which is only one day's lag from Nimule, so that adjustments could be made more quickly by basing regulation at Nimule on the Rejaf gauge. We consider that this combination would offer a simple and practical method of controlling the torrents if the Lake Albert Dam is to be built at Mutir.

NOTE

HYDRO-ELECTRIC POWER AT THE FOLA RAPIDS

It will be seen from the above that it will be essential to build some kind of dam at Nimule to control the torrents; either the Lake Albert Dam itself, or a low one for a balancing reservoir. This being so, we wish to add a short note pointing out the hydro-electric power potential available at the Fola Rapids some 10 km. downstream of the Nimule landing-stage. We were able to carry out a brief survey, and have prepared a plan and longitudinal section of the Fola Rapids (Figs. G 10 and G 11).

The latter shows the position of the site most favoured for structural reasons by the Egyptian Irrigation Department for the dam at Nimule. It will be noted that if the dam were to be built 7·5 km. farther downstream a minimum head of at least 30 m. would always be available. The minimum recorded discharge of the Bahr el Jebel at Nimule was 28 m/d in 1923. The mean flow is 64 m/d, and after the completion of dams on Lakes Victoria and Albert the discharge at Nimule should seldom be less than the mean. However, we have shown that it may be necessary to reduce the flow at Nimule to zero to compensate for the flow of the torrents north of there, which would not be possible if a hydro-electric installation were to be incorporated in the dam. This could be overcome by building another balancing reservoir at Bedden.

Assuming a minimum flow of 30 m/d, the power potential between Nimule and the tail of the Fola Rapids amounts to 140,000 horsepower. The use to which this power might be put is outside the scope of this report, but since the lack of inexhaustible natural fuels is one of the problems of Africa we offer no apology for drawing attention to one potential source of power.

TABLE 341

DATA FOR RESERVOIRS AND DAMS ON THE THREE PRINCIPAL TORRENTS

Item	Unit	Assua-Ateppi	Kit	Kaia
RESERVOIR				
Height of top water-level above bed level at dam site	metres	20·0	12·1	45·0
Surface area of full reservoir ...	sq. km.	7·55	5·44	8·85
'K' ...	constant	0·080	0·146	0·0184
'm' ...	numerical index	2·64	2·57	2·53
Capacity ...	million m³.	45·5	21·0	110·0
DAM				
Height of crest above bed, Main Dam ...	metres	22·0	14·1	47·0
Height of crest above saddle, Subsidiary (1) ...	,,	—	3·7	16·0
Height of crest above saddle, Subsidiary (2) ...	,,	—	—	7·2
Crest length of Main Dam ...	,,	960	650	196
Crest length of Subsidiary (1) ...	,,	—	700	414
Crest length of Subsidiary (2) ...	,,	—	—	100
Total crest length ...	,,	960	1,350	710
'v' for Main Dam ...	numerical index	1·94	2·29	1·52
'v' for Subsidiaries ...	,,	—	1·70	1·64*
'c' for Main Dam ...	constant	22·4	12·3	13·2
'c' for Subsidiaries ...	,,	—	150	53·1*
Cube of concrete in Main Dam ...	cubic metres	68,000	27,000	75,000
Cube of concrete in Subsidiaries ...	cubic metres	—	5,000	33,000*
Total cube of concrete ...	cubic metres	68,000	32,000	108,000
Capacity ÷ Cube ...	ratio	670	660	1,020

* Two Subsidiaries combined.

3. REVISED OPERATION OF THE PROJECT TO SUIT GRAZING AND OTHER NEEDS IN THE SUDAN

We have seen that the major adverse effect of the Equatorial Nile Project as it stands is the loss of riverain pasture in the dry season. We have investigated this in detail and have proposed a number of remedies which will make good those losses directly. The cost of such remedies in terms of money and water will be considerable, and furthermore their practical application in this backward area will present many difficulties. The introduction of centralized schemes as remedies will demand higher standards of education and considerable economic and social development.

These things will require a sound and progressive administration for many years to come. As an alternative to the direct remedies already described, it has been the major objective of the Team to investigate the possibility of so altering the method of operating the Project that it will have the least adverse effect on riverain grazing and at the same time meet the requirements of irrigation farther north. The problem is a new one, involving, as it does, an intensive study of the interrelation between swamp grasses and the natural hydrological régimes on which they largely depend, as well as of pedological and climatic conditions. We do not claim to have reached finality, but the results which are embodied in the proposals which follow are the best that can be devised in the present state of knowledge. We must emphasize that research on grass-water relationships must continue if the Equatorial Nile Project is to be attended with the greatest measure of benefit to the Southern Sudan, as well as to the Northern Sudan and Egypt.

WATER LOSSES

The abundant riverain pasture of today in the Southern and Central Zones of the Jonglei Area is produced by a natural system of irrigation which involves the loss of vast quantities of water. Some of this water is wasted in producing papyrus which is of no value as pasture, and yet more is used in producing *toich* pasture much of which cannot be utilized because it is almost permanently inundated or inaccessible. Clearly only a fraction of the water which is now lost is utilized in the production of pasture which the cattle can graze, and it should be possible to eliminate the wastage of water and still retain sufficient natural spill to irrigate grazing. But first we must discuss the question of water losses throughout the area.

SOUTHERN ZONE

We have seen that the southern swamps are bounded by high ground as far north as Lake Nuong on the west bank and 15 km. north of Bor on the east bank. In the Northern Zone where the swamps are similarly bounded by defined banks, the losses are on the average not more than those of normal transmission (see Analysis of the White Nile Flood, Vol. III, p. 901). It seems reasonable to suppose that so long as the swamps in the Southern Zone are contained within permanent high ground, the losses will be limited to evaporation, transpiration, and absorption by the flood-plain. This is borne out by the following figures for discharges at various points, which, though not strictly comparable because they cover different periods, give an indication of where large losses occur:

Discharge Site	Average Annual Discharge milliards	Period
Mongalla	27·0	1912–42
Terakeka	27·0	1931–42
Gemmeiza, Gigging	26·2	1931–42
Bor ... ..., Lake Papiu Mouth	28·6	1912–42
Jonglei Latitude ...	23·4	1936/7–42

The sum of the discharges at Bor and Lake Papiu mouth is not strictly relevant, but is included to show that the losses on the west are not as large as those on the east, north of Bor, where water spills on to the Eastern Plain, never to return to the Bahr el Jebel system. If the *Sudd* Diversion Channel is to begin at Jonglei, then the first step to take to reduce the losses south of Jonglei is to provide an artificial bank from 15 km. north of Bor to Jonglei on the east side of the River Atem. On the west the Egyptians propose to bank the Bahr el Jebel from Tombe as far as a barrage downstream of the Atem Head to eliminate losses which would otherwise occur in the Aliab Valley. Their proposals, however, are not complete, and we have shown that at the highest flood-escape discharges Bor, for example, would be 3·5 m. under water, and the water-level would be only 1·85 m. lower at the normal maximum discharge of 90 m/d. Since this is obviously quite unacceptable, we suggest two alternatives. Either adequate channel capacity must be provided in the Aliab Valley to take 40 or 50 m/d so that the previous maximum levels at Bor will not be exceeded, or the river bank must be left as it is so that when the discharge exceeds 65 m/d the excess will spill naturally into the Aliab Valley. The reasons for preferring the second alternative are that it would be cheaper and, as will be seen later, that grazing could be reproduced as it is now in the Aliab Valley without resorting to controlled irrigation. There are two ways in which water losses could be kept low. If a barrage were to be constructed across the Bahr el Jebel and its swamps at Jonglei latitude, from the Canal regulator to high ground on the west, it would ensure that whatever water reached that latitude would return to the river, and, if the borrow pit for the bank were to be dug as a continuous channel, the flow could be distributed north of Jonglei between the Bahr el Jebel and the Canal as required. Secondly, if the high discharges were passed during the wet season, when rainfall exceeds evaporation, the only loss would be that of absorption by the flood-plains, which, since the plains would be flooded annually, would not be large. In these ways we consider that losses in the Southern Zone could be reduced to little more than normal transmission losses, so that it should be adequate to assume, as Dr. Amin and Mr. Bambridge have done, that the losses between Mongalla and Jonglei would be reduced to 6%. At a discharge of 90 m/d a loss of 6% between Mongalla and Jonglei corresponds to 208 p.p.m. per kilometre, or nearly three times the transmission losses allowed for in the Northern Zone. The most important point to note is that in this way high flood-escape discharges could be passed safely as far as Jonglei without the expensive engineering works which would be needed either to protect Bor District or to carry the high discharges without exceeding the previous maximum levels there.

CENTRAL ZONE

By far the largest losses in water occur in the Central Zone between Jonglei and the Buffalo Cape–Fangak line, where the swamps are not bounded by high ground and are limited in extent only by evaporation, transpiration, and absorption. We have adopted the following method to determine how much of this water can be regarded as spill. We begin with the assumption that at a discharge of 30 m/d at Jonglei the losses are no more than those of normal transmission, and that there is no spill. By interpolating from Table 195 (p. 438) we find that the corresponding discharge at the Tail of the Swamps would be 26·0 m/d, so that normal transmission losses can be taken as 13·3%. In Table 342 (p. 777) we have first written down the 1912–42 normal discharges at Mongalla in 10-day periods and, by interpolation from Table 195, the corresponding discharges at Jonglei and at the Tail of the Swamps. The fifth column in the table shows what the discharges at the Tail of the Swamps would have been if the losses had been only 13·3% as at 30 m/d at Jonglei. The difference between the discharges in this and the previous column is regarded as the amount lost by spill, and totals 5·9 milliards in an average year. The seventh column goes one step farther and shows the differences between the actual rates of spill and those at the lowest period of the year; these differences total 2·6 milliards in an average year. Though this is not a precise figure, it is a measure of the amount of spill-water which produces grazing in the Central Zone. If we assume, as we have done in examining the effects of the Project in the Central Zone, that the average depth of spill-water is 1·0 m., then the area covered would be 2,600 sq. km. For comparison, the estimate of the area required to accommodate all the cattle which depend on riverain grazing in the Central Zone, based entirely on their numbers and a distribution of grasses as in the Aliab Valley, amounts to 3,830 sq. km., or half as much again as the area calculated from spill.

It is clearly undesirable, in the long run, to continue to use so much water to irrigate pastures by natural spill, because if the cattle could be accommodated on artificial pastures under controlled irrigation the water would be used more economically. The proportions of vegetative cover in that portion of the Aliab Valley which is annually flooded and uncovered by spill from the Bahr el Jebel, given below, show how wasteful this method of irrigation is:

Open Water	12·5%
Cyperus papyrus	7·2%
Vossia cuspidata	12·9%
Echinochloa stagnina	19·1%
Echinochloa pyramidalis	45·9%
Phragmites communis	2·4%

Echinochloa spp., which are the only grasses valuable for grazing, cover only 65% of the area.

Before putting forward our proposals to spill limited amounts of water, it is instructive to find out what happened in the lowest years on record. The total annual discharges at Mongalla were 15·3 milliards in 1922, 20·4 milliards in 1924, and 18·9 milliards in 1925, and an analysis of the spill in those years is given in Table 343 (p. 778) where it will be seen that the average spill, relative to the lowest period, amounted to just over one milliard.

The total annual discharge at Mongalla in 1921 was 16·6 milliards, so that there must have been a shortage of riverain pasture in 1922 and again in 1925, though, as discharges at Mongalla rose to 80 m/d during the rains of 1923, there was probably little shortage in 1924. The quantities spilled in these low years will be used as a guide when we come to decide how much controlled spilling should be allowed in the Central Zone.

NORTHERN ZONE

The flood-plains of the White Nile in the Northern Zone from east of Lake No and those of the Bahr el Zeraf from south of Fangak are bounded by high banks, so that water cannot be lost permanently by spilling away from the river. As will be seen from the analysis of the White Nile flood-plain (Vol. III, pp. 821 et seq.), in some years it is possible to determine the losses on the White Nile with considerable accuracy, whereas in others inflows from Khors Adar, Wol, and Nyadwai, which are not regularly measured, more than offset losses. It is fair to assume, with the authors of *The Nile Basin*, that on the average the losses in these sections of the rivers amount to 75 p.p.m. per kilometre, or about 6% between Malakal and Khartoum.

On the Bahr el Jebel south of Lake No, and as far as Buffalo Cape, Butcher[5] has shown that there are considerable losses by spill into the surrounding swamps when the Sobat is high and the levels at Lake No are affected by backwater. Some of this spill returns to the White Nile via the lower reaches of the Bahr el Ghazal when the levels fall, but banking will be required as part of the Project on the Bahr el Jebel south of Lake No to prevent excessive losses. This will be somewhat more important with the Revised Operation because, as will be seen later, there will be higher discharges and levels at Malakal than normally occur today, although they will occur during the rains when evaporation is lowest.

OPERATION TO SUIT GRAZING

GUIDING PRINCIPLES

SOUTHERN ZONE

The normal discharges at Mongalla, which are given in Table 29 (p. 64), vary from 57·7 m/d in March to 91·9 m/d in September. The flow at Mongalla is made up of two components; from Lake Albert and from the torrents. The former varies from year to year, but is practically constant in any one year and supplies all the water at Mongalla from December to March when there is normally no flow from the torrents. The latter is extremely variable in any one year, but on the average varies from nothing from December to March to a maximum of 28·7 m/d in August. To suit grazing and other natural requirements therefore our aim should be to copy the present normal discharges at Mongalla. When the lakes are under control, one way in which natural conditions could be copied would be by discharging water at a constant rate from the Lake Albert Dam, leaving the torrents to supply the natural variation in flow as they do now; the effects of this method are examined later (pp. 775–6). This has obvious advantages from the engineering point of view since there would be no need to build auxiliary dams for balancing reservoirs to control the torrents, and because, from a practical point of view, it is unlikely that all control works could be constructed at the same time; perhaps many years may pass before control works are built other than at the exits from Lake Victoria and Lake Albert.

In the meantime we must also note the important fact, shown by Butcher in *The Sadd Hydraulics*, that at a Mongalla discharge of 65 m/d all the water reaches Bor with no more than normal transmission losses[6]. There is no advantage to be gained by reducing the discharge at Mongalla below this figure. The discharges in the Southern Zone will therefore consist of a minimum steady discharge of approximately 65 m/d during the grazing months from the middle of January to the middle of May, and a variable flow during the rest of the year reaching approximately 90 m/d in August or September.

CENTRAL ZONE

Natural spill occurs similarly in the Central Zone, though of course the discharges are smaller. In the Bahr el Jebel north of Jonglei, experience has shown that at any discharge below 30 m/d the losses are no more than those due to normal transmission. When the discharge is increased above 30 m/d at Jonglei the river will spill over its banks and irrigate pasture naturally. Since this has been shown to be a somewhat wasteful method of irrigation, the advisability of doing it may be questioned. In support of our proposal we put forward the following arguments:

(i) Since we intend to copy natural conditions, though on a reduced scale, the repercussions on the people and their cattle in the Central Zone will be less than under the Project in its original form.

(ii) By continuing to spill water during the rains, we ensure that the people and their permanent habitations will be kept at some distance from the river, so that in the event of an extremely large flood, larger than any that have occurred in the past and larger than anything which can reasonably be allowed for in the future, the resulting disruption in the Central Zone would be less than under the Project as proposed by the Egyptian Government.

(iii) In addition to providing some grazing, it is possible that the régime which we propose would also suit fisheries. Increased spill during the rains would allow the fish to spawn and breed in the shallow swamps as they do now, and the reduction in the dry season would make it easier for the people to catch the fish which would then be confined only to the deeper lagoons.

(iv) Such a régime as we propose would allow the people to live to a certain extent as they do now and the changes in their mode of life would take effect less abruptly.

(v) It could also be adopted as an interim measure, and later reconsidered when experience has been gained in irrigating artificial pastures and in operating the Project as a whole.

NORTHERN ZONE

In the previous sections we have discussed briefly the relationship between water losses and grazing and have indicated the general principles to be applied in the Southern and Central Zones in order to suit grazing and other needs. Before we come to the detail of the operation to suit grazing and other requirements, we must discuss conditions in the Northern Zone, so that the needs of the three Zones can be combined.

A detailed analysis of the grasses is given in Volume I, Chapter 2, and Table 123 (p. 185) of that section sets out the vital conclusions as to depth and duration of flooding required for the various types of swamp grasses. It is on this analysis that we base our proposals for the Northern Zone. In Chapter 4 of the same volume it is clearly explained that the most important and valuable swamp grazing grass is *Echinochloa stagnina*. This grass not only has a carrying capacity several times greater than any other type, but is also indispensable from the time when the inland grasses become dry and unpalatable until the early rains, which produce the regrowth of the shallow-flooded *toich* grass *Echinochloa pyramidalis*. From Tables 92–3 (p. 173, Vol. I) it will be seen that north of Malakal *Echinochloa stagnina* is flooded on the average to a mean depth of 1·65 m. for 242 days. Not only must we provide these criteria for depth and duration of flooding, but we must also arrange to uncover the deep-flooded grasses so that they are accessible for grazing. In the analysis of the effects of the Project as it stands, it is pointed out that the higher river levels all the year round in the Northern Zone will probably lead to the establishment of undesirable vegetation such as *Cyperus papyrus* and *Vossia cuspidata*, and that in any case the deep-flooded grasses will be inaccessible because they will be permanently flooded. When we consider the time-discharge relationship for the White Nile at Malakal we realize that it consists of an almost constant discharge from the Tail of the Swamps all the year round of 39 m/d, to which is added the flow of the Sobat which varies from 7 m/d in the dry season to 67 m/d during the rains. It is the fluctuation of the Sobat which covers and uncovers the flood-plains and thus makes the valuable riverain pasture available to the cattle in the dry season.

From the above considerations we are led to the conclusion that the best way in which to reproduce natural conditions in the Northern Zone is to maintain a steady discharge from the Canal all the year round. The fluctuations in the Sobat at Malakal will thus still be superimposed on an approximately steady discharge from the Tail of the Swamps. In point of fact the variation will be larger than that due to the Sobat alone because we intend to increase the Bahr el Jebel flow also during the rains to suit pasture and other requirements in the Central Zone; since most of the increase will be dissipated in spill before it reaches the Tail of the Swamps the variation there will not be so great as at Jonglei, but in any case it will work to advantage in the Northern Zone. It may be thought that further benefit could be obtained by varying the discharge from the Canal in the same way, but this would be to the disadvantage of irrigation requirements in the north which demand as much water as possible in the dry season.

DETAILED APPLICATION

Having now presented the principles to be applied in each Zone, we can begin to construct tables for a river régime which will suit them all. It may at first sight appear that, with such different conditions to consider in each Zone, it will be extremely difficult to do so, but extraordinary as it may seem the different parts of the puzzle fit together surprisingly well. We account for this by the fact that we are endeavouring to copy what happens under natural conditions.

We now describe exactly how Table 346 (p. 781) has been drawn up. We start with the discharge at Mongalla, which is assumed to be 27 milliards per year. When this is considered in relation to Lakes Control it may be found desirable to vary this figure according to the contents of the Great Lakes, but for the moment we will assume that the objective of Century Storage—to deliver the long-term mean of 27 milliards per year at Mongalla—can be achieved. Allowing losses between Mongalla and Jonglei latitude at 6%, the corresponding quantity there will be 25·4 milliards per year. The flow at Jonglei must consist of a steady discharge in the Canal all the year round to suit the Northern Zone plus a variable discharge in the Bahr el Jebel, to suit the Central Zone, ranging from a steady low discharge during the grazing period, from the middle of January to the middle of May, to a predetermined maximum at the height of the rainy season in September, and the total must add up to 25·4 milliards. We know that the Bahr el Jebel is an efficient carrier channel at discharges at and below 30 m/d at Jonglei, so from the beginning of January to the end of May (Mongalla dates, to simplify operation) we could write down the discharge in the Bahr el Jebel at 30 m/d. We have adopted a figure of 25 m/d for this period because it results in a slightly higher capacity in the Canal, which is an advantage both to irrigation in the north under normal working, and also in the case of flood-escape discharges. It also increases the difference between high and low discharges in the Southern Zone. Exactly how much water is released in the Central Zone from June to December is a matter of judgment. We have shown that we cannot accommodate all the cattle which use the riverain pasture in this region without an excessive waste of water (3·8 milliards of spill). We have allowed increases to 35, 40, 45 and 50 m/d in June, July, August, and September, falling again in reverse order in October, November, and December. In this way conditions in the Southern Zone will approximate to what happens naturally today (see pp. 775–6 below). We have calculated what this means in terms of spill (Table 349, p. 784), in which the contributions of Khor Moich and the Tapari are included. The resulting spill in the Central Zone amounts to just over one milliard, but of this only some 0·75 milliard is supplied by controlled Bahr el Jebel spill alone. The rest is supplied by Khors Moich and Tapari, which, as has been explained elsewhere, can be considered as contributing about 0·65 milliard to the river in the Central Zone in an average year. The total flow in the Bahr el Jebel per year, determined in the way we have just described, amounts to 12·64 milliards, leaving 12·78 milliards to be taken by the Canal. Hence the steady flow in the Canal at Jonglei will be 35 m/d. The total flow at Jonglei by months is now the sum of the flows in the Bahr el Jebel and the Canal. The corresponding quantities at Mongalla are obtained allowing for losses between the two points at 6%. It will be noticed that the Mongalla discharges vary from a minimum during the grazing period of 64 m/d to a maximum during the rains of 90 m/d, which is similar to the present natural normal régime. In order to obtain the discharges at the Tail of the Swamps, we assume that the losses in the Canal amount to 12·5% and the losses in the Bahr el Jebel are according to Table 195 (p. 438), which is compiled from Butcher's *The Sadd Hydraulics*, and Plate 40 in Volume V of *The Nile Basin*. Since a discharge of 25 m/d is not covered by the table, we have assumed that the losses at that discharge will be 12·5%, the same as at 28·5 m/d at Jonglei. In tabulating the discharges at the Tail of the Swamps, we have assumed that the lag by the Bahr el Jebel route will be 30 days from Jonglei to Malakal, and 5 days by the Canal. The lag from Mongalla to Jonglei has been assumed to be 10 days. These figures have been determined from a consideration of present and future conditions as set out in Tables 344 and 345 (pp. 779–80).

The last step is to compute the discharges at Malakal, and to do this we have taken figures for the 1912–42 10-day mean normal discharges of the Sobat as measured at Hillet Doleib, and have added them to the Tail of the Swamps discharges (Table 348, p. 783).

It will be noted that the total annual flow at Malakal is increased from 27·6 to 34·7 milliards, an increase of 7·1 milliards, equivalent to 5·3 milliards at Aswan. However, from the point of view of irrigation in the north the increase in the timely season, from December 21st to June 30th, is only 2·9 milliards and the rest of the increase occurs during the untimely season. If and when over-year storage on the Main Nile north of Khartoum is made possible this will be of no consequence, because 5 milliards would be accommodated easily at any time for use whenever required. However, it will be some time before such storage is available, and until then in order to store water passing Malakal in the untimely season it will be essential to construct an annual storage reservoir on the Main Nile. This project was proposed before the conception of such over-year storage projects as for instance the Greater Aswan Dam, and it reached the stage of boring for rock samples at the site of the 4th Cataract near Merowe. The reservoir proposed at this site was intended primarily for flood protection for Egypt, with a capacity of 8 milliards, but it was hoped that about 3 milliards could be stored in it annually. In a year when the flood protection storage capacity was filled, ample water would be available for use in the following dry season; additional supplies would not be required from Malakal, and the flow in the Canal should be reduced accordingly, if possible. In any normal year, once the peak of the Blue Nile flood has passed, the capacity of the Main Nile Reservoir could be utilized to store the additional water from Malakal passing in the untimely season. From a study of the records of the natural river at Aswan it will be seen that the peak of the Main Nile flood occurs almost invariably in September, and it is normal practice to begin storing water at Aswan early in October; it is therefore safe to assume that the filling of a new Main Nile Reservoir could begin on October 1st. Since the lag between Malakal and the 4th Cataract is about 23½ days during September, the corresponding date at Malakal is the 6–7th of that month. The maximum flow of the Main Nile, as measured at Tamaniat, occurs during the first 10 days of September, and a normal flood falls to three-quarters of its maximum during the first 10-day period of October. As the lag between Malakal and Khartoum is 20 days at all stages of the river, it is clear that any water passing Malakal after September 11th can be considered as storable in a new Main Nile Reservoir at the 4th Cataract, and the period between September 11th and December 20th can be called the useful storable period at Malakal in the untimely season. The increase in the discharge at Malakal during this period amounts to another 2·6 milliards, making the total increase at Malakal in the timely and storable periods 5·5 milliards, equivalent to 4·1 milliards at Aswan. The remaining increase, 1·6 milliards, occurs between July 1st and September 10th, and it is naturally interesting to see what could be done with this extra water. Since the Blue Nile is normally in flood at this time, it could only in exceptional cases be utilized north of Khartoum. Between Malakal and Khartoum it would be possible to store very nearly all of this water either by heightening the Jebel Aulia Dam, or by building a new dam at Jebelein.

Alternatively the water passed during this period could be used for irrigation by pumps between Malakal and Khartoum to supplement rainfall without running the risk of not being able to fill the Jebel Aulia Reservoir. Perhaps the best use of all to which this water could, and will have to, be put is to maintain navigation in the Jonglei Canal all the year round, and this will be made clear when we come to study the design of the Canal, which we examine after we have considered the question of flood-escape discharges. But before that we must analyse the effects of our proposals in the Jonglei Area in the same way as we have analysed the effects of the Egyptian Project.

EFFECTS OF THE OPERATION TO SUIT GRAZING

SOUTHERN ZONE

Since the discharges at Mongalla under the proposed operation vary from 64 m/d to 90 m/d, compared with 58 m/d to 92 m/d under natural conditions, the areas flooded and uncovered in the Southern Zone will be almost the same as they are today. Basing our figures on the areas flooded in the Mongalla–Gemmeiza *toich* and Aliab Valley surveys, as before, we calculate that the proportions of the total flood-plains inundated and uncovered will be (i) from Juba to Tombe 55/160 (34·4%) instead of 65/160 (40·6%), and (ii) from Tombe to Jonglei 67/156 (43%) instead of 92/156 (59%). It is not thought that these changes will appreciably affect conditions in the Southern Zone (see Table 347, p. 782).

The total areas flooded and uncovered by the Bahr el Jebel only will be (i) from Juba to Tombe 224 instead of 264 sq. km., and (ii) from Tombe to the Atem Head 291 instead of 510 sq. km. In the second reach the flood-plain areas will be reduced by the banking from north of Bor to Jonglei east of the Atem, which is taken into account in the figure given above. The important points to note are that the river seasons will not be reversed, but the flooding and uncovering will be in accord with the natural season, though the areas so flooded and uncovered will be somewhat less than those of the present day.

CENTRAL ZONE

We have estimated the spill in the Central Zone in the same way as before. The details are given in Table 349 (p. 784). We have added the contributions of the Khors Moich and Tapari, assuming, as before, that their total contribution (0·67 milliard) is distributed monthly on the same pattern as the discharges of the Lau (Yei) at Yirol. The total amount of spill is 1·046 milliards, and assuming, as before, that the average depth of spill is one metre, then 1,046 sq. km. will be flooded for various periods up to the maximum of 214 days. From an examination of the cross-section at Peake's Track, and from general considerations, we assume that conditions in the Central Zone in the future will be similar to conditions in the Aliab Valley today, and that the distribution of grasses will also be similar. It should be noted that the discharge at Jonglei corresponding to that on the 24th May 1936 at Peake's Track, with 40 days' lag from Mongalla, was approximately 50 m/d, or similar to the maximum discharge proposed in the Revised Operation. The water-level in the Bahr el Jebel is at the top of the alluvial bank at Peake's Track. At the lowest discharge of 25 m/d at Jonglei, which corresponds to 19 m/d in the Bahr el Jebel at Peake's Latitude, the level there will be 1·1 m. lower, as determined by the gauge-discharge curve for the Bahr el Jebel at Peake's Track given in *The Sadd Hydraulics* (p. 87). It is reasonable to assume that the topography of the ground in the Central Zone is similar to that of the Aliab Valley, and further that the section at Peake's Track represents the northern end of such a valley, because it is near the junction of Peake's Channel with the Bahr el Jebel. The additional 67 sq. km. (Atem Head—Jonglei) should also be noted: see Table 347 (p. 782).

NORTHERN ZONE

It has not been found possible to investigate the effects in the Northern Zone in as much detail as before, but we present an approximate estimate of the areas flooded and the duration of flooding, based on the future gauge-discharge curve for Malakal, and the areas of flood-plain from Malakal to Jebelein related to the Malakal gauge. From the resulting discharges at Malakal (Table 350, p. 785) we have determined the corresponding gauge-readings from the gauge-discharge curve for Malakal (Fig. F 5). The levels throughout the year are plotted in Fig. G 19, together with the normal gauge-readings for Malakal (1912–42). The striking similarity of the two curves is immediately apparent. It will be noted that the future levels will vary from 10·84 m. to 12·99 m. on Malakal gauge, a range of 2·15 m., which compares very favourably with the normal range from 10·04 m. to 12·30 m., a range of 2·26 m. For all practical purposes therefore we can say that the depths of flooding under the proposed method of operation will be the same as at the present day, and the distribution of grasses can be determined from the periods of duration of flooding. In the same table we have listed the areas flooded between Malakal and Jebelein from the curves relating those areas to the Malakal gauge (Fig. F 17), and have plotted the results in Fig. G 20. For part of the year from August to February the Jebel Aulia Reservoir will be full, or nearly full. We also know that the reservoir is practically empty during May and June. For March, April, and July we have interpolated the areas by proportion between the curves for reservoir full and reservoir empty.

A table of areas and duration of flooding has been drawn up (Table 351, p. 785) from the curve Fig. G 20. It will also be seen that the total area which will be flooded and uncovered will be 990 sq. km. between Malakal and Jebelein, whereas at present this area is only 913 sq. km.

CONCLUSIONS

By operating the Equatorial Nile Project in phase with the natural river seasons, the hydrological effects on the flood-plain areas will be as follows:

SOUTHERN ZONE.

Between Juba and the Atem Head 515 sq. km. of flood-plain will be inundated and uncovered, instead of 774 as at present, or 67%.

CENTRAL ZONE.

Controlled spill from the Bahr el Jebel, together with the contributions of Khors Moich and Tapari, will amount to 1·046 milliards (1,046 sq. km.) compared with 2·6 milliards as at present, relative to the dry season. Between Atem Head and Jonglei these will be a further 67 sq. km. flooded and uncovered.

NORTHERN ZONE.

A total of 990 sq. km. will be flooded and uncovered between Malakal and Jebelein, compared with 913 at present. The depths of flooding will be virtually the same as at present.

These effects are interpreted later in terms of grazing and fisheries (pp. 795, 806).

We have not been able, in the time available, to complete the investigation of the hydrological effects in the Northern Zone with an analysis of the backwater effects in the Bahr el Jebel south of Lake No, in the Bahr el Ghazal, Bahr el Zeraf, and Sobat, but the result determined for the reach from Malakal to Jebelein is sufficiently encouraging to suggest that there will be a corresponding benefit to grazing areas in the remainder of the Northern Zone.

We must repeat that where the rivers are not bounded by high banks, as for instance on the Bahr el Jebel south of Lake No and on the Bahr el Ghazal, it will be essential to bank them to prevent the increase in spill losses at the higher levels now proposed. Such banks should be constructed with a flood-plain between them and the river, possibly 3 or 4 km. in width, which could then be flooded and uncovered in the same way as in the rest of the Northern Zone.

FLOOD-ESCAPE DISCHARGES

PRELIMINARY CONSIDERATIONS

Having decided what should be the normal method of regulating the discharges at Mongalla throughout the year, we must investigate how alterations to the normal régime, as for instance during a period of flood-escape, will affect the normal operation. We have seen that in the Southern Zone normally 67% of the flood-plain which is available for grazing today will be flooded and uncovered by varying the discharge at Mongalla from 64 m/d to 90 m/d. Provided that the same range of discharges is arranged by regulation, the effects of increasing the total quantity of water passing Mongalla, within reason, should not be too adverse in the Southern Zone. It will be seen later that there will be some adverse effects, but the problem of dealing with high floods is the most difficult of all to solve and some compromise will be necessary. We must also stipulate that the discharge at Mongalla should not be increased until the grazing period is over, i.e. at the beginning of May at the earliest, and not later than the beginning of September. Since the Revised Operation is designed to be in phase with the natural seasons, this should not be difficult. It will be noted from the study of Lakes Control that in Lake Victoria the highest levels are usually reached in June, and that the maximum levels in Lake Albert usually occur in July, so that this stipulation is not impracticable or unreasonable. There are no permanent settlements on the flood-plains in the Southern Zone, nor are there likely to be any, but it must be remembered that with a more regular river régime the *toiches* in this Zone may be developed for agriculture. Since flood-escape cannot be avoided, we do not recommend such development, but the possibility of its occurring cannot be ignored.

In the Central Zone, where the flood-plains are not bounded by permanent banks, conditions are not the same. After many years of a regular régime of the river—and the last really high flood occurred 33 years ago—the people may tend to move their habitations nearer the main channel of the river, but since the dried-out swamps will probably become largely intermediate land this trend will be slight. What is more important is the possibility that there will be considerable development in agriculture in this region, which would be subject to flooding by any increase in the amount of spill in the Central Zone. For this reason we do not recommend any alteration in the discharge in the Bahr el Jebel at Jonglei during a period of flood-escape unless conditions in the Great Lakes become so alarming that there is no other way of disposing of additional water. For instance, should the level in Lake Victoria be such as to necessitate increasing the outflow to its maximum of 100 m/d, and the level in Lake Albert at the same time rise within one metre of its maximum permissible level, then we consider it would be justifiable to increase the flow in the Bahr el Jebel at Jonglei (or to allow higher velocities in the Jonglei Canal). By exactly how much will be decided later.

It will be realized that the flood-escape requirements of the Southern Zone involve increasing the discharge at Mongalla by a constant quantity throughout the year, and since we do not contemplate increasing the discharge in the Bahr el Jebel in the Central Zone except under very exceptional circumstances, all the increase at Mongalla must be taken by the Jonglei Canal throughout the year. From what has been said about the Northern Zone it will be clear by now that provided the new high discharge in the Canal is maintained steadily throughout the year and the variation in the Sobat flow exposes sufficient flood-plain, conditions will be fairly satisfactory there too. The limiting factor in the Northern Zone will be the discharge which can be carried safely in the White Nile and its flood-plains from Malakal northwards. We will attempt to estimate this too, but first we must turn our attention to the design of the Jonglei Canal.

DESIGN OF THE JONGLEI CANAL

So far, in our proposals for the Revised Operation of the Project, the only point which has been decided about the Jonglei Canal is that it should normally have a capacity of 35 m/d. We do not propose to discuss the alignment of the Jonglei Canal, as that has been the subject of a special study by our predecessors (see *Third Interim Report*, p. 41) and by the Sudan Irrigation Department.

The main reasons why the ' Direct ' Line is preferred to an alignment (known as Line VII), which runs through the swamps east of the Bahr el Jebel, and which parallels the Bahr el Zeraf in its lower reaches, may be summarized as follows. River levels will not be so high in the Bahr el Zeraf below Khor Famyr, or in the White Nile west of the Sobat mouth where backwater effects will be less. A canal on Line VII would encounter numerous cross-drainage problems and interfere with the natural spill or backwater from the river on which pasture depends. The ' Direct ' Line would not incur these disadvantages, but on the contrary would open up new grazing areas by supplying water either for drinking or for irrigating artificial pastures. The ' Direct ' Line is the shorter for land and water communications, and crosses a region which is dry for half the year, in contrast to Line VII which runs largely through swamps. We endorse emphatically the conclusions recorded in that report that from the Sudan's point of view, which is mainly concerned with the effect on grazing, the ' Direct ' Line is the best.

The Jonglei Canal will have many functions to perform, as follows:

(i) First and foremost the Canal must carry the required normal discharge from Jonglei to the White Nile at the Sobat mouth.

(ii) It must also provide for navigation of Sudan Government steamers at all times of the year.

(iii) The Canal, or part of it, must be capable of irrigating pastures or other crops to make good losses in the Central Zone.

(iv) It must be capable also of carrying a greatly increased discharge during a period of flood-escape.

(v) It must always contain sufficient depth of water to prevent weed growth.

(vi) Proper means of crossing the Canal must be provided so as to permit annual migrations of cattle and people.

In addition there are certain design criteria which have been put forward in the Egyptian proposals and which we propose to incorporate. The first of these is that the velocity of water in the Canal should not exceed one metre per second. The objects of this are to suit navigation, and to avoid scour in the Canal. Secondly, for reasons of safety, water-levels in the Canal are to conform as closely as possible to the natural ground-slopes. There would be an economy of masonry cross-regulators in this proposal, and the absence of cross-structures would be an advantage to navigation, but the economy would be offset by additional depth of excavation necessary to bring the water-level down to ground level instead of allowing the Canal to run in command. The natural ground-slopes are 9 cm/km. for the first 175 km., and 7 cm/km. from there to the tail of the Canal. Thirdly, of course, the Canal must not be so wide as to exceed the distance to which excavators or dredgers can dispose of the spoil excavated. Otherwise the costs would be increased by the necessity of double-handling the spoil.

As we have already mentioned when discussing the effects of the Egyptian proposals, we strongly recommend that the functions of irrigation and navigation should be performed by separate canals. We now propose that the irrigation canal should have a capacity of 5 m/d, and that the navigation canal, or canals, should carry the remaining 30 m/d, to make the total normal discharge up to 35 m/d.

IRRIGATION CANAL

The design for the irrigation canal is straightforward. The only considerations are that its capacity must be 5 m/d, and it must run into command of about 0·80 m. within 40 km. of the Jonglei Canal Head regulator, where irrigation will be required. Hence the slope must be 2 cm/km. less than the natural ground-slope or 7 cm/km.

A suitable cross-section would be:

Bed Width 24 m.	Water Slope 7 cm/km.
Water Depth 2·92 m.	Sides Slopes 2:1
Velocity 0·66 m/sec.	Discharge 58 cumecs, or 5 m/d
	$^1/_n$ in Manning's Formula = 45

The irrigation canal should be aligned parallel to and on the west side of the main Jonglei Canal. It should be dug for the whole length of the ' Direct ' Line and join the White Nile at the Sobat mouth. Cross-regulators will have to be sited at the offtakes of canals for irrigating units of 100,000 feddans, and additional crossing-points must be arranged by bridging where necessary. Irrigation water should be used during the rainy season to supplement rainfall, and during the dry season the flow in the canal should be passed to the Sobat mouth. Some irrigation water may have to be extracted during the dry season, if it is found necessary to irrigate pastures. Water not required for irrigation during the rainy season would be transmitted by the irrigation canal to the White Nile.

MAIN JONGLEI CANALS

The main Jonglei Canals will be required to perform three important functions:

(i) They must carry the required discharge of 30 m/d.

(ii) They must be navigable.

(iii) They must carry additional high discharges during a period of flood-escape.

The only stipulation connected with the first function is that the velocity should not exceed 1·0 m/sec. This is the maximum desirable velocity for navigation, which also demands a depth of water of about 4 m., though for a limited period a depth of 2·5 m. may be allowed. In addition, since the maximum width of a complete tow is 24 m., the Canal must not be less than about 45 m. wide if there is to be enough room to navigate. If there is only one canal, crossing-points for steamers must be provided, but it would obviously be better to have two canals, one each for upstream and downstream traffic. Another consideration is that by arranging that the water-level normally conformed to natural ground-slopes, there would be no need for cross-regulators combined with locks, which both increase the cost and impede navigation.

The third function could be performed by the following ingenious method, which is copied from practice in the Fens of England[7]. We have said that it is desirable that the water-level in the canals should normally conform to natural ground levels. When it was necessary to increase the discharge, the water-level could be raised. Further, by digging the two canals some considerable distance apart and by placing all the spoil excavated on the outside of each of the two canals then, when the level was raised, the intervening ground, known as ' washlands ' in the Fens, would be flooded, and provided that the grass was burnt off beforehand some additional flow could be transmitted by the area so flooded. The limit to the amount which could be passed in this way will be set by the depth of water which the banks will hold safely and by the velocity in the canals.

Taking all these factors into consideration we propose a design, details of which are given in Table 352 (p. 786), which calls for little comment.

Since the natural ground-slopes are 9 cm/km. for the first 175 km. and 7 cm/km. thereafter, we divide the Canal into two separate reaches, the upper reach from the Jonglei Canal Head regulators to km. 175, and the lower reach from there to the tail of the Canal at approximately km. 280.

It will be noted that the normal flow of 30 m/d could be doubled during a period of flood-escape without greatly exceeding the maximum permissible velocity in the upper reaches of the canals, and a head of 1·2 m. of water on the banks is perhaps not excessive. There are two other points which require consideration. It is almost certain that the growth of grass, on the sides of the Canal and on the washlands, will reduce the discharges. This has been allowed for in the choice of the value of $^1/_n$ in Manning's Formula. The value of 45 is for freshly dug canals. By the time that grass was established on the sides, probably where the depth was less than 2·5 to 3 m., the unevennesses in the bed of the canal would be smoothed out, friction would be reduced, and the value of $^1/_n$ would increase. Similarly, by assuming that the value of $^1/_n$ for the washlands is only 10, adequate provision has been made for the effect of grasses. It should be noted that by raising the water-level above ground level we could create a *toich* by artificial means. If the level were to be raised a few centimetres for the whole of the rainy season, the tendency would be for shallow-flooded *toich* grasses, such as *Echinocloa pyramidalis*, to become established, which on an area of 320 sq. km. would produce some valuable pasture in the dry season. Alternatively, at the end of the rainy season the natural grasses which are of the intermediate type, such as *Hyparrhenia rufa*, could be burnt off. Then a flush of water could be passed down sufficient to cover the area and ensure regrowth after burning. It is possible that a negligible quantity of water, perhaps about 100 million cubic metres, would be enough for this purpose, i.e. 0·3 m. depth of water over 320 sq. km. This latter method is preferable because it would be more economical in the use of water. One method or the other should be adopted to prevent the establishment of acacia forest, which would otherwise be the natural ecological climax.

The second point to be considered is the question of cattle-crossings. Under normal operation this should present no great difficulty. If it were found that cattle were unable to swim the canals, then crossings could be provided by cable-ferries. Under flood-escape conditions, the ferries would be essential. They could travel across in communicating channels between the two main canals. Care would have to be taken to ensure that the spoil from the excavated cross-cuts did not seriously interfere with the discharge carried by the washlands; this could be achieved by leaving adequate gaps. Alternatively, if the spoil excavated from the channels were used to make raised roads with a sufficient number of culverts in them, the ferries would be needed for crossing only the canals themselves, as under normal operating conditions.

Consideration of the design of the Jonglei Canal has indicated the maximum discharge which could be carried during a period of flood-escape. The actual limit can only be determined from practical application, but for the present it is safe to assume that maximum flood-escape discharge in the Jonglei Canal and washlands would be 60 m/d, plus 5 m/d in the irrigation canal, making a total of 65 m/d at Jonglei.

OPERATION DURING A PERIOD OF FLOOD-ESCAPE

We must now explain, in the same way as for normal operation, how Tables 353 and 354 (pp. 787–8) have been compiled for the flood-escape régime.

We start by writing down the discharges in the Bahr el Jebel at Jonglei, which will be the same as for the normal operation for reasons which we have explained above. The next step is to fill in the column for the discharge of the Jonglei canals, which is 65 m/d at Jonglei throughout the year. The discharges at Mongalla are computed by allowing losses between Mongalla and Jonglei at 6%. This is a conservative figure because, with higher discharges in the dry season as well as during the rains, losses by evaporation would be greater and a larger area would be flooded. The Tail of the Swamps discharges are obtained by adding the Bahr el Jebel discharges there, which will be the same as under normal operation, to the discharges from the tail of the canals, allowing losses at 12·5% as before. The table also shows the number of days' lag between the different gauging points.

EFFECTS OF FLOOD-ESCAPE DISCHARGES

SOUTHERN ZONE

The effects of the flood-escape discharges need not be examined in the same detail as before, but we can give some indication of what they will be. In the Southern Zone, according to Figures H 22 and H 23, the areas of flood-plain inundated and uncovered in the Mongalla–Gemmeiza and Aliab Valleys will be 64/160 and 13/157 sq. km. Thus whereas there will be some slight gain in the area flooded and uncovered south of Gemmeiza (64/160 instead of 55/160), the Aliab Valley will be virtually inundated all the year round. Although this is what has happened in the past under natural conditions, it has usually led to friction and even fighting between tribal sections owing to shortages of grazing, and every effort will have to be made when the Project is operated under control from the Great Lakes to lower the Mongalla discharge as much as possible during the grazing period to avoid trouble in the future. It goes without saying that any such reduction in the grazing period will be of benefit to the Northern Zone as well.

CENTRAL ZONE

As explained above there will be no changes in the Central Zone during a period of flood-escape. The reason why higher discharges can be tolerated (with less adverse effects) in the other Zones, and not in the Central Zone, is because the flood-plains in the other Zones are bounded by defined and permanent high ground, whereas in the Central Zone the spread of spill-water from the river is limited only by evaporation and transpiration losses.

NORTHERN ZONE

It will be seen in Table 354 (p. 788) that the maximum discharge at Malakal, assuming that the flow from the Sobat is normal, will be 160 m/d. This figure was exceeded in 1918 when the discharge at Malakal reached 168 m/d. However, it is not enough to assume that the Sobat flow will be normal, and in point of fact it reached 107 m/d at Hillet Doleib in February 1918. In order to see what would have been the maximum discharge during the 1917–18 period if the Project had been constructed and operated as we propose, we must add the actual flows of the Sobat at Hillet Doleib for that period to the controlled Tail of the Swamps flow as under:

Year and Month	Sobat Monthly Mean Discharges Hillet Doleib m/d	Controlled Tail of Swamps Discharges m/d	Total Flow at Malakal m/d
1917			
July	49·3	83	132·3
August	58·8	88	146·8
September	67·6	90	157·6
October	79·4	92	171·4
November	94·7	92	186·7
December	101·0	90	191·0
1918			
January	104·0	87	191·0
February	107·0	82	189·0
March	93·2	79	172·2
April	39·4	79	118·4
May	30·4	79	109·4
June	42·9	79	121·9

Thus under conditions as severe as have occurred in the past we would expect the discharge at Malakal to rise to 191 m/d. There are good reasons for believing that such a discharge could be passed safely at Malakal. In the first place there are the records of levels and discharges from the past as follows:

Year	Malakal Discharge m/d	Malakal Gauge Reading metres
October 1909	150	13·03
March 1918	168	13·34
December 1946	125	12·92

In order to estimate what would be the level in the White Nile north of Malakal at a discharge of 191 m/d, let us consider the factors in Manning's Formula which affect discharge. Manning's Formula may be written:

$$Q = {}^1/_n \times A \times R^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

where Q is the discharge, ${}^1/_n$ the reciprocal of Manning's coefficient, A the area of the cross-section, S the slope, and R the hydraulic mean depth.

At low river, when Malakal gauge reads 10·00 m., the average depth is approximately 4 m., and the average width of the water surface between Malakal and Melut is 420 m. Since the width is 105 times the depth we can assume that R, the hydraulic mean depth, is equal to the depth, D. The area of the cross-section obviously varies with depth. The only other possible variable is the slope, but it will be seen from the table below that at the three highest recorded discharges this did not change:

Discharge m/d	Reduced Levels of Water Surface at		Difference in Level m.
	Malakal m.	Melut m.	
125	385·03	382·50	2·53
150	385·14	382·67	2·47
168	385·45	382·98	2·47

Therefore the discharge at Malakal is proportional to $AD^{2/3}$, and by trial and error we calculate that the level at Malakal will be 0·55 m. higher than in 1918, at a discharge of 191 m/d. What effect this will have can be seen from the numerous cross-sections of the White Nile, which consist of:

(i) 22 cross-sections taken by the Egyptian Irrigation Department in 1928.

(ii) 3 cross-sections surveyed by the Team during the investigation.

(iii) About 24 cross-sections surveyed by Sir Alexander Gibb and Partners between Malakal and Melut during their investigation of irrigable areas on the White Nile north of Malakal.

From these cross-sections we have extracted the levels of permanent high ground bordering the river, and have plotted them in Fig. G 21 for the critical reach from Malakal to Melut, together with the actual water surface levels for 1909 and 1918, and the computed water surface for a discharge of 191 m/d. The Egyptian cross-sections show that there will be no danger from extra high river levels north of Melut. There are only two doubtful points south of Melut, one at cross-section 103 W., about 40 km. north of Malakal, where the river might spread 3 km. inland before encountering higher ground, and the other at cross-section 105 W., 5 km. south of Malakal, where the river will rise 0·15 m. above the ground and penetrate some 4 km. inland before meeting higher ground. There is, however, another factor which will probably lower the water surface to levels below those we have calculated on the assumption that all the discharge will be taken by the river alone. At the highest level which corresponds to 13·89 m. on Malakal gauge the *toiches*, whose average level corresponds to 11·50 m. on the gauge, will be flooded to a depth of 2·39 m., and in all probability some flow will result. On the basis of our calculations for the washlands in the Central Zone, the flow on the *toiches*, which average about 2 km. in width, may amount to 310 cumecs, with a velocity of 0·066 m/sec., which is equal to 26·7 m/d. Even if the discharge on the *toiches* is only half this value, there will be a considerable reduction in the discharge carried by the river, and therefore in levels.

All things being considered, there should be little adverse effect on the habitations and agricultural activities of the people living on the banks of the White Nile north of Malakal, even though the discharge may rise to 190 m/d in very exceptional circumstances.

Since the diagram of flood-plain areas between Malakal and Jebelein, which have been measured from the Egyptian cross-sections, does not extend above the level of 13·00 m. on Malakal gauge, we are not able to compute what areas will be flooded and uncovered between these highest levels and low river levels. We have, however, plotted the probable levels in the White Nile at Malakal throughout the year on the assumption that the discharge of the Sobat is normal. In this latter case the maximum gauge-reading will be about 13·24 m. and the lowest gauge-reading will be 11·83 m., a range of about 1·41 m., which will expose a total area of well over 780 sq. km. of flood-plain between Malakal and Jebelein, compared with the present area of 913 sq. km. It must be remembered that the gauge-discharge curve for discharges of more than 130 m/d is not exact.

OPERATION TO SUIT GRAZING—TORRENTS UNCONTROLLED

To complete the study of operating the Project in phase with the natural seasons, we will present some preliminary figures to show the effect in the Sudan, assuming that control works are first constructed at Lakes Victoria and Albert, and that it will not be possible, or perhaps necessary, for many years to control the torrents.

We start by examining the approximate total annual discharges of the torrents at Mongalla which have been tabulated in descending order of magnitude for the 44 years between 1907 and 1952 (Table 355, p. 789). The mean for the period is 4·47 milliards per year, with maximum and minimum flows of 11·8 and 1·64 milliards in 1916 and 1918 respectively. We have also computed mean average high and low flows, which are 5·34 and 3·50 milliards respectively; discharges between 3·0 and 6·0 milliards occurred in 31/44 years. The years in which the discharges were extremely low, 1927 and 1918, both followed years in which the discharges were extremely high, 1926—6·3 milliards, and 1917—10·8 milliards. There are 24 years in which the annual flow is below the mean, and 20 years in which the flow is above the mean. To demonstrate the effect of leaving the torrents uncontrolled we have compiled Tables 356, 357 and 358 (pp. 789–91), which show how the flow could have been distributed between the canals and the Bahr el Jebel in (a) a normal year, (b) average high and low years, and (c) extreme high and low years. In the first place the operation in a normal year results in discharges in the Bahr el Jebel and the canals at Jonglei strikingly similar to those proposed for the operation to suit grazing given above. The total annual discharges in them both are exactly the same, though there are slight differences in the monthly distribution in the Bahr el Jebel. There would also have been no real difficulties in the average high and low years. In the average high year the discharge in the Canal would have been increased in July, August, and September to a maximum of 55 m/d to avoid exceeding 50 m/d in the Bahr el Jebel at Jonglei.

The operation in the extremely high and low years, both of which occurred twice in the 44-year period, would have caused some difficulties. In the low years there would have been a shortage of spill in the Central Zone, but as they followed on the heels of extremely high years this might not have had a serious effect on the grazing. In any case it is conceivable that in these extreme cases the flow could have been augmented by regulation from Lake Albert. In the case of the extremely high years, particularly in September 1916, conditions in the Central Zone, where the discharge would have risen to 87 m/d in the Bahr el Jebel at Jonglei, would have been intolerable. It will be noticed that the discharge in the canals at Jonglei is increased to 65 m/d, the maximum flood-escape discharge, as soon as the flow in the Bahr el Jebel reaches 50 m/d. In this case also it is quite conceivable that the flow could have been substantially reduced by regulation from Lake Albert.

TABLE 342

NORMAL SPILL LOSSES IN THE CENTRAL ZONE

Discharges in millions of cubic metres per day. Totals in milliards.

10-Day Period Period		Mongalla 1912–42 Normals	Jonglei 1912–42 Normals	Tail of Swamps	13·3% Losses	Spill by Difference	Spill Relative to Lowest Period 9 m/d
January	1 ...	65·3	58·8	38·9	51·0	12·1	3·1
	2 ...	63·5	57·4	38·4	49·8	11·4	2·4
	3 ...	62·2	56·4	38·1	48·9	10·8	1·8
February	1 ...	60·7	55·2	37·7	47·9	10·2	1·2
	2 ...	59·4	54·2	37·4	47·0	9·6	0·6
	3 ...	58·8	53·7	37·2	46·6	9·4	0·4
March	1 ...	58·4	53·4	37·1	46·3	9·2	0·2
	2 ...	58·1	53·1	37·0	46·0	9·0	—
	3 ...	57·7	52·9	36·9	45·9	9·0	—
April	1 ...	59·4	54·2	37·4	47·0	9·6	0·6
	2 ...	60·7	55·2	37·7	47·9	10·2	1·2
	3 ...	65·6	59·0	39·0	51·2	12·2	3·2
May	1 ...	71·7	64·0	40·4	55·5	15·1	6·1
	2 ...	76·3	67·7	41·4	58·7	17·3	8·3
	3 ...	76·5	67·8	41·4	58·8	17·4	8·4
June	1 ...	73·7	65·6	40·8	56·9	16·1	7·1
	2 ...	73·4	65·3	40·7	56·6	15·9	6·9
	3 ...	73·5	65·5	40·8	56·8	16·0	7·0
July	1 ...	76·6	67·8	41·4	58·8	17·4	8·4
	2 ...	77·8	68·9	41·8	59·7	17·9	8·9
	3 ...	81·6	71·9	42·4	62·3	19·9	10·9
August	1 ...	87·3	76·4	43·9	66·2	23·3	14·3
	2 ...	89·9	78·5	44·6	68·1	23·5	14·5
	3 ...	90·5	79·0	44·7	68·5	23·8	14·8
September	1 ...	91·9	80·0	45·0	69·4	24·4	15·4
	2 ...	90·0	78·6	44·6	68·1	23·5	14·5
	3 ...	87·8	76·8	44·1	66·6	22·5	13·5
October	1 ...	87·5	76·5	44·0	66·3	22·3	13·3
	2 ...	85·4	74·9	43·9	64·9	21·0	12·0
	3 ...	83·3	73·3	43·0	63·6	20·6	11·6
November	1 ...	81·7	71·9	42·6	62·3	19·7	10·7
	2 ...	79·6	70·2	42·1	60·9	18·8	9·8
	3 ...	76·4	67·7	41·4	58·7	17·3	8·3
December	1 ...	72·8	64·9	40·6	56·3	15·7	6·7
	2 ...	70·2	62·8	40·0	54·4	14·4	5·4
	3 ...	68·3	61·2	39·6	53·1	13·5	4·5
Average Year	...	73·8	65·6	40·8	57·0	16·2	7·2
Total	... ...	27·0	24·0	14·9	20·8	5·9	2·6

TABLE 343

ANALYSIS OF NATURAL SPILL IN THE CENTRAL ZONE IN THE LOWEST YEARS

Discharges in millions of cubic metres per day. Totals in milliards.

Year and Month	Mongalla	Jonglei	Tail of Swamps	13·3% Losses	Spill	Spill Relative to Lowest Period
1922						
January	34·5	32·5	27·8	28·2	0·4	0·4
February	31·8	30·2	26·2	26·2	—	—
March	32·2	30·5	26·4	26·5	0·1	0·1
April	35·0	33·0	28·1	28·6	0·5	0·5
May	40·2	37·8	31·0	32·8	1·8	1·8
June	38·8	36·5	30·4	31·6	1·2	1·2
July	40·1	37·7	31·0	32·7	1·7	1·7
August	50·5	47·0	34·8	40·7	5·9	5·9
September	64·9	58·5	38·8	50·7	11·9	11·9
October	50·2	46·7	34·6	40·5	5·9	5·9
November	48·6	45·4	34·2	39·4	5·2	5·2
December	34·7	32·7	27·9	28·4	0·5	0·5
Year	15·3	14·3	11·3	12·4	1·1	1·069
1924						
January	52·8	48·9	35·4	42·4	7·0	3·0
February	49·8	46·4	34·5	40·3	5·8	1·8
March	45·9	42·9	33·2	37·2	4·0	—
April	55·0	50·6	36·0	43·9	7·9	3·9
May	61·5	55·8	37·9	48·4	10·5	6·5
June	51·7	48·0	35·1	41·6	6·5	2·5
July	51·5	47·9	35·1	41·5	6·4	2·4
August	55·4	51·0	36·2	44·2	8·0	4·0
September	64·3	58·0	38·6	50·3	11·7	7·7
October	65·1	58·6	38·8	50·9	12·1	8·1
November	63·8	47·6	35·0	41·3	6·3	2·3
December	53·6	49·6	35·7	43·0	7·3	3·3
Year	20·4	18·4	13·1	16·0	2·9	1·389
1925						
January	49·8	46·4	34·6	40·2	5·6	1·5
February	46·3	43·3	33·4	37·5	4·1	—
March	46·2	43·2	33·3	37·4	4·1	—
April	48·2	45·0	34·0	39·0	5·0	0·9
May	53·9	49·8	35·8	43·2	7·4	3·3
June	50·8	47·2	34·8	41·0	6·2	2·1
July	50·4	46·9	34·7	40·6	5·9	1·8
August	60·0	54·6	37·5	47·4	9·9	5·8
September	53·6	49·6	35·7	43·0	7·3	3·2
October	49·0	45·7	34·3	39·7	5·4	1·3
November	58·3	53·3	37·1	46·2	9·1	5·0
December	53·3	49·3	39·1	42·7	3·6	—
Year	18·9	17·5	12·9	15·2	2·3	0·761

Average for three years above 1·073

TABLE 344

TIME-LAGS OF FLOW IN THE BAHR EL JEBEL

Time of Lag in Days

Place	Mongalla River		Jonglei River		Awai Tails River		Distance in km.	km. per day
	High	Low	High	Low	High	Low		
				Present Day (1)				
Mongalla	0	0	—	—	—	—	0	—
Jonglei	20	10	0	0	—	—	231	12/23
Awai Tails	20	20	0	10	0	0	385	19
Peake's Latitude ...	40	30	20	20	20	10	467	12/16
Malakal	60	45	40	35	40	15	912	15/20
				Future Conditions (2)				
Mongalla	—	0	—	—	—	—	0	—
Jonglei	—	10	—	0	—	—	231	23
Malakal:							from Jonglei	
By Canal	—	15	—	5	—	—	280	56
By Bahr el Jebel ...	—	40	—	30	—	—	681	23

(1) From Mongalla to Peake's Latitude the lag has been determined by an examination of the normal discharges from Mongalla to Peake's Latitude (see Table 345).

From Peake's Latitude to Malakal the lag has been calculated on the basis of rate of travel of a change in discharge, and distance.

(2) This is based on the assumptions that the east bank of the river will be banked from north of Bor to Jonglei, in the Southern Zone, and that the Bahr el Jebel in the Central Zone will be below its normal low level and either confined within its channels or spilling slightly.

TABLE 345

NORMAL DISCHARGES ALONG THE BAHR EL JEBEL AT DIFFERENT LATITUDES

In millions of cubic metres per day. Totals in milliards.

10-day Period		1912–42 at Mongalla	1932–42 at Jonglei	1936–42 at Awai Tails	1927–42 at Peake's Latitude
January	1	65·3	59·7	48·5	44·3
	2	63·5	58·2	47·8	43·9
	3	62·2	56·8	47·2	43·4
February	1	60·7	56·0	46·5	43·0
	2	59·4	55·5	45·6	42·3
	3	58·8	54·8	45·4	41·8
March	1	58·4	54·1	45·4	41·3
	2	58·1	53·7	45·1	40·9
	3	57·7	53·7	44·9	40·6
April	1	59·4	53·6	44·9	40·3
	2	60·7	53·8	44·9	40·2
	3	65·6	54·5	45·0	40·2
May	1	71·7	56·1	45·3	40·2
	2	76·3	58·1	45·7	40·7
	3	76·5	60·8	46·7	40·9
June	1	73·7	63·8	47·9	41·4
	2	73·4	66·0	48·5	41·9
	3	73·5	67·1	49·2	42·3
July	1	76·6	68·1	50·1	42·8
	2	77·8	68·2	50·5	43·9
	3	81·6	69·4	51·1	44·7
August	1	87·3	71·0	52·0	45·2
	2	89·9	71·8	52·0	45·9
	3	90·5	74·3	52·4	46·3
September	1	91·9	76·2	53·1	46·4
	2	90·0	76·9	53·2	46·8
	3	87·8	78·0	53·0	46·9
October	1	87·5	77·7	53·0	47·6
	2	85·4	75·6	52·5	47·5
	3	83·3	72·4	52·0	47·6
November	1	81·7	69·6	51·4	47·5
	2	79·6	67·4	51·2	47·1
	3	76·4	66·0	50·9	46·6
December	1	72·8	65·1	50·5	46·2
	2	70·2	64·0	50·1	45·9
	3	68·3	62·6	49·8	45·4
Average per day ...		74·0	64·1	49·0	44·4
Total year		27·0	23·4	17·9	16·2
Percentage of Mongalla		100%	87%	66·3%	60%

The highest and lowest 10-day mean discharges have been underlined.

TABLE 346

REVISED OPERATION OF THE EQUATORIAL NILE PROJECT
NORMAL DISCHARGES TO SUIT GRAZING AND OTHER NEEDS IN THE SUDAN

In millions of cubic metres per day. Totals in milliards.

At Mongalla		At Jonglei Lag 10 days			At Tail of Swamps		Malakal Total Discharge
10-day Period	Discharge	Total	Canals	Jebel	15 days' lag Canals	40 days' lag Jebel	
January 1 ...	64	70	35	35	30·6	32	96·1
2 ...	64	60	35	25	30·6	29	84·2
3 ...	64	60	35	25	30·6	29	78·0
February 1 ...	64	60	35	25	30·6	29	73·8
2 ...	64	60	35	25	30·6	22	65·7
3 ...	64	60	35	25	30·6	22	64·0
March 1 ...	64	60	35	25	30·6	22	62·7
2 ...	64	60	35	25	30·6	22	61·7
3 ...	64	60	35	25	30·6	22	60·5
April 1 ...	64	60	35	25	30·6	22	59·4
2 ...	64	60	35	25	30·6	22	60·2
3 ...	64	60	35	25	30·6	22	60·5
May 1 ...	64	60	35	25	30·6	22	61·9
2 ...	64	60	35	25	30·6	22	65·6
3 ...	64	60	35	25	30·6	22	70·9
June 1 ...	75	60	35	25	30·6	22	76·9
2 ...	75	70	35	35	30·6	22	82·1
3 ...	75	70	35	35	30·6	22	87·0
July 1 ...	80	70	35	35	30·6	22	91·2
2 ...	80	75	35	40	30·6	29	101·0
3 ...	80	75	35	40	30·6	29	104·4
August 1 ...	85	75	35	40	30·6	29	107·8
2 ...	85	80	35	45	30·6	32	114·6
3 ...	85	80	35	45	30·6	32	117·4
September 1 ...	90	80	35	45	30·6	32	119·8
2 ...	90	85	35	50	30·6	34	123·8
3 ...	90	85	35	50	30·6	34	125·6
October 1 ...	85	85	35	50	30·6	34	127·4
2 ...	85	80	35	45	30·6	36	131·1
3 ...	85	80	35	45	30·6	36	132·4
November 1 ...	80	80	35	45	30·6	36	133·3
2 ...	80	75	35	40	30·6	34	130·8
3 ...	80	75	35	40	30·6	34	129·1
December 1 ...	75	75	35	40	30·6	34	125·8
2 ...	75	70	35	35	30·6	32	117·6
3 ...	75	70	35	35	30·6	32	106·8
Total Year ...	27·0	25·4	12·78	12·64	11·2	10·2	34·7

TABLE 347

REVISED OPERATION OF THE EQUATORIAL NILE PROJECT SOUTHERN AND CENTRAL ZONES AREAS FLOODED AND UNCOVERED

in sq. km.

Place	Total Areas of Flood-Plain				Areas Flooded and Uncovered			
	Right Bank	Left Bank	Total	Cumulative Total	Right Bank	Left Bank	Total	Cumulative Total
				SOUTHERN ZONE				
Juba								
	—	—	175	175	—	—	60	60
Mongalla								
	120	35	155	330	41	12	53	113
Terakeka								
	75	115	190	520	26	40	66	179
Gemmeiza								
	40	90	130	650	14	31	45	224
Tombe								
Tombe								
	65	160	225	225	28	40	68	68
Malek								
	15	130	145	370	6	56	62	130
Bor								
	249	312	561	931	27	134	161	291
Atem Head								
Total Southern Zone ...	—	—	—	1,581	—	—	—	515
				CENTRAL ZONE				
Atem Head								
	256	93	349	349	27	40	67	67
Jonglei								

(1) From Juba to Tombe the areas flooded and uncovered amount to 55/160 of the available flood-plain area, as in the Mongalla-Gemmeiza *toich*.

(2) From Tombe to Jonglei the areas flooded and exposed have been calculated on the following assumptions:
  (i) The area affected by spill from the Bahr el Jebel is 834·5 sq. km., i.e. 1,280 sq. km. less the area irrigated by Khor Gwir, 66·5 sq. km., and less 75% of the available flood-plain on the right bank between Bor and Jonglei where there will be banking.
  (ii) The area flooded and exposed in the north-eastern portion of the Aliab Valley, i.e. 67/156 sq. km., is typical of the flooding from the Bahr el Jebel over the whole reach.

(3) From Bor to Jonglei on the right bank, we have considered only 25% of the available flood-plain because there will be banking east of the Atem.

(4) The area of 67 sq. km. between the Atem Head and Jonglei must be added to the area of spill in the Central Zone, calculated separately.

TABLE 348

REVISED OPERATION OF THE EQUATORIAL NILE PROJECT
NORMAL DISCHARGES TO SUIT GRAZING AND OTHER NEEDS IN THE SUDAN

In millions of cubic metres per day. Totals in milliards.

Malakal 10-day Periods	Discharges			
	Tail of Swamps Total	Sobat 1912–42 Normals	Malakal Total Total	Tail of Swamps 1912–42 Normals
January 1	62·6	33·5	96·1	43·3
2	58·6	25·6	84·2	43·1
3	58·6	19·4	78·0	43·1
February 1	58·6	15·2	73·8	42·0
2	52·6	13·1	65·7	41·2
3	52·6	11·4	64·0	40·9
March 1	52·6	10·1	62·7	40·5
2	52·6	9·1	61·7	40·1
3	52·6	7·9	60·5	39·1
April 1	52·6	6·8	59·4	38·7
2	52·6	7·6	60·2	38·1
3	52·6	7·9	60·5	37·9
May 1	52·6	9·3	61·9	37·3
2	52·6	13·0	65·6	36·9
3	52·6	18·3	70·9	35·9
June 1	52·6	24·3	76·9	35·4
2	52·6	29·5	82·1	35·6
3	52·6	34·4	87·0	35·6
July 1	52·6	38·6	91·2	36·0
2	58·6	42·4	101·0	36·2
3	58·6	45·8	104·4	36·8
August 1	58·6	49·2	107·8	37·5
2	62·6	52·0	114·6	38·0
3	62·6	54·8	117·4	38·5
September 1	62·6	57·2	119·8	39·1
2	64·6	59·2	123·8	39·7
3	64·6	61·0	125·6	40·0
October 1	64·6	62·8	127·4	41·2
2	66·6	64·5	131·1	40·5
3	66·6	65·8	132·4	40·2
November 1	66·6	66·7	133·3	39·3
2	64·6	66·2	130·8	38·8
3	64·6	64·5	129·1	38·5
December 1	64·6	61·2	125·8	38·8
2	62·6	55·0	117·6	40·7
3	62·6	44·2	106·8	42·5
Total Year	21·4	13·3	34·7	14·3
December 21–June 30 ...	10·5	3·5	14·0	7·6
July 1–September 10 ...	4·3	3·5	7·8	2·7
Sept. 11–December 20 ...	6·6	6·3	12·9	4·0

TABLE 349

CONTROLLED SPILL IN THE CENTRAL ZONE
In millions of cubic metres per day. Totals in milliards.

10-Day Period		Discharges at Jonglei			Discharges at Tail of Swamps		
		Bahr el Jebel	Khors Moich and Tapari	Total in Bahr el Jebel	Actual	With 13·3% Losses	Spill by Difference
January	1 ...	35	0	35	29·5	30·3	0·8
	2 ...	25	0	25	22·0	22·0	—
	3 ...	25	0	25	22·0	22·0	—
February	1 ...	25	0	25	22·0	22·0	—
	2 ...	25	0	25	22·0	22·0	—
	3 ...	25	0	25	22·0	22·0	—
March	1 ...	25	0	25	22·0	22·0	—
	2 ...	25	0	25	22·0	22·0	—
	3 ...	25	0	25	22·0	22·0	—
April	1 ...	25	0	25	22·0	22·0	—
	2 ...	25	0	25	22·0	22·0	—
	3 ...	25	0	25	22·0	22·0	—
May	1 ...	25	0	25	22·0	22·0	—
	2 ...	25	0	25	22·0	22·0	—
	3 ...	25	0	25	22·0	22·0	—
June	1 ...	25	2	27	24·0	23·4	0·6
	2 ...	35	2	37	30·6	32·1	0·5
	3 ...	35	2	37	30·6	32·1	0·5
July	1 ...	35	3	38	31·1	32·9	1·8
	2 ...	40	3	43	33·2	37·3	4·1
	3 ...	40	3	43	33·2	37·3	4·1
August	1 ...	40	5	45	34·0	39·0	5·0
	2 ...	45	5	50	35·8	43·4	7·6
	3 ...	45	5	50	35·8	43·4	7·6
September	1 ...	45	5	50	35·8	43·4	7·6
	2 ...	50	5	55	37·7	47·7	10·0
	3 ...	50	5	55	37·7	47·7	10·0
October	1 ...	50	5	55	37·7	47·7	10·0
	2 ...	45	5	50	35·8	43·4	7·6
	3 ...	45	5	50	35·8	43·4	7·6
November	1 ...	45	2	47	34·8	40·7	5·9
	2 ...	40	2	42	32·9	36·4	3·5
	3 ...	40	2	42	32·9	36·4	3·5
December	1 ...	40	0	40	32·0	34·7	2·7
	2 ...	35	0	35	29·5	30·3	0·8
	3 ...	35	0	35	29·5	30·3	0·8
Total Year	...	12·64	0·67	13·31	—	—	1·046

TABLE 350

REVISED OPERATION OF THE EQUATORIAL NILE PROJECT
NORTHERN ZONE
FLOOD-PLAIN AREAS FLOODED AND UNCOVERED BETWEEN MALAKAL AND JEBELEIN

10-Day Period		Malakal Discharge m/d	Malakal Gauge m.	Flood-Plain Areas		
				Jebel Aulia Reservoir		Combined sq. km.
				Full sq. km.	Empty sq. km.	
January	1	96·1	12·14	800	—	800
	2	84·2	11·71	515	—	515
	3	78·0	11·58	465	—	465
February	1	73·8	11·41	420	—	420
	2	65·7	11·10	350	—	350
	3	64·0	11·03	335	—	335
March	1	62·7	11·00	330	150	305
	2	61·7	10·94	315	135	265
	3	60·5	10·88	305	125	230
April	1	59·4	10·84	300	120	200
	2	60·2	10·88	305	135	185
	3	60·5	10·88	305	135	160
May	1	61·9	10·95	315	140	140
	2	65·6	11·10	350	165	165
	3	70·9	11·30	395	205	205
June	1	76·9	11·53	450	255	255
	2	82·1	11·72	525	315	315
	3	87·0	11·87	615	380	380
July	1	91·2	12·00	700	445	525
	2	101·0	12·29	880	615	748
	3	104·4	12·39	925	675	845
August	1	107·8	12·48	955	—	955
	2	114·6	12·66	1,020	—	1,020
	3	117·4	12·72	1,035	—	1,035
September	1	119·8	12·77	1,050	—	1,050
	2	123·8	12·84	1,070	—	1,070
	3	125·6	12·88	1,080	—	1,080
October	1	127·4	12·90	1,090	—	1,090
	2	131·1	12,96	1,120	—	1,120
	3	132·4	12·97	1,125	—	1,125
November	1	133·3	12·99	1,130	—	1,130
	2	130·8	12·96	1,120	—	1,120
	3	129·1	12·93	1,105	—	1,105
December	1	125·8	12·88	1,080	—	1,080
	2	117·6	12·72	1,035	—	1,035
	3	106·8	12·45	950	—	950

TABLE 351

REVISED OPERATION OF THE EQUATORIAL NILE PROJECT
AREAS FLOODED AND DURATION OF FLOODING
MALAKAL–JEBELEIN

No. of Days Flooded		Area Flooded sq. km.
From	To	
0	50	1,100
50	130	1,000
130	150	900
150	170	800
170	180	700
180	180	600
180	200	500
200	220	400
220	260	300
260	310	200
310	365	140

Maximum Area Flooded ... ... 1,130 sq. km.
Minimum Area Flooded ... ... 140 sq. km.

Area Flooded and Uncovered ... ... 990 sq. km.

TABLE 352

REVISED OPERATION OF THE EQUATORIAL NILE PROJECT
DESIGN DETAILS FOR THE MAIN JONGLEI CANALS AND IRRIGATION CANAL

Bed Width m.	Water Depth m.	Water Slope cm./km.	Discharges		$^1/_n$ Manning's Formula	Velocity m/sec.	Total Flood-Escape Discharge m/d
			cumecs	m/d			
(All side slopes 2 : 1)							
I. IRRIGATION CANAL. Upper and Lower Reaches							
24	2·92	7	58	5·0	45	0·66	5·0
II. MAIN AND NAVIGATION CANALS. (Upper Reach Twin Channels)							
48	3·5	9	173·5	15·0	45	0·90	—
48	4·25	9	240	20·8	45	1·00	47·0*
48	4·5	9	265	23·0	45	1·03	54·2*
48	4·7	9	286	24·7	45	1·06	60·5*
48	4·75	9	292	25·2	45	1·07	62·3*
'Washlands' Discharges							
1,000	0·75	9	62	5·4	10	0·080	—
1,000	1·00	9	95	8·2	10	0·095	—
1,000	1·20	9	129	11·1	10	0·108	—
1,000	1·25	9	137·5	11·9	10	0·110	—
Lower Reach (Twin Channels)							
45	3·9	7	173·5	15·0	45	0·835	—
45	4·65	7	234	20·2	45	0·925	46·6*
45	4·9	7	252	21·8	45	0·940	54·2*
45	5·1	7	274	23·7	45	0·972	61·0*
45	5·15	7	278	24·0	45	0·976	62·5*
'Washlands' Discharges							
1,390	0·75	7	72	6·2	10	0·067	—
1,390	1·00	7	124	10·6	10	0·089	—
1,390	1·20	7	157·5	13·6	10	0·095	—
1,390	1·25	7	168	14·5	10	0·097	—

* Main and Navigation Canal and 'Washlands'. The Irrigation Canal will carry an additional 5 m/d.

TABLE 353

REVISED OPERATION OF THE EQUATORIAL NILE PROJECT FLOOD-ESCAPE REGIME

Discharges in millions of cubic metres per day. Totals in milliards.

At Mongalla		At Jonglei. Lag 10 Days Discharges			At Tail of Swamps Discharges		Malakal Total Discharge
10-Day Period	Discharge	Total	Canals	Jebel	15 Days' Lag Canals	40 Days' Lag Jebel	
January 1 ...	96	100	65	35	57	32	122·5
2 ...	96	90	65	25	57	29	111·6
3 ...	96	90	65	25	57	29	105·4
February 1 ...	96	90	65	25	57	29	101·2
2 ...	96	90	65	25	57	22	92·1
3 ...	96	90	65	25	57	22	90·4
March 1 ...	96	90	65	25	57	22	89·1
2 ...	96	90	65	25	57	22	88·1
3 ...	96	90	65	25	57	22	86·9
April 1 ...	96	90	65	25	57	22	85·8
2 ...	96	90	65	25	57	22	86·6
3 ...	96	90	65	25	57	22	86·9
May 1 ...	96	90	65	25	57	22	88·3
2 ...	96	90	65	25	57	22	92·0
3 ...	96	90	65	25	57	22	97·3
June 1 ...	106	90	65	25	57	22	101·3
2 ...	106	100	65	35	57	22	108·5
3 ...	106	100	65	35	57	22	113·4
July 1 ...	112	100	65	35	57	22	117·6
2 ...	112	105	65	40	57	29	128·4
3 ...	112	105	65	40	57	29	131·8
August 1 ...	117	105	65	40	57	29	135·2
2 ...	117	110	65	45	57	32	141·0
3 ...	117	110	65	45	57	32	143·8
September 1 ...	122	110	65	45	57	32	146·2
2 ...	122	115	65	50	57	34	150·2
3 ...	122	115	65	50	57	34	152·0
October 1 ...	117	115	65	50	57	34	153·8
2 ...	117	110	65	45	57	36	157·5
3 ...	117	110	65	45	57	36	158·8
November 1 ...	112	110	65	45	57	36	159·7
2 ...	112	105	65	40	57	34	157·2
3 ...	112	105	65	40	57	34	155·5
December 1 ...	106	105	65	40	57	34	152·2
2 ...	106	100	65	35	57	32	144·0
3 ...	106	100	65	35	57	32	133·2
Total Year ...	38·7	36·37	23·73	12·64	20·8	10·2	44·3

TABLE 354

REVISED OPERATION OF THE EQUATORIAL NILE PROJECT FLOOD-ESCAPE DISCHARGES AT MALAKAL

In millions of cubic metres per day. Totals in milliards.

Malakal 10-day Period	Discharges			
	Tail of Swamps Total	Sobat 1912–42 Normals	Malakal Totals	Malakal Gauge m.
January 1	89	33·5	122·5	12·82
2	86	25·6	111·6	12·58
3	86	19·4	105·4	12·41
February 1	86	15·2	101·2	12·30
2	79	13·1	92·1	12·03
3	79	11·4	90·4	11·98
March 1	79	10·1	89·1	11·94
2	79	9·1	88·1	11·91
3	79	7·9	86·9	11·87
April 1	79	6·8	85·8	11·83
2	79	7·6	86·6	11·86
3	79	7·9	86·9	11·87
May 1	79	9·3	88·3	11·91
2	79	13·0	92·0	12·03
3	79	18·3	97·3	12·18
June 1	79	24·3	101·3	12·30
2	79	29·5	108·5	12·50
3	79	34·4	113·4	12·63
July 1	79	38·6	117·6	12·73
2	86	42·4	128·4	12·92
3	86	45·8	131·8	12·97
August 1	86	49·2	135·2	13·01
2	89	52·0	141·0	13·06
3	89	54·8	143·8	13·10
September 1	89	57·2	146·2	13·12
2	91	59·2	150·2	13·16
3	91	61·0	152·0	13·17
October 1	91	62·8	153·8	13·19
2	93	64·5	157·5	13·22
3	93	65·8	158·8	13·23
November 1	93	66·7	159·7	13·24
2	91	66·2	157·2	13·22
3	91	64·5	155·5	13·20
December 1	91	61·2	152·2	13·17
2	89	55·0	144·0	13·10
3	89	44·2	133·2	12·99
Total Year	31·0	13·3	44·3	—

TABLE 355

TORRENTS DISCHARGES IN ORDER OF MAGNITUDE

In milliards per year

Year	Total Annual Torrents Flow	
1916	11·8	
1917	10·8	
1946	6·79	
1928	6·40	
1926	6·33	
1914	5·78	
1923	5·71	
1932	5·57	
1912	5·55	Average High Year 5·34
1907	5·09	
1909	5·02	
1915	5·00	
1937	5·00	
1950	4·89	
1908	4·70	
1931	4·69	
1941	4·68	
1935	4·68	
1938	4·68	
1948	4·65	
1945	4·42	
1934	4·35	
1942	4·31	
1947	4·27	
1952	4·03	

Year	Total Annual Torrents Flow	
1949	3·98	
1920	3·93	
1919	3·90	
1913	3·75	
1943	3·57	
1944	3·37	Average Low Year 3·50
1929	3·36	
1940	3·31	
1922	3·28	
1933	3·06	
1925	3·03	
1930	2·85	
1936	2·72	
1924	2·71	
1951	2·56	
1921	2·55	
1939	2·34	
1927	1·72	
1918	1·64	
44 Year Mean	4·47	

NOTE:—1910 and 1911 are omitted because the records are incomplete.

TABLE 356

REVISED OPERATION OF THE EQUATORIAL NILE PROJECT STEADY DISCHARGE FROM LAKE ALBERT. TORRENTS UNCONTROLLED.

Discharges in millions of cubic metres per day. Totals in milliards.

Month	MONGALLA			JONGLEI LATITUDE 10 Days' Lag			Proposed Controlled Operation Jebel
	1912–42 Normal Torrents Flow	Controlled Flow from Lake Albert	Total Flow at Mongalla	Total	Canals	Jebel	
			Normal Year				
January	0	62·5	62·5	58·8	35·0	23·8	25·0
February	0	62·5	62·5	58·8	35·0	23·8	25·0
March	0	62·5	62·5	58·8	35·0	23·8	25·0
April	4·9	62·5	67·4	63·4	35·0	28·4	25·0
May	17·3	62·5	79·8	75·0	35·0	40·0	25·0
June	15·0	62·5	77·5	72·8	35·0	37·8	35·0
July	19·7	62·5	82·2	77·3	35·0	42·3	40·0
August	28·7	62·5	91·2	85·7	35·0	50·7	45·0
September	27·1	62·5	89·6	84·2	35·0	49·2	50·0
October	20·3	62·5	82·8	77·8	35·0	42·8	45·0
November	12·0	62·5	74·5	70·0	35·0	35·0	40·0
December	0	62·5	62·5	58·8	35·0	23·8	35·0
Total Year	4·4	22·8	27·2	25·6	12·78	12·84	12·64

TABLE 357

REVISED OPERATION OF THE EQUATORIAL NILE PROJECT STEADY DISCHARGE FROM LAKE ALBERT. TORRENTS UNCONTROLLED.

Discharges in millions of cubic metres per day. Totals in milliards.

Month	At Mongalla			Jonglei Latitude			Proposed Controlled Operation Jebel
				10 Days' Lag			
	Torrents Flow	Controlled Flow Lake Albert	Total Flow	Total	Canals	Jebel	
Average Low Year: 1943							
January	0	62·5	62·5	58·8	35·0	23·8	25·0
February	0	62·5	62·5	58·8	35·0	23·8	25·0
March	0	62·5	62·5	58·8	35·0	23·8	25·0
April	7·1	62·5	69·6	65·4	35·0	30·4	25·0
May	13·9	62·5	76·4	71·8	35·0	36·8	25·0
June	17·6	62·5	80·1	75·3	35·0	40·3	35·0
July	23·9	62·5	86·4	81·2	35·0	46·2	40·0
August	23·0	62·5	85·5	80·4	35·0	45·4	45·0
September... ...	22·3	62·5	84·8	79·7	35·0	34·7	50·0
October	8·8	62·5	71·3	67·0	35·0	32·0	45·0
November... ...	0	62·5	62·5	58·8	35·0	23·8	40·0
December... ...	0	62·5	62·5	58·8	35·0	23·8	35·0
Total Year ...	3·57	22·8	26·37	24·8	12·78	11·73	12·64
Average High Year: 1912							
January	0	62·5	62·5	58·8	35·0	23·8	25·0
February	0	62·5	62·5	58·8	35·0	23·8	25·0
March	0	62·5	62·5	58·8	35·0	23·8	25·0
April	0	62·5	62·5	58·8	35·0	23·8	25·0
May	7·5	62·5	70·0	65·8	35·0	30·8	25·0
June	7·3	62·5	69·8	65·6	35·0	30·6	35·0
July	30·3	62·5	92·8	87·2	37·2	50·0	40·0
August	47·7	62·5	110·2	103·6	53·6	50·0	45·0
September... ...	49·5	62·5	112·0	105·3	55·0	50·0	50·0
October	17·8	62·5	80·3	75·4	35·0	40·4	45·0
November... ...	13·6	62·5	76·1	71·5	35·0	36·5	40·0
December... ...	7·6	62·5	70·1	65·9	35·0	30·9	35·0
Total Year ...	5·55	22·8	28·35	26·6	14·02	12·63	12·64

TABLE 358

REVISED OPERATION OF THE EQUATORIAL NILE PROJECT
STEADY DISCHARGE FROM LAKE ALBERT. TORRENTS UNCONTROLLED.

Discharges in millions of cubic metres per day. Totals in milliards.

Month	At Mongalla			Jonglei Latitude 10 Days' Lag			Proposed Controlled Operation Jebel
	Torrents Flow	Controlled Flow from Lake Albert	Total Flow	Total	Canals	Jebel	
Extremely Low Year: 1918							
January	0	62·5	62·5	58·8	35·0	23·8	25·0
February	0	62·5	62·5	58·8	35·0	23·8	25·0
March	0	62·5	62·5	58·8	35·0	23·8	25·0
April	0	62·5	62·5	58·8	35·0	23·8	25·0
May	6·7	62·5	69·2	65·0	35·0	30·0	25·0
June	6·2	62·5	68·7	64·6	35·0	29·6	35·0
July	5·5	62·5	68·0	63·9	35·0	28·9	40·0
August	11·5	62·5	74·0	69·6	35·0	34·6	45·0
September... ...	7·9	62·5	70·4	66·2	35·0	31·2	50·0
October	11·5	62·5	74·0	69·6	35·0	34·6	45·0
November... ...	4·1	62·5	66·6	62·6	35·0	27·6	40·0
December... ...	0	62·5	62·5	58·8	35·0	23·8	35·0
Total Year ...	1·64	22·8	24·44	23·0	12·78	10·22	12·64
Extremely High Year: 1916							
January	0	62·5	62·5	58·8	35·0	23·8	25·0
February	0	62·5	62·5	58·8	35·0	23·8	25·0
March	0	62·5	62·5	58·8	35·0	23·8	25·0
April	6·5	62·5	69·0	64·9	35·0	29·9	25·0
May	20·9	62·5	83·4	78·4	35·0	43·4	25·0
June	34·9	62·5	97·4	91·6	41·6	50·0	35·0
July	42·1	62·5	104·6	98·3	48·3	50·0	40·0
August	64·3	62·5	126·8	119·2	65·0	54·2	45·0
September... ...	99·4	62·5	161·9	152·2	65·0	87·2	50·0
October	65·9	62·5	128·4	120·7	65·0	55·7	45·0
November... ...	37·6	62·5	100·1	94·1	54·0	40·1	40·0
December... ...	14·7	62·5	77·2	72·6	37·5	35·6	35·0
Total Year ...	11·8	22·8	34·6	32·5	16·8	15·7	12·64

TABLE 359

DIVISION OF DISCHARGES AT JONGLEI BETWEEN THE JONGLEI CANALS AND THE BAHR EL JEBEL

In millions of cubic metres per day.

Month (1) at Mongalla	ALL OPERATIONS Bahr el Jebel north of Jonglei	NORMAL OPERATION		NORMAL MAXIMUM		SPECIAL MAXIMUM	
		Jonglei Canals	Total at Jonglei (2)	Jonglei Canals	Total at Jonglei (2)	Jonglei Canals	Total at Jonglei (2)
January	25	35	60	55	80	65	90
February	25	35	60	55	80	65	90
March	25	35	60	55	80	65	90
April	25	35	60	55	80	65	90
May	25	35	60	55	80	65	90
June	35	35	70	55	90	65	100
July	40	35	75	55	95	65	105
August	45	35	80	55	100	65	110
September ...	50	35	85	55	105	65	115
October	45	35	80	55	110	65	110
November ...	40	35	75	55	95	65	105
December ...	35	35	70	55	90	65	100

(1) The timing is specified as at Mongalla so that the discharges given by months will correspond with those specified previously. It is estimated that the changes at Mongalla will take effect 10 days later at Jonglei.

(2) The losses between Mongalla and Jonglei are estimated at 6%.

NOTES AND REFERENCES

(1) Jonglei Investigation Team, *Third Interim Report*, 1948, p. 51.

(2) Note: the differentiation between rising and falling levels in Lake Victoria was a modification of which we were notified at a late stage in the investigation.

(3) This example has not been carried beyond 1942 for reasons explained earlier.

(4) The effect of differentiating between rising and falling levels in Lake Victoria is examined later.

(5) Butcher, A. D., *The Sadd Hydraulics*, Cairo, 1938, pp. 54, 55.

(6) ibid., Plate XIII, p. 104.

(7) New and Old Bedford Rivers from Earith to Denver Sluice.

CHAPTER 12. THE EFFECTS OF THE REVISED OPERATION

In Part I of this volume (see Chapters 2 to 5) we have described in some detail our estimate of the effects of the Equatorial Nile Project on human interests in the Jonglei Area. These effects referred specifically to the Project as proposed and without modification. We must now consider the effects of the Project under the ' Revised Operation ' proposed in the previous chapter.

1. EFFECTS ON PASTURE AND ANIMAL HUSBANDRY

SOUTHERN ZONE

We have shown how the Revised Operation will result in a combination of hydrological conditions not widely dissimilar to those of the present river régime; there will be a comparatively low discharge (64 m/d) during those months when riverain swamp pasture is needed and a high discharge (maximum 90 m/d) for the rest of the year. Because the proposed minimum discharge will be slightly higher and the proposed maximum slightly lower than at present, there will be a reduction in the area of flood-plain inundated and exposed. This new area will amount to 515 sq. km. instead of 774 sq. km. as at present. Depth and duration of flooding, current velocity, climate and soils are all described previously (see Vol. I, p. 152) and since future conditions will closely resemble present natural conditions further discussion of these factors is unnecessary here. There will be no great change in the composition of vegetation on the flood-plain, except that a small proportion of the deep-flooded pasture will become inaccessible to the herds because it will be flooded at the slightly higher minimum discharge; a further proportion will be replaced at the upper limits by shallow-flooded pasture, owing to the slightly lower maximum discharge. In considering the vegetation and the dry season stock-carrying capacity of the pasture on the river flood-plain we have divided the total area into two, viz. Juba–Tombe and Tombe–Atem Head, a division already employed in our description of the effects of the Equatorial Nile Project.

EFFECTS ON PASTURE TYPES

Juba-Tombe

The effects of the river régime under the Revised Operation on the vegetation of the river flood-plain can best be judged by examining the distribution of vegetation on the Mongalla–Gemmeiza *toich* as recorded in Fig. H 23. Open water and grasses are there shown in relation to areas of permanent flooding, areas subject to flooding by river spill and seasonal exposure, and areas not subject to river spill. There is a certain amount of overlapping of grass species and we have arbitrarily divided the whole flood-plain into areas each of which will be dominated by one species, as listed in Table 360 below. This is the same technique as that adopted in describing the effects of the Project without modification (see p. 468). Having calculated the percentage areas of flood-plain (occupied by each species) permanently inundated, subject to seasonal river spill, and not subject to spill, we then apply these percentages to the whole area of flood-plain between Juba and Tombe, 650 sq. km. The areas so calculated are recorded in Table 361. There is a slight decrease in the total area of *Echinochloa stagnina* (deep-flooded) from 132 sq. km. (see Table 233, p. 471) to 119 sq. km.; the area actually flooded and seasonally exposed is reduced from 119 sq. km. (see Table 361) to 109 sq. km. The reasons for this decrease are first that the lower limits of *E. stagnina* will in future be permanently flooded, and secondly that the upper limits will be subject to reduced flooding, resulting in a replacement of *E. stagnina* by *E. pyramidalis*. *Phragmites communis* is dependent mainly on a combination of rainfall and seepage from a water channel, so that the area it occupies should remain unaltered at 131 sq. km. The area of *E. pyramidalis* is thus increased by an area equivalent to that of the *E. stagnina* displaced, i.e. from 342 to 355 sq. km. *Vossia cuspidata* and *Phragmites communis* are not considered to be useful dry season pasture grasses because of their unpalatability. Thus the only areas of valuable riverain pasture are those composed of *E. pyramidalis* (shallow-flooded) and *E. stagnina* (deep-flooded), and these amount to 355 sq. km. and 109 sq. km. respectively.

Tombe-Atem Head

The present total area of flood-plain over this reach is 931 sq. km. As we have seen, the Bahr el Jebel and Atem River will be banked north of Bor; we estimate that under the Project, whether revised or not, 75% of the flood-plain east of the Atem, approximately 186·8 sq. km.,

TABLE 360

FUTURE DISTRIBUTION OF OPEN WATER AND VEGETATION ON RIVER FLOOD-PLAIN

MONGALLA–GEMMEIZA

	Permanently Flooded		Inundated by River Spill and Exposed		Not Subject to River Spill		Total sq. km.
	sq. km.	% of total	sq. km.	% of total	sq. km.	% of total	
Open Water	2·3	1·4	—	—	—	—	2·3
Cyperus papyrus	4·8	3·0	—	—	—	—	4·8
Vossia cuspidata	3·0	1·9	0·9	0·6	—	—	3·9
Echinochloa stagnina	2·6	1·6	19·5	12·1	7·5	4·6	29·6
Echinochloa pyramidalis	—	—	32·9	20·5	54·9	34·1	87·8
Phragmites communis	—	—	2·0	1·2	30·6	19·0	32·6
	12·7	7·9	55·3	34·4	93·0	57·7	161·0

TABLE 361

FUTURE DISTRIBUTION OF OPEN WATER AND VEGETATION ON RIVER FLOOD-PLAIN

JUBA–TOMBE

.	Permanently flooded sq. km.	Inundated by river spill and exposed sq. km.	Not subject to river spill sq. km.	Accessible in dry season sq. km.	Total sq. km.
Open Water	9	—	—	—	9
Cyperus papyrus	20	—	—	—	20
Vossia cuspidata	12	4	—	4	16
Echinochloa stagnina	10	79	30	109	119
Echinochloa pyramidalis	—	133	222	355	355
Phragmites communis	—	8	123	131	131
	51	224	375	599	650

Areas of accessible deep-flooded and shallow-flooded pasture are underlined.

will not receive river spill. We assume that this area will produce intermediate land grasses, e.g. *Hyparrhenia rufa*. We also assume that the area irrigated by Khor Gwir (66·5 sq. km.) will remain unchanged. We now estimate the future distribution over the remaining area (677·7 sq. km.) on the assumption that it will be the same as the future distribution in the north-eastern portion of the Aliab Valley.

Only the area lying north-east of the River Aliab is affected by river spill to any great extent, the area flooded and exposed being approximately 92 sq. km., the remaining areas being either permanently flooded or not flooded at all. The area seasonally affected by river spill will in future be smaller (67 sq. km. instead of 92 sq. km.), although the actual flooding curve will remain the same over the smaller area. The percentage distribution of species will therefore remain the same, and we have applied the present percentages to the new area (67 sq. km.) to give the new distribution by area over the flood-plain flooded and exposed. The distribution over the remaining areas north-east of the Aliab, i.e. those permanently flooded and not flooded at all, has been treated in a similar way (applying present percentages to future areas) and the results for this whole division are given in Table 362. These percentages are then applied to the remaining area (677·7 sq. km.) and the results are given in Table 363.

Over the whole reach therefore the distribution of vegetation in the future will be as given in Table 364. The total accessible area of valuable pasture species will be:

Echinochloa stagnina	106·0 sq. km.
Echinochloa pyramidalis	278·1 „ „
Oryza barthii	8·0 „ „
Intermediate species (e.g. *Hyparrhenia rufa*)	186·8 „ „

TABLE 362

FUTURE DISTRIBUTION OF OPEN WATER AND VEGETATION IN THE ALIAB VALLEY N.E. OF RIVER ALIAB

	Permanently Flooded		Inundated and Exposed by River Spill		Not Subject to River Spill		Total sq. km.
	sq. km.	% of total	sq. km.	% of total	sq. km.	% of total	
Open Water	28·1	18·0	—	—	—	—	28·1
Cyperus papyrus	16·1	10·4	—	—	—	—	16·1
Vossia cuspidata	20·9	13·4	4·4	2·8	—	—	25·3
Echinochloa stagnina	—	—	21·8	14·0	—	—	21·8
Echinochloa pyramidalis	6·9	4·4	40·8	26·2	12·3	7·9	60·0
Phragmites communis	—	—	—	—	4·5	2·9	4·5
	72·0	46·2	67·0	43·0	16·8	10·8	155·8

TABLE 363

FUTURE DISTRIBUTION OF OPEN WATER AND VEGETATION ON THE RIVER FLOOD-PLAIN AFFECTED BY THE BAHR EL JEBEL TOMBE–ATEM HEAD

	Permanently flooded sq. km.	Inundated by river spill and exposed sq. km.	Not subject to river spill sq. km.	Accessible in dry season sq. km.	Total sq. km.
Open Water	122·0	—	—	—	122·0
Cyperus papyrus	70·5	—	—	—	70·5
Vossia cuspidata	90·8	19·0	—	19·0	109·8
Echinochloa stagnina	—	94·9	—	94·9	94·9
Echinochloa pyramidalis	29·8	177·5	53·5	231·0	260·8
Phragmites communis	—	—	19·7	19·7	19·7
	313·1	291·4	73·2	354·6	677·7

Areas of accessible deep-flooded and shallow-flooded pasture are underlined.

TABLE 364

FUTURE TOTAL DISTRIBUTION OF OPEN WATER AND VEGETATION ON THE RIVER FLOOD-PLAIN TOMBE–ATEM HEAD

	Permanently flooded sq. km.	Inundated by river spill and exposed sq. km.	Not subject to river spill sq. km.	Inundated by Khor Gwir and exposed sq. km.	Accessible in dry season sq. km.	Total sq. km.
Open Water	122·0	—	—	—	—	122·0
Cyperus papyrus	70·5	—	—	—	—	70·5
Vossia cuspidata	90·8	19·0	—	—	19·0	109·8
Echinochloa stagnina ...	—	94·9	—	11·1	106·0	106·0
Echinochloa pyramidalis ...	29·8	177·5	53·5	47·1	278·1	307·9
Oryza barthii	—	—	—	8·0	8·0	8·0
Phragmites communis ...	—	—	19·7	0·3	20·0	20·0
Hyparrhenia rufa	—	—	186·8	—	186·8	186·8
	313·1	291·4	260·0	66·5	617·9	931·0

EFFECTS ON GRAZING AND ANIMAL MANAGEMENT

Juba-Tombe

The areas of shallow-flooded and deep-flooded grasses which will be available as dry season grazing have been shown to be 355 sq. km. and 109 sq. km. respectively. They and their estimated monthly stock-carrying capacities are recorded in Table 365 from which, and from Table 239 (p. 475), we have produced Table 366. These figures indicate that there will be an excess of dry season pasture over present requirements of 170 TAUM, or of a maximum of 47,760 Animal Units in any one month. In March and April it will even exceed the present potential carrying capacity of 2,400 Animal Units per month. This estimate may appear to be optimistic, but at least it is fairly safe to say that the future river régime will so resemble the natural one that there will be no significant adverse effects on potential dry season grazing, and certainly no reduction below present requirements.

Tombe-Atem Head

The areas of dry season pasture grasses which will be available on the flood-plain between the main river and the adjacent high land are as follows (see p. 796):

	sq. km.
Echinochloa stagnina ...	106
Echinochloa pyramidalis ...	278
Oryza barthii	8
Intermediate land species	187
	579

As already stated (see p. 473) we consider that the deep-flooded pasture *E. stagnina* has a stock-carrying capacity of 400 Animal Units per sq. km. in January and February, and 240 Animal Units per sq. km. in March and April. Shallow-flooded pasture (*E. pyramidalis* and *Oryza barthii*) has a carrying capacity of 50, 80, 160, and 160 Animal Units per sq. km. in January, February, March, and April respectively. Intermediate land grass species are estimated to have an average stock-carrying capacity of 17 Animal Units per sq. km. over the dry season (see p. 473). The future areas of each pasture type, together with their stock-carrying capacities are recorded in Table 367 and these carrying capacities are compared with present figures, from Table 240 (p. 475), in Table 368. In this last table it will be seen that there will be a loss of carrying capacity totalling 101 TAUM with a maximum loss of 34,741 Animal Units in February. Because there is a small loss, 8,921 Animal Units, in January, the net loss may be considered to average 25,300 Animal Units throughout the four months January to April inclusive.

TABLE 365

FUTURE STOCK-CARRYING CAPACITY OF RIVER FLOOD-PLAIN
JUBA–TOMBE

Month	Shallow-Flooded			Deep-Flooded			Total
	Area in sq. km.	A.U. per sq. km.	A.U. per area	Area in sq. km.	A.U. per sq. km.	A.U. per area	A.U. per area
January	355	50	17,750	109	400	43,600	61,350
February	355	80	28,400	109	400	43,600	72,000
March	355	160	56,800	109	240	26,160	82,960
April	355	160	56,800	109	240	26,160	82,960
	—	—	159,750	—	—	139,520	299,270

TABLE 366

PRESENT AND FUTURE STOCK-CARRYING CAPACITY OF RIVER FLOOD-PLAIN
JUBA–TOMBE

Month	Present			Future		
	Actual	Potential	Surplus	Potential	Surplus over Actual	Surplus over Potential
January	23,500	63,915	40,415	61,350	37,850	− 2,565
February	35,200	73,656	38,456	72,000	36,800	− 1,656
March	35,200	80,560	45,360	82,960	47,760	+ 2,400
April	35,200	80,560	45,360	82,960	47,760	+ 2,400
	129,100	298,691	169,591	299,270	170,170	579

Note: All figures represent Animal Units.

TABLE 367

FUTURE STOCK-CARRYING CAPACITY OF THE FLOOD-PLAIN
TOMBE–ATEM HEAD

Month	Intermediate			Shallow-Flooded			Deep-Flooded			Total
	Area in sq. km.	A.U. per sq. km.	A.U. per area	Area in sq. km.	A.U. per sq. km.	A.U. per area	Area in sq. km.	A.U. per sq. km.	A.U. per area	A.U. per area
January ...	187	17	3,179	286	50	14,300	106	400	42,400	59,879
February ...	187	17	3,179	286	80	22,880	106	400	42,400	68,459
March ...	187	17	3,179	286	160	45,760	106	240	25,440	74,379
April ...	187	17	3,179	286	160	45,760	106	240	25,440	74,379
	—	—	12,716	—	—	128,700	—	—	135,680	277,096

TABLE 368

PRESENT AND FUTURE STOCK-CARRYING CAPACITY OF FLOOD-PLAIN
TOMBE–ATEM HEAD

Month	Present			Future		
	Actual	Potential	Surplus	Potential	Actual Loss	Loss of Potential
January	68,800	84,925	16,125	59,879	8,921	25,046
February	103,200	97,816	– 5,384	68,459	34,741	29,357
March	103,200	106,816	3,616	74,379	28,821	32,437
April	103,200	106,816	3,616	74,379	28,821	32,437
	378,400	396,373	17,973	277,096	101,304	119,277

Note: All figures represent Animal Units.

CENTRAL ZONE

Under the Revised Operation, whereas in the Southern Zone the river régime will resemble that of the present, in the Central Zone conditions will be similar to those predicted under the Project. The only difference between the effects under the Revised Operation and under the Project without modification is that there will be considerably more river spill under the former, and therefore a larger area of swamp vegetation will be retained. For this reason the effects of the Project on pasture and animal management already described (see pp. 478–80) apply directly here, except that the areas of different types of vegetation and total carrying capacities are altered.

EFFECTS ON PASTURE TYPES

The effect of the Revised Operation north of Jonglei will be to limit the seasonal spill along the Bahr el Jebel to 1·046 milliards, which is assumed to be sufficient to cover an area of 1,046 sq. km. to an average depth of 1 m. and for an average period of 214 days. This spill includes the contribution of the Khors Tapari and Moich. As stated previously (see p. 480) the topography of the flood-plain in the Central Zone is assumed to be similar to that of the part of the Aliab Valley lying to the north-east of the River Aliab. Therefore to the area of flood-plain which will be affected by river spill we apply the vegetation distribution recorded in the north-eastern section of the part of the Aliab Valley surveyed, as given in Table 381 (Vol. III, p. 834).

In so doing, we arrive at the following species distribution by area:

	sq. km.
Open Water	130·8
Cyperus papyrus	75·3
Vossia cuspidata	134·9
Echinochloa stagnina ...	199·8
Echinochloa pyramidalis ...	480·1
Phragmites communis ...	25·1
	1,046·0

We assume that the remaining area of flood-plain (5,159 sq. km.), not subject to river spill, will produce intermediate land grass species (e.g. *Hyparrhenia rufa*). The total amount of useful pasture over the flood-plain in the Central Zone north of Jonglei will therefore be:

Echinochloa stagnina	199·8 sq. km.
Echinochloa pyramidalis	480·1 ,, ,,
Intermediate land grasses (e.g. *Hyparrhenia rufa*)	5,159·0 ,, ,,

South of Jonglei, i.e. between Jonglei and Atem Head, the flood-plain area is 349 sq. km. Under our proposals 157 sq. km. will be affected by river spill. To this area we have applied the percentage distribution from Table 362 to give the following:

	sq. km.
Open Water	28·3
Cyperus papyrus	16·3
Vossia cuspidata	25·4
Echinochloa stagnina ...	22·0
Echinochloa pyramidalis ...	60·4
Phragmites communis ...	4·6
	157·0

We have assumed that the remaining area, i.e. 192 sq. km., which will receive rainfall and run-off only, will change to intermediate grassland of the *Hyparrhenia rufa* type.

Thus over the whole flood-plain of the Central Zone we expect the distribution of grasses (by area) under the Revised Operation to be as follows:

	sq. km.
Open water	159·1
Cyperus papyrus	91·6
Vossia cuspidata	160·3
Echinochloa stagnina	221·8
Echinochloa pyramidalis	540·5
Phragmites communis	29·7
Intermediate grassland of *Hyparrhenia rufa* type	5,351·0
	6,554·0

Elsewhere (i.e. along watercourses and on intermediate land) throughout the Central Zone, the effects on pasture types and associations will be similar to those given previously in connection with the Project as at present proposed (see p. 481).

EFFECTS ON GRAZING AND ANIMAL MANAGEMENT

When discussing the effects of the Project, we divided this Zone into four tribal areas or sectors. The same grouping is applied in this chapter, but the area between Jonglei and Atem Head is treated separately. The areas of flood-plain in each group between Jonglei and the boundary with the Northern Zone are as follows:

	sq. km.	% of Total
Bor Athoich, Twi, Nyareweng, and Ghol Dinka; Gaweir and Thiang (Mainland) Nuer	2,461	39·7
Southern Zeraf Island Nuer	2,040	32·8
Aliab, Chich, and other Lakes District Dinka	154	2·5
Nuong, Dok, Aak, Jagey, and Jikaing Nuer	1,550	25·0
	6,205	100·0

Here we must estimate the future carrying capacity of the reclaimed swamp. For this purpose we assume that the areas affected by spill in each of the four sectors are in the same proportions to the total area of spill as the sector areas are to the total area of swamp. Of the area affected by spill in each sector, 19·1% will carry *Echinochloa stagnina* (deep-flooded pasture) and 45·9% will carry *Echinochloa pyramidalis* (shallow-flooded pasture). The carrying capacity of river swamp pasture is lowest in January, when much of the shallow-flooded coarse growth is burnt and regrowth is still small in quantity. Deep-flooded pasture and shallow-flooded pasture are considered to have carrying capacities of 400 and 50 Animal Units per sq. km. respectively in January and February, and 240 and 160 Animal Units per sq. km. respectively in March and April. The former figures are employed here. It is estimated that the carrying capacity of the intermediate land grasses on the reclaimed swamp will be 17 Animal Units per sq. km. (see p. 484).

Bor Athoich, Twi, Nyareweng and Ghol Dinka; Gaweir and Thiang (Mainland) Nuer

The area of swamp in this sector is 2,717 sq. km., of which 2,461 sq. km. are north of Jonglei. This area is 39·7% of the whole and the area which will be subject to river spill is thus 39·7% of 1,046 sq. km. or 415 sq. km. To this must be added the 64 sq. km. of swamp between Atem Head and Jonglei which will be similar to that in the north-eastern part of the Aliab Valley, plus 192 sq. km. of intermediate land. The future areas of available dry season pasture grasses on the flood-plain will be:

	sq. km.	Stock-Carrying Capacity in Animal Units
Echinochloa stagnina	88	35,200
Echinochloa pyramidalis	215	10,750
Intermediate grass species	2,240	38,080
		84,030

As stated previously (see p. 485), dry season pasture will be made available east of the Jonglei Canal (which will provide drinking-water where this was previously lacking) for 35,500 Animal Units in addition to those which graze in that area at the present time. Thus 119,530 Animal Units will be accommodated on natural dry season pasture out of a total of 179,200 Animal Units; the remainder which will have to be provided with dry season pasture by some other means will be 59,670 Animal Units, instead of 85,141 Animal Units as under the unaltered Project.

Southern Zeraf Island Nuer

The area of swamp in this sector is 2,040 sq. km. or 32·8% of the whole. The area subject to river spill will therefore be 32·8% of 1,046 sq. km. or 343 sq. km., and the area of riverain pasture grasses will be as follows:

	sq. km.	Stock-Carrying Capacity in Animal Units
Echinochloa stagnina	66	26,400
Echinochloa pyramidalis	157	7,850
Intermediate grass species	1,697	28,849
		63,099

The number of livestock dependent on river swamp pasture in this sector is 57,000 Animal Units, so that under the Revised Operation there will be an increase in available dry season pasture over present requirements; a surplus of 6,099 Animal Units. Under the Project without modification there will be a decrease of 13,006 Animal Units.

Aliab, Chich, and Other Lakes District Dinka

The rather varied movements of small tribal sections in this area have been very briefly described in the discussion of the effects of the Project. We have also estimated the stock-carrying capacity of two areas which, although close to the river, will not be subject to river spill as a result of the Project or of our proposal. The area of swamp in this sector is 247 sq. km., of which 154 sq. km. is north of Jonglei. This area is 2·5% of the total for the Zone and the area which will be subject to spill is thus 2·5% of 1,046 sq. km. or 26 sq. km. To this must be added the area of swamp pasture between Atem Head and Jonglei which is 93 sq. km., which will be similar to that in the north-eastern part of the Aliab Valley. The areas of available dry season pasture grasses over the flood-plain will be as follows:

	sq. km.	Stock-carrying Capacity in Animal Units
Echinochloa stagnina	18	7,200
Echinochloa pyramidalis	49	2,450
Intermediate grass species	128	2,176
		11,826

Lake Papiu is likely to produce enough dry season pasture for 7,800 Animal Units and inland depressions no longer subject to river spill are expected to produce pasture for 7,740 Animal Units. The total number of livestock which will be accommodated on natural dry season pasture will therefore be 27,366 Animal Units instead of the present number, 61,900 Animal Units. The loss, 34,534 Animal Units, is here little different from the loss under the Project, i.e. 40,999 Animal Units.

Nuong, Dok, Aak, Jagey, and Jikaing Nuer

In this sector, the area of the swamp being 1,550 sq. km. or 25·0% of the whole swamp in the Central Zone, the area subject to river spill will be 262 sq. km., or 25·0% of 1,046 sq. km. The areas of available dry season pasture grasses on the flood-plain will be:

	sq. km.	Stock-Carrying Capacity in Animal Units
Echinochloa stagnina	50	20,000
Echinochloa pyramidalis	120	6,000
Intermediate grass species	1,288	21,896
		47,896

The number of livestock dependent on main river swamp pasture in this sector is estimated to be 76,000 Animal Units (see p. 486), so that there will be a loss of dry season pasture for 28,104 Animal Units. To this must be added the 8,120 Animal Units displaced from the Waard–Tiak khor system, bringing the total number deprived of dry season pasture to 36,224 Animal Units as compared with 50,785 Animal Units under the Project. The carrying capacity of the Western Plain, 41,180 Animal Units, will remain unaltered.

CONCLUSIONS

Throughout the Central Zone there will be a decrease in available dry season pasture affecting 124,329 Animal Units. The surplus of 6,099 Animal Units grazing on Zeraf Island cannot be set against losses in other sectors; the net loss will therefore be 130,428 Animal Units. This takes into consideration large areas of intermediate land pasture whose dry season value is dependent on rainfall and which, according to our estimates, will support approximately 175,421 Animal Units during the four months' dry season, January to April. The position regarding future areas of natural pasture and their stock-carrying capacities is summarized below:

Location	A.U. per Season	Total
River Flood-Plain		
1. East bank: Atem Head–Fangak ...	84,030	—
2. Southern Zeraf Island	63,099	—
3. West Bank: Atem Head–Shambe ...	11,826	—
4. West Bank: Shambe–Buffalo Cape ...	47,896	206,851
Pasture other than on River Flood-Plain		
5. Along line of the Canal	35,500	—
6. The Western Plain	41,180	—
7. Lake Papiu	7,800	—
8. Lakes District intermediate grasses ...	7,740	92,220
Total carrying capacity of natural pasture ...	70·6%	299,071
Number of livestock accommodated at present ...	100·0%	423,400
Number deprived of dry season pasture	29·4%	124,329
Net loss of dry season pasture	30·8%	130,428
Number deprived of dry season pasture by Equatorial Nile Project	44·9%	189,931

NORTHERN ZONE

Under the Revised Operation the river régime will be similar to that of the present, except that levels will be generally higher. Furthermore, seasonal fluctuations will take place at approximately the same time as at present and grazing will be available in the dry season. The only major change is that there will be a slightly larger area flooded and exposed. The hydrological changes have already been explained (see p. 769); below we attempt to estimate the changes in vegetation and the implications in connection with animal husbandry.

EFFECTS ON PASTURE TYPES

Malakal-Jebelein

Under the Revised Operation the area of the flood-plain inundated and exposed will be increased to 990 sq. km. The present range between river levels is 226 cm., the difference between a minimum gauge level of 10·04 and a maximum gauge level of 12·30. The future range will be 215 cm., the difference between the future minimum gauge level of 10·84 and future maximum level of 12·99. With increased minimum and maximum gauge levels, lower sites in the area now seasonally inundated and exposed will be permanently inundated, whereas higher sites which at present are not flooded will be seasonally inundated and exposed. The future time-flooding curve over the area inundated and exposed will be almost identical with that of the present, so that the flood duration curve will remain unchanged although it will be effective over a larger area. We assume therefore that the percentage distribution of grass species in relation to flood duration will remain unchanged. This assumption, though not precise, will give a reasonable picture of future grass distribution. Below we explain in detail how we have arrived at the new distribution of grass species by area for the whole reach.

The new area flooded and exposed will be 990 sq. km. In Table 113 (Vol. I, p. 182) the distribution of grasses by area for the three reaches Malakal-Melut, Melut-Renk, and Renk-Jebelein is given together with the total area of flood-plain inundated and exposed in each reach. We assume that the future flood-plain area between Malakal and Jebelein will be divided up over the three reaches in the same proportions as at present, i.e. the future area between Malakal and Melut will be 245·6 sq. km., between Melut and Renk 463·6 sq. km., and between Renk and Jebelein 280·8 sq. km. We further assume that the present and future percentages of grass distribution over the flood-plain will be the same as those recorded in Table 113. Applying these percentages to the new flood-plain areas of each reach (see above), we have calculated the total area of swamp pasture grasses which will be flooded and exposed under the Revised Operation. These are given in Table 369 below.

Malakal-Buffalo Cape

The hydrological effects of the Revised Operation have not been assessed in detail for the reaches south of Malakal (see Chap. 11, p. 770) ; consequently we have not been able to assess future grass areas as we have done under the Project. The results of the Revised Operation north of Malakal are, however, sufficiently encouraging for us to assume that there will be no major change from present areas of grass species as already recorded (see pp. 493–5).

TABLE 369

TOTAL AREAS OF SWAMP PASTURE GRASSES FLOODED AND EXPOSED MALAKAL–JEBELEIN

Areas in square kilometres

Reach	*Vossia cuspidata*	*Echinochloa stagnina*	*Oryza barthii*	*Echinochloa pyramidalis*	Open water or bare ground	Total
Malakal–Melut ...	16·7	19·2	46·9	162·8	—	245·6
Melut–Renk ...	26·4	51·9	52·4	332·9	—	463·6
Renk–Jebelein ...	23·3	72·2	21·3	161·2	2·8	280·8
	66·4	143·3	120·6	656·9	2·8	990·0

EFFECTS ON GRAZING AND ANIMAL MANAGEMENT

We have shown that one effect of the Revised Operation will be to increase not only the area of river flood-plain between Malakal and Jebelein but also the areas of deep-flooded and shallow-flooded grasses in this reach. Similarly, upstream of Malakal we consider that the areas of these grasses available in the dry season will not be reduced and may even be increased. We conclude that the stock-carrying capacity of riverain pasture in the dry season will not be less than at present and may even be more. Under the Revised Operation the loss in dry season grazing throughout the Jonglei Area will amount to that required for 155,700 Animal Units. If the potential carrying capacity of present dry season pasture is compared with the carrying capacity under the Revised Operation, the loss will be for 155,400 Animal Units. The losses, actual and potential, under the Revised Operation are summarized in Tables 370 and 371 and are there compared with losses under the Project without revision; grazing for 288,700 and 344,700 Animal Units respectively.

TABLE 370

COMPARATIVE STOCK-CARRYING CAPACITIES OF DRY SEASON PASTURES AFFECTED BY THE WHITE NILE SYSTEM, USING PRESENT LIVESTOCK NUMBERS*

Sector Number	Natural River		Equatorial Nile Project		Revised Operation	
	Present total animal population Animal Units	Livestock wholly or partly dependent on pasture affected by main river Animal Units	Livestock which can be accommodated on available natural pasture Animal Units	Loss of pasture in terms of Animal Units	Livestock which can be accommodated on available natural pasture Animal Units	Loss of pasture in terms of Animal Units
1	37,400	35,200	35,200	Nil	35,200	Nil
2	103,200	103,200	56,300	46,900	77,900	25,300
Southern Zone ...	140,600	138,400	91,500	46,900	113,100	25,300
3	189,600	179,200	94,100	85,100	119,500	59,700
4	57,000	57,000	44,000	13,000	57,000	Nil
5	66,300+	61,900	20,900	41,000	27,400	34,500
6	125,300	125,300	74,500	50,800	89,100	36,200
Central Zone ...	438,200+	423,400	233,500	189,900	293,000	130,400
7	79,200	79,200	74,400	4,800	79,200	Nil
8	55,000	55,000	26,900	28,100	55,000	Nil
9	18,200	18,200	12,200	6,000	18,200	Nil
10	9,100	9,100	9,100	Nil	9,100	Nil
11	16,600	16,600	14,100	2,500	16,600	Nil
12	62,200+	62,200	52,200	10,000	62,200	Nil
Northern Zone ...	240,300+	240,300	188,900	51,400	240,300	Nil
Jonglei Area ...	819,100+	802,100	513,900	288,200	646,400	155,700

* Figures brought to nearest hundred.

Explanation of Table 370

Col. 1. Sector numbers denote areas as defined in Chapter 10 of this volume.

Col. 2. Total animal populations are shown, except in Sectors 5 and 12, where only a fraction of the total make use of riverain pasture along the flood-plain (see Vol. II, Chap. 3, Tables 238, 244, and 255.

Col. 3. Those livestock using pasture on the riverain flood-plain and all the available natural pasture (see Vol. II, Chap. 3, Tables 238, 244, and 255).

Col. 4. Those livestock which can be accommodated on riverain pasture and available natural pasture under the Project. In sectors where there will be surplus grazing only the present animal numbers are given, e.g. in Sector 10.

Col. 5. Losses under the Project derived from Tables 241, 245, and 269.

Col. 6. Those livestock which can be accommodated on riverain pasture and available natural pasture under the Revised Operation.

Col. 7. Losses under the Revised Operation (Vol. II, Chap. 12, pp. 798, 802 and 803).

TABLE 371

COMPARATIVE STOCK-CARRYING CAPACITIES OF DRY SEASON PASTURES AFFECTED BY THE WHITE NILE SYSTEM (POTENTIAL)*

Sector Number	Natural River		Equatorial Nile Project		Revised Operation	
	Present total animal population using riverain pasture Animal Units	Stock-carrying capacity of pasture affected by main river Animal Units	Stock-carrying capacity of available natural pasture Animal Units	Loss of potential dry season grazing Animal Units	Stock-carrying capacity of available natural pasture Animal Units	Loss or gain of potential dry season grazing Animal Units
1	35,200	73,700	30,600	43,100	72,000	− 1,700
2	103,200	97,800	56,300	41,500	68,400	− 29,400
Southern Zone ...	138,400	171,500	86,900	84,600	140,400	− 31,100
3	179,200	179,200+	94,100	85,100	119,500	− 59,700
4	57,000	57,000+	44,000	13,000	63,100	+ 6,100
5	61,900	61,900+	20,900	41,000	27,400	− 34,500
6	125,300	125,300+	74,500	50,800	89,100	− 36,200
Central Zone ...	423,400	423,400+	233,500	189,900	299,100	−124,300
7	79,200	86,000	76,500	9,500	86,000	Nil
8	55,000	64,700	31,800	32,900	64,700	Nil
9	18,200	22,000	12,200	9,800	22,000	Nil
10	9,100	24,400	17,200	7,200	24,400	Nil
11	16,600	7,200	6,400	800	7,200	Nil
12	62,200	36,400	26,400	10,000	36,400	Nil
Northern Zone ...	240,300	240,700	170,500	70,200	240,700	Nil
Jonglei Area ...	802,100	835,600+	490,900	344,700	680,200	−155,400

* Figures brought to nearest hundred.

Explanation of Table 371

Col. 1. Sector numbers denote areas as defined in Chapter 10 of this volume.

Col. 2. Present animal numbers using riverain pasture on the flood-plain of the White Nile system and other available natural pastures (as in Table 370, Col. 3).

Col. 3. Potential stock-carrying capacity of riverain pasture and available natural pasture—present river régime (see Tables 241, 245, 255, 266, 267, and 268).

Col. 4. Potential stock-carrying capacity of riverain pasture and available natural pasture—E.N.P. (see Tables 241, 245, 255, 266, 267, and 268).

Col. 5. Loss of potential carrying capacity under E.N.P. (see Tables 241, 245, and 269).

Col. 6. Potential stock-carrying capacity of riverain pasture and available natural pasture—Revised Operation (see Tables 366 and 368 and pp. 801, 802, and 803).

Col. 7. Loss of potential carrying-capacity under Revised Operation (Tables 366 and 368 and pp. 801, 802, and 803).

2. EFFECTS ON FISH AND FISHERIES

The primary objective of our Revised Operation is to maintain the seasonal aspects of the river régime and to provide riverain swamp pasture at the time of year when it is needed. We must next consider the effects of this Revised Operation on fish and fisheries. Reference should be made to Chapter 4 of this volume where the effects on fisheries of the Project as proposed are described.

SOUTHERN ZONE

Reach No. 1: Nimule to Juba

As already explained (see Vol. I, p. 387, and Vol. II, p. 513), this reach is not important. The present exploitation of fisheries is not a major item in the local economy, and the potentialities of future development do not appear to be great. Under the Revised Operation the river régime will be very similar to that of the present, and the only stipulation will be the provision of fish passes in any dams or barrages constructed in this reach of the Bahr el Jebel.

Reach No. 2: Juba to Tombe

In this reach it is estimated that 224 sq. km. will continue to be flooded and exposed seasonally (in the untimely and timely seasons respectively); in addition there will be a total of 51 sq. km. permanently flooded, making a total of 275 sq. km. Of this, 20 sq. km. will be covered with *Cyperus papyrus* and 8 sq. km. with *Phragmites communis*, so that the total productive area will be 247 sq. km. (see Table 361, p. 796), i.e. 90% of the total.

Reach No. 3: Tombe to Atem Head

In this reach 291 sq. km. will be flooded and exposed and 313 sq. km. permanently inundated. After deducting an area of 70·5 sq. km., covered with *Cyperus papyrus* (there will be little or no *Phragmites* in this reach), we take 534 sq. km. (533·5 sq. km.) as the total of the productive area (see Table 363), i.e. 88·4% of the total.

CENTRAL ZONE

Under the Revised Operation river spill in the Central Zone will be much reduced, but will be a great deal more than under the Project without modification. The total area covered and uncovered seasonally and of permanent swamp will be 1,203 sq. km. We believe that future conditions in this Zone will be similar to present conditions in the north-eastern section of the Aliab Valley. For this reason we apply the same percentage distribution of vegetation and estimate that 90% of the swamp area will be productive in fish, i.e. 1,083 sq. km.

NORTHERN ZONE

In this Zone we estimate that under the Revised Operation the present area flooded and exposed, 1,849 sq. km., will be slightly increased (possibly by about 10%). Taking 90% of the whole as the area productive in fish, the total will be 1,664 sq. km.

However, many parts of the area will be flooded to a greater depth, even at low river; the minimum level will be considerably higher than the normal average (e.g. 80 cm. higher at Malakal). The result will probably be a considerable increase in the fish population, but there may be some disadvantages because the fish may be less concentrated and less easily caught.

FUTURE POTENTIAL

The method of calculating yields is the same as that employed in Part I, Chapter 4, i.e. productive areas are estimated on the basis of the distribution of vegetation types and the yield per feddan is assumed to average 20 kg. per annum. The final figures, brought to the nearest metric ton, are recorded in Table 372.

CONCLUSIONS

When compared with the effects of the Project without modification the Revised Operation has the following advantages:

(i) Seasonal fluctuations in the river will be the same as at present in all Zones and will be in phase with the present breeding and growing habits of the fish.

(ii) Seasonal fluctuations will also facilitate fishing operations, which are normally most successful when the river is low. This applies to the Southern Zone and especially to the Central Zone. In the Northern Zone the disadvantages of a slight increase in minimum levels may be offset by the increase in area flooded.

(iii) In the Southern Zone there will be, if anything, a slight loss in potential. In the Central Zone there will be a very substantial decrease in potential, though not so marked as under the Project without modification. In the Northern Zone there will be an increase in potential, possibly a substantial increase.

The comparative figures are as follows:

Zone	Present Potential metric tons	Future Potential under E.N.P. metric tons	Future Potential under Revised Operation metric tons
Southern	4,693	1,732	3,717
Central	21,839	1,557	5,155
Northern	7,921	7,921	7,921
Total	34,453	11,210	16,793

The loss of potential will still be very considerable, not less than 17,660 metric tons of fish even on the most conservative estimate. Yet the subsistence requirements of the present population, a total of 9,614 metric tons, will almost certainly be met, even though the present surplus—a most valuable economic asset—will be substantially reduced.

TABLE 372

EFFECTS OF THE REVISED OPERATION ON FISHERIES: ESTIMATE OF POTENTIAL IN THE JONGLEI AREA AND REDUCTIONS UNDER THE REVISED OPERATION

		Present River Regime			Revised Operation of the Project				
Zone		Area Seasonally Inundated sq. km.	Area Productive in Fish sq. km.	Present Potential at 20 kg.p.f. metric tons	Area still Productive under Revised Operation sq. km.	Future Potential at 20 kg.p.f. metric tons	Subsistence Requirements at 16 kg. per head metric tons	Deficit to be met by Remedies metric tons	Loss or Gain in Potential metric tons
Southern	Juba–Tombe ...	309	278	1,323	247	1,175	837	Nil	− 148
	Tombe–Atem ...	787	708	3,370	534	2,542	789	Nil	− 828
Central		6,554	4,588	21,839	1,083	5,155	4,282	Nil	−16,684
Northern		1,849	1,664	7,921	1,664	7,921	3,706	Nil	Nil (Possible gain)
Total		9,499	7,238	34,453	3,528	16,793	9,614	Nil	−17,660

Note: Losses and gains should be compared with figures for the Project without revision, see Table 273, p. 524.

3. IMPLICATIONS IN CONNECTION WITH CROP PRODUCTION

The main object of the Revised Operation is to preserve the pastoral potential of the Jonglei Area by disturbing as little as possible the natural river régime while still providing more water for irrigation in Egypt and the northern parts of the Sudan. These modifications are therefore designed primarily for the benefit of pastures, and their influence on the crop producing potential of this area has been considered as only incidental.

The Revised Operation has been considered under three main headings:

(i) Operation to suit grazing.

(ii) Flood control.

(iii) Control of torrents.

While for pasture, modifications in the operation of the Project are obviously the most important, as far as crop production is concerned the control of floods, or at least the possibility of predicting them, is of equal if not greater significance. The possibility of predicting the extent of spill on any part of the riverain flood-plain and the avoidance, at least in the Central Zone, of unexpected excessive floods offers entirely new opportunities for crop production. Although in the first stages of the implementation of the Project the absence of control of torrents might not affect pastoral interests, the effect on agricultural interests must be remembered.

In describing the implications of the Revised Operation on crop production we must make two comparisons: first we must compare the effects on present agricultural potential; secondly we should compare the effects with those of the Project as proposed without modification, since the Revised Operation removes certain possibilities but offers new ones.

SOUTHERN ZONE

As we have seen, the greater part of the *toiches* in the Southern Zone will remain almost unaffected by the proposed operation. There will therefore be no effect on *toich* cultivations, at present occupying only a small proportion of the area. Moreover once the torrents are controlled, the flooding of the *toiches* will be predictable, so that it will be possible to utilize them much more fully. The river levels will be slightly lower during the rainy season and slightly higher during the dry season, and this will affect the costs of pump irrigation. Under the Revised Operation the banking-off of the Aliab Valley will be abandoned and the reversal of the flood season will not take place. Therefore there will be no possibility of perennial gravity irrigation, as there would have been under the original Project. However, the banking-off of the eastern side of the Bahr el Jebel north of Bor and of the Atem will be possible. The flood-plains of these rivers could then be irrigated during the rainy season and parts of them, lying below the river level corresponding to 64 m/d discharge at Mongalla, could also be irrigated during the dry season. Since banking-off east of the Bahr el Jebel and the Atem affects only a small proportion of the total flood-plain, the river levels necessary for flood-escape discharge will be generally lower and will require only a comparatively small increase in the height of the banks to avoid periodic floods, which would otherwise ruin the works and installations necessary for crop production here.

CENTRAL ZONE

The Revised Operation as designed should preserve *toich* grazing for over 60% of the present animal population. Consequently, though grazing losses will be less than under the Project without modification, the reliance of the local inhabitants on crop production will increase as a result of the implementation even of the modified proposals. However, the crop production potential will be improved. Spill will be controlled and predictable; therefore it should be possible to design a crop husbandry system, based on rice production, in which full use would be made of annual flooding.

Further, small and comparatively inexpensive banking could provide complete control of flooding (see Chapter 7, p. 607) and so increase the range of possible crops. The flood-plains will be free from the complications of high flood-escape discharges, and their wider agricultural utilization should therefore be safe and economical. If such utilization is attempted, natural pasture will be partly replaced by crops. However, by introducing a cropping system as described under the heading of 'Rice-Pasture Scheme' (see p. 660), crops could be produced in addition to, and not instead of, livestock. The livestock numbers could even be increased (compare the stock-carrying capacity per feddan of natural *toich* pastures and of the rice-pasture scheme).

The space between the two canals left for flood-escape discharges could also probably be used for cropping in years of normal discharges, with irrigation provided, if necessary, by flush spill from the two canals.

NORTHERN ZONE

In the Northern Zone the river régime under the Revised Operation will be essentially similar to the present natural régime, though both maximum and minimum river levels will be somewhat higher. Consequently the *toich* cultivations will have to be moved higher up the riverain flood-plain. This difference in levels will have a beneficial effect on the costs of pump irrigation. Also the level *toiches* round Lake No will probably be flooded, and rice production there should be more practicable. It must be remembered that there are no proposals, at this stage, for control of the River Sobat, and consequently variations of river levels and danger of floods will be considerable in this Zone. Even more important from the agricultural point of view, they will remain unpredictable.

CHAPTER 13. APPLICATION AND COSTS OF THE REVISED OPERATION

In the previous chapter we have examined, though not in great detail, the effects on local interests if the Revised Operation of the Project were accepted and applied. A glance at Table 370 (p. 804) will show how much the losses in riverain swamp pasture would be reduced (grazing for 155,700 Animal Units as compared with 288,200 Animal Units under the Project). In those sectors, mainly in the Central Zone, where there would still be losses in pasture 'direct remedies' would have to be applied. Practical, economic, and other considerations are the same. Suggested remedies, their application and costs are set forth in the following charts.

(Reference should be made to the description of each sector recorded on p. 689 of Chapter 10 and to Map 6 on which tribal boundaries are marked.)

TABLE 373

REVISED OPERATION: LOSSES IN RIVERAIN SWAMP GRAZING EXPRESSED IN TERMS OF ANIMAL UNITS[1]

Sector Number	Tribe	Proportion of Tribe	Total Human Population	Total Animal Units	Total Animal Units Using Riverain Pasture	Total Losses in Animal Units	Percentage Loss
1	Bari	—	—	16,300	16,300	—	—
	Mandari	—	—	21,100	18,900	—	—
		—	52,300	37,400	35,200	Nil (possible slight gain)	—
2	Bor Agok	—	—	45,300	45,300	—	—
	Bor Athoich	1/5	—	7,900	7,900	—	—
	Aliab	5/6	—	50,000	50,000	—	—
		—	49,300	103,200	103,200	25,300	24·5
TOTAL SOUTHERN ZONE		—	101,600	140,600	138,400	25,300	18·3
3	Bor Athoich	4/5	—	31,300	31,300	—	—
	Twi	—	—	76,800	75,800	—	—
	Nyareweng	—	—	25,600	24,500	—	—
	Ghol	—	—	17,400	14,300	—	—
	Gaweir	—	—	37,500	32,300	—	—
	Thiang	—	—	1,000	1,000	—	—
		—	117,100	189,600	179,200	59,700	33·3
4	Zeraf Island:						
	Gaweir	—	—	12,500	12,500	—	—
	Thiang	—	—	14,400	14,400	—	—
	Lak	—	—	30,100	30,100	Gain	—
		—	41,000	57,000	57,000	+6,100	—
5	Chich	—	—	54,400	38,000	—	—
	Aliab	1/6	—	11,900	11,900	—	—
	Others... ... ... (Lakes District)	—	—	[2]	12,000	—	—
		—	48,200	66,300+	61,900	34,500	55·7
6	Nuong...	—	—	26,300	26,300	—	—
	Dok and Aak ...	—	—	49,000	49,000	—	—
	Jagey	—	—	37,800	37,800	—	—
	W. Jikaing	1/3	—	12,200	12,200	—	—
		—	61,400	125,300	125,300	36,200	28·9
TOTAL CENTRAL ZONE		—	267,700	438,200+	423,400	130,400	30·8
TOTAL NORTHERN ZONE (7–12) ...		—	230,900	240,300+	240,300+	Nil	—
TOTAL JONGLEI AREA		—	600,200	819,100+	802,200+	155,700	19·4

(1) Figures taken to nearest hundred.
(2) Total of Animal Units is considerable, but is not entered because only scattered sections use the river-front grazing.

1. PASTURE AND AGRICULTURAL REMEDIES

SECTOR No. 1 (BARI AND MANDARI)

Under the Revised Operation there will be no loss in this sector. In fact there will be a slight increase in available dry season pasture, sufficient for approximately 600 Animal Units.

SECTOR No. 2 (BOR AGOK, BOR ATHOICH AND ALIAB DINKA IN SOUTHERN ZONE)

Pasture Remedies				Agricultural Remedies				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	£E	Water mill. m³.
I	25,300	1,639,440	Nil	—	—	—	—	—	—	—	—	1,639,440	Nil

In the Revised Operation the raising of the left bank of the Bahr el Jebel north of Tombe (as proposed under the Project) is omitted. It is estimated that in this sector riverain swamp pasture for only 25,300 Animal Units will be lost. This loss will occur mainly in the Aliab Valley, which will be partly flooded in the dry season. The loss concerns the Bor Dinka, and remedial measures could be most conveniently applied in the Eastern Plain (Remedy No. I—Improved Intermediate Land Pasture). Irrigation schemes in the Aliab Valley would not be possible.

SECTOR No. 3 (BOR ATHOICH, TWI, NYAREWENG AND GHOL DINKA, GAWEIR AND THIANG NUER)

Pasture Remedies				Agricultural Remedies				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	£E	Water mill. m³.
I	59,700	3,868,560	Nil	—	—	—	—	—	—	—	—	3,868,560	Nil
IV	59,700	4,817,790	109	—	—	—	—	—	—	—	—	4,817,790	109
—	—	—	—	V A	59,700	1,713,390	182*	—	—	—	—	1,713,390	182*
—	—	—	—	—	—	—	—	VIII	59,700	1,731,300	178	1,731,300	178
I	30,000	1,944,000	Nil	—	—	—	—	VIII	29,700	861,300	89	2,805,300	89

* Water-duties for the southern part of the Flood Region.

It is estimated that under the Revised Operation the loss in this sector will be riverain swamp pasture for 59,700 Animal Units. This loss could be met by applying Remedy No. I (Improved Intermediate Land Pastures in the Eastern Plain), Remedy No. IV (Irrigated Pasture Schemes), Remedy No. V A (Gravity Irrigated Crop Production along the line of the Jonglei Canal), or Remedy No. VIII (Rice-Pasture Schemes along the line of the Canal). Considerations are the same as under the Project without revision. Since Remedy No. IV would require perpetual subsidy, and Remedy No. V A would require the introduction of long staple cotton—an uncertain measure—the most satisfactory solution would be the application of Remedies I and VIII.

SECTOR No. 4 (GAWEIR, THIANG AND LAK NUER—SOUTHERN ZERAF ISLAND).

There will be no loss of grazing in this sector. In fact there will be a slight gain, sufficient to support approximately 6,100 Animal Units.

SECTOR No. 5 (ALIAB, CHICH AND OTHER WESTERN DINKA)

Pasture Remedies				Agricultural Remedies				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	Remedy Number	Animal Units	£E	Water mill. m³.	£E	Water mill. m³.
IV	34,500	2,784,150	63	—	—	—	—	—	—	—	—	2,784,150	63
—	—	—	—	V A	34,500	990,150	105*	—	—	—	—	990,150	105*
—	—	—	—	—	—	—	—	VIII	34,500	1,000,500	103	1,000,500	103

* Water-duties for the southern part of the Flood Region.

It is estimated that in this sector the loss will be riverain swamp pasture for 34,500 Animal Units. Remedies west of the Bahr el Jebel would be uncertain; alternative dry season pasture could be produced by irrigation along the line of the Jonglei Canal. This would involve seasonal migration, but the presence of a permanent line of communication across the Jonglei barrage would greatly facilitate movement. Remedies Nos. IV (Irrigated Pasture Scheme) and VIII (Rice–Pasture Schemes) could both be applied, as elsewhere economic considerations being heavily in favour of the latter. If seasonal migration across the river were undesirable or impracticable, Remedy No. V A (Gravity Irrigated Crop Production) could be equally well applied, but such measures would involve resettlement of the population and—as already stated—uncertainties, e.g., the necessity to introduce blackarm-resistant long staple cotton, etc.

SECTOR No. 6 (NUONG, DOK, JAGEY AND WESTERN JIKAING NUER)

Pasture Remedies				Agricultural Remedies				Combined Remedies				Total Costs	
Remedy Number	Animal Units	£E	Water mill. m^3	Remedy Number	Animal Units	£E	Water mill. m^3	Remedy Number	Animal Units	£E	Water mill. m^3	£E	Water mill. m^3
I	36,200	2,345,760	Nil	—	—	—	—	—	—	—	—	2,345,760	Nil
—	—	—	—	—	—	—	—	VIII	36,200	1,049,800	108	1,049,800	108
—	—	—	—	V A	36,200	1,038,940	110*	—	—	—	—	1,038,940	110*

* Water-duties for the southern part of the Flood Region.

It is estimated that in this sector the loss will be riverain swamp pasture for 36,200 Animal Units. Though the extent of the loss under the Revised Operation will be substantially less than under the Project as proposed, the problems are identical (see p. 696). Remedies No. I (Improved Intermediate Land Pasture in the Western Plain), No. V A (Gravity Irrigated Crop Production) and No. VIII (Rice–Pasture Schemes) could be applied; for the reasons already stated in connection with this sector (see p. 696), an irrigated crop production scheme along the line of the Canal appears to us the safest and most certain remedy, even though it would involve resettlement and a sedentary existence to which the people of this sector might well object.

SECTORS Nos. 7, 8, 9, 10, 11 and 12

These sectors are all within the Northern Zone. As already explained, the hydrological effects and hence the effects on riverain swamp pasture will be small under the Revised Operation, the new river régime being very similar to that of the present. There should be no loss of riverain grazing in the dry season.

2. OTHER REMEDIES

The effects on fisheries, as already explained, would be negligible under the Revised Operation. A small subsidy only would be necessary to put right any adverse effects on communications. Total costs in money and water are set forth in Table 374.

TABLE 374

REVISED OPERATION: SUMMARY OF COSTS IN MONEY AND WATER

Sector	Most Expensive			Least Expensive			Suggested		
	Remedy	£E	Water mill. m³.	Remedy	£E	Water mill. m³.	Remedy	£E	Water mill. m³.
1	—	—	—	—	—	—	—	—	—
2	I	1,639,440	—	I	1,639,440	—	I	1,639,440	—
3	IV	4,817,790	109	V A	1,713,390	182	I and VIII	2,805,300	89
4	—	—	—	—	—	—	—	—	—
5	IV	2,784,150	63	V A	990,150	105	VIII	1,000,500	103
6	I	2,345,760	—	V A	1,038,940	110	V A	1,038,940	110
7—12	—	—	—	—	—	—	—	—	—
Pastoral and Agricultural Remedies ...	—	11,587,140	172	—	5,381,920	397	—	6,484,180	302
Fisheries Remedies	—	Nil	Nil	—	Nil	Nil	—	Nil	Nil
Communications	—	100,000	—	—	100,000	—	—	100,000	—
Water (additional for Revised Operation)...	—	—	750	—	—	750	—	—	750
Grand Total	—	11,687,140	922	—	5,481,920	1,147	—	6,584,180	1,052