

THE EQUATORIAL NILE PROJECT

AND ITS EFFECTS IN THE ANGLO-EGYPTIAN SUDAN

Being the Report
of the Jonglei Investigation Team

ERRATA

- INTRODUCTION AND SUMMARY
Members of the J.I.T. Osman eff. Abu Rennat should not be included under the heading of Sudan Veterinary Service.
p. lxii, para 2, L.2 . . . should read " . . . 13 milliards' storage capacity above 23.0 m. . . ."
- VOLUME I
p. 218. para 2 . . . for " UAC " read " LUAC "
- VOLUME III
pp. 905 and 907. . . Tables 420 and 421 are referred to as Tables 10 and 11 in Fig. J 10.
p. 917 . . . insert bracket between " 2L " and " $\frac{h^3}{3}$ " in the equation at the bottom of the page.
p. 979, para 3, L.6 . . . should read " . . . so that a detailed study . . . "

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INTRODUCTION

THE PROJECT AND THE PROBLEMS

The conservation of water, the regulation of rivers for irrigation purposes, and the production of hydro-electric power are matters of growing importance and interest in the world today. Increases in populations and the demand for higher standards of living mean that natural resources must be used for the benefit of mankind with maximum efficiency. These observations are particularly true of the Nile Valley. Both the Blue Nile and the White Nile pass through a variety of country, and both are a source of livelihood for the inhabitants. They make possible irrigation schemes in Egypt and the Northern Sudan; the natural fluctuations of the White Nile play a vital part in the present economy of the peoples of the Southern Sudan; in East Africa the waters of the Nile are a source of hydro-electric power for industrial development and may also be required for irrigation in the future. Both rivers cross national frontiers and are of international concern. It would be idle to deny that these matters have the widest political implications, but we wish to state at once that the political aspects are no concern of ours. The opinions expressed are our own and not necessarily those of the Sudan Government to whom this report is submitted, and we are concerned only to present the facts as they appear to us as the result of our investigation. It is the earnest hope of the Jonglei Investigation Team that its contributions to knowledge of that part of the White Nile system with which it is concerned may be of assistance in finding the best form of river control for the benefit of all inhabitants of the Nile Valley.

The most distant source of the White Nile⁽¹⁾ is the Luvironza River which enters Lake Victoria, whose only outlet is at Jinja. From here the Victoria Nile descends, at first in a series of falls and rapids, then slowly through the placid papyrus-fringed waters of Lake Kioga, and then through another series of rapids, ending in the Murchison Falls, to enter Lake Albert. This lake also receives water from the Semliki River which is thus another source of the Nile, but the only exit from the lake is at its northern end where the river flows through a flat plain to Nimule at the Sudan frontier. This part of the river is sometimes referred to as the Albert Nile, but the whole reach from Lake Albert to Lake No is called in Arabic the Bahr el Jebel and it is by this name that it is usually known. At Nimule the river plunges once more through a narrow, rocky gorge in a series of rapids and fast-flowing reaches until it enters the Sudan plain just below Rejaf. From then onwards the character of the river changes. On either side the flood-plain widens, and is inundated when the water-level is high and exposed when the river is low. The distinctive feature is the fringe of swamp and marsh which gradually increases in width until, after passing along the eastern side of the Aliab Valley, the river enters the region known to the Sudanese as the *Sudd*. Here the main channel of the river has numerous side-channels and winds its way in a serpentine course through the thick vegetation of the swamps, which extend for miles on either side. At one point water is taken off through an artificial cut into the Bahr el Zeraf which rejoins the main channel lower down and is thus used as a distributory. At Lake No the river is joined by the Bahr el Ghazal which derives its water from a different catchment in the west, but its contributions are very small. Downstream of this point the river is referred to as the White Nile and takes a sharp turn to the east, being joined first by the Bahr el Zeraf again and a few miles lower by the Sobat. The Sobat, deriving its water from the Baro and the Pibor whose catchments are in the foothills of Ethiopia and in the Southern Sudan, comes down in spate during the rainy season and contributes a large volume of water, almost equal to that of the main river itself. After this the White Nile turns north again and the bordering marshes begin to narrow, being confined on either bank to a width which rarely exceeds one mile. It then flows slowly northwards through the reservoir of the Jebel Aulia Dam, which causes greater inundation of the flood-plain on both sides of the river, until it joins the Blue Nile at Khartoum.

This very brief description of the White Nile system gives some idea of its course, but there are certain distinctive features which must be stressed. In the first place its seasonal aspect is all-important. In the south from about April onwards and in the north from about June the river rises as the rain-water which has fallen on its main catchment in the region of the Great Lakes and the Ethiopian foothills begins to take effect. It is then supplemented by local rainfall until, usually in November in the south and January in the north, having passed its peak flood, it begins to drop again. In the second place, in all reaches where it is flanked by low marshes and swamps well below the level of the river banks, the water 'spills' over and inundates the adjoining country. This process of spilling causes great losses of water, for

(1) See Map 1.

although some of it may eventually return to the main channels of the river downstream, most of it is lost by evaporation and transpiration in the swamps. It is estimated that in an average year 27 milliards (27,000,000,000 cubic metres of water) enter the *Sudd* at Mongalla, but only 14 milliards emerge at the Tail of the Swamps, the rest being lost. To this account must be added nearly a metre of rainfall, on the average, precipitated in the area and which is also lost. Finally it should be stressed that although this water is 'lost' from the main river, in fact it serves a useful purpose in irrigating by natural means a vast area of vegetation, much of which is subsequently used as pasture during the dry months of the year, and provides in the swamps a most productive breeding and growing area for a great variety of fish. The water is not therefore all wasted, but provides resources which are of immense importance in the livelihood of the inhabitants of the area; yet it must be admitted that the system is wasteful and it seems obvious that equivalent local benefits could be provided with a considerable economy in water for use farther north.

We are here concerned with what is now usually called the Equatorial Nile Project, also sometimes referred to as the Victoria-Albert-Jonglei Scheme or simply the Jonglei Scheme. The Project is part of a comprehensive plan for control of the Nile. This includes the Lake Tana Scheme, which involves an over-year storage reservoir for irrigation purposes in the Sudan and Egypt, and is aimed to provide a supplementary reserve and to assist in flood protection for both countries. It includes also plans for one or more reservoirs between Atbara and Wadi Halfa on the main Nile for storage and flood protection.

The idea of avoiding the very large losses by river spill and subsequent evaporation and transpiration in the *Sudd* region is not new. It was first conceived by Sir William Garstin in 1904, and since then, with the accumulation of hydrological data, plans have gradually developed. Various proposals have been made; one is the Veveno-Pibor Scheme by which water would be carried to the Veveno in a cut and from there to the Pibor, Sobat, and White Nile (1932); another is the Jonglei Canal Scheme whereby water would be carried past the *Sudd* in a more direct manner (1936); and another is the Bahr el Jebel Banking Scheme in which losses by spill would be prevented by building banks along the natural channels of the river (1938).

These proposals eventually culminated in the Equatorial Nile Project as described in *The Nile Basin, Vol. VII: Future Conservation of the Nile*, published in 1946 by the Egyptian Ministry of Works, together with subsequent modifications suggested in 1948 by Dr. Mohamed Amin and Mr. H. G. Bambridge. It must be appreciated that the Project as a whole is intended not only to save the losses in the swamps, but also to control the water and deliver it at the time of year it is wanted. It incorporates new ideas, including 'over-year storage' in the Great Lakes, and 'virtual storage' by co-ordinating its operation with that of the Lake Tana Scheme and main Nile dams mentioned above. A concise account of these proposals is given in the first chapter of Volume II of this report and in abbreviated form in the summary which follows this introduction.⁽²⁾ We need not repeat the details here, but it will be as well to describe the main principles.

The object of the projects put forward in Volume VII of the *Nile Basin*, as of all previous proposals, is to provide more water for irrigation at the time of year when the natural supply is inadequate. The Blue Nile and Atbara come down in flood in July and provide more than enough water during half the year, but not enough during the remainder. These two divisions of the year are usually referred to as the 'untimely' and 'timely' periods respectively. It is thus during the timely period that additional water is needed, and the object of the Equatorial Nile Project is to store it during the untimely period for release when supplies from the Blue Nile run short, thus ensuring a reliable and predictable amount of water throughout the year. The plan of control aims to provide more water by over-year storage and by reducing losses in transmission and to deliver it exactly as it is required. It is intended to store water in Lake Victoria and Lake Albert, and to avoid losses in the *Sudd* by digging a canal from Jonglei (about 80 kilometres north of Bor on the Bahr el Jebel) to the White Nile near the mouth of the Sobat, transmitting the major portion of the water through the canal and cutting down the discharge in the natural channels of the river in order to reduce the spill into the surrounding swamps to a minimum.

FORMATION OF THE JONGLEI COMMITTEE AND JONGLEI INVESTIGATION TEAM

In view of these proposals, in January 1946 His Excellency the Governor-General of the Sudan approved the appointment of a Committee—known as the Jonglei Committee—and a Team of Investigators known as the Jonglei Investigation Team. The terms of reference of the Team were laid down as follows:

(2) The reader may also refer to *The Nile Basin, Vol. VII*, and the two summary accounts previously issued by the Jonglei Investigation Team: 'The Equatorial Nile Project', *Sudan Notes & Records, Vol. XXXIII, Part I*, 1952, and 'The Equatorial Nile Project and Its Effects in the Sudan', *The Geographical Journal, Vol. CXIX, Part I*, March 1953.

" The Team will :

- (a) Study in detail the proposals as submitted by the Egyptian Government, and all information at present available concerning them.
- (b) Make such investigations as are desirable in order to provide reliable information as to the effects of the proposals on the interests of the Sudan, under the following heads and such others as may be found necessary, and in cases where damage to those interests is foreseen to make recommendations as to the compensation required.
 - (i) Local Interests
 - (a) Flooding, by rain or river water, and drainage.
 - (b) Grazing.
 - (c) Agriculture, including irrigation.
 - (d) Fishing and hunting.
 - (e) Tribal communications.
 - (f) Other tribal interests.
 - (ii) General Interests
 - (a) Through communications by water.
 - (b) Through communications by land.
 - (c) River ports and access to them.
- (c) Investigate and consider possible alternative alignments for the canal, and their effects, under the same heads as in (b) above.
- (d) Investigate and consider the effects of the Scheme in the Sudan outside the *Sudd* area, particularly the resulting conditions in the various reaches of the river at the different seasons of the year.
- (e) Consider the proposed programme of construction, and also whether it is desirable that the Lake Albert Dam should be completed and come into operation at the same time as the ' First Cut ' of the Jonglei Canal.
- (f) As the result of these investigations, to report and to make recommendations for the consideration of the Jonglei Committee.
- (g) Make interim reports and recommendations, as the conclusions are reached on certain points, in order to hasten the completion of the investigation, and the consideration of the whole project, as between the Sudan and Egyptian Governments."

INVESTIGATION. PHASE I: THE THREE INTERIM REPORTS

The Jonglei Committee was formed under the chairmanship of the Financial Secretary (first Sir Edington Miller, K.B.E., C.M.G., and later Sir Louis Chick, K.B.E.) with the Directors of the Ministry of Agriculture, the Sudan Irrigation Department, and the Sudan Veterinary Service, the Governor of the Upper Nile Province, and the Irrigation Adviser as members. Mr. H. A. W. Morrice, B.A., A.M.I.C.E., M.Am.Soc.C.E., of the Sudan Irrigation Department (now Director of Irrigation and Irrigation Adviser) was appointed Chairman of the Jonglei Investigation Team, and Mr. J. Winder of the Sudan Political Service (now Governor of the Upper Nile Province) as Secretary. It was not until 1947 that a Veterinary Member and a Surveyor were added to the Team, so that the first three Interim Reports were largely the work of two Members of the Team only; this fact alone bears witness to the magnitude of their achievement. It is with admiration that we acknowledge their contribution, which has provided the starting point of our own investigations. It should be noted that their *First Interim Report*, published in 1946, was concerned with the proposals set out in *Upper Nile Projects—Jonglei Scheme*, published by the Egyptian Ministry of Works in 1938. The proposals in the form described in the *Nile Basin*, Vol. VII, were only made available in March 1947. The *Second Interim Report* published in 1947 concerns these proposals, as do subsequent reports, with the suggested modifications already mentioned and on the assumption that the alignment of the Jonglei Canal will be on the ' Direct ' Line as recommended by Mr. Morrice and Mr. Winder.

In the introduction to the *Third Interim Report*, published in 1948, the Team concluded :

" We have been concerned to formulate the main problems and to suggest methods of solution. Such a preliminary stage is an essential part of any investigation on the present scale, but there comes a time when the immediate task changes from opening up the principal problems to their methodical solution. In our opinion the *Third Interim Report* marks such a change, and with its completion we can therefore say that the first stage of the Jonglei Investigation is ended. We believe that in future this investigation will be less general and mainly devoted to the solution of specific problems."

The report then enumerates those problems which appeared most urgent at the time of writing. The new Team, which in the first year consisted of the Chairman, two Irrigation Engineers, a Veterinary Inspector, an Inspector of Surveys, one Sudanese Surveyor, and a Sudanese Agriculturist, started work at the end of 1948. It was soon clear that many problems requiring ' methodical solution ' needed further preliminary survey. Survey work began

in the Aliab Valley, further statistical information was obtained concerning the cattle population, and a close study was made of the hydrology of Western Nuer District, where the problem of spill from the Bahr el Jebel is of particular importance. Some advance was made in the matter of fisheries with the assistance of a party from University College, Khartoum, consisting of Dr. H. Sandon, Dr. J. Rzoska, Dr. K. Macleay, and Mr. Pile. The Team also had the services of Mr. R. E. Taylor, M.B.E., Fisheries Officer, and experiments were carried-out in the effectiveness of various netting techniques and also in methods of curing fish. In addition a reconnaissance of the Nimule-Juba reach was made in order to investigate the possibility of building a balancing reservoir. The Jonglei Committee had by then decided that no further full-scale interim reports should be produced, but the results of these investigations have been recorded in some detail in our Progress Report for 1948-1949.

INVESTIGATION. PHASE II: OBJECTIVES AND PROGRAMME OF WORK

Early in 1949 a meeting of the Jonglei Committee was held in Khartoum and the Team's terms of reference were altered to place greater emphasis on the need to suggest sound remedial measures for any losses which might take place as the result of the Equatorial Nile Project. The relevant extract from the minutes of that meeting is as follows:

"The Committee decided that the Team should be asked to provide a *reasonable forecast* of the necessary remedial measures and of compensation expressed in terms of money and water".⁽³⁾

This was really a turning point in the investigation and the Team was asked to put forward proposals for a three-year programme of work, giving the number of staff and the nature of the services required.

Before describing these proposals we must digress here to outline in general terms the problems raised by the Project, which were by then clear from the reports of the previous Team. The investigation carried out by Messrs. Morrice and Winder had revealed certain salient facts to which they drew the attention of the Sudan Government. It was clear that the Project would seriously affect the interests of the inhabitants through whose country the water would flow. Under present circumstances, from a point downstream of Refaj, where the river enters the plains of what we call the Flood Region, the environment seems best suited to a pastoral economy. It would be an exaggeration to say that all peoples in this area rely exclusively on animal husbandry as a source of livelihood, for rain-grown crops are of great importance in their subsistence economy. Yet the production of grain crops is on the whole a precarious undertaking. In this region the mean annual rainfall is usually adequate, but its monthly distribution is extremely variable. Moreover in most parts the soil is heavy and impermeable, the slope is exceptionally small, and the drainage system often inadequate to carry away the accumulations of rainfall. In the early months of the wet season there is sometimes so little rain that the newly planted crops perish from drought, whereas later in the year they may be damaged by torrential storms or drowned by heavy flooding. The very laborious processes of crop production are for these reasons cut to a minimum and the people rarely attempt to grow more grain than would be sufficient to meet their own needs were they successful. Cattle and other animal stock are therefore of paramount importance because they provide the only reliable alternative to crop husbandry. Peoples in nearly all parts of this area also rely on fish to supplement their diet, and fish are usually available in large quantities in the pools and lagoons on the flood-plain of the Nile. These observations apply less acutely in the northern parts of the area, in what we call the Semi-Arid Region, but there are other disadvantages; the annual mean rainfall is lower and often inadequate, while shortage of domestic water supplies in the dry season sometimes makes the harvesting of crops in the hinterland a difficult undertaking.

Having drawn attention to the importance of meat, milk, and fish in the diet of the people, we must now stress the seasonal nature of the local economy and the absolute necessity to migrate to the river-front in search of pasture and fishing pools at certain times of the year. During the rainy season from April or May until December the river overflows its banks and the people are forced to move inland to higher ground where they can take refuge from the floods and biting insects. Here they build their permanent settlements, cultivate their crops on the best drained land available, and graze their herds in the immediate vicinity, protecting them from the heavy rain and insect pests in large, well-built cattle-byres or in carefully sited camps. Conditions change rapidly once the rains are over. The cultivation season is at an end and the crops are harvested. Above all water supplies soon begin to run short and the animals are then driven, usually in small scattered herds rather than in large concentrations, into the vast

(3) Minute of the Fifth Meeting of the Jonglei Committee, February 1949. The italics are our own.

plains which surround the islands of higher ground. By January, or February drinking-water is again running short and the perennial grasses, previously burnt off to produce a green regrowth, are exhausted. At this point there is no alternative but to move to the flood-plains of the main rivers and watercourses where, as the water-levels drop, an abundance of succulent and nutritive pasture is made available. Here the people concentrate for the remaining months of the dry season, supplementing their meagre supplies of grain with milk and meat, and fish from the pools and water channels. Then, as the rains start to fall, they return again to higher ground; the annual cycle of movements, dictated by the natural conditions of the environment, begins once more.

This regular rhythm of seasonal migrations and different economic activities is typical of the area. We have been speaking mainly of the Nilotic tribes living south of approximately lat. 12° N., but the same applies, for somewhat different reasons, to the Baggara Arab pastoralists living north of them on both sides of the White Nile. During the rainy season these people are compelled to drive their animals northwards and away from the river to escape the heavy rain and insect pests; during the dry season shortage of water and pasture inland forces many of them to move to the river-front.

The Nile therefore produces for the inhabitants, by a simple process of natural irrigation, adequate pasture for their animal stock and plentiful supplies of fish at a time of year when such vital assets are not available elsewhere. Between Rejaf and Jelebein some 700,000 people and 800,000 Animal Units⁽⁴⁾ are in one way or another dependent for their very existence for from four to five months of the year on the flood-plain of the river. This is the most significant point to grasp in connection with the effects of the Equatorial Nile Project in the Sudan, for it is just this natural system of irrigation which will be most affected by the altered river régime. In some parts of the area the seasonal fluctuations will be reversed, the flood-plains being inundated and therefore inaccessible in the dry or timely period of the year, and subject to rainfall only in the untimely period; in others the flood-plains will no longer be inundated by river spill and will be subject to rainfall only, with a probable change in vegetation; in still others they will be permanently under water throughout the year.

In addition to the effects of the Project on dry season grazing and fisheries, there will be other more general interests affected by the altered régime of the river. Communications and navigation along the natural channels will in some places be made difficult unless certain stipulations are followed. On the other hand the Jonglei Canal will itself provide a better and more direct line of communication from south to north. The problem of flood protection is also of enormous importance. It is essential that the peoples of this part of the Sudan should be fully protected from disastrous floods. Even with the storage capacity reserved specifically for this purpose in the Albert Reservoir, supplemented by storage in balancing reservoirs in the Nimule-Juba reach, the necessity to allow excess water to escape at much higher discharges than the normal over a period of several years is bound to disturb local interests.

These facts were known to us at the outset of our programme of investigation and considerable detail was already available in the reports of our predecessors. Nevertheless, it was clear that the main task would be to translate general observations concerning the effects of the Project into terms of quantity.

Accordingly we submitted to the Jonglei Committee our proposals in the form of a memorandum entitled 'Jonglei Investigation: Phase II: The Investigation of Remedial Measures'. In this we defined the objectives of our investigation as follows:

- (a) To estimate how much riverain pasture, and other assets of vital concern to the people of the Sudan, would be lost as a result of the altered river régime, and to assess the extent of the remedial measures required.
- (b) To find out what natural alternatives would be available and where these are lacking what remedial schemes could be applied.
- (c) To assess the costs in money and water of such remedial measures.

It was soon clear that this was a more formidable task than we had anticipated. To estimate the direct effects of the Project would necessitate a thorough investigation of the flood-plains of the Nile between Nimule and Kosti, a distance of 1,625 km. by river, involving extensive surveys of the topography, soils, vegetation, and other aspects of sample areas; detailed analyses of the results; and then a general assessment of the effects on the whole reach. The proper investigation of remedial measures, however, would carry us over a very much larger area and would require a careful survey of the hinterland, where alternatives might be found or remedial schemes introduced. This would involve an investigation of parts of Equatoria Province, the eastern half of Bahr el Ghazal Province, the major part of Upper

(4) One Animal Unit (A.U.) = 1 head of cattle = 8 sheep or goats.

Nile Province, and the southern part of Kosti District in Blue Nile Province, an area of not less than 512,000 sq. km. (200,000 sq. miles). The investigation of remedial measures would also demand a programme of experiments and trials to determine the best means of providing dry season pasture and, besides, alternatives in the form of crops.

Our programme was to include three years work in the field, one for each of three zones into which we had divided the area. The Team was to consist of Hydrological, Administrative, Animal Husbandry and Pasture Research, Agricultural, Fisheries, and Survey Sections. Apart from the investigation of certain specified problems, such as flood protection and control of the Great Lakes, in broad outline the programme of work was to be carried out with the following objectives :

HYDROLOGICAL SECTION

- (i) To carry out general and detailed surveys of the hydrology of the flood-plain and swamp formations of the Nile system between Nimule and Kosti in order to determine the hydrological effects of the Project.
- (ii) To carry out a general survey of the topography, climate, and hydrology of the whole area involved, including inland watercourses and tributaries of the Nile.
- (iii) To investigate domestic and stock water supplies in the area; this to include a programme of experimental drilling to determine the availability of underground water resources.
- (iv) To investigate all communications, including navigation on the main channels of the river.

PASTURE RESEARCH AND AGRICULTURAL SECTIONS COMBINED

To investigate the general ecology of the area inland and on the flood-plains, to classify the main soil and vegetation types, and to assess the factors which determine their distribution.

ADMINISTRATIVE SECTION

To investigate the sociological and administrative implications of the Project and to obtain all relevant information, including vital statistics.

ANIMAL HUSBANDRY AND PASTURE RESEARCH SECTIONS

- (i) To study the grasslands of the area and their relative nutritional and feeding values.
- (ii) To study pasture management and to determine the present degree of pasture utilization.
- (iii) To study the livestock of the area, including their management, and the economic aspects of the cattle trade, present and potential.
- (iv) To determine the effects of the Project on riverain pasture and to estimate any losses.
- (v) By observation and experiment, to determine the best means of providing alternative pasture.

AGRICULTURAL SECTION

- (i) To study present crop husbandry practice, including local crops, cropping systems, and cultural operations.
- (ii) To study the implications of local environment on the crop husbandry system; and to assess the factors limiting crop production, including floods, droughts, pests, diseases, weeds, etc.
- (iii) To examine all economic aspects of crop production.
- (iv) To investigate the effects of the Project on the present and potential utilization of the flood-plains for crop husbandry.
- (v) By observation and experiment to investigate possible agricultural alternatives which may be needed to meet losses under the Project where alternative pasture cannot be found or provided.

FISHERIES SECTION

- (i) To investigate the species of fish to be found in the area, the ecological conditions in which they flourish, their migrations, breeding habits, and distribution.
- (ii) To investigate local fishing techniques, methods of curing, and the part played by fish in the diet of the peoples, and to determine the potentialities of fisheries development in the area.
- (iii) To estimate the effects of the Project on the fish population and on local methods of catching fish.
- (iv) To investigate possible remedies for any losses likely to be sustained.

SURVEY SECTION

- (i) To carry out ground and aerial surveys required in connection with all aspects of the investigation.
- (ii) To undertake the preparation and production of maps and diagrams required for all reports.

It was clear from the start that nearly all these objectives could only be achieved by the closest co-operation between the various sections of the Team, and that careful co-ordination of approach was essential. The very magnitude and complexity of the problems made this a difficult task. We scarcely need say that any Team working on problems such as these must be 'balanced', i.e. that all technical services involved must be represented and that the staff

must be appointed simultaneously. It was therefore unfortunate that the staff recommended and approved was not immediately available, and that the Agricultural and Pasture Research members did not join the Team until after the first year of the programme had been completed. For this reason the investigation of certain aspects tended to lag behind the others, with disadvantages which caused considerable delay in the preparation of this report. The Fisheries Section was not represented and what little information we have been able to record is the work of a layman.

In the 1949-50 season the Team concentrated its efforts in the Northern Zone⁽⁵⁾ between Kosti and Malakal. Particular attention was paid to the Machar Marshes, the area lying between the Baro-Sobat river system and the White Nile. This included a topographical survey of the lower part of the Khor Adar, the only drainage-channel from these marshes. The hydrological survey was completed, further work on the cattle census was carried out, and pasture tests started, mainly in Kosti District and at the Malakal Experimental Station. The results of this season's work were recorded briefly in the Progress Report for 1949-50. After that, on the express instructions of the Jonglei Committee, no further progress reports were produced.

Though work on the Northern Zone was not entirely completed, the field season of 1950-51 was mainly spent in the Central Zone, south of the line Buffalo Cape to Fangak and north of the Jonglei latitude. The hydrological survey of that Zone was completed, and the survey of the Aliab Valley, started in the 1948-49 season, was continued. All aspects of this area were investigated, including topography, hydrology, soils, vegetation, pasture utilization, and fisheries.

In the 1951-52 field season work was confined mainly to the Central Zone, though the Team turned also to the problems of the Southern Zone, i.e. south of the Jonglei latitude. The season's work included the hydrological survey of the latter Zone, a detailed survey of the Juba-Gemmeiza flood-plains, and surveys of the southern torrents and possible dam sites on them.

Our programme also included experimental work which had to be carried out simultaneously with more general investigation in the field, always a difficult problem for the Team since no additional staff was available. It was decided early in the programme that any experimental work undertaken by the Team would have to take the form of short-term trials to give approximate rather than precise results in the limited time available. A full account of experimental work carried out by the Team is included in Volume III of this report. Very briefly, experimental schemes included:

MALAKAL EXPERIMENTAL PUMP SCHEME: The primary object of this scheme was to carry out experiments in irrigated pasture on higher ground. Some 30 feddans of land were made available and a 6-inch pump installed. Later, when it became clear that pastoral remedies for losses under the Project might be inadequate, or uneconomic, the scheme was expanded to include experiments in the introduction of improved and new varieties of crops and in improved methods of crop husbandry. This scheme, referred to in our report as the Malakal Experimental Farm or Station, was rapidly developed and was later extended and run in co-operation with Ministry of Agriculture. As an addition an extension on the flood-plain of the west bank opposite Malakal was made in 1952. This and all other schemes started by the Team were taken over by the Ministry of Agriculture in 1953.

OTHER EXPERIMENTAL SCHEMES AND TRIALS: Experiments in rain-grown crops and improved methods of crop husbandry were carried out by the Team at Kodok (Shilluk District), Fangak (Central Nuer District), and Arielbek (Bor District).

Pasture trials and grazing tests were carried out on all types of grassland in various parts of the area, notably in Kosti District, at Detwok, at Malakal and Nagdiar, and at Pariak and Pengko. An elaborate system of experimental quadrats was put in at intervals round the 'Eastern Plain'. A small experimental banking scheme was carried out at Chotyl in Western Nuer District.

Mention must also be made of the Jerkwot scheme. One of the main effects of the Project will be to prevent the flooding of land normally inundated by spill from the river. In order to determine the effects on riverain pasture grasses, an area (at Jerkwot just south of Bor) was banked off on all sides in 1947. It was later found that the site was not typical of the flood-plain and that owing to seepage the area was not entirely insulated from the river. Future conditions were not reproduced and the scheme was not continued after 1950. A similar scheme to test the effects of depriving permanent papyrus swamp of normal river flooding was proposed but, since no reliable results could be expected in so short a period, the proposal was not carried out.

(⁵) For definition of Zones see p. xii.

LAYOUT AND PRESENTATION OF THE REPORT

Field and experimental work ended in 1952, and in November of that year work began on the formidable task of collating the material and writing the final report. The aim of this report is to give a picture of the present position in the area affected by the Project; the main features and operation of the Project; the hydrological effects—the effects on the ecology of the flood-plains and hence the effects on the present form of livelihood of the inhabitants in animal husbandry, crop husbandry, and fisheries, and on more general interests. Then, from a study of the present position and the effects of the Project on the natural resources of the area, to suggest and examine the various forms of remedial measures which we consider possible, and finally to estimate the costs in money and water.

In Volume I, under the title of 'A Survey of the Area Affected' by the Equatorial Nile Project, the main characteristics of the area are discussed under six main chapter headings. Chapter 1 describes the topography, climate, hydrology, and communications of the area. Chapter 2 presents a general picture of the ecology; the soils and vegetations. In Chapter 3 we describe briefly the inhabitants of the area, their social and political structure, and the main features of their economy. In Chapters 4 and 5 we discuss in greater detail the exploitation of natural resources in the form of animal and crop husbandry. In the final chapter of Volume I we give an outline of the fisheries resources.

In Volume II we begin with an outline account of the Project (Chapter 1) and then proceed (in Chapters 2–5) to its effects, first on the hydrology of the river between Nimule and Kosti, then on pasture and animal husbandry, on fisheries, and finally on other interests—climate, crop husbandry, communications, and navigation.

In the second part of Volume II (Chapters 6–8) we turn to possible remedial measures. We begin by discussing the potentialities of the area in general terms under the chapter headings of pasture and animal husbandry, agricultural alternatives, and engineering potentialities. In Chapter 9 we consider these potentialities in more detail, and outline a number of schemes which we consider might be applied as remedies to meet the losses which will result from the Project. We should stress here, and will certainly stress again, that these proposals would require much further research, experiment, and trials in the form of pilot schemes before they could be applied with any certainty of success. From our point of view they are primarily designed to provide a 'yardstick' upon which we can fulfil one of the main items in our terms of reference: to give a *reasonable forecast* of the costs of remedial measures in terms of money and water. This is, as far as we are aware, the only method by which such a forecast could be made. Such a method ignores one of the fundamental difficulties with which the Sudan will be faced; the natural reluctance of the inhabitants to abandon their present form of economy and to turn to other forms of livelihood. This is a problem which cannot be solved in a short period of time and certainly no theoretical study could provide an immediate solution.

At the end of Chapter 9 a summary of unit costs is given. This is a précis of a much larger document in which the details of our costings are recorded. We have decided, however, not to publish these in full, partly because of the inevitable future fluctuations in the value of money, partly because the data upon which the costing is based are derived from other parts of the Sudan and the world and may therefore not be entirely reliable, and because practical experience in the area where the remedies are to be applied is lacking. Since most of the remedies will require irrigation, it has also been necessary to estimate unit costs in terms of water.

For the purpose of totalling the costs of remedial measures in money and water we have, in Chapter 10, divided the area into twelve sectors and considered the most suitable remedies to be applied in each of them. Our results are tabulated under each sector. These proposals we call 'direct remedies', in other words remedies for direct application to meet losses under the Project as at present proposed.

In contrast to direct remedies we suggest, in the third part of Volume II, an alternative method of operating the Project so as to avoid its adverse effects as far as possible. This we call the 'Revised Operation of the Project', and in Chapter 11 the bases of our proposals are given. It should be stressed that much further research would be necessary before we could be certain of success, but the general principles appear to us to be fundamentally sound. By revising the operation of the Project the losses may be cut down by nearly half and the remedies needed reduced proportionately, though a slight increase in the amount of water required locally would be necessary. This we do not regard as inequitable. Under present circumstances the inhabitants of the area make use of a natural, albeit wasteful, system of irrigation; it is only right that they should continue to use the waters of the Nile to meet their own needs, but the wastage should be reduced to a minimum, thereby achieving an economy of water which the sponsors of the Project may use for their own purposes. The necessary reduction in the amount of water saved for irrigation farther north is in any case only about 4% of the total

saved under the Project as originally proposed, which in our opinion is a reasonable quantity to allow for the people in whose country the hydrological changes will have the adverse effects we have mentioned.

In Chapter 12 we describe the effects which will still take place under this Revised Operation, and in Chapter 13 apply the same technique as in Chapter 10 to estimate the costs of remedial measures in these new circumstances. Table 370 gives the comparative results. Volume III contains the results of special investigations and experiments upon which many of our conclusions concerning the effects of the Project and our recommendations for remedial measures are based. The maps and diagrams required to illustrate this report are bound together in Volume IV. Pages in Volumes I to III are numbered consecutively from 1 to 1076.

This introduction is followed by summaries of the salient points recorded in each chapter of the first two volumes of our report. We recommend the reader to turn to these summaries after reading the introduction, and then to the main volumes for further detail.

The main body of the report is really intended to be a work of reference. We make no apology for the detail which we have recorded, though we admit that, had there been time, it might have been possible to condense our material into more manageable form. We have felt throughout our investigation, however, that it was essential to record as much relevant information as possible—the information we ourselves would have liked to have had at the start of our investigation. There are many reasons for this. In the first place with the staff and time available we have not been able to do more than examine general principles, and when work on the Project begins much further investigation and experimental work will be required before remedies can be safely introduced. Our results must be recorded in detail sufficient for those who may have to carry the investigation further to start where we left off. In the second place it must be remembered that the design of the Project may in the final event be different from that on which our investigations have been based; the alignment of the Canal may not be the same or it may be decided that banking of the Bahr el Jebel will provide a cheaper and better alternative; the operation of the Project may be modified. This being so we have attempted to record our data in detail sufficient to allow for reinterpretation in the event of any future alternative or modification.

CLASSIFICATIONS AND DEFINITIONS

From the outset of our investigation it has been necessary to make certain classifications, since the area affected by the Equatorial Nile Project is very large and is in no sense homogeneous. It will be realized that these classifications, depending on so many different factors—topographical, physiographic, climatic, hydrological, edaphic, biotic, ethnological, and so on—cause many difficulties of presentation. Different factors do not always correspond and there are in fact many ways in which the whole area could be divided into different regions. Our classifications are therefore somewhat arbitrary, a point which must be emphasized, but it is nonetheless essential that the reader should be familiar with them from the start. Their significance in the presentation and form of this report is considerable and for this reason all 'Regions' and 'Zones' are printed throughout with an initial capital.

THE JONGLEI AREA

By the 'Jonglei Area' we mean the territory through which the water will flow along the natural channels of the river and along the line of the Jonglei Canal, and which is occupied by those tribes who, relying as they do on the flood-plains of the White Nile system, will in one way or another and to a greater or lesser degree be directly affected by the Equatorial Nile Project. The boundaries of these tribes, and therefore of the Jonglei Area, are marked on Map 6, to which reference should be made. It must be appreciated that other tribes whose territories lie farther away from the main river, and who depend for dry season grazing and fishing on minor rivers and watercourses deriving mainly from other catchment areas, may well be indirectly affected. Pressure will almost certainly be put upon them by people living nearer the main river if those people lose much of their summer pastures and fisheries and no reasonable alternatives are provided. The tendency will always be to seek alternatives inland in areas already exploited to the full and thus to cause a further drain on local resources. Strictly speaking, however, those tribes who may be indirectly affected are not included in the Jonglei Area.

Apart from this it must be realized that our investigation has carried us well beyond the boundaries of the Jonglei Area. Rivers have had to be followed to their sources, the nature of the soil and the ecology of the area could only be studied in relation to the whole. In one way or another our investigation has involved a study of a very large part of the Southern Sudan. Certain purely geographical divisions of the Jonglei Area have been made—e.g. the South-Eastern Area, the Northern Area, etc. (see pp. 2-5)—but these are largely for the purpose of topographical descriptions and are defined later.

ECOLOGICAL REGIONS

For the purpose of this report we have divided the Jonglei Area into three main regions, the title in each case being derived from their dominant features. These dominant features are not consistent. In the southern parts of the Jonglei Area the main characteristic is the ironstone, the dominant feature therefore being geological. In the central, and by far the largest, part of the area the most obvious characteristic is the liability to flooding during the rainy season, caused by a variety of factors—mainly topographical and hydrological. The principal characteristic of the northern part is climatic, the mean annual rainfall being much less than farther south. Thus we have the Ironstone Region, the Flood Region, and the Semi-Arid Region (see Maps 7 and 8), which are described briefly below.

THE IRONSTONE REGION

The geological make-up of this Region is the principal factor responsible for its physiographic, and consequently its ecological, character. The soils have been formed *in situ* from the parent rocks. The topography is undulating and the soils are generally texturally lighter and more permeable than in the Flood Region. Drainage is generally free, and inundation from rainfall is unusual except in the watercourses and rivers. The vegetation ranges from thick gallery forest (strictly speaking well outside the Jonglei Area), through mixed deciduous broad-leaved woodland with perennial grasses, to the open grassland found in the lowest levels in the area, mainly in the northernmost parts. Annual mean rainfall is between 1,000 and 1,400 mm. Only the northern and north-eastern parts of this Region—i.e. in the reach between roughly Juba and Mongalla, and the eastern parts of Bahr el Ghazal Province—fall within the Jonglei Area. Areas with similar types of vegetation are to be found on the north-eastern edges of the Flood Region, i.e. in the area near the Ethiopian frontier, and also north of Lake No.

THE FLOOD REGION

The main part of the Jonglei Area falls within this Region, which extends eastwards and westwards well beyond the boundaries of those tribes who will be directly affected by the Project. The main features upon which this classification is made are physiographic, edaphic, and hydrological. The lack of slope (rarely exceeding 10 cm./km.), the heavy impermeable nature of the soils, the comparatively heavy though variable rainfall (between 600 and 900 mm.) with drainage-channels generally insufficient to carry it, mean that nearly the whole Region is subject to a greater or lesser degree of flooding during the rainy season. The islands of slightly higher ground provide a refuge for man and beast during the months of heavier rainfall, but in many parts the difference in ground level is very small and even the permanent villages are often subject to sporadic rainfloods. The vegetation is mainly tall grass savannah and acacia forest, the variations—which are considerable—being classified into units which are described in detail in Volume I, Chapter 2.

Here a further classification is relevant and important. Within the Flood Region we speak of 'high land', 'intermediate land', and swamp—toich and sudd, and it is necessary to define these terms from the start (see Fig. E 1).

HIGH LAND

One of the most obvious and significant features in this Region is the scarcity of ground high enough to be relatively free from flood during the rainy season. Such areas are of particular significance from the human point of view since they are the only refuge available for the occupants and their livestock, and their distribution has important effects on the demography of the whole Region. In this extremely flat country it is not necessarily the relative level of the land which alone determines its susceptibility to flooding; the slope and soil permeability, as well as vegetation, are factors of equal or often greater importance.

INTERMEDIATE LAND

By far the larger part of the Flood Region consists of the flat plains subject to periodical flooding or at least waterlogging from heavy storms and accumulations of rainfall. In this area, at any rate in the early part of the rainy season, periods of flooding alternate with conditions of drought. Sometimes saturation of the soil, heavy rainfall augmented in some cases by river spill, small slope, and the inability of the drainage-channels to carry the run-off, cause a solid sheet of water several centimetres deep to advance slowly across country in the general direction of the slope, a phenomenon which we call 'creeping flow'. These areas lie between the high land and the flood-plains of the rivers and drainage-channels, and we refer to them as 'intermediate land,' the definition being valid not only because they are intermediate in level, but because, as will be seen later, their principal economic value is to provide grazing between the end of the rains and the beginning of the dry season.

SWAMP

TOICH LAND. The main rivers and larger watercourses are fringed by flood-plains inundated seasonally by spill-water. In the Nilotic languages these are known as *toich* (*toc*, *toiç*), though the meaning of this word is really no more precise than 'marsh' or 'water-meadow' is in English. Within the Jonglei Area the word is sufficiently exact for general application, though it is worthwhile stressing here that outside that area (particularly in Bahr el Ghazal Province) it often corresponds more closely with the lower levels of what we have defined as intermediate land, producing grasses which we regard as typical of intermediate land, e.g., *Hyparrhenia rufa*, rather than *Echinochloa* spp. and *Vossia cuspidata* which we regard as typical of the *toich*.

SUDD. Below the level of the *toich* is permanent swamp, which we frequently refer to as *sudd*, where the dominant species of the vegetation is *Cyperus papyrus*, and where a layer of peat is nearly always present.

Closer analysis will show that these definitions of land types are essentially relative. For example the so-called high land is sometimes well below the ground level of intermediate land or even *toich*, but the purely physical action of the vegetation prevents the spill-water from the river channels reaching it before the onset of the dry season, when the water rapidly evaporates. The terms are sufficiently descriptive for the purpose of this report and must stand until a wider and more detailed survey of the Flood Region allows a more precise definition of land types and of the many variations within them.

THE TRANSITIONAL BELT

North of the Flood Region is an area which we refer to as the Transitional Belt. The mean annual rainfall is between 640 and 750 mm., and here neither the characteristics of the Flood Region nor those of the Semi-Arid Region are sufficiently sharply defined to classify the land as falling within either Region.

THE SEMI-ARID REGION

The northern parts of the Jonglei Area fall within the region where the mean annual rainfall is generally lower than 640 mm., and where there are alternations of clay and sand, generally better drained than in the Flood Region. The basis for this classification is therefore mainly climatic and topographical, the characteristic vegetation being *Acacia mellifera* and *Acacia seyal* with mixed tall and short annual grasses. This Region has a predominance of annual grasses which are generally palatable in a dry mature state, in contrast to the predominantly

perennial grasses of the Flood Region which are of little value when in this condition. The Region might therefore be referred to as 'sweet veldt'—in contrast to the 'sour veldt' of the Flood Region—but these terms (which are South African in origin) refer mainly to pasture and in any case are not sufficiently precise for application here; moreover 'sweet veldt' is not entirely absent in the Flood Region, nor 'sour veldt' in the Semi-Arid Region.

The pitfalls of such broad classifications, based as they are on generalizations and a wide variety of factors, are obvious, but some division of the area is essential for our work. They are, however, sufficiently distinct to have more than purely academic value since, roughly, they correspond to divisions which are racially, administratively, and to some extent economically distinct. Thus the Ironstone Region, or that part of it which falls within the Jonglei Area, is occupied by people of the Bari-Mandari group, with some Nilotics (Dinka) living in its western extension. The Flood Region is occupied almost exclusively by Nilotic tribes—Dinka, Nuer, and Shilluk. The Semi-Arid Region within the Jonglei Area is occupied almost exclusively by the mixed Arab pastoralists and cultivators of Kosti District. This is subject to a few exceptions. For example the Mandari are partly in the Ironstone Region, partly in the Flood Region, and their country is really transitional between the two, while some of the Dinka living in the western part of the Ironstone Region bring their cattle into the *toiches* of the Flood Region during the dry season. Some Nilotic tribes are in the Transitional Belt (notably the Paloich Dinka and some of the northern Shilluk), while the Abialang Dinka are definitely within the boundaries of the Semi-Arid Region. Economically all three Regions have many points in common. All are occupied by peoples whose economy is dominated by their pastoral activities and their seasonal movements. In nearly all places the economy is almost exclusively designed for subsistence rather than trade. Only in the Semi-Arid Region, which is clearly economically more advanced, is a cash economy firmly established, a distinction which has become more significant in recent years with the astonishingly rapid and remunerative development of pump irrigation schemes.

We have already noted that the classification of land types into high land, intermediate land, and swamp applies specifically to the Flood Region. It is not fully valid in other Regions. It must be stressed, however, that there is one type of land which is common to all Regions. This is the *toich* or flood-plain of the Nile—which the Arabs of the Semi-Arid Region call *farsh*—which transects the Jonglei Area. Its seasonal inundation when the river is high and its exposure when the river drops are characteristic throughout, and although there are minor variations from south to north the ecological conditions are generally similar. In the chapters concerning ecology and grassland husbandry we therefore refer to this type of land as 'Inter-Regional'. This is really the most significant fact in our investigation, for it is this land, seasonally inundated and exposed, which will be most affected by hydrological changes which will result from the Equatorial Nile Project.

ZONES

In the second volume of this report it has been necessary to classify the Jonglei Area into three Zones according to the different hydrological effects of the Project (see Map 5). These are:

THE SOUTHERN ZONE

The southern boundary of this Zone is the Sudan-Uganda frontier at Nimule. The northern boundary will be at Jonglei; but it is important to note that this applies only to the intermediate constructional stages. When the 55 m/d Canal stage is reached, the boundary will be at the Bahr el Jebel barrage at Atem Head. Under the method of operation proposed by the Egyptian Irrigation Department the river discharges in this reach will be high and will approximate to the present natural maximum during the timely period—roughly during the dry season, at a time of year when the river is normally low. During the untimely period—roughly the rainy season—the river will be low and nearer to its present minimum. Thus the present seasonal conditions will be reversed.

THE CENTRAL ZONE

The southern boundary will be at Canal Head at Jonglei or at Atem Head as described above. The northern boundary is 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 River Sobat. In this reach the water-levels in the natural channels will be kept low throughout the year in order to prevent losses by spill in the swamps. The major proportion of the water will be transmitted through the Jonglei Canal.

THE NORTHERN ZONE

From the northern boundary of the Central Zone described above to Kosti. In this reach the Sobat flood will keep the water-levels high in the untimely period, and during the timely period the levels will still remain high owing to the higher discharges passed through the Canal. The river will therefore remain permanently higher throughout the year, with a considerable reduction in the present range of levels. This will apply as far north as Melut; below that point the Jebel Aulia Dam will modify this effect.

The different hydrological effects of the Project and the reasons for these distinctions are explained in Chapter 2 of Volume II and summarized on pp. xlv-vi of this volume.

TECHNICAL TERMS AND ABBREVIATIONS

Timely season (period):	The time of year when water is required for irrigation in Egypt. The period will be: At Mutir: December 5th to June 14th. At Mongalla: December 11th to June 20th. At Malakal: December 21st to June 30th. At Aswan: February 1st to July 31st. In the south the timely season therefore approximates to the dry season.
Untimely season (period):	The remainder of the year. In the south the untimely season therefore approximates to the rainy season.
Mds:	Milliards (one milliard=1,000 million cubic metres of water per year).
m/d:	Millions of cubic metres of water per day.
55 m/d Canal stage:	The stage in construction of the Jonglei Canal when the maximum discharge through the Canal amounts to 55 m/d. Hence also 10 m/d Canal stage; 80 m/d Canal stage; etc.

mm.	Millimetre.
cm.	Centimetre.
m.	Metre.
m ³ .	Cubic metre.
km.	Kilometre.
sq. km.	Square kilometre.
cm./km.	Centimetres per kilometre.
m ³ /sec.	Cubic metres per second.
cumecs.	Cubic metres per second.
m ³ .p.f.	Cubic metres per feddan.
m ³ .p.f./day	Cubic metres per feddan per day.
kg.p.f.	Kilogrammes per feddan.
R.L.	Reduced Level.
A.U.	Animal Unit(s). 1 A.U.=1 head of cattle = 8 sheep or goats.
TAUM	Thousand Animal Units per Month.
J.I.T.	Jonglei Investigation Team.
F.I.R.	First Interim Report
S.I.R.	Second Interim Report
T.I.R.	Third Interim Report
S.N. & R.	Sudan Notes and Records. A local journal of a scientific nature.
E.I.D.	Egyptian Irrigation Department.

SOME COMMON ARABIC TERMS

<i>dura</i>	Sorghum, millet.
<i>hafir</i>	Surface storage tank.
<i>haraq</i>	From the root <i>haraq</i> , to burn. A method of cultivation in which the old stand of coarse grass is burnt off to clear the ground.
<i>jebel</i>	Hill, mountain.
<i>khor</i>	Natural watercourse or minor river channel.
<i>maya</i>	Basin, lagoon, lake; usually with a direct channel leading to the river.
<i>goz</i>	Sand dune, sandy outcrop.
<i>saqia</i>	'Persian water-wheel'; an irrigation water-raising device using animal power.
<i>shaduf</i>	A hand-operated irrigation water-lifting device.
<i>sudd</i>	Lit. a barrier; general term denoting the area of swamp between roughly Mongalla and Lake No. Also used to refer to types of vegetation characteristic of permanent swamp, in particular papyrus.
<i>toich</i>	River flood-plain inundated seasonally from the river; marshland; water-meadow.

ORTHOGRAPHY

The spelling of place names recorded in the text of this report and on the maps and diagrams follows generally the Gazetteer of the Sudan Survey Department. We are aware that many of these names are incorrectly spelt, but consider that consistency with existing maps of the Sudan is on the whole more important than phonetic accuracy. Local vernacular words—always in italics—are not rendered phonetically in this report and sounds are given the nearest English equivalent; e.g. *toich* (phon. *toc*).

CONVERSION FACTORS

Throughout this report the metric system of weights and measures is used, with the important exceptions of the units of area where the local 'feddan' unit is employed and of certain weights and capacities where 'rotls' and 'kantars' are sometimes used.

The following table will be of assistance to readers more familiar with the British system:

Units of Length

1 metre	= 3.28 feet
	= 1.09 yards
1 kilometre	= 0.621 mile

Units of Area

1 square metre	= 10.76 square feet
1 square kilometre	= 0.386 square mile
	= 248 acres
	= 238 feddans
1 feddan	= 4,200 square metres
	= 0.420 hectare
	= 1.037 acre

Units of Volume or Capacity

1 cubic metre	= 35.31 cubic feet
	= 1.308 cubic yards
	= 220.1 Imperial gallons
	= 0.000811 acre feet
1 rotl (liquid)	= 451 cubic centimetres
	= 0.97 pint

Units of Flow

1 million cubic metres per day	= 11.6 cubic metres per second
	= 408 cusecs or second-feet
	= 153,000 Imperial gallons per minute

Units of Slope

1 cm./km.	= 0.0528 feet/mile
	= 1/100,000

Units of Weight

1 kilogramme	= 2,205 lb.
1 metric ton (1,000 kg.)	= 0.984 long ton (2,240 lb.)
1 rotl (weight)	= 449.28 grammes
	= 0.99 lb.
1 kantar*	= 44.93 kilogrammes
	= 99.05 lb.

Units of Money

One Pound Egyptian £E.1.000	= £Stg.1. 0s. 6d.
	= \$ 2.77

*Cotton is usually quoted by the 'kantar' and when applied to ginned cotton this is the normal kantar of 100 rotls. For unginned cotton, however, it may be equivalent to 100, 105, or 315 rotls. When the unit appears in this report, the number of rotls (or pounds) in the particular kantar is specified in brackets: e.g. 'Kantars (315)'.

SUMMARY
OF
VOLUMES I and II

VOLUME I. A SURVEY OF THE AREA AFFECTED

CHAPTER 1. HYDROLOGY

TOPOGRAPHY

(See Maps 1 and 6)

For its topographical description, the Jonglei Area can conveniently be divided into the following sections :

- (a) The river itself, i.e. the Bahr el Jebel and the White Nile from Nimule to Kosti.
- (b) The South-Eastern Area—east of the Bahr el Jebel and south of the White Nile and Sobat.
- (c) The South-Western Area—west of the Bahr el Jebel and south of the Bahr el Ghazal.
- (d) The Northern Area—north of the White Nile from Lake No to the Sobat mouth, and north of the Sobat.

The Bahr el Jebel and the White Nile: Between Nimule and Kosti the longitudinal slope of the main river decreases progressively from south to north from more than 100 cm/km. to less than 1 cm/km. From Nimule to the neighbourhood of Juba the Bahr el Jebel lies in a well-defined valley with hills on both sides. From Juba to Bor the river runs between alluvial banks in a flood-plain limited by high ground on either side to a maximum width of about 10 km. This high ground continues to about 15 km. north of Bor on the east bank, and to Lake Nuong on the west bank, 610 km. and 356 km. from Lake No respectively. North of the limits of high ground the width of the flood-plain is not marked by any topographical features, and the river runs between belts of papyrus on a deltaic ridge of alluvium. From east of Lake No on the White Nile (and south of Fangak on the Bahr el Zeraf) the formation is similar to that south of Bor, the flood-plain being limited in width by high ground to 2 km. on the average. Here the high ground is in the form of ridges, running parallel to the Nile, which we have named the 'Shilluk ridges'. On the inland sides of the ridges are depressions or plateaux, slightly dished in shape, beyond which are slight but steady rises in ground level. North of Jelelein the river appears to lie in a valley whose sides slope gradually but perceptibly towards the river.

The South-Eastern Area (see Figs. A 26 and D 27) : The South-Eastern Area is characterized by groups of isolated mountains on the southern border, of which the highest is Mt. Kinyeti (3,187 metres). Between the 4th and 5th parallels N. the foothills terminate, and northwards the country is a vast plain with a gentle slope varying from more than 50 cm/km. in the south to about 10 cm/km. in the north, bounded on the east by the line of the rivers Kengen, Akobo, and Pibor.

The South-Western Area (see Figs. A 30 and D 53) : The South-Western Area is characterized by a plateau extending northwards from the Sudan border on the Nile-Congo divide, with a few isolated peaks of which the highest is about 1,700 metres. Northwards the plateau gives place to an ironstone peneplain, inclined northwards and disappearing below the clay plain at about the 400 m. contour between the 7th and 8th parallels N. The clay plains are confined to the northern portion of the area between the Bahr el Ghazal and the Bahr el Jebel, and to a narrow strip bordering the river southwards to Juba.

The Northern Area (see Fig. D 56) : The Northern Area consists of a flat valley cut in two by the White Nile and bounded by the Ethiopian foothills in the east and the Nuba Mountains (or Eastern Kordofan Jebels) in the west.

CLIMATE

(See Map 3)

The Jonglei Area lies within two climatic zones ; the zone of steppe climate, and the zone of grassland-savannah climate. The 640 mm. (25 inch) isohyet may be taken as the rough boundary between the two. Since the southernmost point of this isohyet is at Melut, where it crosses the White Nile, the larger portion of the area is in the grassland-savannah zone. Rainfall is the principal limiting climatic factor, not only because of its direct effect, but also because of its indirect influence on humidity, temperature, insolation, and air movements.

Rainfall (see Fig. B 1) : The South Atlantic Ocean is the main source region of rainfall over the Southern Sudan, and precipitation is caused by convection, orography, and the meeting of cold north and warm, moist south winds. Topography has a marked influence on rainfall intensity ; in the south in the mountains rainfall averages about 1,400 mm. per year, whereas in the plains it is no more than about 900 mm. In the north in the Nuba Mountains the average annual rainfall is about 800 mm., whereas at Kosti on the river in the centre of the plain it averages only 400 mm. The swamps of the Flood Region appear to have the local effect of increasing the rainfall at Tonga, Malakal, and possibly Fangak. It cannot be over-emphasized that the average annual rainfall intensities mean very little ; there are long dry periods between the rainy seasons, of 5 months' duration in the south and 9 months' duration in the north ; the standard deviations of rainfall intensity are between 20% and 30% of the annual intensities, and between 50% and 60% in individual months. For this reason the effect of the equatorial double maximum intensity of rainfall with a relatively dry period in between may be felt as far north as Malakal in any one year. The wide variability of rainfall combined with the narrow range of useful soil moisture of the plains on which it falls has the important result that drought and flooding (' creeping flow ') can follow each other in quick succession.

Other Climatic Factors (see Figs. B 2-5) : The average annual evaporation varies from one metre in the south-east mountains to three metres at Kosti (0.5 x Piche). The variations in temperature ranges according to geographical position are rarely more than 5°C., so that as far as temperature is concerned the Jonglei Area can be considered an entity. The seasonal occurrence of rainfall results in wide ranges of relative humidity throughout the year, from 10% to 90%, though the effect of the dry north wind disappears between Malakal and Renk. Insolation, as indicated by cloud intensities at a few stations, decreases from north to south. Wind velocities increase from south to north, and the effect on them of the equatorial rain distribution is not noticeable at Juba.

HYDROLOGY

MAIN RIVERS

The Bahr el Jebel from Nimule to Mongalla : The river in this reach flows swiftly in a well-defined and narrow channel as far as Juba, where it begins to spill on to the flood-plains at its highest discharges. The flow at Mongalla is made up of a fairly steady discharge from Lake Albert to which is added the seasonal run-off in numerous local torrents which join the river after it leaves the lake.

The Bahr el Jebel from Mongalla to the Tail of the Swamps : This reach of the river is usually referred to as the *Sudd* region. The river enters it in one channel at Mongalla and leaves it in one channel, the White Nile. Between these points it spreads out, with numerous side-channels, forming a vast swamp of papyrus and other vegetation, where about half of the water is lost, mainly by evaporation. The passage of water through the swamps is slow and the effects of extremely high floods in one year can be observed in the outflow a year later. The flow at Mongalla normally averages 74 m/d, but has averaged 110 m/d and 50 m/d in different five-year periods. Corresponding figures for the flow at the Tail of the Swamps are 39, 47, and 32 m/d. The main river channels can carry 65 m/d between Mongalla and Bor, and 30 m/d north of Jonglei without excessive losses. At higher discharges the water spills into a series of swampy basins such as the Aliab, the Atem-Awai, and other less distinct systems farther north. The basins are usually terminated at their northern ends by bluffs of land which cause expanses of open water to form, such as Lake Papiu, Lake Nuong, and Shambe lagoon, and which force some of the water spilled out from the river back into it. The flow in the swamps can be gauged and related to discharges at Mongalla and is the sum of the discharges in all the channels intersected by lines at certain latitudes, namely at Jonglei and downstream of the Zeraf Cuts. The Bahr el Zeraf starts in the eastern swamps of the Bahr el Jebel, is connected to it by two artificial channels, parallels it in its lower reaches, and joins the White Nile in its easterly course from Lake No to the Sobat mouth. North of Bor on the east bank and of Lake Nuong on the west bank, where there is no high ground to limit its spread, water spills from the river over both banks in varying proportions on to plains and much of it never returns to the main river. From Buffalo Cape on the Bahr el Jebel, and from south of Fangak on the Bahr el Zeraf, river levels and the amount of spill depend more on the backwater effect of the Sobat where it joins the White Nile. The area of swamp has been estimated (from air surveys in 1930-31) to be 8,300 sq. km. The flow at the Tail of the Swamps is computed by subtracting the observed discharge of the Sobat near its mouth from that of the White Nile at Malakal.

The White Nile from the Tail of the Swamps to Kosti : The flow at Malakal is composed of an almost steady discharge from the swamps, about 39 m/d, and the discharge of the Sobat, which varies from 7 m/d to 67 m/d at its mouth. Thus the Malakal discharge normally varies from 45 m/d to 106 m/d, though extremes of 28 m/d and 168 m/d have been recorded. The range of levels from Malakal to Melut is normally 2.25 m. North of Melut the levels depend on the operation of the Jebel Aulia Dam, and the ranges are 2.8 m. at Renk, 4.0 m. at Kosti, and 6.0 m. at Jebel Aulia. Water losses north of Malakal are small because the flood-plains are limited in width to about 2 km. by high ground, and the actual losses are sometimes obscured by inflow from Khors Nyadwai and Adar.

The Bahr el Ghazal : The contribution of the Bahr el Ghazal to the White Nile is a small fraction of one milliard in a normal year and is therefore negligible.

The Sobat and its Tributaries : The hydrology of the Sobat and its tributaries is important in the Jonglei Area because it is connected with drainage from the South-Eastern Area, and because spill from its main tributary, the Baro, is the principal source of water reaching the Machar Marshes which lie to the north-east of Malakal. The Sobat is formed by the junction of the Baro, which rises in Ethiopia, and the Pibor, which drains part of the Eastern Plain in the Sudan. No large quantities of water are spilled from the Sobat west of Nasir, but there are some minor channels connecting the Sobat with the Wakau-Wol branch of the marshes on its north bank, and others draining the Eastern Plain on its south bank. Normally water from the Sobat fills these channels on the rising flood, and returns to it when the flood is falling. In years of abnormally high floods inflow from the southern tributaries, and possibly from the northern ones, is considerable. Even in normal years, when the flow into the side-channels, is insignificant in comparison with that of the Sobat, it is sufficient to have an important effect on the vegetation in the channels and thus on the livelihood of the inhabitants.

SWAMP FORMATIONS

On the Bahr el Jebel and the White Nile the swamps fall into three divisions : those in the south which are bounded by high ground, those in the centre which extend over the plains, and those in the north which are contained by the ' Shilluk ridges '.

The Southern Swamps : The southern swamps, as indicated by detailed surveys carried out in the Mongalla-Gemmeiza reach and Aliab Valley (see Volume III, Chapter I), are formed on the flood-plains of the Bahr el Jebel, which are shallow, dished depressions, lying in general below the water-level in the river. They are usually bounded topographically by high ground on one side and by the alluvial bank of the river on the other. They are also intersected by several old and minor channels whose alluvial banks form barriers interrupting the spread of spill-water from the river. These swampy basins receive moisture in five different ways : by spill from the main river, by backwater from the river, from local run-off, by seepage underground, and from rainfall. In the southern swamps the extent of flooding from the river depends largely on the backwater, and thus on the river's seasonal rise and fall.

The Central Swamps : The central swamps differ from the others mainly because there is no high ground to limit the spread of water. Also, since the river here normally spills over its banks all the year round, there is little distinction between spill and backwater. The highest discharges of the river, and thus the greatest spill, occur at the same time as the heaviest rainfall, and conversely the lowest discharges, and least spill, occur when evaporation is greatest. The boundaries of the swamps therefore expand and contract in phase with the seasons, and, as will be seen later, riverain pastures in the dry season result from this flooding and uncovering.

The Northern Swamps : These are similar to the southern swamps but differ in degree ; they are not so wide, the range of river levels is greater, and the longitudinal slopes are smaller than in the south. Thus flooding depends almost entirely on the seasonal fluctuations of the river which are some three months out of phase with the rainy season.

INLAND WATER-SYSTEMS

THE SOUTH-EASTERN AREA

The South-Eastern Torrents (see Fig. A 26) : A few of the torrents of the South-Eastern Area join the Bahr el Jebel south of Juba ; others flow northwards from the south-eastern mountains to the plains, and never reach the river. The latter torrents comprise the Kudo, Kinyeti, Koss, Kidepo, Singaita and Lokalyan. The total flow of these torrents, assessed by records (for a year or two only) of gauges sited in the foothills, amounts to about three-quarters of a milliard, but this water is quickly dissipated when the rivers reach the plains, and under normal conditions flooding does not extend far beyond the 5th parallel N. Much of the

run-off in the four western torrents is lost in underground seepage, but the country through which the eastern two run consists of impermeable clay. The upper catchments of the western four are well forested, rainfall is heavy, and some of these torrents flow perennially in their upper reaches. The catchments of the eastern two are deforested by overgrazing, rainfall is lighter, and the rivers flow in spasmodic spates.

The Kabowen and Badigeru Swamps : The Kabowen Swamps are formed by the junction of the Lokalyan with the Kurun which flows westwards from the Ethiopian plateau. The Kengen, a wide, grassy depression which cannot carry a significant discharge, emerges from the swamps and can be followed to its junction with the Pibor at Akobo ; it is the only defined channel connecting the south-eastern torrents with the Pibor tributaries. The Badigeru Swamp appears to be formed by flood-waters from the Kudo and the Kinyeti, though there is no sign on air photographs of any defined channel connection.

The Southern Impermeable Plain : Observations on the Kinyeti and the Kidepo show that flooding from them does not normally extend far beyond the 5th parallel N., and so does not normally have any effect on 'creeping flow', or overland flooding, at Pengko, 100 km. farther north, as was previously supposed. However, under conditions of abnormally heavy rainfall on the plain and run-off from the mountains it is more than probable that flooding on the plains does reach that point. The Vevno collects run-off from the eastern part of the plain ; there is one drainage depression east of Pengko by which water can pass to the north.

The Eastern Plain (see Fig. D 27) : The country north of a line from Bor to Pibor, east of the Bahr el Jebel and Bahr el Zeraf, and south of the White Nile and Sobat. It is characterized by the phenomenon of 'creeping flow' which is due to a combination of factors such as the existence of wide, shallow drainage depressions which eventually become watercourses in the north (e.g. Khors Atar, Geni, Fullus, etc.), heavy rainfall, spill from the Atem-Awai system in the west, spill from the Pibor in the east, in certain circumstances drainage from farther south via the Pengko depression, and above all the small moisture capacity of the soil (see Fig. D 28). The available evidence shows that local rainfall is the main cause of this type of flooding.

THE ZERAF ISLAND

The extremely flat area contained within the Bahr el Jebel, Bahr el Zeraf, and White Nile, known as the Zeraf Island (see Fig. D 30), is intersected by numerous wide, shallow, grassy watercourses running east-west and south-north. The flow in them is small, but they play an important part in the livelihood of the people by providing drainage for habitations, cultivation and roads on their deltaic banks during the rains, and grazing and water supplies in the dry season. They are also affected by water-levels in the main rivers.

THE SOUTH-WESTERN AREA

The South-Western Torrents (see Fig. A 30) : The torrential streams of the South-Western Area comprise a number which join the Bahr el Jebel and flood its *toiches* as far north as Lake Nuong, and others which flow northwards to the swamps between the Bahr el Jebel and the Bahr el Ghazal. The total average annual run-off of those in the former category is estimated to be 1.2 milliards, and in the latter 3.2 milliards measured on the line of the road from Yirol to Tonj. As the northward-flowing torrents begin to spill south of that line on to flood-plains which increase in width northwards, only a fraction of that flow reaches the swamps in a normal year, though, as in the east, abnormally heavy rainfall and river spill result in widespread flooding.

The Western Plain (see Fig. D 53) : The 'Western Plain', where this flooding occurs, is the triangle of land between the Bahr el Ghazal and the Bahr el Jebel, and it is estimated that about 6 milliards are lost in spill westwards from the Bahr el Jebel between Lake Nuong and Buffalo Cape, in addition to whatever water reaches it from the torrents and the Bahr el Ghazal. The plain is intersected with watercourses similar to those on the Zeraf Island.

THE NORTHERN AREA

East Bank of the White Nile (see Fig. D 56) : North of the Sobat and east of Malakal lie the Machar Marshes (the subject of a special investigation—see Volume III) which are fed by spill from the Baro, by run-off from the Ethiopian plateau in torrents in the east, and by rainfall, in quantities of water of the order of 3, 2 and 15 milliards respectively. Water passes through the swamps by three main routes : from one branch of Khor Machar north-west to Khor Adar ; from a westerly branch of the Khor Machar to Khor Wol ; and from the eastern

torrents to the Khor Adar. Small exchanges of water occur through minor channels connecting the Khor Machar-Khor Wol branch of the swamps with the Sobat. The two drainage-channels, Khors Wol and Adar, do not discharge more than about 0.3 milliards in a normal year, although in the conditions of abnormal rainfall and flooding from the Baro which occurred in 1946-47 drainage from the marshes between Malakal and Melut was of the order of 1.5 milliards. The size of the swamps is extremely variable and in the five years from 1940 to 1945, when rainfall and spill were below normal, they were known to be very dry, whereas in the five years from 1945 to 1949, when rainfall and spill were well above normal, the swamps covered about 20,000 sq. km. and were maintained throughout the dry season. North of the 11th parallel N. inland watercourses originate from isolated rocky outcrops. The flow in them, during the rains, consists of spasmodic flushes which seldom reach the Nile.

The West Bank of the White Nile (see Fig. D. 56) : The Nuba Mountains do not compare in height and extent with the Ethiopian highlands, and the run-off from them in many small watercourses is quickly spread out over the flat plain which lies between them and the White Nile. The Raqaba is a shallow, saucer-shaped depression which parallels the White Nile from Khor Turor near Tonga to Khor Farnad north of Malakal, and because of its topography is characterized by flooding from local rainfall. Rain-water in the depression cannot drain either to the Nile, because of a ridge, or northwards, owing to lack of slope. The Nyadwai forms a compact inland drainage system near Kodok, and is one of the few inland areas occupied by the Shilluk tribe, who otherwise confine themselves to ridges of higher ground near the river. North of the 11th parallel N. inland water-systems can only be discerned in their upper reaches near the Nuba Mountains. On the plains they can occasionally be traced by lines of larger trees which grow near their edges, but they have no defined or continuous channels.

DOMESTIC AND STOCK WATER SUPPLIES

The people of the Jonglei Area normally obtain drinking-water for themselves and their animals from natural sources such as the main rivers, the larger inland watercourses, and from pools in the beds of the wide, shallow watercourses of the central plains.

Hafirs : Surface conservation of rainfall in artificially constructed ponds, or hafirs, has not been widely practised until recently, when an extensive programme of hafir-digging by machinery was started by the Rural Water Supplies and Soil Conservation Board. These hafirs average 10,000 m³. in capacity, each providing water for between 250 and 750 head of cattle, depending on location.

Wells : Though wells are common in the Ironstone Region west of the Bahr el Jebel, they are scarce in the east in the foothills of the south-eastern mountains. On the plains wells are few and far between, except in Bor District where an energetic District Commissioner has exploited particularly favourable conditions which are not to be found elsewhere. Here, owing to homogeneous strata and the proximity of the sources of underground supply, water can usually be found at less than 120 feet below the surface (see Fig. D 58). Elsewhere wells have been successful when sited near drainage depressions where there are sandy outcrops, such as along the Duk Ridge on the Eastern Plain and at Ler and Kwernyang on the Western Plain. Owing to the migratory habits of the people in the Northern Area there are few wells, except in Kosti District where the palatability of the inland grasses in the dry season is a factor which has encouraged well-digging in a favourable sub-soil.

Deep Bores : The results of the Team's survey of underground water supplies were that water was found in all of the eleven deep bores sunk ; that the water west of the White Nile and north of the Sobat was saline, whereas that to the south was potable ; that yields of 1,000 g.p.h. could be expected over the area ; and that the shape of the underground basin was generally in accordance with the deductions from geological considerations, although none of the bores succeeded in reaching basement complex. Twin-bore water-yards in Kordofan are capable of watering 2,500 head of cattle per day on the average, and twice that number when occasion demands.

IRRIGATION

It is suggested that irrigation water can be used more economically to supplement rainfall than to produce crops in an area which is rainless.

Natural Irrigation : The riverain marshes of the *Sudd* region, the *Māchar* Marshes and the flood-plains of the northward-flowing torrents can all be regarded as examples of natural gravity irrigation in the Jonglei Area.

Pump Irrigation : A gross area of about 22,000 feddans was irrigated by pumping from the White Nile in the Jonglei Area in 1952.

Areas Suitable for Controlled Irrigation : Wherever natural irrigation exists today artificial control might be introduced with advantage. Other areas suitable for controlled irrigation schemes would be on the Eastern Plain from the Jonglei Canal, or on the Western Plain with a suitable canal leading to it from Jonglei. Considerable extension of pump irrigation in the Northern Area could be made.

DRAINAGE

Main Rivers : In the Flood Region of the Jonglei Area lack of natural drainage where rainfall is heavy and the soil impermeable is partly responsible for an economy in which cattle play a predominant part. The outstanding feature of the main channels in the *Sudd* region is that they spill on to the plains, so that they are useless as drainage-channels for the areas through which they flow. Exceptions are the Bahr el Jebel in the far south, the White Nile from east of Lake No, and the Bahr el Zeraf from south of Fangak.

The South-Eastern Area : The south-eastern torrents are the natural drainage-channels from the mountains, but they flood the plain between the foothills and the 5th parallel N. With one or two exceptions the plains northward are characterized by the lack of defined drainage-channels. Even the distinct watercourses in the northern fringe of the area do not drain the plains until the Sobat flood has subsided. The inland watercourses of Zeraf Island provide drainage for limited areas on their alluvial banks.

The South-Western Area : The south-western torrents drain the plateau and peneplain of the Ironstone Region as far north as the 7th or 8th parallel. From there northwards natural drainage is confined to the alluvial banks of inland watercourses, as on the Zeraf Island.

The Northern Area : In this area torrents drain the Ethiopian and Ingessana hills in the east, and the eastern side of the Nuba Mountains in the west. The main drainage-channels of the plains between the hills and the White Nile are Khors Adar, Wol, and Nyadwai, but the existence of the Machar Marshes shows how ineffective the first two are, and the third is extremely limited in extent.

Areas Suitable for Artificial Drainage : The uniform north-south slope of the Eastern Plain indicates that some artificial drainage is possible, but disposal of the water so drained in the north would be difficult owing to the high levels of the Sobat and the White Nile during the rains. The limited areas on the alluvial banks of the inland watercourses of Zeraf Island, the Eastern and Western Plains, and of the Northern Area might be extended by artificial drainage systems leading to cuts through the alluvial banks into the watercourses. The only outstanding examples of suitable conditions for artificial drainage are on the banks of the White Nile from east of Lake No and on the Bahr el Zeraf from south of Fangak northwards.

COMMUNICATIONS

(See Map 4)

River Transport : In the Flood Region, where most roads are impassable for six months of the year, river transport is at present of prime importance, but during the dry season a few navigational difficulties are encountered. Between Juba and Terakeka steamer services are often held up because of shifting sandbanks and insufficient depth of water. The waterway is also restricted in width and depth at a bottle-neck in the Bahr el Jebel south of Lake Papiu. Other difficulties which should be mentioned are the fast current near Juba during floods, *sudd* blocks on the Bahr el Jebel, and the tortuous channel through the *Sudd* region. North of Malakal there are obstacles at low river in the form of shallows and rocks at Jebel Ahmed Agha, Ez Zeleit, and Abu Zaid Ford.

Roads : Since there are no railways in the Jonglei Area, road communications are next in importance to river transport. Road types are related to the ecological divisions of the area ; in the Ironstone Region there are good all-weather roads and substantial bridges ; in the Flood Region roads are frequently embanked across inland watercourses and drainage depressions, and bridges are small and of semi-permanent construction ; in the Semi-Arid Region roads are for the most part only tracks made by vehicles over open country, and only in a few cases are made by clearing grass and grading the soil. In the latter two Regions the roads, being made from local clay soil, are usually impassable during the rains, and must be cleared and repaired annually after the wet season.

In the Ironstone Region roads are aligned from river ports to centres of habitation, and for this reason the positions of the navigational heads of the rivers are important. Juba is the main port for Equatoria Province, but its place may have to be taken by another port at Terakeka. Wau is the navigational head of the Jur River, but is only accessible for a few months in the year. The serpentine course of the river, often blocked by *sudd*, can only be navigated with great difficulty, and progress is slow. For these reasons Shambe on the Bahr el Jebel would undoubtedly be a better port for Bahr el Ghazal Province. In the Flood Region roads have been constructed primarily for administrative purposes, and therefore link the more permanent villages. The latter are of necessity set on the only high ground available, on the alluvial banks of inland watercourses along which the roads therefore usually run. Recently large areas have been opened up for the production of crops by roads graded mechanically by the hafir-digging teams. In the Semi-Arid Region roads were originally aligned largely for administrative convenience, but the need to tap districts where crops are grown in increasing amounts has now become of greater importance.

Air Services : Internal air services have been introduced comparatively recently, but in 1952 they carried about one-twelfth of the number of passengers transported on the river in one year, though the tonnage of freight was about 1/1,000 of that carried by steamers.

CHAPTER 2. ECOLOGY

PART I. SOILS

The soils of the Jonglei Area can be classified into four main groups (see Map 8 and Fig. E 2). Three of these groups correspond geographically to the three main Regions into which this area has been divided on the basis of environmental, soil, and ecological characteristics. The fourth group, common to all three Regions, has developed under the influence of special hydrological conditions, associated with seasonal inundation by spill from the annually rising rivers and watercourses transecting the Jonglei Area.

THE SOILS OF THE IRONSTONE REGION

These can be regarded as mature. They have mainly developed *in situ* on the rocks of basement complex and other minor geological formations. The laterization of these soils, though not necessarily contemporary, reflects the more humid climate and superior drainage of the Region. The topography has played a considerable part in the formation of the soils, and a catenary succession of soil as well as of vegetation types is common in this Region. Crop cultivations are mainly found on colluvial soils and deeper eluvial soils. The illuvial, often mixed with alluvial, soils, though inherently the most fertile, are subject to drainage difficulties.

THE SOILS OF THE FLOOD REGION

These soils, as well as the great majority of those of the Semi-Arid Region, owe their origin to predominantly clayey alluvia, though lighter alluvial formations are also present. The extremely flat topography, the inferior drainage system and the character of parent materials are responsible for the frequent occurrence of floods, which, as well as local rainfall, control moisture conditions. The soils of the Flood Region can be broadly divided into two types : (i) the periodically flooded soils of intermediate land, and (ii) the non-flooded soils of high land. In the first type, which predominates in this part of the Jonglei Area, the periodic occurrence of anaerobic and reducing conditions, alternating with periods of drought, has left several impressions on soil profile and properties. From the agricultural point of view the impeded drainage of these soils is the chief factor limiting their wider utilization and present crop yields. The non-flooded soils are limited in acreage, and very often show signs of overcultivation and the effects of heavy grazing during the rainy season. Both these types can be further sub-divided on the basis of their texture into clays, loams, and sandy soils. The cracking clays (often wrongly called 'the cotton soils') are the most common class in the Flood Region.

THE SOILS OF THE SEMI-ARID REGION

These can be regarded as typical for this climatic zone. Their textural properties are the best basis for their classification. The clay soils can be classified further into Blue Nile (or 'Gezira' type) clays, according to their geological origin which is reflected in their appearance and properties. The sandy soils owe their origin mainly to alluvial but also to aeolian deposits, as well as to rocks of the basement complex protruding in a few localities of this Region through the matrix of the transported, newer material. The majority of them are found in 'qoz' (sandy dune) formations and, as the topography has affected their development, they can be sub-divided further into eluvial, colluvial, illuvial, and illuvial-alluvial soils of the Qoz Catena. With the exception of non-cracking sandy-clay soils found in both the Semi-Arid and Flood Regions, which, though of great scientific interest, are very infertile, the soils of this part of the Jonglei Area can be regarded as of average fertility. The lack of moisture is the main factor affecting their vegetation cover.

INTER-REGIONAL SOILS

These are found throughout this area on *toich* and *sudd* land bordering the rivers and larger watercourses. Flooding by spill, which produces seasonal anaerobic and reducing conditions, is also the best basis for their classification. The *sudd* soils are flooded for a great part of the year and waterlogged all the year round. The accumulation of organic matter due to the low rate of decomposition under anaerobic conditions produces a peat layer which is absent in all other soils of the Jonglei Area (see Fig. E 3). This horizon, composed of a vegetation mat, floating during the high river seasons and resting on the decomposed peat layer at low river, varies according to the site as well as the river level. At present these *sudd* soils are not utilized for agricultural purposes. *Toich* soils, flooded by spill from two to six months every year, though lacking a purely organic horizon, have an organic matter content considerably higher than inland soils. Their fertility is of a proportionately higher order, but their agricultural utilization is at present limited by variable depth and duration of flooding. Their principal advantage is that they produce green pasture grasses throughout the dry season, a time of the year when inland pastures are unsuitable for various reasons.

PART II. VEGETATION

As a preliminary to our study of the vegetation of the Jonglei Area it has been necessary to attempt a classification of the plant species into manageable groups. Most classifications of vegetation are ecological in their conception, since major differences can be attributed to some change in environment. Different environments arise from variations in climatic, edaphic, physiographic and biotic factors. Of these the climatic factor—particularly rainfall—and the edaphic (soil) factor appear to us to be of major significance in determining the more obvious physiognomic features of vegetation in the area. Major physiographic variations occur only in the southern parts of the Jonglei Area, where they give rise to the development of vegetation very different from that found farther north. Elsewhere less noticeable changes in topography, often associated with different soil types, determine much less distinct variations in vegetation.

The difficulties of classification are considerable. As demonstrated by Smith⁽¹⁾, no tree species is strictly limited in its distribution to a particular rainfall range or to a particular soil type if these two are considered separate factors. On the other hand a tree species has a definite and peculiarly limited rainfall range on any definite or particular soil type, and on the same soil type in a different rainfall range other species will establish themselves, the first tree species being absent. Nearly all tree species show a change of rainfall requirements with a change of soil on datum sites, i.e. sites that receive their moisture by direct rain precipitation only and from no other source. In general terms "the tree species which requires $3 \times X$ inches of rain on clay soils requires less than $2 \times X$ inches of rain on sands".⁽²⁾ This Smith considers to be due to a direct relationship between the percentage of clay in the soil and the ability of the soil to make the water it receives as rainfall available to the plant. This contention is questioned by Harrison,⁽³⁾ who quotes as an example the scantier and drier type of vegetation found on non-cracking clay flats which have a lower clay fraction than the cracking clays. Moreover, in connection with the distribution of grass species, Harrison points out that grass—in general terms—follows the same line of distribution in relation to the soil texture-rainfall factor as

(1) Smith, J., "Distribution of Tree Species in the Sudan in Relation to Rainfall and Soil Texture", *Min. of Agric. Bull.* No. 4, Khartoum.

(2) *Ibid.*, p. 43.

(3) Harrison, M. N., "Report of a Survey of the Grazing Areas of the Sudan", unpublished Sudan Government Report.

trees, but that the pattern is not so clearly distinct in that grasses are more confined in their distribution to certain areas, and unlike trees do not usually extend from one extreme of soil type to another. This also applies in respect of rainfall, the most obvious example being the grasses of the *hariq* grassland areas (see p. 134) which are only found on cracking clay soils and never found on sandy soils whatever the rainfall.

There is therefore a definite distributional trend of both tree and grass species in relation to the soil texture-rainfall factor, which would appear to obscure any definite zoning of species in relation to the rainfall factor or the soil factor separately. Nevertheless we find that over so large an area it is possible to divide and classify the vegetation into large units which are different in their main characteristics. Within these larger units it is also possible to make smaller divisions based on less distinctive ecological differences.

In general the major classifications of the vegetation correspond with the three main Regions of the Jonglei Area (see p. x), but the very great variety of vegetation makes a summary difficult unless it is to consist of a comprehensive list of vegetation species. The main characteristics (see Map 7 and Fig. E 2) are as follows :

THE VEGETATION OF THE IRONSTONE REGION

In this Region is an area of mixed deciduous broad-leaved woodland with tall, perennial grasses, and in some parts gallery, depression and cloud forests. The main characteristic of the mixed deciduous broad-leaved woodland is the very large variety of tree species, the most notable being *Khaya senegalensis*, *Terminalia mollis*, *Anogeissus schimperi*, *Butyrospermum parkii* var. *niloticum*, and *Combretum* spp. Of the tall, clumpy perennial grasses *Hyparrhenia rufa*, *H. dissoluta*, and *Andropogon gayanus* are widespread ; some annual grasses are found, generally on old cultivation sites. The flood-plains of the rivers and watercourses which transect the area have heavier clay soils and are characterized by *Acacia seyal*, *A. senegal* and *Balanites aegyptiaca* at the higher levels ; at the lower levels there is open grassland, mainly *Hyparrhenia rufa* with some *Vetiveria nigritana* or *Sporobolus pyramidalis*, and *Echinochloa* spp. in those parts subject to greater depths of flooding. The distribution of both tree and grass species follows the catenary succession of the lateritic soils of the Region.⁽⁴⁾ Fires sweep through the area regularly every dry season and this factor, as well as human activities, has modified the characteristics of the vegetation in some parts.

THE VEGETATION OF THE FLOOD REGION

The main vegetative characteristic of the Flood Region is the vast areas of open grassland. Various types of forests occur but these are less frequent and less luxuriant than those of the Ironstone Region. Variations in the type of grassland and forest occur with different soil types and particularly with the minor changes in topographical levels. The extreme flatness of the Region, combined with heavy rainfall and the impermeability of the clay soils, results in heavy flooding of very large areas during the rainy season. Moreover the Region is transected by a network of watercourses which, like the Nile itself, spill and inundate their flood-plains when the water-levels are high during and just after the rainy season. This incidence of flooding, or more precisely the various levels at which different degrees of flooding occur, has formed the basis upon which we have classified the vegetation of the Flood Region into smaller units. Thus we have areas of comparatively flood-free higher ground, which we call high land ; intermediate land, where the ground is saturated and often heavily flooded during the rainy season ; and swamp (see p. xi and Fig. E 1), where flooding is primarily due to river spill, run-off, and accumulations of rainfall, and which ranges from the *toich* land, which is seasonally inundated, to papyrus swamp, which is permanently under water. The main vegetative characteristics of these land types are as follows :

HIGH LAND: Forest includes the palm type (mainly *Hyphaene thebiaca*—the *dom* palm—and *Borassus aethiopicum*—the *doleib* palm); poorly developed mixed deciduous broad-leaved woodland ; mixed acacia dominated forest land ; and *Acacia seyal*–*Balanites aegyptiaca* forest. All these are found on high land in relation to ground levels and soil types. Grassland is composed of predominantly annual grasses such as *Pennisetum ramosum*, *Aristida* spp., *Eragrostis* spp. in the open areas, and *Rottboellia exaltata* and *Leptochloa chinensis* in the shade of the forests. The perennial grass *Setaria incrassata* is also extremely common, as is *Sporobolus pyramidalis*.

⁽⁴⁾ As demonstrated by Morrison, C. G. T., et al., " Tropical Soil Vegetation Catenas and Mosaics ", *Journal Ecology* 36, 1948.

INTERMEDIATE LAND: The soil is predominantly clay, although in many areas it has a high sand content. The main forest type is *Acacia seyal*-*Balanites aegyptiaca*, which is found mainly on the higher levels of intermediate land, where flooding is generally less severe than on the vast open grasslands which are typical of the lower levels. The main grass types are both perennial—*Setaria incrassata* and *Hyparrhenia rufa*. The former is found dominant on the higher levels of intermediate land, often in areas associated with *Acacia seyal*-*Balanites aegyptiaca*; the latter grass is characteristic of the lower levels where flooding lasts for many months in the year and where trees are generally absent.

SWAMP: *Toich* land or swamp which is seasonally inundated by river spill is true open grassland carrying what we call inland khor-bed grasslands and riverain grasslands, both of which are dominated by *Echinochloa* spp. The dominant vegetation type in permanent swamp, or *sudd*, is *Cyperus papyrus*. Swamp land—both seasonally and permanently inundated—is common to all three Regions of the Jonglei Area since it is found on the flood-plains of the Nile, which flows through them all. For this reason we treat this kind of land as ‘inter-regional’ and in greater detail than other types of land (see p. 150) since, from the point of view of the Equatorial Nile Project, it is the most important of all and the most significant in our investigation of the Project’s effects.

VEGETATION OF THE TRANSITIONAL BELT

North of the Flood Region and south of the Semi-Arid Region is an area in which the characteristics of neither region are well defined. This we refer to as the ‘Transitional Belt’. Within this area the forests are mainly of the *Acacia seyal*-*Balanites aegyptiaca* type, similar to that found in the Flood Region, while the grasses are predominantly annual, but tall annuals which differ from the short annual grasses of the Semi-Arid Region. These tall annuals are mainly *Sorghum purpureo-sericeum* and *Hyparrhenia pseudocymbaria* (*hariaq* grasses). There are also wide areas of the perennial *Setaria incrassata*.

VEGETATION OF THE SEMI-ARID REGION

Immediately north of the Transitional Belt is an area of *Acacia mellifera* thicket with open grassland of mixed tall and annual grasses, some of them tall annuals such as *Sorghum purpureo-sericeum* and *Hyparrhenia pseudocymbaria*, but mainly shorter annuals—*Sehima ischaemoides*, *Schoenefeldia gracilis*, *Tetrapogon spathaceus* and *Aristida* spp., etc. North of this again—and in the northernmost part of the Jonglei Area—is what we call the ‘acacia-short grass (*Qoz Catena*)’ area. The main feature is the regular changing pattern of the acacia forests and short annual grasses with the catenary succession of soil types (the sand of the *qozes* and the clay of the intervening plains). The larger acacias and associated bushes occur on the *qozes*, near the edges of the watercourses and near permanent water-points, whereas the clay plains usually carry a scanty grass covering of short annual grasses such as *Schoenefeldia gracilis*, except near the *qozes* where *Acacia mellifera* bush sometimes occurs.

INTER-REGIONAL : SWAMP VEGETATION OF THE JONGLEI AREA

The flood-plain of the Nile is a feature common to all three Regions of the Jonglei Area. Along the flood-plain there has developed a type of vegetation peculiar to the conditions produced by the present régime of the river. This applies also to the flood-plains of other large rivers—the Bahr el Ghazal, Bahr el Zeraf and Sobat—as well as to those of smaller channels and inland watercourses. In addition an ecological study of the *sudd*, or permanent papyrus swamp, is included in our survey since it owes its development to the Nile, although it is not truly inter-regional, being generally restricted to the lower reaches of the Bahr el Jebel between roughly Mongalla and the ‘Tail of the Swamps’, and is not found in large quantities north of the latter point. In our investigation, the study of both types of vegetation—the riverain grasslands or *toich* and the papyrus swamp or *sudd*—has involved the identification of the main constituents and the factors governing their distribution along the flood-plain between Juba and Kosti. The main species of the riverain grasslands are *Echinochloa pyramidalis*, *Oryza barthii*, *Echinochloa stagnina*, *Vossia cuspidata*, and in some areas *Phragmites communis*. *Cyperus papyrus* is the dominant plant in permanent swamp. There are many other plants (mainly climbers), but their distribution is closely associated with papyrus.

Of the factors governing the distribution of the above species along the flood-plain, the most important are the normal régime of the river and its seasonal fluctuations (i.e. flooding—both in depth and duration—and the rate at which the flood waters rise), current velocity, and soils and soil moisture. Other factors, which include rainfall, the annual firing of the

grass, and grazing by both domestic and wild animals, also influence the distribution of vegetation. Finally, there is competition between the plants themselves. All these have been studied both qualitatively and quantitatively, and we conclude that, of the measurable factors which affect the distribution of vegetation species along the flood-plain, depth and duration of flooding are the most significant. We may anticipate the next volume of our report by pointing out that it is just these factors which will be altered in the future when the Project takes effect. From detailed studies of the distribution of vegetation along different sections of the river and by the application of various techniques, ranges for both depth of flooding and duration of flooding for each of the main species have been assessed and tabulated. Employing these figures and statistical methods, an estimate of the distribution of the various species by area over various reaches of the river (in particular Malakal to Jelebein) has been attempted. In other reaches more detailed mapping combined with survey levelling (in particular in the Mongalla-Gemmeiza reach and the Aliab Valley: see Volume III) has enabled us to produce more detailed records of the distribution of vegetation in sample areas. From this we have also attempted to set out the distribution of the main species in terms of the area they occupy. This has been necessary in order to measure the grazing value of the vegetation. In addition, figures bearing out the importance of current velocity, and also of rainfall in relation to the rise of the river levels, have been recorded in order to clarify the present phase relationship between the time and rate of rise of the flood-waters and the incidence of rainfall.

CHAPTER 3. THE INHABITANTS

Our definition of the 'Jonglei Area' is given in the Introduction (p. x) and reference should be made to Map 6. There are three main sets of people concerned:

- (i) The Madi, Bari and Mandari tribes of Equatoria Province. The total population is estimated to be about 60,000, though not all will be directly affected by the Project.
- (ii) The majority of the Nilotic tribes: Dinka, Nuer and Shilluk. The total population is not less than one and a half millions, of which about 480,000 have a direct interest in the resources of the Nile flood-plain and will be affected by the Project, and about 400,000 will in one way or another be bound to feel the effects indirectly, though not all with the same intensity.
- (iii) The pastoral (Baggara) Arabs and other Northern Sudanese living between the boundaries of the Upper Nile Province and Kosti. The total population is estimated to be 213,500, of which about 120,000 will be directly affected.

Roughly this division of the people into these three groups—the Madi-Bari-Mandari group, the Nilotes, and the Baggara Arabs—corresponds with the three main ecological regions of the Jonglei Area described previously (see pp. x-xi). The Madi and Bari are confined to the Ironstone Region, while the Mandari occupy country which is really transitional between that and the Flood Region. With the exception of a few Dinka tribes who live within the boundaries of the Ironstone Region and the Abialang Dinka who are found in the Semi-Arid Region, all Nilotic tribes in the Jonglei Area are found in the Flood Region. The Baggara of Kosti District are confined to the Semi-Arid Region.

As will be seen from Map 6, the three southern provinces and part of the Blue Nile Province are involved, the administrative districts being as follows:

EQUATORIA PROVINCE: Central District (H.Q. Juba) and Torit District (H.Q. Torit).
 BAHR EL GHAZAL PROVINCE: Lakes District (H.Q. Rumbek and Yirol). UPPER NILE PROVINCE:
 Bor District (H.Q. Bor); Western Nuer District (H.Q. Bentiu); Central Nuer District⁽¹⁾ (H.Q. Fangak); Malakal and Shilluk District (H.Q. Malakal and Kodok); Renk District (H.Q. Renk). BLUE NILE PROVINCE: Kosti District (H.Q. Kosti).

THE MADI-BARI-MANDARI GROUP (See Map 6)

The Madi are part of a tribe of that name living in northern Uganda. In the Sudan the tribe consists of a number of elements of different tribal origin who, in the past, formed semi-autonomous groups living on the east bank of the Bahr el Jebel from Nimule to the Bari

(¹) Now split into Zeraf District and Lau Nuer District (1954).

boundary along the Uma. These people are mainly cultivators keeping a few goats and sheep (and latterly a few cattle), with a few sections who depend largely on fishing. Apart from fishing activities they make little use of the Nile, which in this reach has virtually no flood-plain and is infested with tsetse fly. The effects of the Project upon their economic interests will therefore be negligible.

The Bari are a larger tribe—also of mixed origin—living on both banks of the river for some considerable distance inland, and the majority are cultivators, though it seems probable that they once had greater numbers of cattle than at present. Only those who make use of the flood-plain of the Bahr el Jebel, between Juba and roughly the latitude of Terakeka, to graze their cattle and other stock during the dry season will be affected by the Project. Limited use is made of the flood-plain for crop husbandry and such interests must also be taken into account.

The Mandari have two distinct areas of settlement (see Fig. E 4): the 'inland or Boronga Mandari' living in the vicinity of Tali Post, and the 'riverain Mandari', whose villages are built on the high ground above the flood-plain along both banks of the river between roughly the latitude of Terakeka and that of Tombe. It is the latter people who will be principally affected by the Project since they depend on the flood-plain for dry season pasture, fishing, and, to a limited extent, crops. The Mandari are enterprising and energetic cultivators and produce a greater variety of food crops than most tribes in the Jonglei Area, but they are turning with increasing interest to cattle, of which they now have considerable numbers and which play an important part in their economy.

THE NILOTES

(See Map 6 and Figs. E 5–10)

The three Nilotic peoples, Nuer, Dinka and Shilluk, have certain similarities of culture, means of livelihood, physical type, and in particular language, though their languages are not mutually intelligible.

The Nuer comprise eleven distinct tribes, of which seven will be directly affected by the Equatorial Nile Project. Each tribe has a distinct territory which includes all types of land necessary for a seasonal and migratory way of life in which cattle play a predominant social and an important economic part.

The Dinka, by far the most numerous and widely distributed of all peoples in the Jonglei Area, are also divided into a number of distinct tribes. Contacts with other peoples, variations in physical conditions and other factors have resulted in cultural differences between the various Dinka tribes but, as will be seen later, the broad principles of their culture and economy are similar. Like the Nuer they practise a mixed economy in which cattle are of great importance.

The Shilluk are less like the Nuer and Dinka, are a more compact tribe, and have a relatively more organized state system with a king or *Reth* at the head. They are, moreover, less dependent on animal husbandry and, in relation to population, have fewer cattle than other Nilotic tribes and place greater reliance on crop husbandry and fishing.

The most significant feature of Nilotic society is the part played by cattle both in the economy and in the social system. In the first place the products of cattle—both for food and for technological purposes—are of profound importance. At present the economy is largely one of subsistence, for there is little trade or demand for imported goods. The main constituents of diet are grain, meat, milk, fish, and to a lesser extent game animals and the edible parts of indigenous vegetation. Cereals, mainly *dura*, can be regarded as the main constituent, but for topographical and climatic reasons crop husbandry is a precarious and often unsuccessful undertaking and cereals are frequently in short supply. Cattle provide an insurance against years of poor crops and are therefore an essential item in the economy, apart from the fact that they add food of quality to an otherwise poor standard of diet. The seasonal aspects of the economy must also be stressed, because there are not only years, but also periods in the year, when stocks of grain run short or are difficult to obtain. There are seasonal variations in the relative dependence on the various sources of food, as well as seasonal variations in the level of nutrition. Milk, meat and fish are available when cereals run short and the availability of one item of diet tends to balance shortages in another according to the season (see Fig. E 12). A reasonable standard of nutrition is thus maintained, but any reduction in cattle would

undoubtedly upset the balance and result in extreme hardship. The economy is maintained barely at subsistence level: a decrease in numbers of domestic stock and in the supply of fish—which the Equatorial Nile Project as proposed will certainly cause—would result in a diet below subsistence level and in periods of malnutrition.

The second point of significance is the part played by cattle in the social system, for they are used as symbols of exchange. The majority of the Nilotic tribes marry with cattle, cattle being transferred as bridewealth; cattle are paid as indemnities for legal wrongs—adultery, seduction, hurt, defamation of character, homicide, and so on. It is incorrect to speak of cattle as a form of currency, for the objectives of these transactions cannot be described as simple purchase or as pecuniary damages. The marital system is exogamous and the ultimate object of bridewealth, paid in cattle, is to restore the balance when it is disturbed by the transfer in marriage of a woman from one kinship group to another. Likewise the payment of compensation in cattle for the killing of a member of one kinship group by a member of another is intended to restore the balance by providing the means to acquire a woman in marriage. It is impossible to summarize the complexities of this system in a few words, but it will be realised that a substantial and perhaps relatively sudden reduction in the numbers of animal stock would inevitably lead to social maladjustments and probably also to breaches of public security.

THE BAGGARA ARABS OF KOSTI DISTRICT (See Map 6 and Fig. E 11)

In this area are a mixture of peoples of true Baggara origin, cattle-owning migrants from the western Sudan, and others whose pastoral way of life is not dissimilar, though they are of different origin. There is also a large sedentary population. Some sections (*Omadias*) are primarily cattle-owners; others own approximately equal numbers of cattle, sheep and goats; still others have a greater proportion of sheep and goats than cattle. Sheep generally predominate on the east bank. Some sections are almost entirely dependent on the flood-plain of the Nile for dry season pastures; others, with better water supplies and more abundant inland grazing which remains palatable and nutritious even in the dry season, send only a proportion of their animals to the river-front during the dry months of the year. It is probable that the prevalence of biting-flies and liver-fluke in the riverain pastures would be sufficient to deter most of the people from bringing their animals to the river at all, were they able to subsist inland. Seasonal movements are not generally on the scale found among most true Baggara tribes. On the west bank the direction of the movement is generally eastwards to the river-front and then southwards as riverain grazing is consumed. This applies also to the east bank, though in some areas there is a simpler and more direct migration from cultivation areas to riverain pasture.

The effects of the Jebel Aulia régime have been to increase the area of riverain grazing (particularly a palatable form of *Vossia cuspidata*) very considerably. Since these pastures are now heavily overgrazed one must assume a proportional increase in animal stock since the building of the dam in 1936. The advantages of the increased area of grazing are partly outweighed by the fact that the riverain pastures remain under water until the dam is opened in February or March, much later in the year than before. This has adverse effects, particularly on those sections who own larger numbers of sheep, since these animals are not able to utilize riverain grazing until water-levels have dropped, while cattle are able to graze the pasture and derive some benefit even when it is flooded. The fact that these riverain pastures are grazed to capacity by the middle of the dry season has resulted in increased pressure to enter grazing grounds farther south in Dinka and Shilluk country. The demand increases and reaches a crisis in some years when peoples are compelled to move south from areas north of Kosti, usually sufficient to meet their own needs, or when inland pastures in the hinterland are less extensive than usual owing to poor rainfall, and as a result more than the average number of animals must be brought to the river.

The recent astonishing development of irrigated schemes on both banks of the river has altered the whole economic and sociological character of the district in the space of a few years. On the whole the pastoral elements of the district, who will be most affected by the Equatorial Nile Project, have been least affected by these changes. As yet few of the Arabs are sufficiently attracted by the benefits which these schemes might offer them to abandon their pastoral pursuits for a more sedentary existence as tenants on the pump schemes, though many spend part of their time as cotton pickers and general labourers. This situation may well change or it may lead to a clash of interests in the future.

VITAL STATISTICS

At present there are no reliable figures available, though the sample census now taking place will ultimately provide more accurate methods of assessment. The estimates given in Tables 128 and 129 (pp. 230-1) have been obtained by the simple method of multiplying taxpayer figures (i.e. adult able-bodied males) by 4.5, a method which is obviously open to a high percentage of error. These estimates indicate that a total in round figures of not less than 660,000 people will be directly affected by the Equatorial Nile Project and that perhaps 400,000 will be indirectly affected. Population densities vary between 7 and 60 to the square mile (see p. 232), but there are large areas of uninhabited and practically unexploited country.

The tables mentioned above also give the total number of cattle and smaller animal stock owned by the people. Here again the method of assessment is subject to error. In some cases estimates are based on actual counts carried out during inoculation campaigns; it is certain that all cattle were not produced for inoculation, and the figures probably show less than 80% of the total. At any rate in all cases the figures represent, in our opinion, a very conservative estimate of the whole.

SOME ASPECTS OF HUMAN ECOLOGY

From the point of view of the Equatorial Nile Project the most important aspect of land utilization in the Jonglei Area is the part played by the flood-plain of the Nile system in the seasonal economic activities of the inhabitants. *With some exceptions—Madi, Bari and a large proportion of the people living in Kosti District—the peoples of the Jonglei Area are primarily pastoralists and move with the seasons according to the availability of grazing and water supplies during the dry months of the year and freedom from excessive floods and insect pests during the rains.

Physical and climatic conditions in the Flood Region occupied by the Nilotic tribes are peculiar to that area alone and have produced a marked consistency in their way of life. Common to all is the seasonal utilization of the three main types of land—high land, intermediate land, and swamp (*toich*: see Fig. E 1), although the difference in level between high and intermediate land is rarely noticeable to the eye. Permanent villages are set on higher ground and the distribution of settlements and individual holdings follows the topography of each area. In many cases high land is confined to the alluvial banks of the numerous rivers and drainage-channels which transect the country and where the relatively steeper slope allows better drainage for cultivation and some degree of protection from floods during the rains. It is to these settlements that the people retreat during the wet months, bringing their livestock with them. As soon as the rains are over and the crops have been harvested, the herds are driven on to the intermediate plains where the regrowth from the perennial grasses is sufficient to support them until water supplies run dry. There is then no alternative but to move to the flood-plains of the main rivers, and the majority of the inhabitants of the Jonglei Area are forced to move to the Nile. The cycle of movements and changes in concentration of the population are variable according to local conditions. At one extreme are the Shilluk, the Mandari, and some Dinka tribes, whose territory contains sufficient areas of all three types of land within a short distance of the river. Villages on the higher ground are almost continuously occupied, and although these people set up cattle-camps near riverain grazing grounds, there is constant contact between all elements of the population. At the other extreme are those tribes—the majority of the Nuer and Dinka—who have to move from the small and scattered areas of high land, through the vast intermediate plains, to the riverain pastures, a distance of anything between ten and a hundred miles. The direction of these seasonal movements and the distribution of permanent settlements will be clear from a comparison of Fig. E 1 and Figs. E 4-10.

The particular form of migratory economy characteristic of the Flood Region has certain points in common and certain points of contrast with that found in other parts of the Jonglei Area. During the rainy season the Nilotics move to higher ground to escape the floods and must there build themselves well-constructed houses and cattle-byres to protect their animal stock. The Baggara Arab of Kosti District do not attempt to stay within the same area of rainfall, but move northwards where the rainfall is lighter and where the sandier, more undulating country gives them freedom from floods and to some extent from insect pests. In the dry season the Nilotics are forced to move to the *toich* because there is nowhere else where nutritive grazing and water supplies can be found. A large proportion of the Baggara Arabs are also compelled to move to the river-front, though mainly because grazing grasses are exhausted and water supplies are insufficient to support the total animal population. These observations also apply to those of the Bari who own cattle in any numbers.

Thus, though there are wide differences in race, culture and language, all inhabitants of the Jonglei Area have many points in common. Most important of these is that all are dependent during the dry months of the year for water supplies, pasture and fisheries provided by the normal rise and fall of the river. Without these resources their present economy could not continue.

We do not examine in detail in our second volume the effects of the Project on the social system of the Nilotic tribes, in which cattle play an all-important part, for these things cannot be assessed in terms of quantity, but it will be realized that any reduction in riverain grazing, and thus in animal stock, will lead not only to detrimental effects on the economy and standard of diet, as will be the case among all inhabitants of the Jonglei Area, but also to social difficulties which, without suitable remedies, may well lead to a complete breakdown in the present political and social organization before a new and sound system can be built up.

CHAPTER 4. ANIMAL AND GRASSLAND HUSBANDRY

GRASSLAND TYPES AND ASSOCIATIONS: NUTRITIONAL AND FEEDING VALUES

The ecological characteristics of the Jonglei Area and the distribution of vegetation have been outlined in the summary of Chapter 2. Here we must consider the value of the grasses as pasture. Pastures are almost exclusively graminaceous; the contribution of legumes is negligible, particularly in the Flood Region. In some areas, notably in the Semi-Arid Region, the value of the pasture is enhanced by a plentiful supply of nutritious pods from trees and acacia bushes. As before we consider the particular characteristics of the grasslands under the main Regions of the Jonglei Area, the grasslands of the riverain flood-plains being treated as inter-regional.

THE GRASSLANDS OF THE IRONSTONE REGION

Grasses here are almost all perennials, with the exception of a few annuals found in the vicinity of deserted cultivations. The Ironstone Region is mainly outside the area of our survey and those parts included are really transitional. For this reason a detailed study of the characteristics and feeding values of the predominant grasses has not been attempted.

THE GRASSLANDS OF THE FLOOD REGION

The grasslands of the Flood Region have two main divisions:

INTERMEDIATE LAND GRASSLANDS: The predominantly perennial grasslands associated with intermediate land, and which occupy the majority of the Region, are of two more or less distinct types: the *Setaria incrassata* type and the *Hyparrhenia rufa* type, the latter favouring areas more heavily flooded in the rainy season than the former. Both these grassland types dry out after the rains and in many areas the *Hyparrhenia rufa* type is deliberately fired, since after burning it produces variable amounts of green and nutritive regrowth which is of value as pasture. The *Setaria incrassata* type produces a negligible amount of regrowth after burning, and is therefore of little value as pasture in the dry season, except as bulk when in a dry mature condition. In the majority of areas covered with these types of grassland water supplies are exhausted early in the dry season and the utilization of these grasslands is therefore limited. During the early part of the rainy season both types of pasture provide good grazing, but their value decreases as the rainy season progresses because of the heavy flooding which limits their utilization. The livestock cannot graze under these conditions and are forced to turn to the relatively flood-free parts of the higher ground. Only the edges of the grasslands are grazed and the remainder grows tall and coarse. Thus, although they both have some value as pasture in the early rains and provide useful roughage after the rains, and *Hyparrhenia rufa* produces a nutritive regrowth early in the dry season, neither type is of extensive or continuous value throughout the year. As far as it has been possible to do so their nutritive values and estimates of the amount of herbage produced at various stages of growth, together with estimates of stock-carrying capacities, have been recorded in tabulated form (see Tables 134-40, Vol. I, pp. 258-63).

The amount of herbage produced is enormous, and the major proportion of it is burnt off and therefore wasted. No attempt is made by the inhabitants to conserve this herbage since it is not needed at present, but, even if it were necessary, our limited experience indicates that conservation would be a very difficult operation. The main drawback is the high humidity and uncertain climatic conditions at the time of the year when the herbage should be cut, together with varying degrees of surface flooding during the rains which make cutting almost impossible. By the time climatic and ground conditions begin to improve at the end of the rains, the grasses are already tall and coarse and generally unsuitable for conservation. Attempts to conserve this type of pasture were generally unsuccessful, the analyses of such samples of hay and silage which were produced being recorded in Tables 136-7 and 140.

HIGH LAND GRASSLANDS: The predominantly annual grasses of the high land in the Flood Region provide excellent grazing during the rainy season while they last, but in general they are exhausted by the end of that period and there is rarely sufficient left to carry more than a very small proportion of the animal stock through the dry season.

GRASSLANDS OF THE TRANSITIONAL BELT

The tall annual grasses of this area (the *hariq* grasses) provide good grazing during the rainy season and are of some value during the dry months of the year where water supplies are available. Their utilization for cultivation purposes (for *hariq* cultivation see p. xxxviii) is not compatible with animal husbandry, and with the rapid development of crop production larger and larger areas are being preserved from fire and livestock.

THE GRASSLANDS OF THE SEMI-ARID REGION

The grasslands of this Region are of the annual short grass type, and although the feeding value decreases in the dry season as the herbage matures and dries out, they provide grazing throughout all seasons of the year. This is a major advantage. Yet the amount of herbage produced is limited and there is rarely sufficient pasture to carry the very large animal population of the area throughout the dry season, even if permanent water supplies were everywhere available. Tables 144-8 give analyses of various pasture grasses at all stages of growth found in the Semi-Arid Region.

INTER-REGIONAL GRASSLANDS

The riverain grasslands or *toich*, seasonally flooded and exposed, are found throughout the Jonglei Area along the flood-plains of the main rivers and in particular along the Nile. The significance of depth and duration of flooding has already been stressed (see p. xxvi) and variations give rise to different forms of vegetation. Two main types of grasses are distinguishable and these we refer to as 'shallow-flooded' and 'deep-flooded'. Both types are largely inaccessible when under water, but both provide grazing which, when exposed, is of a very high quality compared with the pastures inland during the dry season.

SHALLOW-FLOODED TYPE: The major grass constituents of this type are *Echinochloa pyramidalis*, *Oryza barthii* and *Oryza punctata*, which are found growing either in association or in pure stands. The old herbage (i.e. the flood season growth) is coarse and unpalatable, but when burnt the grasses produce excellent green regrowth which is of great value as pasture. In addition *Phragmites communis* is found—especially in the southern reaches of the Jonglei Area—but is of no value as pasture.

DEEP-FLOODED TYPE: The major grass constituents of this type are *Echinochloa stagnina* and *Vossia cuspidata*, which are sometimes found growing in association but more often as pure stands. Deep-flooded pasture is only accessible fairly late in the dry season when the river levels are low. *Echinochloa stagnina* is palatable to stock at all stages of growth. *Vossia cuspidata* is less palatable when mature, and is only of real value as grazing in the northern part of the Jonglei Area.

Analyses of herbage from both types of pasture are given in Tables 149, 150 and 153. Their stock-carrying capacities vary considerably, but in general that of the deep-flooded type is three times that of the shallow flooded-type. The conservation of these grasses for fodder has been considered; conservation during the rains would be difficult for climatic reasons, but would be possible during the early part of the dry season. Analyses of hay and silage cut from both types of pasture are given in Tables 151, 152 and 154.

PASTURE MANAGEMENT

Domestic animals in the Jonglei Area depend on natural vegetation for fodder at all seasons of the year, even though there is a season of at least five or six months without rain during

which inland grasses show little or no growth. This is possible for various reasons, but the most important, common throughout, is that the annual fluctuations in the level of the Nile and other rivers permit the production of green pasture during the dry months of the year. From our point of view this is the most significant aspect of pasture management in the whole area.

During the wet season the herds are driven inland to graze the pastures on intermediate or high land in the Ironstone and Flood Regions already described, and the inland annual short grass pastures in the Semi-Arid Region. During the dry season they graze the regrowth of the perennial grasses on intermediate land, or khor-bed swamp pastures which are found in many parts of the Flood Region, or dry annual grasses in the Semi-Arid Region. A very large proportion must, however, be moved to the main riverain pastures of the Nile system, either because inland pastures run short or because domestic water supplies dry out. For this reason all systems of pasture management assume that riverain pasture on the *toich* will be available in the low-river season—January to April in the south, January to June in the central parts of the Jonglei Area, and March to June in the north where the fluctuations in river level are dependent on the Jebel Aulia régime.

This generalization applies throughout the Jonglei Area, but there are minor differences in pasture management in the three main Regions which can best be summarized in tabulated form. Reference should also be made to Figures E 4 to E 11 which show the general direction of the grazing movements.

IRONSTONE REGION	FLOOD REGION	SEMI-ARID REGION
BARI	MANDARI, DINKA, NUER AND SHILLUK	DINKA AND ARABS (KOSTI DISTRICT)
Majority of livestock kept in the villages and grazed in the vicinity throughout the year, but a few are moved to cattle-camps on the river flood-plain during the dry season.	In most areas livestock kept in the permanent villages in the rainy season and protected from rain and insect pests at night by well-built cattle-byres. In a few areas (some Mandari and Dinka) livestock moved to special rains season camps. Large majority move to the riverain pastures in the dry season.	Livestock kept in camps close to but apart from the cultivation areas for part of the rainy season, but driven northwards at the height of the rains. Large but variable proportion of the livestock moved to camps along the flood-plain during the dry season, others being kept inland round well-centres.
<i>May, June, July</i> Inland grasses plentiful; livestock herded over wide areas.	<i>May, June, July (south) : June, July, August (north)</i> Inland pastures on high land and the higher parts of intermediate land plentiful; livestock herded over wide areas.	<i>June/July, August, September</i> Inland pastures plentiful: Arabs move north to sparsely inhabited <i>qoz</i> land at height of rainy season.
<i>August, September, October, November, December</i> Inland grasses tall and coarse and riverain grasses under water; livestock grazed on higher ground near villages—grass cropped short and remains palatable.	<i>August/September, October, November, December</i> Intermediate land pastures largely flooded and grasses tall and coarse; livestock grazed on high land pastures near the villages. Finer annual grasses grazed to extinction; some of the perennial grasses grazed short and kept reasonably palatable.	<i>October, November, December</i> Inland grasses still plentiful. Dinka still in village and cultivation areas or may move to camps near river, watering at the river and grazing inland. Arabs return to village and cultivation areas to assist in the harvest, or move south to ungrazed pasture inland.
<i>January, February, March, April</i> Inland grasses dry, coarse, unpalatable and mostly burnt off to destroy cover for game animals. Riverain swamp grasses on the <i>toich</i> exposed, providing pasture for all animal stock.	<i>January, February, March, April/May</i> Inland intermediate grasses mature, coarse and unpalatable. After burning perennial grasses provide useful pasture for variable periods. Later riverain swamp grasses exposed and most livestock moved to the river-front.	<i>January, February, March, April, May/June</i> Inland pasture still palatable, but beginning to run short. Some herds taken to the river-front where they graze inland grasses and riverain grasses at edge of flood-plain. Flood-plain exposed in February/March when Jebel Aulia Dam opened; majority of livestock then moved on to the flood-plain.

DEGREE OF PASTURE UTILIZATION

In the Jonglei Area no single type of land, or the pasture associated with it, will support a large number of livestock throughout the year. Two or more of the main land-pasture types are essential for livestock production and this fact is recognized in the tribal division of land.

Inland and riverain pastures are complementary, the one practically valueless without the other. From the point of view of the Equatorial Nile Project we are concerned only with pasture which is of use during the dry (low river) season. For the purpose of an estimate stock-carrying capacities are expressed in terms of Animal Units (1 A.U. = 1 adult head of cattle = 8 sheep = 8 goats) or Thousand Animal Unit Months (1 TAUM being sufficient to support 1,000 Animal Units for one month). Any excess of dry season pasture over present requirements is best summarized in tabulated form, dividing the Jonglei Area into sectors, i.e. according to Zones rather than tribal boundaries (as in Volume II, Chapter 10):

EXCESS OF DRY SEASON PASTURE AVAILABLE
IN ANIMAL UNITS

Sector	Without additional water supplies	With additional water supplies	TOTAL
SOUTHERN ZONE			
1. Bari and Mandari	38,500	—	38,500
2. Bor Agok, Bor Athoich (1/5), and Aliab (5/6) Dinka	3,600	20,000	23,600
CENTRAL ZONE			
3. Bor Athoich (4/5), Twi, Nyare- weng and Ghol Dinka; Gaweir and Thiang (Mainland) Nuer ...	33,000	25,000	58,000
4. Gaweir, Thiang and Lak Nuer; Southern Zeraf Island	—	—	—
5. Aliab (1/6), Chich and other Lakes District Dinka	—	—	—
6. Nuong, Dok, Jagey and Western Jikaing (1/3) Nuer	—	20,000	20,000
NORTHERN ZONE			
7. Western Jikaing (2/3) and Lak Nuer; Ruweng (Kwil) Dinka; Rut, Thoi, Ruweng (Paweng) and Luaich Dinka	—	—	—
8. Shilluk	—	—	—
9. Dunjol and Paloich Dinka ...	3,800	12,000*	15,800
10. Abialang Dinka and Ta'aisha ...	12,000	—	12,000
11. East Bank Baggara	—	—	—
12. West Bank Baggara	—	8,000	8,000
	90,900	85,000	175,900

* In the Machar Marshes.

LIVESTOCK

ECOLOGICAL CONSIDERATIONS

THE IRONSTONE REGION

Much of the land is covered with thick forest and inland pasture is limited, and south of Juba the presence of tsetse fly precludes the rearing of livestock in appreciable numbers. Numbers were greatly depleted in the latter half of the 19th century, but have been increased since then by purchase from the Mandari and Dinka, and also from the Latuka. The preponderance of high, well-drained land encourages the rearing of smaller stock—sheep and goats—rather than cattle, and between Juba and the northern boundary of the Region riverain pasture suitable for cattle in the dry season is fully utilized.

THE FLOOD REGION

Flooding, both from the river and from accumulations of rainfall, is the principal ecological factor in this Region and is one of the main reasons for the comparatively low proportion of sheep and goats and the absence of other domestic animals; only cattle can survive and produce successfully. Grass is abundant but, as we have seen, is often inaccessible during the rains because of heavy flooding, or in the dry season because of lack of water supplies. Tsetse fly is not a problem, but biting-flies—*Tabanus*, *Stomoxys* and *Simulium*—are an absolute limiting factor, preventing, by disease and loss of condition in the animals, the development of a prosperous livestock industry. Moreover the former lack of public security, fear of disease, and the social implications of the cattle-exchange system among the Nilotic tribes have encouraged the desire for numbers rather than quality.

THE SEMI-ARID REGION

In the northern part of this Region the land is undulating, the soil sandy, and the rainfall light and spread over five months of the year (June–October). There is little or no surface flooding in the hinterland and pasture and water supplies are plentiful in the rainy season. In the dry season inland pasture is scarce, and there are a few areas of grass which are unexploited owing to the complete lack of water supplies. Livestock are accustomed to eating dry grass and to walking long distances between water-points. Large numbers of stock have to be moved to the river-front in the dry season and to graze the riverain pastures when exposed. On the flood-plain they have to contend with biting-flies, and liver-fluke disease (*Fascioliasis*) has reached serious proportions since the building of the Jebel Aulia Dam. Livestock consists of cattle, sheep, goats of the Arab type, and a few camels (especially in the northern parts) and donkeys. In the southern part of the Region the land is flatter, the rainfall heavier, the soil less sandy, the vegetation taller and more rank, and flooding during the rains is more common. This area extends into what we have called the Transitional Belt. Here the basic livestock are Nilotic in strain, but there has been a considerable admixture of Arab stock, especially in recent years.

The spectacular development of crop husbandry (mainly cotton and dura) in this Region may result in a clash of interests, but it has certainly not led to any reduction in animal numbers. Rather the reverse has taken place because wealth acquired from the sale of cotton and grain is so often invested in the purchase of additional livestock.

LIVESTOCK TYPES

CATTLE: There are three main types of cattle to be found in the Jonglei Area. **THE MONGALLA TYPE OF NKEDI ZEBU:** Found in the Ironstone Region, mainly south of the Dinka belt. **THE NILOTIC TYPE:** It is debatable whether the cattle owned by the Nilotic tribes constitute a single breed, but they have many characteristics in common. There are several almost distinct varieties which may at one time have been limited to particular districts but which have been widely dispersed owing to cattle raids, trade, and the exchange of cattle in marriage settlements. The long-horned cattle of the Dinka are now quite commonly seen in Mandari herds and also among the Nuer. The small, fine-boned and short-horned cattle of the Lau Nuer are still fairly distinct. The Shilluk and Northern Dinka herds show considerable admixture of Arab types. **THE KENANA TYPE:** This is the predominant breed of the Arabs of the Semi-Arid Region. During the *Mahdia* the cattle population of this Region was much depleted, but since then it seems that the offspring of one particular herd have so multiplied as to become a distinct type.

SHEEP: Sheep even more than cattle present a great variety of colours, shapes and sizes, but three distinct types are recognizable, although only two of these are really typical of the Jonglei Area. **THE TAPOSA FAT-TAILED SHEEP:** Generally found much farther east of the Nile, though a few are present in the flocks of the Bari and Mandari. **THE NILOTIC SHEEP:** A small animal classed as one type which is found south of latitude 12° N. to the edges of the southern mountain ranges. **THE DESERT SHEEP:** Found in the Semi-Arid Region of the Jonglei Area and most parts of the Northern Sudan.

GOATS: The distribution of goats follows generally that of sheep, the dividing line being roughly latitude 12° N. **THE NILOTIC GOAT:** This name covers a multitude of forms, but the Nilotic goat is generally a very small, sleek animal which flourishes in most difficult conditions. **THE NUBIAN GOAT** and the **DESERT GOAT** are found mainly in the Semi-Arid Region, though the latter is not common.

LIVESTOCK MANAGEMENT

There is little difference in the basic principals of animal management in the three Regions and the salient points are best tabulated as follows (see also under pasture management, p. xxxii):

	IRONSTONE REGION		
	BARI	MANDARI, DINKA, NUER AND SHILLUK	DINKA AND ARABS (KOSTI DISTRICT)
Seasonal Movements	Villages near the river; movements short and only in dry season.	Villages all scattered; movements often over great distances in the cycle village-plain-khobed-main river-village. Some move to rain season camps.	Movements two way—From village to <i>qoz</i> land to the north in the rains; then back to village and on to river at beginning of dry season. Then back to village at the beginning of rains.
Daily Routine	Milked 7 a.m.; sent to graze 9–10 a.m. Back to camp 4–5 p.m. Milked 6 p.m. Sleep in camp and protected by smoke fires.	As for Ironstone Region. Sometimes cattle released 6 a.m. and return for morning milking at 10 a.m., then released midday for further grazing till 5 p.m.	During the rains milking carried out in the early morning. Cattle graze all day and drink at surface pools and are milked again in evening. In the dry season water is scarce and milking takes place only once daily or every second day.
Milking	Morning and evening milking. Calf allowed to suck first to stimulate milk flow; then milk drawn into vegetable gourd. When the flow stops the calf is allowed to suck again and then the cow is milked again by hand. Finally the calf is allowed to suck the remainder. Wet milking is the rule.		
Breeding	Bulls are often selected from good milking dams. There is generally one bull to twenty or thirty adult cows and bulls run freely with the herd. No special arrangements are made for cows about to calve. Calves are not weaned until their dams cease to give milk—except where milk is sold in towns, when weaning is carried out at four to six months. Arabs rarely if ever castrate their bulls; Nilotics castrate all but selected stud bulls.		
By-Products	Practically every part of the animal is put to some use, but milk is the product most in demand. A considerable quantity of meat is also consumed (most animals that die a natural death are eaten). Hides are either frame-dried or ground-dried. Blood drawn from the jugular vein is not common in the Nilotic diet, though it is used in time of famine.		
	Milk is by far the most important product. In times of plenty (the rainy season) surplus milk is converted into clarified butter (<i>semn</i>) for sale in towns. Beef is not in great demand, mutton being more popular. Hides may be dry salted, but are generally air-dried.		

TRADE

In the Jonglei Area there has been a fairly steady increase in the number of cattle and sheep sold through public auction markets and produced for local slaughter, but this trade is confined to the larger towns where there are sufficient people with a money income to create a demand. Apart from a regular trade in cattle, sheep and camels to the Northern Sudan and Egypt (from districts mainly outside the Jonglei Area) there is no export of livestock, and the present inadequate system of marketing does not encourage the producer to part with his stock. The numbers of livestock have greatly increased during the last few years owing to the widespread use of veterinary prophylactics, and only lack of systematic marketing prevents proper use being made of this expanding asset. Because of lack of communications and the reluctance of the people to sell their cattle, the new meat canning factory at Kosti has had as yet little or no effect on trade in the Flood Region, where herds have greatly increased. 'Exports' from Bór District to Juba and from Lakes District to Equatoria Province amount to about 3,000 head of cattle a year.

The sale of hides is a valuable source of revenue. Almost all hides in the Jonglei Area are air-dried, either on frames or on the ground. The value of hides sent out of Upper Nile Province in the period July 1951–June 1952 was £E.60,000, but only one-fifth of the total number were frame-dried. An improvement in the standard of flaying and drying would greatly increase the value of this trade. Milk is an article of trade only in the larger towns where the price varies from two to three piastres a pint, and the supply, generally from a government-owned dairy, seldom meets the demand. Elsewhere there is rarely any surplus of milk for sale, except in Kosti District (during the rains) where it is made into clarified butter.

POTENTIAL

The main factors limiting the quality and quantity of Sudan cattle in the Jonglei Area are climate and topography, vegetation, animal disease and arthropod parasites. In the Ironstone Region the tsetse fly is an absolute limiting factor, the livestock being confined to the cleared areas along the river. If the tsetse fly were removed conditions would be suitable for an increase in livestock numbers.

Alternate flooding and drought characterize the Flood Region, and the livestock consequently develop in stages separated by periods of mere maintenance or even loss of condition. This is evident in the type of livestock and in their low rate of production. In addition biting-flies are very numerous inland during the rains, and at the river in the dry season; they cause lowering of condition and loss of production. Epizootic diseases (rinderpest, trypanosomiasis, contagious bovine pleuro-pneumonia, etc.) can be controlled, though they have not yet been eliminated, and the vegetation will allow of some increase in numbers (see p. xxxiv), but drastic culling and the introduction of some systematic method of breeding will be required before there is any increase in productivity. Moreover there must be an increase in productivity in order that the local requirements may be satisfied before a large export drive can be launched.

In the Semi-Arid Region lack of water supplies is generally the limiting factor. Inland the short annual grasses have the advantage of being palatable when mature and dry, but some areas cannot be grazed in the dry season for lack of water. Dry season pasture by the river is grazed to capacity and the provision of water-points inland where there is some surplus grass would accommodate only a very limited number of animals (about 8,000 A.U.). Thus in the Semi-Arid Region livestock numbers have already almost reached the capacity of the land. No further increase should be permitted and efforts should be directed to the improvement of the type of livestock and the carrying capacity of the pastures.

In all three Regions any reduction of the dry season river pasture would certainly curtail the development of the livestock industry, which is undoubtedly of great potential value to the Sudan as a country.

CHAPTER 5. CROP HUSBANDRY

While the environment in the Jonglei Area is generally favourable to animal husbandry, it must be regarded as difficult for crop production. It is therefore not surprising that though crops are economically more important, the life of the people is largely adjusted to the requirements of animal husbandry. This preoccupation with cattle is also responsible for the emotional attitude of the people toward their crops and animals. Since crops demand hard and often unrewarding labour they are regarded as a necessary evil, while interest and affection are centred on cattle.

LIMITING FACTORS

The limiting factors of the environment differ in importance in the three Regions of the area:

THE IRONSTONE REGION: It is difficult to ascertain which factor here is of the greatest importance, but in general it is the low fertility of the soils rather than adverse moisture conditions. The natural vegetation, in which bush and forest predominate on the more fertile land, necessitates considerable work in clearing, and undoubtedly limits the area sown.

THE FLOOD REGION: Moisture conditions are here undoubtedly the chief limiting factor. The great majority of the land in this Region is liable to waterlogging and flooding by rain and spill from the numerous watercourses. This not only causes direct damage to crops, but also leads to overcultivation of the higher patches of land, where the resulting accumulation of pests and diseases, especially the parasite *Striga hermonthica*, causes low yields. Apart from flooding, drought conditions are also common in this Region, and may be regarded as a limiting factor almost as important as flooding.

THE TRANSITIONAL BELT: This area, lying between the Flood and Semi-Arid Regions, is the most suitable for crops. It has the advantages of both Regions, and there are wide areas of natural grassland suitable for *hariq* cultivation (see Fig. E 14). Here lack of inland drinking-water supplies during the greater part of the year limits crop output. The recent introduction of surface storage tanks has resulted in very considerable development in crop production.

THE SEMI-ARID REGION: Lack of moisture even during the short rainy season is undoubtedly the chief factor limiting crop production.

Because of environmental hazards, crop husbandry is a risky and often unrewarding undertaking throughout the Jonglei Area, and in consequence there is little incentive to expand output and production is kept to an essential minimum. Through generations of trial and error the peoples of the Jonglei Area have adapted their crop husbandry system, as far as their limited means permit, to an obviously difficult environment. To reduce the risks of cultivation, the cultivator sows his crops, as far as he can, on high land, intermediate land and, in some parts of the area, on the *toich*, and also spreads his sowing as far as possible throughout the rainy season. Stands of mixed varieties and often of mixed crops, differing in susceptibility to flood and drought, are planted to provide for environmental risks.

The implements used for cultivation in this area are rudimentary and inadequate, and must be considered as one of the main factors limiting crop production. They are not only responsible for the limited area sown, but also for the often ineffective land preparation and serious competition from weeds. Animal-drawn implements have only recently appeared in the pump schemes of the Semi-Arid Region, and elsewhere work is carried out manually. In most parts of the Jonglei Area the scarcity of labour at present available for crop production seriously restricts output. The reasons for this are the low density of population and the low effectiveness of labour; moreover seasonal migrations, and other operations necessary in animal husbandry, limit the time available for crop production, and there is much waste of time involved in walking between homesteads and cultivations, which are often far apart.

Trade is not at the moment conducive to agricultural development, because on the one hand demand for imported commodities is small and on the other hand supply is deficient and unimaginative, and the marketing system is badly organized. Undeveloped communications and disproportionately high costs of transport also limit trade.

CROPPING SYSTEMS

The following cropping systems are practised in the area:

INTENSIVE CULTIVATION: the difficulty of clearing land and of protecting crops against wild animals leads, in the Ironstone Region, to the cropping of the same land for many years in succession, particularly in the vicinity of the homesteads. In the Flood Region shortage of high land produces the same results. In the Semi-Arid Region shortage of rainfall causes intensive cultivation of sites where run-off supplements soil moisture and of sandy soils which are allegedly better able to support plant life in times of drought and are easier to work. While in the poorer soils of the Ironstone Region and Semi-Arid Region nutrient exhaustion may be a cause of poor yields on intensively cultivated land, on the strong clays of the Flood Region physical deterioration is certainly more important. Continuous cropping, especially with a single crop, with the emphasis on sorghum, leads also to the accumulation of pests and diseases and an increase in weed infestation. The most important factor responsible for deterioration of yields of cereals under intensive cultivation is undoubtedly *Striga hermonthica*.

The local cultivators do not practise any orthodox rotation to counteract deterioration in fertility. In some areas, however, mixed cropping, which may be regarded as a simultaneous rotation, is carried out on intensively cultivated land. Orthodox manuring is also unknown in this area, though land adjoining the homesteads undoubtedly receives incidental benefits from the presence of the domestic animals which are tethered there. The Shilluk practice of *path*, common on intensively cultivated land and consisting of the burning of grasses brought from the *toich*, is worth special mention.

SHIFTING CULTIVATION: This is the most important cropping system as far as area sown and crop output are concerned. The system is possible in the Jonglei Area because up to the present there has been no shortage of land. It is a simple form of rotation, with a period under crop alternating with a period of fallow long enough for the recovery of fertility. Unfortunately the period of cultivation is often too long and the recovery period too short. The choice of the first crop of newly opened land is important, as there are indications that yields of sorghum do not achieve their maximum until about the third year of cultivation.

HARIQ CULTIVATION: In the belt between the 450 and 750 mm. isohyets the natural grass-land is suitable for this type of cultivation, which makes use of old grass growth to get rid of new by burning the old and the new together, leaving the land clean for sowing. This method also conserves soil moisture. The timing of burning is most important for the successful cleaning of the land, and depends not only on judgment but also on luck. The disadvantages

of *hariq* cultivation are that burning has often to be delayed, and crops and cultivators suffer from lack of water at the end of the season. In the southern part of the *hariq* belt, regular burning tends to change the grass stand from annuals to perennials which are unsuitable for this method of cultivation. In recent years the organization of fire protection and improvement of drinking-water supplies and communications, carried out under Government auspices, have caused the development of *hariq* from a simple method of cultivation into a more advanced farming system. There has been a very considerable increase in crop output in the *hariq* belt, which has become a granary for the southern part of the area and also produces a considerable quantity of rain-grown cotton.

IRRIGATED CROP GROWING: The development of this type of farming in the Semi-Arid Region has taken place during the last few years—since 1950—as a result of the high prices of cotton. It is mainly based on private pump schemes run by a partnership of landlords and tenants, sharing the profits. It differs from the Gezira and government White Nile pump schemes mainly in that very little sorghum and practically no leguminous crops are grown, production being largely concentrated on cotton alone.

The gross irrigated area in the 1952–53 season was more than 22,000 feddans, with about 6,500 feddans under cotton. Apart from pump schemes there were also about 150 *saqia* schemes growing approximately 3,000 feddans of cotton. The technique of growing cotton and sorghum on these schemes is similar to that in the Gezira, but the standard of husbandry is generally lower. A twenty-five mile wide cotton-free belt has been imposed south of Jebel Ahmed Agha, dividing the long staple irrigated from the short staple rain-grown cotton, in order to control the spread of pests and diseases as well as to prevent the possible mixing of the two types of cotton, which would endanger the reputation of Sudan produce on international markets.

TOICH CULTIVATIONS: These, though subsidiary and mainly limited to the vicinity of the river in the southernmost and northernmost parts of the area, are important as they will be directly affected by the Equatorial Nile Project. In the Bari and Mandari area a considerable variety of crops is grown on the flood-plains throughout most of the year. In the Kosti area cucurbits are the main crop planted on *toich* cultivations during the dry season.

CROPS

Sorghum is the backbone of agriculture in the Jonglei Area, and crop production is almost entirely concentrated on it. Sorghum is especially well adapted to the environmental conditions. The local cultivator classifies this crop, according to its maturation period, into quick and slow-maturing types. Each type of sorghum is composed of several ill-defined strains which are generally planted in a mixed stand. The interesting adaptation of strains to conditions prevailing in the different environmental Regions can be observed.

Besides sorghum, maize is cultivated throughout the area in small quantities. Bulrush millet is grown in the Semi-Arid Region and in parts of the Ironstone Region. Finger millet has recently been spreading into Bari and Mandari country and among the Dinka of Lakes District. Rice is cultivated on a small scale by the Fellata people opposite Jebelein. When compared with sorghum the importance of these cereals is negligible.

Of the leguminous crops, cowpeas and beans are the most important. They are grown throughout the area on the better drained land, usually in stands mixed with sorghum and other crops. Groundnuts are grown in the Semi-Arid Region and Ironstone Region, and very occasionally in the Flood Region, and often as a cash crop. Other legumes occasionally seen in the Ironstone Region are pigeon peas and Bambara groundnuts.

Of oil crops, sesame is the most important, being widely grown in the Semi-Arid and Ironstone Regions. The conditions in the Flood Region are generally unsuitable for this crop. Other oil crops met with in this area are Shea nut, indigenous in parts of the Ironstone Region; melon seed, grown in the Kosti area; castor, occasionally planted by Nilotics, Bari and Mandari, the oil being used for anointing; and hyptis, sometimes found in the southernmost part of the Jonglei Area.

Cotton provides a useful lesson concerning the introduction of cash crops. It has been grown in various parts of this area since the early 1920's, and the efforts of the Department of Agriculture were very largely centred on its production. It was never popular amongst the inhabitants, and only propaganda, persuasion, or even compulsion, could keep production going. When, during the war, the official policy changed, the production of cotton practically ceased. It has revived in the northern part of the Jonglei Area under the natural stimulus of post-war prices, and now needs little official encouragement. Two factors must be regarded as

responsible for this change; pre-war prices of cotton were insufficient incentive; secondly, in pre-war days, cotton competed with and partly replaced food crops, while at present its production is concentrated in areas where *hariq* cultivation has permitted considerable enlargement of the total area under cultivation, and in Kosti district where investment of capital provides for the development of pump schemes.

Other crops cultivated in the Jonglei Area include pumpkins and marrows, grown throughout the area; sweet potatoes and cassava, grown in the Ironstone Region; melons, cucumbers, and a number of other Sudanese vegetables grown mainly in the northern part of the area.

WEEDS, DISEASES AND PESTS

It is impossible in this short summary to enumerate the weeds, diseases and pests which cause considerable damage to crops in this area. The weeding problem is difficult, largely because of the primitive implements at the disposal of the cultivator. Fungoid diseases are, not surprisingly, common in the warm and, during the rains, humid climate of the Flood and Ironstone Regions. Pests range from the minute sorghum midge to elephants, and are very often responsible for considerable damage. The parasitic *Striga hermonthica* requires special mention again, as we have estimated that, in the Flood Region, it causes an average loss of sorghum yields of the order of 30%, and on intensively cultivated lands often reduces yields to practically nothing.

As a whole, the Jonglei Area can be regarded as self-sufficient in food crops. Exports from the Semi-Arid Region to the north, and very limited exports from the Bari and Mandari area to the south, are roughly balanced by imports of grain from the Northern Sudan, Eastern Nuer district, Maban country and Kordofan. Within the Jonglei Area a considerable grain surplus is produced in the Transitional Belt between the Flood and Semi-Arid Regions. The Ruweng (Kwil and Awet) Dinka, north of the Bahr el Ghazal, the Chich and Atwot Dinka, and a few of the Bari and Mandari have on the average some surplus. The Lak and Thiang Nuer and Luaich and Ruweng (Paweng) Dinka, as well as sections of the Gaweir Nuer and the Eastern Mandari, are on the whole self-sufficient. The Bor Dinka, Western Nuer tribes and the majority of the Gaweir Nuer, as well as the southern Shilluk, are generally short of grain. It should be noted that these are general trends and year to year variations are very considerable. Besides grain the Jonglei Area produces and exports mainly cotton, but also small quantities of gum arabic and oil seeds.

CHAPTER 6. FISHERIES

The seasonal aspects of the subsistence economy of the inhabitants of the Jonglei Area have been explained in Chapter 3. Fish plays an important part in the diet at certain times of the year when it is available to supplement the major constituents—grain, milk and meat. Among some tribes there are specialist elements who rely almost entirely on fishing for their livelihood. Of these the Monythany Dinka of Bor District are the most notable example. Some tribes depend on fishing more than others, the Shilluk being generally the most skilled and enterprising fishermen.

In the Jonglei Area there are many varieties of fish available of varying economic value, the most common and important being *Citharinus citharus* (Ar. *batkoiya*), *Distichodus niloticus* (Ar. *khraish*), *Heterotis niloticus* (Ar. *nok*), *Tilapia nilotica* (Ar. *bulti*, *khadim miri*), the large number of species described loosely as 'cat-fish' (*Bagridae*, *Clariidae*, *Mochidae*, *Schilbeidae*, etc.) and *Lates niloticus* (the Nile Perch).⁽¹⁾

There is as yet only limited information concerning the distribution, breeding habits and growing rates of fish in this part of the Nile system, and the Team has been handicapped by the absence of specialist staff to deal with the problem. Generally speaking the perennial waters—the main channels of the river and the numerous lakes and pools found in the flood-plain—serve as a reservoir of fish stocks during the dry season when the water-levels are low and the flood-plain has dried out. When the waters rise and inundate the flood-plain and the inland

⁽¹⁾ These and some others are briefly described on pp. 377–79 (Vol. I) and a more comprehensive list, together with Arabic and vernacular names, is given in Table 179, p. 388.

watercourses begin to flow the fish disperse over a very large area and thrive on the almost unlimited food supplies then available to them. Then, as the floods recede, they are concentrated again in the more restricted area of permanent water where food is less abundant. The seasonal rise and fall of the river is therefore of paramount importance in the life cycle of the fish. Seasonal fluctuation in water-levels is also important in another respect for, apart from fisheries sponsored by the government, the fishing techniques employed by the inhabitants are rudimentary and generally only effective in shallow water. The multi-barbed fish-spear and the harpoon—the most common weapons, plunged in a somewhat haphazard manner into the water, are not very productive unless the fish are concentrated in the pools when the water is low during the dry season. In the rainy season the inhabitants rely on damming the watercourses at a time when the fish are moving upstream, or later in the year returning to the main rivers as the water begins to drop. Other methods, including traps, short and poorly made gill-nets, cast nets, and long-lines, are used but are uncommon.

In recent years the comparatively high prices paid for sun-dried salted fish have led to the rapid development of commercial fisheries, many of which operate within the Jonglei Area. Further expansion will undoubtedly take place and the potentialities appear to be considerable. The potentialities are, however, not easy to estimate in terms of quantity. Under present conditions local fishing methods are sufficiently discriminate to avoid serious depletion of stock, but the introduction of modern netting techniques is a different matter. It is clear that the development of commercial fisheries cannot continue without careful regulation and control—measures which have already been introduced.

A systematic study of the fisheries resources of the Jonglei Area is required—of distribution, breeding habits, rates of growth, and relative yields—before an attempt is made to assess in quantitative terms the present consumption of fish by the inhabitants and the potential which may safely be used for trade purposes without harm to local needs or to the continuance of present stocks. For the purpose of this report we have had to attempt (in Volume II) some sort of quantitative estimate, but it must be realized that the data are inadequate, and that even with the best information it is rarely possible to produce accurate estimates of yields. The vast area involved and the seasonal nature and wide distribution of the fisheries make this task doubly difficult.

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VOLUME II. THE EQUATORIAL NILE PROJECT: ITS EFFECTS AND THE REMEDIES

CHAPTER 1. THE PROJECT

An outline of the main objectives of the Equatorial Nile Project has been given in the Introduction (pp. i-ii) and need not be repeated here. This plan for controlling the upper White Nile is the culmination of the work of studying and gauging the river which began in 1904. It is also one part of a comprehensive plan of control for the whole Nile Basin, of which the other main parts are new dams on the Main Nile and at Lake Tana. A summary description of the Egyptian Project as submitted (*The Nile Basin*, Vol. VII) and modified by Dr. Mohamed Amin and Mr. H. G. Bambridge in 1948 is as follows:

Lake Victoria: The century storage reservoir will be in Lake Victoria with a dam at the Owen Falls. It will have a capacity of 200 milliards between levels of 9·80 m. and 12·80 m. on Entebbe gauge. Its outflow will be regulated between a minimum of 44 m/d required for electric power and a maximum of 100 m/d, and will normally average 55 m/d, or 20 milliards a year.

Lake Kioga: A regulator will be built at the outlet from Lake Kioga to eliminate the time-lag between Lakes Victoria and Albert.

Lake Albert: The storage capacity required in Lake Albert to equalize its outflows to the long-term mean has been estimated to be 62 milliards in 42 years. By increasing the outflow and reducing the inflow during high floods, the required capacity could be substantially reduced, and it is considered that 49 milliards, between levels of 10·00 m. and 18·50 m. on Butiaba gauge, would be sufficient, though the dam (at Mutir) should be built to allow for raising if necessary. The following working arrangements for the operation of Lake Albert are suggested (see Map 5 and Fig. F 1):

- (i) The extreme range of levels will be from 9·00 to 18·50 m. on Butiaba gauge.
- (ii) For normal regulation the lake level will not exceed 14·00 m.
- (iii) The storage available between 14·00 m. and 18·50 m. will be reserved for flood protection.
- (iv) The object of regulation will be to discharge 17 milliards at Mongalla in the timely season.
- (v) Since about 10 milliards will be discharged in the untimely season the flow at Mongalla will be the long-term mean natural discharge of 27 milliards per year.
- (vi) The timely quota will be reduced to 9 milliards, or increased to 22 milliards at Mongalla according to an annual forecast of Main Nile requirements.
- (vii) The untimely quota will also vary because the minimum for navigation downstream of Mutir will be about 40 m/d, to which will be added the flow of the torrents.
- (viii) The timely season at Mutir will be from December 1st to June 10th.
- (ix) As soon as the storage dams at Owen Falls and Mutir are completed, the regulation at Mutir will "tend to a gradual reversal of the seasons".
- (x) The minimum discharge at Mutir dam is estimated to be 44 m/d for navigation.
- (xi) When the level in Lake Albert exceeds 14·00 m. on Butiaba gauge the outflow will be increased to the maximum possible, provided that the flow at Mongalla does not exceed the mean rates of 150 m/d over 24 hours, 140 m/d over 10 days, 130 m/d over 30 days and 120 m/d over 6 months.
- (xii) Escape at the maximum rate will continue until the available data indicate that the flood is falling, when the flow at Mutir will be reduced to normal, allowing Lake Albert to be emptied gradually and making full use of flood-water stored above 14·00 m.

Site of the Lake Albert Dam: The site suggested for the Lake Albert dam is at Mutir, 79 km. north of the lake exit, but a site at Nimule would have several hydrological and engineering advantages, namely good rock foundations, ability to control the torrents, and unimpeded navigation on the reservoir to Nimule.

Torrents Balancing Reservoir: If the dam is built at Mutir it will be necessary to build other dams between Mutir and Rejaf to control the torrents.

Sudd Diversion Channel: This is the name given to the whole system in which water is to be diverted from the Bahr el Jebel, carried past the swamps, and delivered to the White Nile at the Sobat mouth. In the 55 m/d Canal stage, it will consist of the 'Atem Inlet Channel', from the Atem Head to Jonglei, and the 'Jonglei Canal' from Jonglei to the Sobat mouth along what is referred to as the 'Direct Line'.

The engineering works required for the 55 m/d Canal Stage of the Project will be:

- (i) Banking on the left of the Bahr el Jebel from Tombe to the Atem barrage.
- (ii) A regulator and lock on the Atem at its head.
- (iii) A barrage, regulator and lock on the Bahr el Jebel downstream of the Atem head.
- (iv) Embanking and remodelling of the Atem to carry 80 m/d from its head to Jonglei—the Atem Inlet Channel.
- (v) A regulator and lock at the head of the Canal at Jonglei.
- (vi) A barrage and regulator across the lower Atem downstream of the Canal regulator.
- (vii) The Jonglei Canal (actually two canals) from Jonglei on the 'Direct' line to the Sobat mouth.
- (viii) Either cross-drainage works for the Khor Atar at Mogogh, or training works to divert its flow into the Kwanjor and Fullus.
- (ix) A regulator—falls and lock—at the tail of the Canal.

Design of the Jonglei Canal: The velocity will not exceed 1.0 m./sec.; water-levels will conform to ground level; and there will be no intermediate regulators. There will be two canals of 27.5 m/d capacity; they will each be about 76 m. wide and 4 m. deep.

Operation of the Project: Our estimate of the effects of the Project, given later, is based on conditions in the 55 m/d Canal stage, which will be as follows:

Site	Discharges in m/d	
	Timely	Untimely
Mongalla	90	57
Atem Head latitude	85	52
„ „ regulator	55	17
Bahr el Jebel barrage	30	35
Lower Atem „	—	—

Progressive Stages in the Construction of the Project: There will be five constructional stages before the Project reaches that in which the capacity of the Canal will be 55 m/d.

Stage I: Storage Dams only.

Stage II: 10 m/d Canal: Malakal discharge unaltered.

Stage III: 10 m/d Canal: Malakal timely flow increased by one milliard.

Stage IV: 27.5 m/d Canal: Malakal timely flow increased by three milliards.

Stage V: 55 m/d Canal: Malakal timely flow increased by seven milliards.

Storage in Lakes Victoria and Albert will be built up as soon as both dams are completed. In Stage II there will be regulators with locks to suit Stage IV at the head and tail of a 10 m/d canal. Stage III will require a change in the mode of operation only. Stage IV will require enlargement of the canal only, but Stage V will require the construction of all the engineering works listed previously. In this last stage the head of the *Sudd Diversion Channel* will be moved from Jonglei to the Atem Head.

Discharges at Mongalla, the Tail of the Swamps, and Malakal, in each of the five stages, are given in a series of tables (Tables 186–190, pp. 407–411). When the 55 m/d Canal stage is reached, 22 milliards out of 27 passing Mongalla will reach the Tail of the Swamps instead of 14.2 milliards as at present, the difference of 5 milliards representing normal transmission losses.

Time Factor: According to the report by Dr. Mohamed Amin and Mr. H. G. Bambridge the 55 m/d Canal stage is expected to be completed in 25 years from the day of approval.

80 m/d Canal Stage: It is intended eventually to extend the Project further by increasing the capacity of the *Sudd Diversion Channel* to 80 m/d, though the method of doing so has not been decided. Water from the Great Lakes could then be used to make good shortages in supply in other parts of the Nile basin.

Flood Protection: Reserve storage in Lake Albert between 14:00 m. and 18:50 m. on Butiaba gauge, and suitable operation of Lake Victoria (and possibly Lake Kioga) are the measures which will be taken to protect the Sudan from severe flooding. Even so, the discharge at Mongalla may have to average 120 m/d for long periods, and it is clear from the report that the Egyptian Government intend to dispose of this by reflooding the Central Zone.

PART I. THE EFFECTS ON LOCAL INTERESTS

CHAPTER 2. HYDROLOGICAL CHANGES AND EFFECTS

The aim of the Equatorial Nile Project is to provide water for irrigation in Egypt and the Northern Sudan during the timely period. Since the timely period approximates to the dry season or period of low river, the general effect will be to reverse the natural seasonal fluctuations. In parts of the Southern Zone these effects will be modified and the adjacent flood-plains never inundated by river spill because the natural banks of the river will be raised. In the Central Zone there will be only minor fluctuations in river level which will be kept low to prevent spill. In the Northern Zone the river levels will be generally higher at all times of the year because a high discharge will be passed through the canal in the timely season, and during the untimely season the Sobat flood (which will not be controlled) will keep the levels high. Assuming that the Project will be as designed in the reports mentioned previously and summarized in the preceding chapter, the effects will be as follows:

EFFECTS IN THE 55 M/D CANAL STAGE

MAIN RIVERS

SOUTHERN ZONE: 774 sq. km. of flood-plain normally covered and uncovered by fluctuations in discharges of the Bahr el Jebel will be lost because they will be flooded at the wrong time of the year or not flooded at all. 200 sq. km. of land bordering the river will continue as now to produce grasses whose roots will reach an underground water-table, and 200 sq. km. of *toich* will continue as now to produce grasses under natural irrigation from local watercourses. Though there will be some overlapping of the areas flooded by high discharges in the dry season with the areas which will still be irrigated naturally by local watercourses and from the underground water-table, it is not thought that this will be extensive.

CENTRAL ZONE: Of the present area of 6,554 sq. km. of swamps between the Atem Barrage and the Buffalo Cape-Fangak line, only about 362 sq. km. bordering the river, in valleys similar to the Aliab and Mongalla-Gemmeiza *toiches* which were surveyed in the Southern Zone (see Volume III, Chapter 1), will continue to be flooded by spill from the Bahr el Jebel, augmented by run-off from local watercourses such as the Tapari and Khor Moich.

NORTHERN ZONE: Between Lake No and Malakal on the White Nile 487 sq. km. of flood-plain will be inundated and uncovered instead of 596 sq. km. as at present—a reduction of 18%. Between Malakal and Jelebein 630 sq. km. of flood-plain will be flooded and uncovered instead of 913 sq. km. as now—a reduction of 31%. North of Jelebein the reduction will be about 8% as represented by a cross-section at Rabak (Kosti).

INLAND WATER-SYSTEMS

SOUTHERN ZONE: Inland watercourses will be unaffected.

CENTRAL ZONE: The area bounded by the Jonglei Canal, the Bahr el Jebel, the Bahr el Zeraf and the White Nile will be protected from overland flooding and no longer subject to river spill on the Jonglei plain. East of the Canal overland flooding will be intensified, especially if the Khor Atar cross-drainage syphon is not included and its flow diverted to Khors Kwanjor and Fullus. Drainage into the numerous watercourses such as those which intersect Zeraf Island will be improved because river levels will be low in the rains, but khor-bed grazing will no longer be irrigated naturally by spill in the dry season. Probably about 810 sq. km. will continue to be irrigated on the Western Plain, at the tail end of the Tonj, Gel, Na'am and Lau, when spill from the Bahr el Jebel is eliminated.

NORTHERN ZONE: In the Khor Fullus the backwater in the dry season will be extended about 22 km. in the lower reaches, where the river is narrow, deep, and well defined with little or no flood-plain. In the Khor Atar there will be increased backflow from January onwards, drying out slowly to higher minimum levels in April, but on balance no change in the area irrigated. Khor Yirr Gwol will apparently be unaffected by levels in the White Nile. In the Khor Wol backwater effect will extend probably less than 10 km. upstream, which is insignificant in comparison with the rest of the system. In the Khor Nyadwai the results will be the same as in the Khor Wol. In the Khor Adar the flood-plain will be unaffected.

DOMESTIC WATER SUPPLIES

SOUTHERN ZONE: There will be no effects.

CENTRAL ZONE: Inland water-systems, which are extensive, particularly on the Zeraf Island and in Western Nuer District, will be deprived of spill, which constitutes a very important source of domestic water supplies in the dry season.

NORTHERN ZONE: There will be a slight benefit from extended backwaters in inland water-systems.

IRRIGATION AND DRAINAGE

SOUTHERN ZONE: The reversal of the seasons will result in better drainage on the river flood-plains which will not be inundated by spill water in the rainy season; high discharges in the dry season will facilitate irrigation. Since the Aliab Valley will be banked off, irrigation could be under control there. Elsewhere flooding could be controlled by blocking up spill-channels and backwater channels.

CENTRAL ZONE: About 6,192 sq. km. of swamps will be dried out. This area will be irrigable, as it is now commanded naturally by the river, but inundations during a period of flood-escape make irrigation extremely inadvisable. The portion of the Eastern Plain traversed by the 'Direct' Line of the Canal is available for irrigation from it, but water would have to be pumped or the design of the Canal changed. Drainage will be vastly improved because rain-water will be able to run off into the depressions bordering the river which are now permanent swamp.

NORTHERN ZONE: Higher minimum levels in the dry season will be of immense benefit to pumped irrigation from east of Lake No, Fangak, and Abwong to Renk. In addition to lower lifts, higher minimum levels will assist in the selection of pump sites, which is the main difficulty at present. Future maximum levels in the rainy season will be only slightly higher at Malakal and drainage will not be affected to any appreciable extent.

EFFECTS IN OTHER STAGES AND OPERATIONS

INTERMEDIATE CONSTRUCTIONAL STAGES

NORTHERN ZONE: No appreciable adverse effects will be felt on the areas of flood-plain in the intermediate stages.

CENTRAL ZONE: Each intermediate stage will result in a river régime differing in kind and degree from the others. The Jonglei Canal will become navigable in the 27.5 m/d Canal stage, but the proposed untimely discharge of 17 m/d will be inadequate for this purpose.

SOUTHERN ZONE: From the first stage (i.e. storage dams only) the *toiches* will be completely deprived of flooding. Changes in the operational régimes for each stage will cause dislocations and severe inconveniences to the inhabitants, as in the Central Zone.

80 M/D CANAL STAGE

There will be 100% loss of flood-plain in the Southern and Northern Zones. There will be practically no change in the Central Zone from conditions in the 55 m/d Canal stage.

FLOOD-ESCAPE DISCHARGES

It is intended to discharge as much as 120 m/d into the Bahr el Jebel at Jonglei for short periods, and about 93 m/d for several years. Such discharges are expected to give rise to conditions north of Jonglei "no worse than in the untimely season of 1917 when 34 milliards passed Mongalla in 6 months". After a 'drying out' interval of perhaps 25 years, when the discharge at Jonglei in the Bahr el Jebel will not have exceeded 35 m/d, such discharges (i.e. 34 milliards in 6 months = 120 m/d) would produce intolerable conditions in the Southern

and Central Zones and the proposal cannot be accepted. The Egyptian proposals, as they stand, contain no details of how high flood-escape discharges will be passed between Tombe and the Atem Head. It appears that Bor will be inundated. In the Northern Zone, on the other hand, as much flood-plain would be inundated and uncovered as at present, and the maximum discharge at Malakal would be 133 m/d and 37.5 milliards per year.

CHAPTER 3. EFFECTS ON ANIMAL HUSBANDRY AND PASTURE

The importance of the flood-plains of the Nile system, providing as they do the principal, and in some cases only, source of nutritive pasture during the dry months of the year, has already been stressed. The alterations in hydrological conditions described above will cause changes in the ecological characteristics of the flood-plains and these in turn will affect their utilization by the inhabitants of the Jonglei Area.

SOUTHERN ZONE

In this Zone the river will be low during the untimely season (mid-June to December) which corresponds approximately with the rainy season and present period of high river; it will be high in the timely season which corresponds approximately with the dry season and present period of low river—an almost complete reversal of the natural régime of the river. Moreover, the land at present subject to seasonal inundation will be flooded to a greater depth than at present and there will be larger areas of permanent swamp. This general effect will in this reach be modified by artificial banking which is proposed in order to prevent river spill and losses by evaporation and transpiration. For the purposes of estimating the effects of the Project on natural pasture in this Zone it is therefore necessary to divide it into two reaches.

South of Tombe: Since there are as yet no proposals for banking this reach, it must be assumed that there will be a complete reversal of the present seasonal inundation and exposure of the flood-plains. Swamp grasses will still be produced, but only a comparatively small proportion will be accessible when required in the dry season. In this reach there will be no actual loss over the season as a whole, but there will be a shortage in February of grazing for 4,600 Animal Units, reduced to a total of 3,000 A.U. owing to a surplus in January. Since the total livestock population does not depend entirely on riverain pasture for its grazing requirements, this deficit need not be considered, though there will be a loss in potential which should not be overlooked.

Tombe–Atem Head: Except for a comparatively limited area on the east bank between the Tombe latitude and a point some 15 km. north of Bor, where the banking will start, the whole of the flood-plain in this reach will be banked off and no longer subject to river spill. The effects will therefore be not dissimilar to those in the Central Zone since, apart from seepage, rainfall, and run-off from the hinterland, there will be no flooding. Some riverain swamp pasture will remain in the depressions, provided there is adequate depth and duration of flooding, but it is expected that much of it will be replaced by grasses normally found on intermediate land, i.e. by grasses which flourish where the depth and duration of flooding is much less. At the present time the estimated animal population using this area of riverain pasture is 103,200 Animal Units and there is a small surplus available (except in February). We estimate that under future conditions the area will not support more than 74,300 Animal Units, and only 56,300 in February. Thus the maximum loss will be grazing for 46,900 Animal Units in February and there are no natural alternative grazing areas. Another effect of lesser importance is that the river will be much higher at the time of year when the many thousands of cattle, sheep and goats from the east bank have to cross into the Aliab Valley by swimming across the main channel of the Bahr el Jebel. The risks of this operation, already a hazardous one, will therefore be increased considerably.

CENTRAL ZONE

The object of the Jonglei Canal is to carry the main discharge and to keep the natural channels of the river below spill level. Some spill will inevitably take place through natural breaks in the river banks—unless these are banked off—but losses will be relatively small. Thus nearly the whole of this vast area of *toich* and swamp will no longer be flooded. The effect on the vegetation will be similar to that in the Tombe–Atem Head reach; in only a comparatively small area will the depth and duration of flooding be sufficient to produce

riverain swamp grasses, i.e., in those areas subject to a combination of seepage, precipitation, run-off and the contributions of tributaries which, being uncontrolled, may increase the very limited amount of river spill. Large areas, now permanent swamp and rarely accessible even when the river is low, will dry out and will probably produce vegetation similar to that found on intermediate land, and will be of value as grazing only in those areas where sufficient soil moisture remains in the dry season to promote the robust regrowth of the perennial grasses. The present area of swamp, permanently flooded or seasonally exposed, is estimated to be 6,554 sq. km.; under future conditions it is expected that only 362 sq. km. will produce riverain swamp pasture; the remainder will produce intermediate land grass types, mainly *Hyparrhenia rufa*.

On the Eastern Plain east to west drainage will to some extent be held up by the Jonglei Canal, and it seems probable that the consequent heavier flooding east of the Canal during the rains will increase the quantity of regrowth from the intermediate land grasses in the dry season, thus raising the stock-carrying capacity of the area. West of the Canal there will be little or no spill from the Bahr el Jebel or the Zeraf and very little rain-flooding, and it is probable that in most areas the grasslands will change from the *Hyparrhenia* to the less valuable *Setaria* type. The Canal itself will have beneficial results in providing water supplies in an area which is at present vacated in the dry season owing to the lack of drinking-water.

Several large watercourses and numerous smaller ones in this Zone derive at least part of their water from the main river. These watercourses spill over their banks, producing large areas of riverain swamp pasture and water supplies which are fully utilized and must be regarded as part of the grazing facilities provided by the natural régime of the Nile system. Under the Project the contribution of the main river channels will be eliminated or much reduced, and these resources will be diminished accordingly. This applies in particular to the area west of the Bahr el Jebel where a large proportion of the livestock is dependent in the dry season on pasture produced in this manner, and also to some of the khor-bed grazing areas in the Zeraf Island and along the east bank of the upper Zeraf.

Over the whole Zone we estimate that 423,400 Animal Units are dependent in the dry season on pasture produced directly or indirectly in the manner described by the natural fluctuations of the main river. We estimate that under the Equatorial Nile Project the remaining nutritive dry season pastures will accommodate only 233,500, a direct loss of grazing for 189,900 Animal Units.

NORTHERN ZONE

Under the future régime the fluctuation in river levels will be governed, as at present, by the Sobat flood, and north of Melut by the Jebel Aulia Dam. Along the Bahr el Jebel from km. 60 to Lake No and along the Bahr el Ghazal river levels will not change perceptibly and the effects on riverain pasture will be negligible. Along the lower Sobat the minimum river level will be higher owing to backwater from the Canal, but will not be sufficient to inundate the flood-plains in the dry season and pasture will still be available when required. Only on the flood-plains of the Khor Fullus, which at present provides very limited dry season grazing, will the river levels be sufficiently high to make it inaccessible. On the White Nile between Lake No and Tonga there is at present very little spill on the left bank and the effects of the Project on grazing facilities will be very small, but on the right bank much larger areas of deep-flooded pasture will be permanently under water and therefore inaccessible. Similarly on both banks between Tonga and Malakal higher minimum levels will cause loss of riverain pasture. Although these changes may be partly offset by the flooding and exposure of new land at higher levels, the losses will not be entirely eliminated because the stock-carrying capacity of deep-flooded pasture is so much higher than that of the shallow-flooded pasture and of the intermediate pasture which will be produced at these higher levels.

It is estimated that between Malakal and Melut the area of the flood-plain inundated and exposed under present circumstances will be reduced by 36.3%. From Melut to Renk, where the effects of the Jebel Aulia Dam begin to be felt, the reduction will be 33.7%, and between Renk and Jelebein 18%. North of Jelebein the reduction will only be 8% and the areas permanently flooded will be mainly those which are at present bare and useless mud-flats, so the loss of grazing will be very small. Over the whole of the Northern Zone we estimate that the actual loss of dry season pasture will be for 51,400 Animal Units. In addition to loss of pasture other adverse effects may be expected. There will be larger areas of permanent swamp and open water providing conditions for an increase in disease-carrying snails, for their infection with the intermediate stages of liver-fluke (and bilharzia) parasites, and for the re-infection of the primary host. The increased incidence of liver-fluke disease in Kosti District since the building of the Jebel Aulia Dam has already been noted, and a further increase may well take place as a result of the Equatorial Nile Project.

Total losses in riverain grazing in the Jonglei Area (expressed in Animal Units and taken to the nearest hundred) will be as follows:

EQUATORIAL NILE PROJECT: EFFECTS ON RIVERAIN PASTURE EXPRESSED IN TERMS OF ANIMAL UNITS

Zone	Livestock wholly or partly dependent on pasture affected by main river	Loss of riverain pasture	Percentage loss
SOUTHERN	138,400	46,900	33.9
CENTRAL	423,400	189,900	44.9
NORTHERN	240,300	51,400	21.4
TOTAL Jonglei Area	802,100	288,200	35.9

CHAPTER 4. EFFECTS ON FISH AND FISHERIES

The effects of the altered hydrological régime under the Equatorial Nile Project on fisheries are not easy to predict since so little reliable information is available concerning the breeding habits and distribution of the fish. It is clear that when the river rises and inundates the marshland and swamp along its flood-plain a vast and highly productive area is made available for the fish; the seasonal migration of fish into these flooded areas is a distinct characteristic of their life cycle. In those reaches where there will be a complete reversal of the present seasonal régime the effect on fisheries is impossible to assess, though we assume that the fish will adapt themselves to the new conditions. In those reaches where the levels will always be higher than the present levels, no detrimental effects need be expected and, indeed, an increase is possible. It is manifest, however, that in those reaches where the present area of the flood-plain will be partly or totally deprived of spill-water from the river, the fish will remain confined to the perennial channels and a big reduction in numbers will be inevitable.

Apart from reductions in the fish population, other adverse effects on fisheries may be expected. Under present circumstances fishing methods are rudimentary and generally only effective in shallow waters and in water where the fish are comparatively concentrated, i.e. in the pools and lakes of the flood-plain, especially when the river is low. In some parts of the Jonglei Area the water will remain deep and the fish dispersed throughout the year, and unless more modern techniques are employed—techniques which are more suitable for commercial and specialized enterprise—the amount of fish available for the population will decrease substantially. There will thus not only be a reduction in some parts in the actual number of fish, but also greater difficulties in catching them in other parts where fish are still available. The different effects in the different Zones may be summarized as follows:

SOUTHERN ZONE

In this Zone the over-all effect of the Project will be the reversal of the present seasonal rise and fall of the Nile.

Nimule-Juba: In this reach the reversal in seasonal discharges will not necessarily cause any reduction in fish since there is scarcely any flood-plain, and in any case the present fisheries potential is not great. The principle disadvantage, affecting mainly the Madi tribe, will be that low discharges, which provide more favourable fishing conditions, will occur when the people are fully occupied with their cultivations. Moreover the migration of fish up the Fola Rapids will be prevented—assuming that the dam will be at Nimule—and fish-ladders will be needed, a stipulation which must also apply to any balancing reservoirs in this reach.

Juba-Tombe: In this reach it is assumed that there will be no artificial banking to prevent spill from the river. The effects will be two-fold. In the first place the fish will be scattered and water-levels will be high during the dry season, making local fishing techniques far less effective than at present; moreover this will occur at a time of the year when the people are concentrated along the river-front, herding their cattle and free from the laborious tasks of

cultivation. In the second place, commercial fisheries—now rapidly developing—may be less successful because the best fishing conditions will coincide with the rainy season when relative humidity is high and the production and storage of sun-dried salted fish is more difficult.

Tombe-Atem Head: It is assumed that between Tombe and Atem Head on the left bank and a point some 15 km. north of Bor to Atem Head on the right bank steps will be taken to prevent spill from the river by raising the banks. The major portion of the flood-plain will therefore no longer be inundated at any time of the year, and the fish which at present make use of the flood-plain will no longer be available.

CENTRAL ZONE

In this Zone a vast area of seasonally inundated and permanent swamp will no longer be flooded from the river and a very large reduction in the fish population is inevitable. In addition many of the larger watercourses, partly fed by spill-water from the Nile, at present provide excellent fisheries during the rainy season; subject to local rainfall and run-off only, the water in these watercourses will be reduced with obvious effects on the fisheries.

NORTHERN ZONE

The general hydrological effect in the Zone will be that river levels will remain throughout the year appreciably higher than at present and a larger area of the flood-plain will be permanently under water. It is not expected that this will cause any decrease in the fish population, though there may be inconvenient alterations in the seasonal movements of certain fish species. The waters will remain generally deeper than at present and the fish more widely dispersed. Local fishing methods will be less effective and even modern techniques of netting may be less productive. Further, the fact that the period of comparatively lower water-levels when fish are more easily caught will coincide with the rainy and humid season may, as in parts of the Southern Zone, make the curing, storage and shipment of fish more difficult.

The importance of fish in the diet of the inhabitants of the Jonglei Area cannot be stressed too strongly. Fish is of particular importance at certain times of the year when other food-stuffs are in short supply. Apart from actual reductions in the fish population in some reaches of the river and greater difficulties of catching them in others, one major disadvantage must also be mentioned. It is that in present circumstances fish are available and easily caught in those areas to which the people must move during the dry season. In fact the people judge their dry season grazing grounds not only by the excellence of the pasture, but also by the availability of productive fishing pools and channels. If, in the future, pasture is no longer to be found near to these fisheries, the bulk of the population will be without fish when it is most needed. The introduction of commercial fisheries to provide for them will be necessary and among a people whose economy is largely unspecialized, with no developed system of marketing foodstuffs, this is no small consideration.

It is easy enough to predict the effects of the Equatorial Nile Project on fisheries in general terms. It is a much more difficult task to do so in terms of quantity. No reliable figures for natural yields are available and a full programme of research would be necessary to obtain even approximate figures. Estimates from other parts of the world do not apply. We have, however, assumed that those areas of the flood-plain which produce certain species of vegetation (i.e. subject to certain seasonal depths and periods of immersion from the floods) also produce fish, and these areas have been estimated. We have taken the somewhat conservative figure of 20 kilogrammes per feddan as the potential yield. The average consumption of fish is not a known factor, but we have assumed that it is 16 kg. of fresh unboned fish per annum per head of population. Taking these figures (which are given in detail in Table 273, p. 524), the losses which must be met by remedial measures amount to 2,962 metric tons. This refers only to local subsistence requirements; calculated by this method, the loss in potential which might well be exploited in the future amounts to 20,281 metric tons after deducting that required to meet the present requirements of the local population.

CHAPTER 5. OTHER EFFECTS

EFFECTS ON TOPOGRAPHY AND CLIMATE

The Equatorial Nile Project will not have any marked effect on the topography of the Jonglei Area, but it is worth noting that in other parts of Africa the draining of swamps has been followed by a slow and steady lowering of the level of the land. This will be inevitable

in the areas of papyrus swamp, but not necessarily on *toich* land where the soils contain only a small amount of organic matter. Effects on climate over the Sudan as a whole are likely to be negligible, but there may be slight changes in temperature and humidity in places in and adjacent to the swamps.

EFFECTS ON CROP PRODUCTION

The Project will directly affect only cultivations on the *toich*. *Toich* cultivations are at present extremely limited, and areas of *toich* still remaining under the new régime will be more than sufficient to meet present demands. The potentialities of crop production on *toich* land (rice during the rains and other crops in the dry season) are very considerable, and the loss of potential must be borne in mind. Losses in potential will, however, be at least partly off-set by certain advantages; for example the reversal of seasonal discharges in the Southern Zone combined with the raising of the river banks will open up new agricultural potentialities in the form of gravity irrigation in the Aliab-Atem area.

Indirectly the Project may in some areas cause a clash of economic interests, since new grazing areas will have to be opened up to meet losses in the riverain pastures and the new areas may coincide with land of potential value for crop production. *Hariq* areas in the Northern Zone are a particular example.

The cessation of seasonal inundation, and hence seasonal anaerobic conditions, will result in the oxidation of a considerable proportion of the organic matter in the soils. How far these changes will affect soil fertility is difficult to estimate without long-term experiments, but, from such observations as have been possible during the Team's short period of experimental work, it may be assumed that there will be some loss of fertility in *toich* soils. With regard to *sudd* soils on reclaimed land—i.e. drained papyrus swamp—effects on fertility are no less difficult to assess. Swamp soils of the Jonglei Area differ considerably, but experience of swamp drainage in other parts of Africa has demonstrated the complexity of the problem and that drainage often leads to rapid deterioration. The economic aspects of the utilization of these reclaimed soils are of importance; the advantages of the increased fertility of the soils, if it can be maintained, may well be nullified by the increased costs of installations and management. Moreover the reclaimed areas will occur in the Central Zone and will be subject to re-flooding in years of flood-escape discharges unless steps are taken to overcome this difficulty.

Finally it should be stressed that the ultimate effect of the Project may be to alter the whole economic character of the area, since in those places where no alternative pasture can be found for cattle displaced from the flood-plain a reduction in livestock is inevitable and much greater reliance will have to be placed on crop husbandry than hitherto.

EFFECTS ON COMMUNICATIONS

Navigation : In the Southern Zone the Project will probably hasten the natural process of scouring and silting between Rejaf and Tombe, but this disadvantage will be more than offset by control of the river, so that the discharge at Mongalla will never drop below 57 m/d (above the discharge required for navigation in this reach) nor exceed 90 m/d, except during a period of flood-escape. In the Central Zone communications between north and south will be much improved by the more direct route provided by the Jonglei Canal—a saving of 354 kilometres in distance and roughly three days' upstream sailing time. It must be mentioned, however, that a discharge of 17 m/d in the untimely season will be quite inadequate to maintain navigation in one canal designed to carry 27.5 m/d with 4 metres depth of water, and to keep down weeds in the other; the proposal to connect the two canals will make it impossible to run the canals at different levels and discharges. Special stipulations concerning the design of the canal are therefore essential.

If the Canal becomes the main line of communication, the Atem Head regulator and barrage will become a main port. In the natural channels of the river shuttle services will still be able to operate on the Bahr el Jebel and the Bahr el Zeraf, but navigation of the bottle-neck upstream of Lake Papiu will be more difficult than it is today. Navigation will still be possible to Shambe, at present one of the main ports of the Bahr el Ghazal Province, but the best line of communication in the future will be to the Atem Head regulator direct. In the Northern Zone higher minimum levels will lead to a general improvement in navigation on the White Nile, particularly at Jebel Ahmed Agha, Ez Zuleit Rocks and Abu Zaid Ford, where there are at present navigational difficulties during the dry season.

Roads : Dry season roads in the Southern Zone will not be affected. In the Central Zone the Jonglei Canal will cut across two main and two secondary roads. The Canal also intercepts the line of the annual migration to and from the Bahr el Jebel. The number of cattle which

will be required to move in this direction in the future will be reduced, but bridges or ferries will be needed in addition to the only two crossings provided by the Jonglei Canal head and tail regulators. It should be stressed that the banks of the Jonglei Canal will be suitable for a trunk road or railway, linking north and south through an area where the difficulties are at present very great.

PART II. DIRECT REMEDIES

CHAPTER 6. PASTURE REMEDIES

The first objective of remedial measures must be to provide alternative pastures for the livestock displaced in the dry season from riverain pastures by the alteration in the natural river régime. We begin, in this chapter, by considering in general terms what alternatives, natural or artificial, are possible. Before doing so we must draw attention to those sections of our report in which the ecological aspects, distribution and carrying capacities of indigenous grasses are described (Vol. I, Chap. 4, and Vol. III, Chap. 6).

The first form of possible remedy to be examined must be the utilization of natural pastures at present unexploited for various reasons, or the use of herbage at present allowed to run to waste.

FULLER UTILIZATION OF NATURAL PASTURES

PROVISION OF DOMESTIC WATER SUPPLIES: Within the Jonglei Area useful pastures exist which are at present unused owing to lack of water supplies, but they are not extensive and are to be found mainly in the Flood and Semi-Arid Regions. In the Flood Region the three most promising areas are the western fringe of the Eastern Plain in Bor and Central Nuer Districts, the southern part of the Western Plain in Western Nuer District, and the Machar Marshes north-east of Malakal. In the first two areas the grass is mainly of the *Hyparrhenia rufa* type which provides dry season grazing in the form of regrowth which has a low stock-carrying capacity (approximately 20 A.U. per sq. km.). Information concerning the Machar Marshes is scanty, but it seems probable that water supplies suitably placed to provide a safe route across the waterless areas, which intervene between there and the areas of settlement near the river, would open up pastures for many thousands of animals. In the Semi-Arid Region only a few pasture areas are unexploited at present, and many of these are already earmarked for agricultural development. Moreover the comparatively low rainfall and the lack of suitable catchment areas mean that there are few suitable hafir sites, while deep boring has indicated that underground water supplies have a phenomenally high salinity.

IMPROVEMENT OF PASTURE MANAGEMENT: Progressive systems of pasture management are not at present practised by the inhabitants, and overgrazing, undergrazing, and uncontrolled fires mean that there is considerable waste of existing resources. In the Ironstone and Flood Regions undergrazing—which in most areas cannot be avoided owing to the flooding or saturation of the land—allows vast quantities of perennial grasses to become tall and unpalatable. Heavier stocking of selected better-drained areas during the height of the rains would probably provide more palatable herbage in the dry season. By contrast, overgrazing is the principal problem in the Semi-Arid Region, and is largely unavoidable unless stock numbers can be reduced with an improvement in quality to balance the reduction.

CONSERVATION OF FODDER: Where grass land is undergrazed or burnt off annually, it might be possible to cut the herbage and conserve it as fodder for feeding in the dry season. Our own experiments in the conservation of fodder have not shown promising results and have merely demonstrated the difficulties. In the Ironstone and Flood Regions unsettled weather conditions, and particularly the high humidity, make the process of hay-making both arduous and rarely successful; severe flood conditions and the tussocky nature of the main grasses would make mechanical operations almost impossible at the best time for the cut. Later in the year, when climatic conditions are better, the grasses have already reached a coarse stage and their nutritive value is by then almost negligible. These difficulties also apply, but to a lesser extent, in the Semi-Arid Region, where in addition the grasslands are generally lacking in bulk so that very large areas would have to be cut. Moreover the problem here is overgrazing and most of the grass is consumed on the ground. Silage is another possibility, but the difficulties of cutting at the optimum period also apply. Another method of conservation, grass drying, would also be faced with these difficulties and would also be expensive and uneconomic.

Thus no large-scale alternative to riverain pasture is generally to be found in the existing natural inland pastures, either by improved management or by conservation. Only in certain selected areas can this form of alternative to the pastures of the Nile flood-plain be found.

IMPROVEMENT OF NATURAL PASTURES

Pasture could be improved by following a system of pasture management and:

- (1) By draining the land, thus permitting year-round grazing and preventing the grass from becoming rank. This applies mainly to those areas of intermediate land in the Flood Region carrying *Hyparrhenia rufa* or *Setaria incrassata*, which, although flooded during the rainy season, are not flooded sufficiently or long enough to produce regrowth when the old herbage is burnt. Drainage would enable this type of pasture to be grazed in the rainy period, thus keeping the grass down. If the cattle were removed by about September, the grass would have at least a month to six weeks to regrow—the grass at the end being more palatable than that usually obtained from ungrazed areas, because it would be mainly leaf, not stem. Such pasture might carry one Animal Unit per feddan for one month, but drainage is a difficult problem in the Flood Region and only in very limited areas could this method be applied.
- (2) By increasing the flooding of intermediate land pasture and improving dry season regrowth. This would only be applicable in the Flood Region, mainly in the area referred to as the Eastern Plain. Dry season regrowth from the intermediate land type pasture (e.g. *Hyparrhenia rufa*) occurs only where sufficient moisture is available in the soil—usually only in depressions and the low-lying parts of the plain. When all surface water dries up, cracks appear in the soil and the moisture in the lower layers around the roots of the plants is lost. By holding moisture on the surface this cracking could be delayed and the period of moisture available in the vicinity of the roots lengthened accordingly. In this way regrowth could be increased. For this purpose methods of impounding the water—banking or contour bunding—could be applied, their success depending on rainfall, subsequent evaporation and transpiration rates, and the nature of the soil.
- (3) By increasing the area of pasture by clearing the bush. This method would be applicable only in the Semi-Arid Region where there are large areas covered by almost impenetrable *kitr* bush (*Acacia mellifera*), and where the environment favours short annual grasses, palatable and nutritive throughout the dry season, which would establish themselves naturally or could be established by broadcasting seed. Costs would be relatively high; mechanical clearance is an expensive undertaking, chemical methods are costly and untried in this area; if hand labour were employed a very large labour force would be required. In almost all areas domestic water supplies would also have to be provided.
- (4) By the extension and introduction of superior grasses and legumes. Pastures having varied compositions contain some grasses superior to others. By suitable systems of grazing management, or by the direct introduction of seed, the dominance of the superior types could be established and maintained. The Team has given considerable attention to the various indigenous grasses and legumes (the introduction of legumes is of importance in all Regions, for they are generally absent) and a number of species imported from other parts of Africa and the world, but trials in their introduction on a larger scale have not been possible with the limited staff and time available. Specific recommendations cannot be made at this stage, but, with the many environmental difficulties to be faced, it seems likely that this method would only have limited application and mainly in those areas where bush clearance was undertaken.
- (5) By the banking of inland watercourses and drainage channels, thus producing greater quantities of green pasture (of the swamp or khor-bed type) in their flood-plains. In general the principles involved are identical with those described in (2) above, but the aim is different, being to bring about an actual change in the grass composition by increasing the depth and duration of flooding (see p. 561). That the impounding of water during the rainy season causes such changes is amply demonstrated in the Jebel Aulia reservoir, where increased flooding has produced very much larger areas of riverain grassland (mainly *Vossia cuspidata*), and the principle is to be seen in a less conspicuous way at the sides of road ramps in the Flood Region where small quantities of *Echinochloa pyramidalis* and other swamp grasses have established themselves. Such ground surveys as have been carried out by the Team, general observations, and a few trials, indicate that this method is almost bound to be successful in places where

the type of watercourse, the slope and the nature of the soil is suitable and the rainfall is adequate. It is, however, difficult to assess the amount of dry season grazing which could be produced by these means without a detailed survey of all available resources, scattered as they are in the intricate network of watercourses all over the Flood Region.

IRRIGATION OF PASTURES AND FODDER CROPS

In general it would be possible to provide irrigated pasture and fodder crops wherever the site is suitable, i.e. along the flood-plains of the main rivers and larger watercourses by simple flush irrigation methods. We have concluded, however, that if pasture is to be irrigated at all it can best be done on properly regulated schemes, complete with distributary and drainage-channels. The most suitable type of pasture for such schemes has also been considered, i.e. whether the irrigated land should be permanently under pasture or in the form of a ley alternating with other crops. On agronomic and economic grounds a system of leys grown in rotation with other crops, the most suitable being rice, appears the most promising. This method raises many problems: what available seed mixtures would be most successful, whether the pasture should be sown out in the form of a sward or in rows. Estimates show that the stock-carrying capacity would not be less than 1.5 A.U. per feddan throughout the dry season, and since the paddocks would not be grazed during the rains additional fodder could be obtained by conservation methods. Such schemes would require modifications in the present system of pasture management and could only be run under strict control, with consequent administrative and economic disadvantages. Other possibilities examined by the Team are the growing of fodder crops for conservation or for direct feeding, i.e. soiling, in place of established pasture, but there are many drawbacks, and such methods appear to us unsuitable both on practical and on economic grounds.

IMPROVEMENT OF LIVESTOCK

Livestock in the Jonglei Area are of a low standard, and throughout the emphasis is on numbers rather than quality. Apart from the obvious difficulties of overcoming local prejudices, it seems to us that no policy of improvement by breeding and selection can ever be successful until limiting factors—such as insect irritation, disease, and periodic shortages of grazing and water—have been removed and the general standards of animal husbandry have been raised. At this stage we cannot recommend the improvement of stock as a remedial measure, for the period of time required and the difficulties involved would be considerable, but it is undoubtedly necessary that the potential of the local livestock be determined under such improved conditions as may be possible by experimental methods.

CHAPTER 7. AGRICULTURAL ALTERNATIVES

The present economy and the whole mode of life of the inhabitants of the Jonglei Area have been shaped by the environment, which offers special opportunities for the development of livestock production, while making crop husbandry a laborious and uncertain occupation. Although the Project will lower the stock-producing potential of the area, the crop-producing potential will remain practically unaffected. Remedies must therefore be sought which will reduce the negative effects of the Project on the pastoral wealth of the area, or, where that is impossible, will develop crop output to compensate for losses in livestock.

Pastoral remedies aim at the maintenance of the *status quo* by preserving the present livestock population. The development of crop output would, on the other hand, replace one form of wealth by another, and hence demand considerable changes in the economic and social life of the people. Consequently we frequently use the term 'agricultural alternatives' rather than 'agricultural remedies'.

It should be realized that there is no basic difference between normal development of crop production in this area and its development as a measure to remedy grazing losses under the Project. Indeed, the progressive development of natural resources will reduce the problems which will have to be faced when the Project is implemented. Increase in crop output is a requisite in both cases. It should also be realized that the bases on which our recommendations concerning agricultural alternatives are founded are necessarily slender, being limited to the data which could be accumulated during only three years of work. These recommendations

must be regarded as suggestions only and they may well prove impractical in future trials. It would be dangerous to replace existing well-tried, though perhaps backward, local husbandry methods by innovations until they have been proved sound.

Crop output in the Jonglei Area could be increased by the following principal methods: enlargement of the area under cultivation; reducing the risks of crop failures and near-failures due to environmental difficulties; agronomic improvements aimed at increasing yields and value per unit area. The first method offers the greatest opportunities, as land in this part of the country is practically unlimited. However, it would not be worthwhile unless at the same time better and more reliable yields were assured. One of the main obstacles to increase in area under cultivation, particularly in the Nilotic area, is the present scarcity and low standard of efficiency of local labour. Though little can be done about the low density of population, apart from increased medical facilities, the waste of labour involved in annual migrations to dry season grazing will be reduced by the Project itself. Further, the waste connected with the scattered character of peasant cultivations could be reduced by improvements such as drainage, which would make it possible for the cultivations to be more concentrated and nearer to the centres of permanent settlement. Improvements in health services should also, in time, better the physical stamina of the local cultivator.

The most promising method of increasing labour output is to provide better tools. Better hand tools could obviously achieve only slight improvement. Considerable improvement could be gained by the introduction of animal-drawn implements. In this case, however, especially in the Nilotic areas, not only would the conservatism of the people have to be overcome, but also their present reluctance to use their cattle for any form of work. Mechanization of crop production offers special opportunities. Parts of the Jonglei Area are environmentally well suited to this type of agriculture. The main difficulties in introducing mechanization on an economically sound basis is the distance of the Jonglei Area from markets and supply centres, and the high cost of transport. Moreover, mechanization increases financial risks by reducing the flexibility of production costs. Mechanization would also mean a complete change from the present economy of self-sufficiency on a purely subsistence level to a much more complex economic system. This, in an undeveloped country with an unsophisticated population, means a radical and difficult change. The introduction of mechanization would further require a change from the present pattern of individual holdings to a much more centralized and carefully controlled system of agriculture.

In the Transitional Belt between the Flood and Semi-Arid Regions the introduction of *hariq* farming is particularly promising. Losses under the Project in the *hariq* belt are small, but if in the final event the principle of resettlement were to be accepted, this area could accommodate part of the population affected elsewhere.

One of the main factors limiting present crop output is the unreliability of rainfall. The local cultivator is faced very often by crop failure, due either to drought or flood or both. Consequently any increase in crop production must be mainly based on drainage and irrigation. The first is obviously most important in the Flood Region. However, from the agricultural point of view drainage means the creation of a sufficiently aerated layer of soil, and not just the removal of surface water; the problems in this Region are therefore very considerable. Moreover, even in the Flood Region, periodic drought during the cropping season is nearly as serious a factor. To assure crop output irrigation is therefore desirable. It should also be remembered that in the Jonglei Area irrigation should be used to supplement rainfall, and hence output per unit of water applied artificially should be higher than in the north, where irrigation largely replaces rainfall. From the financial point of view we have considered the economics of irrigation and have little doubt that it would bring in handsome returns, at any rate in those areas nearest the market.

We have also considered the possibilities of utilizing the natural annual variations in river levels and annual inundation of the *toiches* for gravity irrigation. The chief difficulty in the utilization of the flood-plains is the irregularity of the river variations and, in the future, the danger of periodic excessive flooding in years of flood-escape discharges. In the Southern Zone the banking off of the Aliab and Atem valleys will offer opportunities for perennial gravity irrigation, but special measures will be necessary to prevent the inundation of these valleys by flood-escape discharges. In the Central Zone gravity irrigation from the natural channels of the river will not be possible because the discharges will always be low. In the Northern Zone flooding will not be controlled by protective banking, and the erection of such banks for agricultural purposes alone is not considered financially justifiable. Moreover, in the Northern Zone the unevenness of the *toiches* would present considerable difficulties in their cultivation, and the cost of levelling would be prohibitive.

The need for agronomic improvements varies in different Regions and different circumstances within the Jonglei Area. They are probably most needed in the Flood Region, where production is largely restricted to the comparatively limited patches of high, flood-free land. Our work provides no more than indications of the possibilities in this direction, but the main means of improvement can be summarized as follows:

- (1) Better care of crops—by improvement in land preparation, in methods of crop establishment, and by reduction of weed competition.
- (2) Maintenance and improvement of soil fertility—by the introduction of regular crop rotation and application of manures available locally.
- (3) Introduction of improved varieties better suited to local conditions and of new crops not at present grown in the area but which would be suitable. By these means the production factors—mainly labour and different classes of land—could be better utilized, and risks of failure reduced by spreading them over a wider range of crops.
- (4) Protection against pests and diseases, which at present take a considerable toll of crops, and in particular control of witchweed (*Striga hermonthica*), probably the most important single factor limiting yields on some classes of land.

It should be remembered that agronomic work is necessarily slow, and each set of different environmental circumstances produces different problems which must be solved by different experiments. There are generally no short cuts. Experimental work has only just begun in the Jonglei Area. Moreover, in order to increase crop output, improvements not directly concerned with crop growing are also needed, e.g. improvement in domestic water supplies, communications, trade, storage of produce, etc.

The development of the agricultural potentialities of this area as a remedy for the grazing losses under the Project presents special problems. We have found it difficult to arrive at a satisfactory way of equating the present animal wealth to future crop wealth. It could not be done on the simple basis of monetary values, as local prices in this area cannot be taken to represent the comparative long-term value of different animal and crop produce, while it is impossible to establish their relationship to world prices. The dietary basis is also unsatisfactory, as there is no straightforward comparison between the food values of animal and vegetable products. We have finally decided to choose the fodder value of agricultural by-products as a basis for conversion.

The present pattern of settlement of the population in this area is largely shaped by the location of dry season riverain pastures. As these will be affected by the Project, and as the sources of livelihood will also change from pastoral to agricultural in those areas where pasture remedies cannot be found, a new pattern based on crop producing potentialities will have to be evolved. This might involve large-scale resettlement, which would undoubtedly prove difficult in the present stage of development of the people. In designing agricultural remedies we have therefore tried to avoid resettlement as far as possible.

Though from many aspects improvement in crop production based on the present peasant structure and carried out by extension methods might be desirable, this could be achieved only very slowly, and the costs are very difficult to ascertain. The organization of centralized schemes where close supervision assures the use of improved husbandry methods, and hence more efficient utilization of capital, is a quicker and, in our opinion, more certain way.

We consider that the retention of the maximum number of livestock in this area under future conditions is most desirable from the point of view of the local population, and from the point of view of the Sudan as a whole. Though it might be possible in time to change the local pastoralists into cultivators, in our recommendations we have tried to provide for the retention of the present number of livestock, even on schemes in which the primary objective is the production of crops.

CHAPTER 8. THE ENGINEERING ASPECTS OF REMEDIAL MEASURES

Having examined the general potentialities of animal and crop husbandry, and before turning to more specific recommendations, it is necessary to examine the potentialities from the purely engineering point of view.

SOUTHERN ZONE

Irrigation by Gravity Flow : The flood-plains in this Zone are topographically suitable for gravity irrigation under normal operation, but they are liable to inundation during a period of flood-escape discharges unless protected by banking or canalization of the additional flow.

Irrigation by Pumps : Probably the only suitable area is on the east bank, north of Kursomba.

Drainage : The *toiches* will be drained, except under flood-escape conditions, in the rainy season. Both banks of the river are drained naturally, except for the east bank between Kursomba and the Atem Head. Artificial drainage could be installed in this latter area as far north as a point 15 km. north of Bor.

Domestic Water Supplies : Water could be provided from deep bores, or open wells: the water-table is generally at less than 100 feet; the one bore drilled in this Zone showed an artesian effect after drilling to about 200 feet. The soil is generally too sandy and permeable for the construction of hafirs.

CENTRAL ZONE

Irrigation by Gravity Flow : Re-irrigation of the dried-out swamp lands is possible, but they would be liable to flooding during a period of flood-escape discharges. Irrigation of the Eastern Plain, either directly from the Jonglei Canal or by feeder canals from upstream of the Canal Head regulator, would provide very considerable possibilities. East of the Canal the aim should be to increase the period of inundation of the plain to encourage the regrowth of natural grasses (*Hyparrhenia rufa*). West of the Canal the aim should be to irrigate other crops, supplementing rainfall. This inland area is not liable to flooding from the river during a period of high flood-escape. On the Western Plain and the Zeraf Island gravity irrigation is possible, but slopes are small and barrages would be necessary.

Irrigation by Pumps : This will be possible from the Jonglei Canal, if the water-levels in it conform to ground levels, as designed. It will also be possible to irrigate the Western Plain and the Zeraf Island by this method, instead of using barrages.

Drainage : Depressions bordering the river where there are now swamps will have a large proportion of drainable land. On the Eastern Plain drainage would be possible but inadvisable, since it would result in a decrease in regrowth pasture. This is an area of 'creeping flow' and it would be better to prevent drainage by contour banking and damming watercourses. West of the Canal there are suitable natural drainage-channels which could be developed. In Western Nuer District and on the Zeraf Island there are numerous inland watercourses which might be utilized to drain land outside their alluvial banks, provided levels were suitable, and by combining this operation with banking and hafirs pasture could be improved and water-points assured. The cross-sections which we have taken show that this is practicable.

Domestic Water Supplies : Twin-bore water-yards are suitable for cattle grazing on *Hyparrhenia rufa* regrowth, but in this area they would stand idle for nearly three-quarters of the year, and would be very expensive to install and operate. Hafirs could be sited almost anywhere in a region where hydrological conditions are suitable for *Hyparrhenia rufa*. They are comparable in capital cost per head of cattle watered with tube wells, but require less maintenance.

NORTHERN ZONE

Irrigation by Gravity Flow : The riverain flood-plains could be utilized to irrigate, by natural inundation when the river was high, specific crops which can tolerate a wide range of flooding conditions. Parts of the same flood-plains could be protected by banking and irrigated under control when the river was high, but in both cases the areas would be liable to inundation in the event of a high Sobat or flood-escape discharges from the Great Lakes. In the Machar Marshes suitable natural conditions are found for producing dry season grazing which could be utilized by providing water-points on convenient access routes, and the area is eminently suitable for hafirs. Complete control and development of the Machar area, while highly desirable, would be a gigantic undertaking and hardly practicable as a remedy.

Irrigation by Pumps : It appears that pump irrigation to the extent of about 12,000 sq. km. would be possible on the banks of the White Nile, Bahr el Zeraf and Sobat as far as levels and pump sites are concerned. The exact extent of irrigable areas could not be assessed without detailed surveys. The Project itself assists in this respect by reducing the range of river levels.

Drainage : Almost all the area suitable for pump schemes could be drained artificially to the river. At Melut and Kodok the distances inland which could be drained are limited by small differences between land and river levels, and under flood-escape conditions drainage would not be possible, though the White Nile would not be at its highest when drainage would be needed. As in the Central Zone, there are a number of inland watercourses to which drainage schemes could be easily applied, combined with damming to produce pasture and hafirs for water-points.

Domestic Water Supplies : South of the 640 mm. isohyet there are sufficient sites in watercourses and depressions for hafirs on both banks of the river. In Renk District a number of *gardud qozes* have been utilized successfully to fill hafirs. The rainfall there is about 700 mm. and the so-called *qozes* are in fact weathered mounds. North of the 640 mm. isohyet, to be filled successfully, hafirs must be sited at the foot of rocky outcrops; these are limited in number. The *qozes* in Kosti District are Kordofan sands, and the sub-soil is generally not suitable for hafirs. Underground supplies are, in general, highly saline north of the Lake No-Sobat line, and at variable depths of from 200 to 400 feet.

WATER-DUTIES AND DRAINAGE FACTORS

Irrigated pastures would require watering at the rate of 860 m³.p.f. per month, or a total of 5,160 m³.p.f. in the six-month dry season from December to May. Other agricultural crops irrigated in the dry season would require 950 m³.p.f. per month (30 days).

The same crops irrigated during the rainy season would require maximum supplements of irrigation water of between 400 and 450 m³.p.f. per month. Irrigation water needed to supplement normal rainfall would average from 230 to 270 m³.p.f. per month. These figures apply only to the Flood Region. There would be slight differences for the Ironstone Region, and in the Semi-Arid Region water requirements would not differ radically from those in the Gezira. Rice irrigated in the Flood Region during the rains would require supplementary irrigation at the rate of 1,750, 3,250 and 4,750 m³.p.f. for varieties maturing in 4, 5 and 6 months respectively. The water duty would reach a maximum of 1,500 m³.p.f. per month during the dry season. Experiments are needed to obtain practical experience of drainage requirements in the Jonglei Area where rainfall is much heavier than in the Gezira. Formulae have been suggested from which the run-off can be calculated from this area, with and without supplementary irrigation.

COMMUNICATIONS

On the whole the design of the Project makes adequate provision for communication by river and canal. One exception to this occurs in the Jonglei Canal, where the depth of water will be insufficient for navigation under the discharge proposed for the untimely season. The only remedy necessary would be alteration of the discharge; as designed the control regulators are provided with locks. The Jonglei Canal and Bahr el Jebel barrage will improve communications to Bahr el Ghazal Province, though Shambe may fall into disuse as a port. It is highly desirable to know when the Project is expected to reach the 55 m/d Canal stage, and whether the barrage will be at Jonglei or at the Atem Head. In the 280 km. of the Jonglei Canal, 12 cable-ferries will be needed for crossing the two major canals at six points. Bridges will also be needed to cross an irrigation canal, assuming that there will be a separate canal of small capacity for this purpose.

CHAPTER 9. SOME SELECTED REMEDIES

In the previous chapters (6, 7 and 8) the general resources and potentialities of the Jonglei Area have been examined with the object of providing alternatives to the riverain pasture and other local interests which will be effected when the Equatorial Nile Project comes into effect. It has, however, been necessary to select the most promising remedies as a basis for our recommendations and to enable us to "provide a reasonable forecast of the necessary remedial measures and of compensation expressed in terms of money and water", as explained in the Introduction (see p. iv). We refer to these as 'direct' remedies, i.e. remedies required to meet losses sustained under the Project as proposed in *The Nile Basin, Vol. VII*, with the subsequent modifications mentioned previously. In most cases, as is not unnatural in an undeveloped area, there is little or no practical experience on which to base our recommendations, and it is obvious

that in all cases much further research and trial is needed before full reliance can be placed upon our suggestions. Moreover most remedial measures involve centralized control, training, education, and guidance for the people, who will have to turn to a form of livelihood very different from their present one. Their inevitable reluctance to face these changes and to turn to a new and unfamiliar way of life is not the least difficulty in a highly complex problem, in which environmental difficulties must also be overcome.

Our selected remedies are presented under four main headings: pasture remedies, including improved intermediate land pasture, improved khor-bed pasture, fuller utilization of inland pasture, and gravity irrigated pasture schemes; agricultural alternatives, including irrigated crop production schemes, drainage schemes, and *hariq* cultivation schemes; combined remedies, i.e. those in which fodder and food crops are grown in rotation; and fisheries remedies. In addition a number of other possible remedies and alternatives have been briefly considered. A detailed list is given on page 638 (Vol. II) and need not be repeated. Suggestions and designs are outlined in the main body of the text and cannot be effectively summarized.

At the end of Chapter 9 (see Vol. II, pp. 681-87) summaries are given of unit costs, expressed in terms of Animal Units, metric tons of fish, and cubic metres of water, upon which our calculations are based. Details of our costings are reserved for the files of the Sudan Government.

CHAPTER 10. APPLICATION AND COSTS OF DIRECT REMEDIES

In the selection of these various forms of remedy a large number of factors has been taken into account: the relative economic advantages, general potentialities, the comparative ease with which the remedies might be introduced to the inhabitants, and so on. In Chapter 10 we have had to proceed a stage farther and to suggest the best forms of remedy in the various parts of the Jonglei Area, bearing in mind local conditions and interests. For this purpose we have divided the area into twelve sectors, the divisions also being based on a variety of factors: tribal boundaries, the boundaries of the three Zones, and a number of practical considerations of local significance. The results are produced in tabulated form (pp. 692-703). In each sector there appear to be a number of possible remedies, and the total costs are recorded in Table 305. Our forecast of the costs of remedial measures is summarized below:

EQUATORIAL NILE PROJECT: FORECAST OF COSTS OF DIRECT REMEDIES

REMEDIES	MOST EXPENSIVE		LEAST EXPENSIVE		SUGGESTED	
	£E.	Mill. m ³ .	£E.	Mill. m ³ .	£E.	Mill. m ³ .
Pastoral and Agricultural ...	21,755,570	571	8,044,930	748	10,703,400	574
Fisheries ...	1,115,000	18	1,115,000	18	1,115,000	18
Communications ...	84,000	—	84,000	—	84,000	—
TOTAL ...	22,954,570	589	9,243,930	766	11,902,400	592
Say ...	23,000,000	590	9,200,000	770	11,900,000	590

It should be noted that the last column is based upon the selection of certain types of remedy in each sector, and does not represent a figure midway between the first two columns. The basis of our selection can only be understood from a study of the tables in the main text. These estimates cover the costs of the establishment and subsequent running of the suggested schemes. No account is taken of the wider financial commitments, e.g. additional expenditure on increased administrative organization, transport systems, public health and educational facilities, all of which will undoubtedly be required in any Project which has such wide economic and social implications.

PART III. REVISED OPERATION OF THE PROJECT

Our investigation has so far been concerned with the effects of the Equatorial Nile Project as proposed in Volume VII of *The Nile Basin*, with subsequent modifications suggested by Dr. Mohamed Amin and Mr. H. G. Bambridge. It will be appreciated that the adverse effects upon the interests of the local population will be considerable and the costs of remedies high. It appears to us that there are other and better ways of dealing with this problem—to reduce the adverse effects to the minimum and to avoid as far as possible the need for remedial measures, which are not only expensive and untried, but would also require a revolution in the present mode of livelihood of the people, with all the social and economic repercussions which such drastic measures would inevitably involve. We have therefore attempted to re-design the operation of the Project with the object of reducing the losses while still providing the maximum amount of water for irrigation purposes farther north. We believe that the Nile system must be regarded as a single unit and that the exploitation of its waters must be designed for the maximum benefit of all people who are in one way or another dependent upon those waters.

We have already explained how the Nile in this reach provides, by a natural, albeit wasteful, system of irrigation, vital resources in the form of green nutritive pasture at a time of year when grazing is not available elsewhere, and plentiful fish when other foodstuffs are often in short supply. We have drawn attention to the fact that the present system of land utilization is based on the balanced and seasonal use of all types of land and that the removal or reduction of the resources on any one type will inevitably disturb this balance, unless suitable remedies or alternatives can be found. Losses in riverain grazing will occur because either, as in some reaches, the seasonal fluctuations of the river will be reversed so that dry season pastures will be under water when they are required or, as in other reaches, the flood-plains will be deprived of natural river spill and the result will be a change of vegetation to grassland types far less nutritive than those which flourish on the flood-plains at present, or in some cases valueless as pasture. Similar effects on fisheries resources have also been described. The general principle of the Revised Operation is therefore to simulate as far as is possible the natural fluctuations of the river, and therefore to reduce the losses to a minimum, while still providing a great saving in water which may be used for irrigation purposes by the sponsors of the Project.

CHAPTER 11. THE REVISED OPERATION OF THE PROJECT

In the main body of the text we have considered fully the revised method of operation of the Equatorial Nile Project in each of its major aspects. We begin with the Great Lakes and proceed with the description on a south to north basis, i.e. in the way in which the river runs. The main principles of our proposal are as follows:

Lake Victoria: Lake Victoria would be the main century storage reservoir for the whole Equatorial Nile Project, being controlled by the dam at Owen Falls, which has been completed. The permissible range of levels of the lake would be from 9.80 m. to 12.8 m. on Entebbe gauge. The outflow from the lake would be regulated between a minimum of 44 m/d, required for the hydro-electric power station, and a maximum of 100 m/d. When the lake level dropped to 10.15 m. on Entebbe gauge the outflow would be reduced to 44 m/d. When the lake level exceeded 12.00 m. when rising, or 12.50 m. when falling, the outflow would be increased to 100 m/d. Within the limits specified above, the principle on which control of the lake would be based would be to meet the requirements in Lake Albert, which are given later; that is to say, the outflow from Lake Victoria would be reduced to the minimum if necessary, or increased to the maximum, to reduce or increase the total inflow into Lake Albert so that its level would be kept within the normal working range.

Lake Kioga: There would be a regulator near Masindi Port at the mouth of Lake Kioga, the primary function of which would be to eliminate the time-lag of changes in discharge between Lake Victoria and Lake Albert. We have not considered the possibility of storage in Lake Kioga, but we have assumed that 10% of the discharge from Lake Victoria would be lost during its passage through Lake Kioga.

Lake Albert: There would be a reservoir in Lake Albert which would normally be used so that the outflow from the lake could be regulated monthly throughout the year according to the requirements of the Revised Operation. It would also be used to store flood-waters, and

part of its storage capacity would be reserved specifically for this purpose. The normal range of levels would be from 12.50 m. to 15.00 m., and the normal maximum permissible level would be 23.00 m. on Butiaba gauge. The storage capacity between 15.00 m. and 23.00 m. would be reserved for flood protection. The reservoir would be controlled by a dam at Mutir, and the outflow regulated from zero to 117 m/d. The principle on which the control of the lake would be based would be that the annual discharge at Mongalla, including the flow of the torrents, would be equal to the long-term mean annual discharge, which from past records is 27 milliards (28.35 milliards per year at the lake exit). Throughout each year the discharge would be varied according to the Revised Operation to suit local interests in the Southern Sudan, for which purpose the average daily discharges during each month would be as follows:

AVERAGE DISCHARGES AT MONGALLA

					m/d
January	...	...	...	...	64
February	...	...	...	...	64
March	...	...	...	...	64
April	...	...	...	...	64
May	...	...	...	...	64
June	...	...	...	...	75
July	...	...	...	...	80
August	...	...	...	...	85
September	...	...	...	...	90
October	...	...	...	...	85
November	...	...	...	...	80
December	...	...	...	...	75

If the level in Lake Albert should rise above 15.00 m. on Butiaba gauge, the outflow from the lake would be regulated according to the following sliding scale:

BUTIABA GAUGE	LAKE ALBERT	CORRESPONDING ANNUAL
metres	ANNUAL OUTFLOW	DISCHARGE AT MONGALLA
	milliards	milliards
14.00	28.35	27.00
15.00	29.00	27.75
16.00	30.00	28.50
17.00	31.50	29.93
18.00	33.00	31.35
19.00	36.50	34.67

Under these conditions the discharges throughout the year would be *increased by a constant amount*, so that when, for instance, the discharge at Mongalla was increased to 34.67 milliards per year (equivalent to 36.5 milliards per year at the lake exit), the average daily discharges would be increased by 21 m/d, and would then be as follows:

AVERAGE DISCHARGES AT MONGALLA

					m/d
January	...	...	...	...	85
February	...	...	...	...	85
March	...	...	...	...	85
April	...	...	...	...	85
May	...	...	...	...	85
June	...	...	...	...	96
July	...	...	...	...	101
August	...	...	...	...	106
September	...	...	...	...	111
October	...	...	...	...	106
November	...	...	...	...	101
December	...	...	...	...	96

Special Maximum Levels and Discharges : It should be noted that the maximum levels and discharges given above would have been adequate provision for flood protection if regulation had been applied between 1905 and 1952 (see Regulations G-2, G-4 and G-6, pp. 748-51). Furthermore, the maximum discharge of 36.5 milliards a year could have been passed through

the Southern Sudan without reflooding the Central Zone and without increasing the velocity in the Jonglei Canals appreciably above 1.0 m/sec. (the total discharge in all the Jonglei Canals would have been 55 m/d, cf. Table 352). We have given reasons (p. 710) for supposing that in the course of time a flood will occur higher than any yet recorded. Therefore we recommend that in addition to the normal maximum levels and discharges given above, provision in the form of special maximum levels and discharges should be made from the first to cover this unusual, but nevertheless inevitable, occurrence.

The special maximum level in Lake Albert is a matter which we alone cannot decide, but we suggest that a level of 25.00 m., or about 13 milliards, storage capacity above 23.0 m. on Butiaba gauge, is the least 'factor of safety' that any engineer would be prepared to accept.

With regard to the special maximum rate of escape, we have shown that the capacity of all the Jonglei Canals could be increased to 65 m/d by increasing the maximum velocity to 1.06 m/sec. and by raising the water-level to 1.20 m. above ground level. We suggest that these are reasonable criteria for fixing the special maximum discharge, which in this case would therefore be 38.70 milliards (Table 353) per year at Mongalla (equivalent to 40.60 milliards per year at the lake exit). Under these conditions the average daily discharges throughout the year would be increased by the constant amount of 32 m/d, and would vary from 96 m/d to 122 m/d at Mongalla. We propose therefore that the special maximum permissible level in Lake Albert should be 25.00 m., and the special maximum rate of escape be 38.70 milliards per year at Mongalla.

Torrents Balancing Reservoir : In our proposals for the control of Lake Albert we have assumed that the torrents would be controlled. For this purpose a low dam would be required to impound the river to a depth of 5 m. at Nimule. By regulating at Nimule on gauge-readings at Rejaf it should be possible to control the torrents effectively. If the daily discharge at Mongalla should rise above the average daily discharge specified for any month, given in the tables above, then it should be reduced later so that the average over the month remained the same.

Sudd Diversion Channel : In the Project according to Dr. Amin and Mr. Bambridge the Sudd Diversion Channel will start at the Atem Head and will consist of two portions, the banked and remodelled Atem from the Head to Jonglei, and the Jonglei Canals from Jonglei to the White Nile. In our Revised Operation, the Sudd Diversion Channel would consist only of the Jonglei Canals from Jonglei to the White Nile at the Sobat mouth. South of Jonglei there would be no engineering works except a bank on the east of the Atem from a point north of Bor to Jonglei, whose purpose would be to prevent losses by spill on to the Jonglei plain. At Jonglei there would be a regulator on the Bahr el Jebel whose capacity would be 50 m/d, the maximum discharge proposed in the Bahr el Jebel north of Jonglei. There would also be regulators at the heads of the Jonglei Canals whose capacities would be: one of 5 m/d for the Jonglei irrigation canal, and two of 30 m/d capacity to pass the special maximum discharge of 60 m/d. The division of water between the Bahr el Jebel and the canals at Jonglei would be facilitated by a channel parallel to the bank of the barrage. This arrangement would allow spoil excavated from the channel to be used in the barrage.

The Jonglei Canals should be aligned on the 'Direct' Line. This starts at Jonglei and runs directly to Mogogh (lat. 8° 30' N, long. 31° 23' E.). From Mogogh the line bears 14° east of north and rejoins the White Nile at the Sobat mouth. The Jonglei Canals would consist first of one irrigation canal of 5 m/d capacity whose purpose would be to irrigate schemes to the west of it necessary to meet the losses in grazing in the Central Zone. Then there would be two other canals whose normal capacity would be 15 m/d each and whose purpose would be as follows:

- (i) To carry the required normal discharge from Jonglei to the White Nile.
- (ii) To provide for navigation all the year round.
- (iii) To carry additional discharges in times of flood-escape.

For this latter purpose the canals would be dug some distance apart, varying from 1,000 m. from the head to km. 175, to 1,390 m. from km. 175 to the tail. The earth dug from these two canals would be placed on the outside of each canal and the space in between would be reserved for carrying additional flood-escape discharges up to a total of 60 m/d (including the 'washlands') when necessary. The dimensions of the canals would be as specified in Table 352 for a discharge of 15 m/d. There would also be control regulators at the tail of the canals where they discharged into the White Nile.

The division of the discharges in the river at Jonglei between the canals and the Bahr el Jebel would be according to the table given below, which covers normal operation, normal maximum, and special maximum flood-escape discharges.

**DIVISION OF DISCHARGES AT JONGLEI BETWEEN THE JONGLEI CANALS AND THE
BAHR EL JEBEL**

In millions of cubic metres per day

Month at Mongalla ⁽¹⁾	All Operations	Normal Operation		Normal Maximum		Special Maximum	
	Bahr el Jebel north of Jonglei	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 time is specified as at Mongalla so that the discharges given by months will correspond with those specified previously for Mongalla. 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%.

Navigation : The minimum discharge in each of the two main Jonglei Canals would be 15 m/d, and the dimensions of the channels we propose would be width 48 m. and depth 3.5 m. With side slopes at 2 : 1, the width of the waterway would be 62 m. This would be ample for navigation of one complete tow whose width is 24 m. One canal would be used for upstream traffic and one canal for downstream traffic. In order to complete the provision for navigation the canals should be connected by cross-cuts at each end, and one of each of the two sets of regulators at each end should be fitted with locks. There would therefore be two locks, one at the head and one at the tail of the canals. Their dimensions would be as specified in the description of the Project, namely 100 m. long by 18 m. wide.

Cross-communication : The siting of canal crossings is important, and we have concluded that six crossing-points would be required at 40 km. intervals along the line of the canal (see p. 773). Under the Revised Operation the same number would be needed and it only remains to consider the type of crossing. For the Jonglei irrigation canal, which would be of small capacity (5 m/d), masonry bridges would be sufficient. In some cases the headworks of the irrigation schemes needed to remedy losses in the Central Zone would provide the necessary bridges.

When the main canals were operated normally the water-level in the canals should conform to natural ground-slopes, and all that would be necessary would be six pairs of cable-ferries, one ferry for each canal at the six crossing-points. However, during a period when high floods were being escaped, the 'washlands' would be covered. Under these conditions the ferries would have to travel across the 'washlands' as well as the canals, and cross-cuts would have to be provided for them. Care would have to be taken to ensure that the spoil excavated from these cross-cuts did not form a continuous bank which would block the waterway on the 'washlands'.

Intermediate Constructional Stages : In the Project as described by Dr. Amin and Mr. Bambridge there are five intermediate stages in the construction of the scheme to the 55 m/d Canal stage. We have pointed out, when considering the effects of the intermediate stages, that there would be serious adverse effects in both the Southern and Central Zones from the

very beginning of the first stage in which only the storage dams would be built. Furthermore the effects would change with the application of each successive stage, so that the people whose livelihood depends on the river would no sooner get accustomed to one new régime of the river than the régime would be altered again by the next stage.

Under the Revised Operation no such drastic upheavals need result, provided that two rules are observed. The first is that the regulation applied at Lake Albert should result in discharges at Mongalla varying throughout the year according to the pattern we have suggested (Table 346, p. 781). The second is that whatever size the canal (or canals) may be in the intermediate stages, it is essential that the discharge in it should be constant all the year round. In the beginning it would probably be necessary to reduce the annual flow at Mongalla so as to accumulate storage in the lakes, but provided that a constant daily rate of discharge was subtracted from the normal discharges specified at Mongalla throughout the year, then the adverse effects of the Revised Operation would be reduced to the minimum possible. This will be obvious from the figures in the table given above, which are examples of additions to the normal discharges at Jonglei.

HYDROLOGICAL EFFECTS UNDER THE REVISED OPERATION

SOUTHERN ZONE: Between Juba and Atem Head 515 sq. km. would continue to be inundated and uncovered—a loss of 259 sq. km. instead of a loss of 774 sq. km. under the Project as proposed.

CENTRAL ZONE: 1,046 sq. km.—plus 67 sq. km. between Atem Head and Jonglei (previously included in the Southern Zone)—would continue to be inundated and uncovered, a total of 1,113 sq. km. instead of only 362 sq. km. under the Project as proposed.

NORTHERN ZONE: It is not possible at this stage to give estimates for the whole reach, but between Malakal and Jebelein a total of 990 sq. km. would continue to be inundated and uncovered, instead of 630 sq. km. under the Project as proposed.

CHAPTER 12. THE EFFECTS OF THE REVISED OPERATION

The Revised Operation of the Project described above would reduce the losses in riverain pasture and fisheries, but it could not obviate all adverse effects. It is now necessary to examine and assess these effects in terms of quantity.

The techniques employed are similar to those applied in the case of the Project as originally proposed and the results can be best summarized in tabulated form:

REVISED OPERATION: EFFECTS ON RIVERAIN PASTURE EXPRESSED IN TERMS OF ANIMAL UNITS

Zone	Livestock wholly or partly dependent on pasture affected by main river	Loss of riverain pasture	Percentage loss
SOUTHERN	138,400	25,300	18·3
CENTRAL	423,400	130,400	30·8
NORTHERN	240,300	Nil	—
TOTAL Jonglei Area ...	802,100	155,700	19·4

These figures should be compared with those given on p. xlix where the effects of the Project unrevised are given. The over-all losses in grazing under the Revised Operations are for 155,700 Animal Units as compared with 288,200; 19·4% of the total animal population using the riverain grazing as compared with 35·9%.

Where fisheries are concerned there would be sufficient to meet the subsistence requirements of the present population and no remedial measures would be necessary. There would, however, be a loss of potential, mainly in the Central Zone (see Table 372, p. 807).

CHAPTER 13. APPLICATION AND COSTS OF THE REVISED OPERATION

Although our Revised Operation would reduce losses substantially, there would still be losses to be met by remedies of the kind described in Chapter 9. In order to produce our 'forecast of the costs of remedial measures in terms of money and water' we apply the same technique as in Chapter 10, the Jonglei Area being divided into twelve sectors and our suggestions being recorded in tabulated form (see Vol. II, pp. 811-6). Summarized, the results are as follows:

REVISED OPERATION: FORECAST OF COSTS OF REMEDIAL MEASURES

Remedies	MOST EXPENSIVE		LEAST EXPENSIVE		SUGGESTED	
	£E.	Mill. m ³ .	£E.	Mill. m ³ .	£E.	Mill. m ³ .
Pastoral and Agricultural	11,587,140	172	5,381,920	397	6,484,180	302
Fisheries	Nil	Nil	Nil	Nil	Nil	Nil
Communications	100,000	—	100,000	—	100,000	—
Water (Additional) for Revised Operation	—	750	—	750	—	750
TOTAL	11,687,140	922	5,481,920	1,147	6,584,180	1,052
Say	11,700,000	920	5,500,000	1,150	6,600,000	1,050

COMPARATIVE BENEFITS: A direct comparison between the Equatorial Nile Project as proposed and the Revised Operation is not easy because certain factors, such as spill in the Central Zone and the contributions of torrents, tend to obscure the main issues. Briefly the comparative benefits are as follows:

EQUATORIAL NILE PROJECT AS PROPOSED

(see Table 189, p. 410)

ANNUAL DISCHARGES AT THE TAIL OF THE SWAMPS:

E.N.P.	22.0	milliards
1912-1942 Normals	14.3	milliards
Gross saving at Malakal	7.7	milliards

Assuming that the water required for direct remedies will be 0.59 milliard as suggested (see Table 305, p. 703), the net saving amounts to 7.11 milliards.

REVISED OPERATION OF THE PROJECT

(see Table 348, p. 783)

ANNUAL DISCHARGES AT THE TAIL OF THE SWAMPS:

Revised Operation... ..	21.4	milliards*
1912-1942 Normals	14.3	milliards
Gross saving at Malakal	7.1	milliards

Assuming that the water required for remedial measures under the Revised Operation will be 0.3 milliard (see Table 374, p. 816), the net saving amounts to 6.8 milliards.

Equatorial Nile Project	7.11	milliards
Revised Operation... ..	6.8	milliards
Difference	0.31	milliard

This amounts to only 4%.

*Ignoring the contributions of the Tapari and Moich, which are dissipated in spill, and allowing for spill in the Central Zone.

SUMMARY OF CONCLUSIONS

The subject of our investigation has been the Equatorial Nile Project, as designed in Volume VII of *The Nile Basin*, with subsequent modifications suggested by Dr. Mohamed Amin and Mr. H. G. Bambridge. Reduced to the simplest terms, the conclusions to be drawn from our investigation are as follows :

THE EFFECTS OF THE PROJECT AS PROPOSED

1. In nearly all parts of the 'Jonglei Area' the inhabitants practise a mixed economy in which cattle and other animal stock are of primary importance. The present economy is adapted to the environment in such a way that all types of land must be utilized, according to the seasons. One type of land is to be found on the flood-plains of the Nile, where the natural fluctuations of the river produce pasture grasses which are essential during the dry months of the year, when grazing is not available elsewhere. It follows that any reduction in the area seasonally inundated and exposed will inevitably cause serious losses in livestock, and therefore great hardship to the people concerned, unless suitable remedies can be found.

2. The total population likely to be directly affected will not be less than 660,000, though not all will be affected to the same extent. Moreover, since these people, without alternatives, will be forced to turn to similar resources in the territories of others, still others may be indirectly affected ; these amount to about 400,000, so that it can be said with some certainty that at least a million people will in one way or another be affected by the altered river régime.

3. In terms of quantity the effects of the Project as proposed will be that riverain pasture for approximately 288,000 Animal Units will be lost ; this amounts to about 36 per cent. of the total livestock population now dependent on the pastures produced by the main river. This estimate takes no account of losses in riverain pasture at present unexploited, but the amount involved is not great.

4. Although the adverse effects of the altered hydrological régime will be mainly on existing dry season grazing, other resources of great importance will be affected. In particular the Project will undoubtedly cause a serious reduction in the fisheries resources of the area, and these are also of vital importance in the local economy. We estimate that the annual reduction in potential will, in round figures, be not less than 23,000 metric tons of fish. At present this amount is not fully exploited, but in the various parts of the area affected a deficit in the subsistence requirements of the people amounting to about 3,000 metric tons will have to be met by remedies. The remaining 20,000 tons must be regarded as a loss of valuable potential and should not be forgotten.

5. In present circumstances only very limited use is made of the flood-plains for crop production, but they could be of very great potential value for this purpose and losses in potential must not be overlooked.

6. The Project will also have adverse effects on local communications, for which provision must be made ; these effects will be at least partly balanced by certain advantages, e.g., a more direct navigation route through the Jonglei Canal, and more stable river conditions between Juba and Terakeka.

DIRECT REMEDIES

7. If the Project were to be implemented and operated in the form proposed, what we call 'direct' remedies would have to be applied to meet these losses. It is impossible, without further experiment and trial, to recommend remedial measures which are certain to be successful, but the main objective should be, in our opinion, to provide alternative pasture during the dry season equivalent to that lost on the flood-plains, and thus to maintain the present form of economy with the least possible disturbance. This policy should be adopted with the proviso that it should in no way compromise future economic development in the Jonglei Area. Where no such alternative pastures can be made available, agricultural alternatives in the form of crop production schemes must be introduced ; these should also aim at the retention of the maximum number of livestock.

FORECAST OF THE COSTS OF REMEDIAL MEASURES IN MONEY AND WATER

8. We have not found it possible to give a certain or precise estimate of the costs of remedial measures, which at this stage are largely untried. However, by assessing the unit costs of specific measures which appear to us to show most promise, and bearing in mind local conditions and

circumstances in the various parts of the Jonglei Area, we estimate that the capital costs would—in round figures—not be more than £E.23,000,000 plus 590 mill. m³. of water per annum, nor less than £E.9,200,000 plus 770 mill. m³. of water. The application of those remedies which appear to us most suitable would cost £E.11,900,000 plus 590 mill. m³. of water. Apart from the costs of these remedies, further financial commitments in the form of additional public services are not included in this estimate and must not be overlooked.

9. It should be stressed once more that our 'suggested' remedies have not yet been tested; even those we now consider most suitable may prove inadequate to provide a sound and sufficient alternative livelihood for those adversely affected by the Project, but we do not think that any more accurate estimate is possible at this stage. The Project will in any case be carried out in successive stages, and our conclusions must be checked and revised in the light of further data, as and when these are available.

REVISED OPERATION OF THE PROJECT

10. The application of 'direct' remedies of this nature would involve drastic changes in the economy of the Jonglei Area, and these would naturally give rise to many complex social, political and economic problems. Our investigations have shown that the extent of the adverse effects, and of the changes involved, could be much reduced by adopting a revised method of operation, which would still provide almost as much water for irrigation as originally intended. The form of the revised operation which we propose appears to fulfil the principal objectives of the Project, though only the general principles rather than the details can be determined at this stage.

11. According to our estimates the losses in riverain pasture could by this means be reduced from that required for 288,000 Animal Units to that for 156,000, i.e. to roughly 19% of the total livestock dependent on the flood-plains of the main river, instead of 36%. Moreover, under this method of operation there would be no losses in the fisheries resources required by the present population, though there would still be a considerable reduction in potential.

12. Adverse effects would nevertheless occur, and the costs of remedial measures would, according to our estimates, amount—in round figures—to a capital sum of not more than £E.11,700,000 plus 170 mill. m³. of water, nor less than £E.5,500,000 plus 400 mill. m³. of water. The application of those remedies which appear to us most suitable would involve expenditure of about £E.6,600,000 plus 300 mill. m³. of water.

13. In addition to the amount of water required for the application of remedial measures, our estimate of the additional water for the Revised Operation amounts to 750 mill. m³., but the net mean benefit of the Project under the Revised Operation, after deduction of that required for remedial measures, would be 6·8 milliards at Malakal, as compared with 7·11 milliards under the Project as proposed, a difference of only 0·31 milliard.

14. The Project in the form proposed appears to us to be unacceptable; the Sudan is one country and any adverse effects on local interests are of more than purely local importance. The Revised Operation which we advocate involves very much less expenditure in capital costs. Moreover, it is designed to cause the least possible disturbance of local interests, whatever the costs and water requirements—and they are not inequitable when compared with the total saving, while still fulfilling the primary objective of the Equatorial Nile Project, which is to provide more water, much needed for irrigation in Egypt and the northern parts of the Sudan. Furthermore, the Revised Operation includes a comprehensive plan for flood protection which is lacking in the Project as proposed.

SPECIAL STIPULATIONS

15. We must also recommend that certain stipulations be made concerning the engineering works and methods of operation of the Project if it is to be implemented as proposed, without the revised operation we suggest. These stipulations have been summarized on pages 675-7 (Volume II), and include certain observations on the subject of Lakes Victoria, Kioga and Albert, the site of the Lake Albert Dam, the Torrents' Balancing Reservoir, the *Sudd* Diversion Channel, flood protection and flood-escape discharges, and the alignment and design of the Jonglei Canal. These observations need not be repeated in detail here, but there are certain points of especial importance to the Sudan which must be further emphasized:

- (i) *Lake Albert*. We consider that a range of levels from 10·00 m. to 18·50 m. on Butiaba gauge is totally inadequate for flood protection. Our own investigations indicate that a top level of about 25·00 m. should be provided.

- (ii) *Flood-escape Discharges : Tombe-Atem Barrage.* The Project contains no specific proposals for carrying flood-escape discharges in safety past the Aliab Valley from Tombe to Atem. The proposed banking would, it appears, have the effect of inundating Bor District.
- (iii) *Flood-escape Discharges : Central Zone.* Under the Project as designed it is clearly the intention to dispose of flood-water in the Central Zone at a rate of 120 m/d for long periods and at even higher rates for short periods. In view of the possibility that a period of 20 to 30 years, during which the present swamps will dry out, may elapse before such high discharges may occur, such a proposal is unacceptable. Our view is that all additional flood-escape discharges must be carried in safety past the Central Zone through the *Sudd* Diversion Channel, which should be constructed with adequate capacity for this purpose.
- (iv) *Alignment of the Jonglei Canal.* The 'Direct' Line of the Jonglei Canal is preferable to all others because it will not cut across the numerous watercourses, which would be intercepted by alignments closer to the river, and will not impede drainage and backflow which are important for the production of riverain pasture, but will open up areas where artificial pastures and crops can be irrigated.
- (v) *Design of the Jonglei Canal.* It appears that the Project cannot be operated as designed without further modification because a discharge of 17 m/d in the two 27.5 m/d canals is insufficient to maintain navigation and to keep down weed growth in them. It is our view that there should be one irrigation canal of 5 m/d capacity specifically for irrigation required in connection with the remedial measures we suggest, two main canals of 15 m/d capacity each, separated by 'washlands', to carry the water required to the north and for navigation, and that all three should be designed to carry a flood-escape discharge of 65 m/d.
- (vi) *Intermediate Constructional Stages.* The Project, though designed for application in five successive stages, will radically affect the Southern and Central Zones from the beginning of the first stage. Its operation must be altered in such a way that changes in the hydrological régime take place gradually, in phase with each successive stage.

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