VOLUME III

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INTRODUCTION

This volume of our report contains the results of special surveys, investigations, and experiments upon which many of our conclusions concerning the effects of the Equatorial Nile Project and our recommendations for remedial measures are based.

Chapter I describes survey work carried out in the reach of the Bahr el Jebel between Juba and Bor. This survey is of particular importance since our estimates of the vegetation species on the flood-plain of that reach are based upon the detailed investigation of sample areas. It has also thrown much light on the problem of the factors which govern the distribution of vegetation on *toich* land and swamp in other reaches of the river.

Chapters 2, 3, and 4 need particular mention. They cover respectively the White Nile between Malakal and Renk, the Sobat, and the Machar Marshes which form the greater part of the area lying between those rivers. Chapters 2 and 3 have been wholly, and the hydrological section of Chapter 4 partly, written by Mr. J. W. Wright of the Sudan Survey Department. Mr. Wright became interested in the Equatorial Nile Project when, in 1947, he started the compilation of maps of this area from the American air photographs. Our grateful thanks are due to him for his substantial contributions to our investigation and his great interest in our work.

It had from the first been one of the Team's main problems to relate the areas flooded by the White Nile each year to the height of the river. This was stressed in the *First Interim Report*, a rough estimate of the average total area flooded annually being deduced indirectly from the observed discharges at Malakal and Renk. Our predecessors also asked for air photographs to be taken at various stages of a flood in order to obtain this relationship directly. Mr. Wright showed that in this reach air photographs were unlikely to give an accurate result, mainly because of the height of the grass, and also that they were unnecessary since a sufficiently accurate result could be obtained from the cross-sections which had been measured some years ago by the Egyptian Irrigation Department.

His results were included as Appendix IV in the Team's *Third Interim Report* in 1949, and they have been used by us in estimating the effects on grazing along the White Nile of various proposals for control of the river upstream of Malakal. Meanwhile, from this relationship between the rise above mean low level and the average width, Mr. Wright had been able to calculate tables of surface area and trough volume in terms of the gauge-readings between Malakal and Renk. From these and records of rainfall and evaporation he was able to make an analysis of fifteen floods on the White Nile, and to estimate during the course of each the volumes of water stored temporarily in the trough, gained by rainfall, and lost by evaporation and by absorption into the flood-plain. Comparing the totals of these with the difference between the observed discharges into this reach at Malakal and out of it at Renk, he was able to deduce the amounts of water contributed by the small tributary watercourses entering from both sides along this reach. While it seems likely that his estimates for this inflow may be in error for the years when it was small, in three out of the four years where his deduced flow exceeded a milliard there was ample evidence, in local administrativerecords, of heavy discharges in these tributary khors. For the fourth year no records could be found. These results form the chapter entitled ' An Analysis of the White Nile Flood between Malakal and Renk ', which was received by the Team in 1949.

Mr. Wright then turned to the Sobat, and attempted to apply the same method of analysis but with two important differences. The first was that there were only four complete cross-sections of the Sobat available and these were all on the lower third of its course, which is affected by the backwater of the White Nile and where the average rise and fall and the width in flood are very much less than they are in the upper two-thirds. The second difference was that the tributary watercourses of this river had apparently been investigated more thoroughly than those of the White Nile, so that in most years all important tributary discharges had been recorded. It therefore seemed likely that in most years the differences between the observed discharges into the Sobat at Sobat Head and those out of it at Hillet Doleib (8 km. above its mouth) were almost entirely due to the change in trough volume, gains by rainfall, and losses by evaporation and absorption, once all the observed tributary discharges were allowed for.

Mr. Wright then assumed that on the upper Sobat the general shape of the valley bore a family resemblance to that of the White Nile, and deduced the actual average cross-section from the observed discharges at its head and tail by a process of successive approximation, until he was able to produce a curve of average cumulative differences between the two sets of discharges which agreed closely with that observed. He was then able to calculate from this average cross-section tables of surface area and trough volume in terms of the gauge-readings along the Sobat, and so to analyse each of thirteen floods exactly as on the White Nile. He also studied the behaviour of the tributary watercourses—particularly the Wakau and the Twalor—in more detail than had been done before, and was able to deduce from them the probable behaviour of the water in that part of the Machar Marshes lying immediately north of the Sobat. These results form the chapter entitled ' An Analysis of the Sobat Flood ', received by us in June 1953.

Chapter 4, which concerns the Machar Marshes, was originally written by us before this analysis of the Sobat flood was available. As the deductions in the analysis differed in some respects from ours, Chapter 4 required a certain amount of re-writing, and this was undertaken on our behalf by Mr. Wright after the main outlines had been agreed between us. The result is that all three parts form a coherent whole, in which our field investigations have been combined with Mr. Wright's theoretical analyses, to produce what we hope is a reliable picture of conditions in the area. It should be emphasized, however, that while Chapter 4 and certain conclusions, given in Volume 1, which are based on Chapter 2 and 3 of this volume, represent our considered views as a Team, these two chapters themselves are Mr. Wright's individual contributions, and his conclusions must remain to some extent a matter of opinion until their very theoretical basis is supported by further observations.

Chapters 5 and 6 of this volume contain records of data obtained by experimental methods. It should be stressed again that the time available for experimental work was very small. Qualified staff was not available until comparatively late in the Team's three-year programme, and all members of the Team had many other duties to perform which carried them far and wide over the vast area involved. In most cases the experiments can best be described as ' short-term trials '. The results have had to be accepted with considerable reserve and there are naturally many omissions.

PART I.

SPECIAL INVESTIGATIONS

CHAPTER 1. THE BAHR EL JEBEL FLOOD-PLAIN BETWEEN JUBA AND BOR

1. OBJECTIVES OF SURVEY

The objectives of the survey may be defined as follows:

(1) Investigation of the topography and hydrology of the Bahr el Jebel flood-plain between Juba and Bor, with concentration on two specimen areas, the Aliab Valley between Tombe and Bor and the *toich* on the east bank between Mongalla and Gemmeiza, in order to correlate levels and areas of flooding with Mongalla discharges.

(2) Collection of information on the ecology of the area—in particular the relationship between flooding, soils, and vegetation.

(3) Collection of basic information on the economy of the area—agriculture, animal husbandry, and fishing—and its relationship to the ecological régime.

(4) Assessment of the effects of the Equatorial Nile Project in this reach of the river.

(5) Investigation of the possibility of carrying high discharges through this reach by banking of the Bahr el Jebel or by canalization of the River Aliab.

(6) Investigation of the possibility of using the Aliab Valley or other parts of the flood-plain as a remedy for losses under the Equatorial Nile Project by producing artificial grazing or irrigated crop production schemes.

2. ACCOUNT OF SURVEY

The importance of a survey of the Aliab Valley was first stressed by the Team in 1947 (see *Second Interim Report*, pp. 8, 37, 105), when it was proposed to use the area to produce artificial grazing, grain, and sugar, assuming that the River Aliab would be canalized and the left bank of the Bahr el Jebel strengthened to eliminate spill. In 1948 the Team recommended in their *Third Interim Report* that a detailed survey should be made of this area, and later in that year it was decided that conditions, though not favourable, were good enough to start work immediately. The plan was that cross-sections should be surveyed as the basis of a contour map of the Aliab Valley; it would then be possible to make the preliminary design for an irrigation scheme.

Survey work began on 10th December 1948, and ended on 8th May 1949. The average strength of the party was seventy, including chainmen and unskilled labour to clear the lines. Extremely high discharges and river levels—December to March average 70·6 m/d—resulted in very swampy conditions and made levelling on the *toich* impracticable until very late in the dry season. The preliminary work of clearing a road and survey line from Tombe gauge to Yalakot (see Fig. H 1) and levelling to Khor Gwir was begun, but the extreme density of the forest and undergrowth on the western side of the valley made progress slow; average clearance on the line was about 300 m. a day, with a labour force reduced by sickness to 50. By the end of the season the longitudinal section had been cleared and surveyed as far as Yalakot, and two and a half cross-sections of the *toich* were completed (see *Progress Report*, 1948–49, p. 7). A programme of soil sampling was started.

No work was done in this area during the 1949–50 season as the Team was concentrating its activities as far as possible in the Northern Zone, but the survey was continued between 20th January and 10th May 1951 under favourable conditions (December to March average discharge 42·3 m/d). At the southern end of the valley the survey line already completed was used as a framework; in the north, where communications were easier, the sections were based directly on existing E.I.D. bench-marks. Twelve and a half cross-sections of the valley between Tombe and Bor—several of them over 10 km. in length—making a total of 15, and two cross-sections of Khor Gwir, were completed. The opportunity was taken to relate the cross-sections to soil types and vegetation. A comprehensive soil survey was made, involving the collection of 900 samples from 150 soil pits, and a detailed survey of vegetation was also carried out. At the same time a survey of cattle-camps was made, their positions being noted, together with cattle population and movements and the way in which pasture was utilized. The distribution of fish was also investigated.

These cross-sections were plotted; from these the alluvial formation of the banks of the Bahr el Jebel became evident. Since the sections also indicated a fall in bank level relative to water-level from south to north, it was realized that a longitudinal section of the bank crest, including all spill-channels, was necessary to determine the amount of spilling into the Aliab

Valley and thus to complete the survey. This was done during the 1951–52 field season, when the survey was extended farther south to cover the whole Bahr el Jebel flood-plain between Juba and Bor. As it was possible to start work early in the dry season at the southern end of the reach, where conditions were fairly dry, the survey began on 24th November 1951 and was completed by 7th May 1952. Twelve cross-sections of the flood-plain were surveyed from the high ground on the east to that on the west, while four Aliab sections were extended as far as the high ground on the east, to complete sixteen cross-sections at approximately 10 km. intervals from Juba to Bor. In addition to the Aliab Valley one other area, the Mongalla-Gemmeiza *toich*, was surveyed in detail. Eight additional cross-sections of the latter were interposed to give twelve evenly-spaced sections, while longitudinal bank sections from Tombe to Bor and from Mongalla to Gemmeiza were completed. Three sections were extended to the east of the Mongalla–Gemmeiza road. All these sections were based directly on the line of E.I.D. bench-marks down the east bank.

METHODS

The cross-sections were set out by compass and ranging-rod and later positioned on air photographs or air survey maps. Nilotic labourers in parties of 20 cleared the lines under the supervision of a senior chainman. Progress varied according to the conditions; it averaged a few hundred metres a day in thick forest, one kilometre in medium bush or thick grass, and two kilometres in good conditions on the *toich*. Where the survey lines passed through water, taping was combined with the soundings of channels and swamps; pegs were driven to water-level for the data of the soundings to be determined by the levelling party. It was often necessary to use small boats to cross deep channels, and on occasion three boats were used for taping, one for each end of the tape, and a third for the sounding party. Soundings of the main channels were taken at first by means of a sounding cable and later by tacheometry; the intervals at which soundings were taken were measured by reading a staff in the boat from an instrument on the bank. Surface current speeds were taken by float and stop-watch. At first stakes were driven into the mud to support the instrument and staves when levelling in swamp, but it was found that the necessary accuracy—that of control levelling—could be achieved by judicious placing of the instrument and by levelling in one direction, reading both metric and arbitrary scales. At change-points the staff was placed either on specially constructed large base-plates or on a large peg. In the Aliab Valley the level was often carried across lake or swamp by driving stakes to water-level at both sides of the obstacle.

A survey of vegetation was made along each line in conjunction with the taping; the proportion of ground covered by each species was noted, together with the position of changes. Specimens were collected, their vernacular names being noted, and were later identified. Soil sample pits were dug to a depth of six feet at kilometre or half-kilometre intervals along the sections, samples being collected at foot intervals, and described, together with the site, vegetation, and moisture content. All cattle-camps and permanent villages were visited, and the tribe and section were noted, together with animal population and movements, watering places and grazing areas, and also areas of cultivation. Two fishermen visited all the khors and lakes with casting-nets; their catch was tabulated, the species, weight, and size being noted, together with the time spent in fishing.

RESULTS

As far as possible, the results of the investigation have been reduced to diagrammatic form. These are dealt with in detail below, and comprise:

	Figure No.
JUBA–BOR REACH	
16 cross-sections of the flood-plain	A 2–9
3 cross-sections of the forest to the east of the river	A 10–12
Key plan	A 1
ALIAB VALLEY	
15 cross-sections of the valley	H 4–9
2 cross-sections of Khor Gwir	H 6
Longitudinal bank section	H 10–11
Map—contours and flooding	H 1
Map—soil texture, surface organic horizon, and water-table	H 2
Map—vegetation, pasture utilization, and fishing	H 3
MONGALLA–GEMMEIZA *TOICH*	
12 cross-sections of the valley	H 14–16
Longitudinal bank section	H 17–18
Map—contours and flooding ... ... — —	H 12
Map—vegetation, pasture utilization, and fishing	H 13

3. JUBA TO BOR: GENERAL

Sixteen cross-sections of the flood-plain at approximately 10 km. intervals between Juba and Bor, together with a map of the area, give a general picture of this reach. The flood-plain, defined by high banks on either side which mark the limit of the forest, increases steadily in width from 4·5 km. at Juba to 9 km. at Bor. The Bahr el Jebel, confined in parts to one channel and in other parts divided into as many as three channels, swings from one side of the flood-plain to the other, dividing the area up into segments bounded by the river and the forest or into islands.

Between Juba and Bor there are eight main segments of flood-plain, three on each bank of the river and two large islands. The two islands, between Gemmeiza and Tombe, are heavily flooded; this is possibly due to the banking-up above Tombe of the water which used to flow down the River Aliab, since the latter is now blocked by *sudd*. Apart from these islands, flooding is least near Juba and greatest in the north near Bor. The cross-sections, which include normal high and low water-levels—based on maximum and minimum 10-day normals, 92 m./d and 58 m./d at Mongalla—show how the water-level rises from south to north in relation to the levels of the bank and flood-plain. Fig. H 21, which is derived from the cross-sections, shows this most clearly. This rise is reflected in increased flooding and a transition in vegetation from the *Phragmites* dominated *toich* near Juba to the papyrus swamp opposite Bor.

But this transition is not uniform. Each segment of the flood-plain is a hydrological unit, and, as Fig. H 21 also shows, within each unit there is a similar transition from south to north in relative height of bank and therefore in flooding and in vegetation. In order to elucidate this double transition, within and between units of the flood-plain, two specimen areas were surveyed in detail. These areas, the Aliab Valley and the Mongalla-Gemmeiza *toich*, will be dealt with in turn below.

4. THE ALIAB VALLEY

TOPOGRAPHY

The topographical description of the Aliab Valley is based on the survey work carried out, together with general observations in the field. The survey work (see Fig. H 1) consists of fifteen cross-sections from the high ground on the west of the valley to the Bahr el Jebel, from Tombe to near Bor. At the southern end, where they are based on a longitudinal survey through the forest, the sections are at 2 km. intervals and vary in length from 1 km. to 6 km., the average being 4 km. Farther north, where they are based on E.I.D. bench-marks, the sections are at approximately 4 km. intervals and the average length is 9 km. Two cross-sections of Khor Gwir, one near Lake Dijir and one 10 km. upstream, and a longitudinal section along the left bank of the Bahr el Jebel from Tombe to opposite Bor, 58 km. long, complete the work. These sections have been positioned on a 1/50,000 map of the Aliab Valley, which was traced from E.I.D. air survey maps based on photographs taken during the years 1930–31.

A contour map has been prepared from this work. Because of the broken alluvial nature of the ground there are considerable variations in height, but the mean ground level has been taken in determining the intercepts of contours along the sections. Between the cross-sections the contours have been interpolated according to the topography, and they would therefore be more correctly described as form lines; the large number of small khors and depressions would make it impracticable to produce a contour map on this scale, however much survey work was done. The map does, however, give a general picture of the topography, brings out its inverted nature—the rivers being above the plains they traverse—and thus complements the cross-sections. The names of as many channels as possible have been included on the map, but there is not space for all. These, together with general and detailed topographical information, are available in traverse notes and the descriptions of soil sample sites.

The Aliab Valley is the name—derived from the Aliab Dinka who utilize the western side during the dry season—given to an arbitrary portion of the flood-plain bounded on the west by forested high ground and on the east by the Tombe channel (from Tombe where it leaves the forest), by the west channel, and finally by the main channel, of the Bahr el Jebel. Thus, although the flood-plain widens steadily from south to north from an over-all width of 8 km. at Tombe to 9 km. at Bor, the Aliab Valley varies considerably in width, as the map shows. The total length of the valley from Tombe to Lake Papiu is about 90 km., and its total area is approximately 480 sq. km. The area surveyed is 250 sq. km., or about half the whole valley.

The western limit of the flood-plain is a comparatively steep bank, whose height remains fairly constant at about 4 m. The higher ground west of this bank is thickly forested; the bank itself forms a well-defined boundary between forest and open flood-plain. Between Tombe and Yalakot, where the forest is extremely thick, several small drainage-channels form re-entrants into the forest and bank. Just north of Panabang the bank is broken by Khor Gwir, a seasonal stream fed by local rainfall, which spreads out from a well-defined channel into a grass-choked depression feeding Lake Dijir. North of Khor Gwir the high ground is set back to the west, and the forest spreads to the east of it and merges gradually into the flat, open *toich*. At Minkaman the forest gives way to thick bush, but the bank once again marks the boundary between higher ground, covered with thick bush, and *toich*.

The Aliab Valley has as its eastern boundary the left bank of the Bahr el Jebel which, by deposition of silt, has been built up to a height of 2 m. above the adjacent flood-plain. This process is continuing; in many places it was found that levées were forming on the river side of former banks, and in such cases the higher of the two banks was surveyed. The longitudinal section of the bank from Tombe to Bor (Figs. H 10–11), showing the crest level of the bank every 50 m. and the invert level of every spill-channel, gives a clear picture of the bank. As its origin would lead one to expect, the crest of the bank is extremely even in height, variations from a mean line drawn through the section being of the order of only 15 cm.

The bank is, however, broken by many spill-channels, large and small; between Tombe and Bor there are 22 channels whose depths are greater than 1 m., 67 between 1 m. and 50 cm., and 281 less than 50 cm. They vary in width from 1 m. at bank level to 28 m. in the case of Nyin Akujai near Bor, the average width being 2 m. The larger channels are dammed at their mouths by the Dinka during the dry season to allow the *toich* to dry out for grazing and to enable the cattle to reach the grazing areas by a route along the Bahr el Jebel. These dams are usually washed away as the river rises. The Dinka also dig small channels where the bank is low in order to trap fish, but most channels appear to be started by hippos forcing their way on to the bank of the river. This is a point which must be borne in mind when banking of the river to prevent spill is considered. The heads of all channels have the same appearance, a funnel opening towards the river, the channel being narrowest at its highest point or invert, then sloping away down to the *toich*. Once such a track has been started cattle use it as a watering place, and when the river rises spill-water finds its way through the gap in the bank and erodes a channel down the slope from the river to the *toich*. Many of the smaller channels are choked with *Phragmites communis*, so that the channel grows or closes up according to whether scour from the river competes successfully or not with grass growth and silt. The map, on which all the larger channels are marked, shows how they have formed where flow from the river is greatest, either on the outside of a bend or where there is a drainage-channel parallel to the river and close to the bank. This means that a large proportion of the spill-water is led directly into drainage-channels and is carried north in a defined channel.

Comparison of the present topography with air photographs and maps dating from 1931, and also with ground surveys made at that time, shows that the large channels have changed little in the interval. Although the southern head of Khor Ker at Amathhom is now so silted up that its course is unrecognizable on the ground and the bank of the Tombe channel is unbroken, the course of Khor Ker still shows up clearly from the air, so it may have been blocked before the map was made. Two changes in the course of the river are noticeable; the two loops in the river near B.M. A 18 and B.M. A 22 have been cut off and remain as ox-bow lagoons.

When the bank crest was surveyed, the water-level in the Bahr el Jebel was taken every kilometre. The river level was almost constant over the period of the survey, but these levels have been reduced to a single Tombe gauge-reading to give one river profile between Tombe and Bor; the slope is found to be constant in each channel, but it changes at channel junctions. A correlation between Mongalla discharges and Tombe, Malek, and Bor gauge-readings has been deduced from the monthly means of 1938 to 1942 (see Fig. H 20); for each steady Mongalla discharge between 50 m/d and 120 m/d, at 10 m/d intervals, a river profile has been drawn and superimposed on the bank section (see Figs. H 10 and H 11).

This combined section demonstrates clearly that the longitudinal slope of the bank is greater than the slope of the river water-level at all discharges. Therefore for each steady discharge above a certain level there exists a point at which the bank and water-level coincide. As their angle of incidence is very small it is necessary, in order to find this point accurately, to re-plot the longitudinal section on a greatly increased vertical scale (see Fig. H 21 for a reduced copy of the working drawing). At each kilometre the mean level of the bank over the kilometre has been plotted, together with a lower point, such that 100 m. of the bank is below it. This latter point, about 10 cm. below the mean level, is taken to be the effective bank level, and the points at which the water profile for each Mongalla discharge cross this curve have been deduced and are marked on the river bank on the contour and flooding map (Fig. H 1). As the discharge increases, so the point of intersection moves farther upstream. North of this point the bank is under water and widespread spilling occurs. Because of the height of the alluvial bank above the flood-plain this water spreads laterally from the river, hindered only by the resistance of the vegetation, until an obstacle is reached. South of the point where the bank is inundated, spill occurs through channels and by seepage through the alluvial bank. As already stated, most of this spill is led directly into channels parallel to the river and flows northwards, largely confined to these channels, until an obstacle in the form of a lateral bank is reached or until the channel debouches into widespread flooding; this spill-water helps to maintain the flooding level across the valley. It has therefore been assumed that this combination of spill over the bank and through channels will maintain backwater flooding at the level of the point of intersection, and for this reason the contours have been followed back from these points to give the areas flooded at each discharge (see Fig. H 1).

This picture of flooding spreading from north to south is supported by field observation. The width of the alluvial bank increases from south to north, indicating that spill is greatest in the north. Where the bank is low in relation to water-level south of Bor, channels, dry at the time, were seen leading away from the river but only starting about 30 m. from the bank, here unbroken; in the same area in May 1952 the bank was submerged and water was pouring over it. In 1951 Lake Barnyieu, fed largely by Nyin Akujai, spread back to C.S. 14 and C.S. 15, while the water-levels on C.S. 13 were approximately the same as the lake level. The picture fits in well with the discharges at which spilling is known to occur south of Bor and Malek. As Fig. H 20 shows, spilling increases rapidly south of Bor at a Mongalla discharge of 65 m/d, and south of Malek at between 75 and 95 m/d.

The valley itself, the depression contained between the Bahr el Jebel and the afforested high ground, is too extensive and varied to describe in detail. The cross-sections (Figs. H 4–9) should be studied, but field observations may be summarized as follows. On all lines the valley was found to change in character at Khor Ker; not only was the ground itself flat or rolling to the west and more broken to the east, but the vegetation (see Fig. H 3), the depth of flooding of soil pits (see Fig. H 2), and the nature of drainage-channels were different. Variation was not continuous from south to north. Between Khor Ker and the Bahr el Jebel, C.S. 2, C.S. 3, and C.S. 4 got steadily wetter. C.S. 5 was comparatively dry, but C.S. 6 and C.S. 8 grew wetter; C.S. 9 was again dry, but north of it the lines became more and more flooded until C.S. 15, crossing Lake Barnyieu and a papyrus swamp, was reached.

As the cross-sections, together with the contour map, show, the area is transected by a network of spill and drainage-channels whose general direction is parallel to the Bahr el Jebel. All these spill-channels have formed their own alluvial banks; the River Aliab or Khor Ker, the largest channel, winding down the centre of the valley, has banks little lower than the Bahr el Jebel itself and forms a barrier to lateral flooding. Although the river is covered with vegetation and partly blocked throughout its course, it carries away to the north most of the water which tops its bank. The original head of the river at Amathhom has silted up, and the river is now fed by a head near B.M. A 22. Its course from this head to Yalakot provides a transverse obstacle to drainage from south to north and isolates the two basins to the south. Thus the banks of the River Aliab effectively divide the area surveyed into four basins, each with its own sources of flooding and drainage systems.

The largest basin, north-east of the River Aliab, receives spill from several large channels near Mathiang and south of Malek; this spill drains north, concentrated in Nyin Koriom and the system of lakes down the centre of the basin, until backwater flooding is reached. The latter governs flooding in this area, which varies from high ground on the banks of the Khor Ker, seldom inundated, to an area of permanent flooding in the north.

The map shows a separate system to the west in the smaller basin contained between the River Aliab and the forest from Yalakot to Minkaman. Protected normally by the high banks of the River Aliab from river flooding, this area is fed by Khor Gwir and by run-off collected by Khor Nyankojii south of Lake Dijir. A drainage system runs north from Lake Dijir and finally joins Khor Ker where it comes close to the forest at Ahou. This basin, being free of silt-laden spill-water, is characterized by a smaller variation in flooding, flat or gently rolling ground, and open (*sudd*-free) channels without alluvial banks.

The two small basins south of Yalakot, divided by Khor Ker between Amathhom and Gukthon, each receive spill through several large channels and are inundated by spill over the bank at discharges between 90 and 100 m/d. However, there is a difference between them. Whereas in the eastern basin Khor Bargeik and Khor Kolnyang drain into a cul-de-sac, producing the lake marked on the map and an area of semi-permanent swamp only subject to evaporation, the western basin is partly drained by Khor Lalop, which flows into Khor Ker at Yalakot; to the east of Khor Lalop, Khor Adutcier fans out into the formation shown on the map, as was confirmed during a reconnaissance flight. Thus the western basin dries out first as the river drops; once the eastern basin is full, spill from the river flows straight into a flooded area and silt is deposited near the river. For this reason the eastern basin is about 1 m. lower than the western and has a high and narrow alluvial bank. This partition into four basins explains all the phenomena noticed in the field and mentioned earlier.

Thus, given the topographical conditions described above, there is for each steady Mongalla discharge an equilibrium position of flooding. Because the flooding of the valley is determined by backwater and because the river bank falls relatively to the water surface, a change in discharge causes a greater change in the level of flooding in the valley than in the level of the river. The areas normally flooded and uncovered seasonally are dealt with quantitatively in the next section.

HYDROLOGY

We now turn to the hydrological aspects of the Aliab Valley, which must be introduced with a brief summary of the relevant topographical features.

The total area surveyed amounts to 250 sq. km. Approximately 156 sq. km. are flooded by the Bahr el Jebel north and east of the River Aliab; 66 sq. km. west of the Aliab receive flooding from Khor Gwir; and 27 sq. km. south of Khor Ker form separate basins flooded by the Bahr el Jebel.

The River Aliab, or Khor Ker, takes a winding course down the centre of the valley, which it effectively divides, by its alluvial ridge, into eastern and western portions. The old course of the Aliab from the southern apex of the valley is blocked with silt; the river is now fed by a new offtake near Gukthon, and a new channel, the Khor Ker, runs from south-east to north-west across the valley to Yalakot. Since this too has alluvial banks it also divides the valley into small areas to the south and larger areas to the north.

The level of the floor of the valley is on the average nearly 2 m. below the crest level of the left bank of the river, varying from 0·9 m. in the south to 2·6 m. in the north of the area surveyed. This bank is not more than 200–300 m. wide at the southern end, but increases in width northwards, so that from Cross-Section 9, downstream of the junction of the eastern and western channels of the river, it averages 1 km. in width. The reader should refer to Tables 375, 376, and 377 for further details.

The following average slopes from south to north have been calculated:

Average slope of the bank crest	10·8 cm/km.
Average water slope at the mean Mongalla discharge of 75 m/d	9·75 cm/km.
Average *toich* slope	15·2 cm/km.

As already explained (see Vol. I, p. 15), water reaches the Aliab Valley in five different ways:

(1) From the Bahr el Jebel by spill over the crest of its left bank and in large and small channels.
(2) From the Bahr el Jebel by backwater from the northern end of the valley.
(3) From Khor Gwir, a watercourse of local origin, and from the River Gel or Tapari in the area outside this survey.
(4) From the underground water-table.
(5) From direct rainfall.

Spill through large channels, of which there are 22 between Tombe and Bor, begins at the lowest discharges of 50 m/d or 60 m/d at Mongalla. The depth of water in Nyin Akujai (Unyam Koji) just south of Bor is 4·3 m. when the Mongalla discharge is 50 m/d. The southern part of the valley between Tombe and Khor Ker is flooded through spill-channels which draw water at the low discharge of 50 m/d. The water spilled is ponded by the ridge formation of Khor Ker, and the areas bounded by these features are therefore semi-permanent swamp. There are 67 smaller channels between 1·0 m. and 0·5 m. in depth and 281 of less than 0·5 m. between Tombe and Bor. There are also low points on the bank 15 cm. below the crest levels given in Table 376. It can therefore be safely assumed that when the water-level reaches the crest levels shown in Table 376 spill is passing over the crest in appreciable quantities.

Spill over the bank crest begins at a Mongalla discharge of 70 m/d at the northernmost end, and the whole bank is submerged when the discharge reaches 120 m/d at Mongalla. It will also be noted that the largest spill-channel is the Nyin Akujai, at the northern end of the area surveyed, which feeds the backwater lake.

The River Aliab forms a bank effectively barring the ingress of Bahr el Jebel spill to the western portion of the valley, which is therefore only watered by rainfall and run-off from Khor Gwir (except possibly at the very highest levels). Field observations showed a marked difference both in grass types and in the underground water-table in soil sample pits east and west of the Aliab channel.

The main underground water-table extends from the Bahr el Jebel to a distance of about 1·5 km. within its alluvial left bank. There are also subsidiary water-tables created by surface flooding, and by flooding in spill-channels. The soil is by no means homogeneous, and contains banks of silty sand deposited by old and recent minor channels in the valley.

Rainfall over the area averages 903 mm. per year at Bor.

We have calculated the areas of the valley which are inundated at Mongalla discharge above 50 m/d, and have plotted the duration of each discharge for the period 1946–50, with the figures for 1950 included twice, according to an empirical rule (see Vol. I, p. 156) decided upon by the Team (Table 379, p. 830, and Fig. H 22). The area to the west of the River Aliab has not been included in these areas because there is evidence to show that it was not flooded by spill from the Bahr el Jebel in the period considered, and the two areas south of Khor Ker are also not included. The analysis of grass species shows that flow in large spill-channels is confined to those channels as they run down the valley and to a narrow strip on each side of them. The factor which controls widespread flooding is the backwater from the north.

TABLE 375

ALIAB VALLEY

HYDROLOGICAL DETAILS

Section Number	Water-Levels at Mongalla Discharges in m/d							
	50	60	70	80	90	100	110	120
1	423·98(²)	424·50	424·87	425·10	425·25	425·40	425·50	425·60(¹)
2	3·13	3·91(³)	4·27	4·50	4·65	4·79	4·88	4·96
3	3·30(³)	3·65(²)	4·01	4·24	4·39	4·53	4·62	4·70(¹)
4	2·90(²)(³)	3·42	3·79	4·01	4·16	4·29	4·38	4·45
5	2·66	3·17(²)(³)	3·55	3·77	3·91	4·04	4·12	4·20(¹)
6	2·38	2·89(²)(³)	3·26	3·49	3·63	3·75	3·84	3·90
7	2·09(³)	2·58	2·95(³)	3·18	3·32	3·45	3·52	3·58
8	1·89(³)	2·39	2·75(³)	2·98	3·12	3·24	3·29	3·35
9	1·79(³)	2·19	2·55	2·77	2·91	3·03	3·10	3·15
10	1·29(²)(³)	1·78	2·16	2·36	2·50	2·60	2·67	2·70
11	1·06(³)	1·56	1·92	2·13	2·26	2·36	2·42(¹)	2·46
12	0·75(²)(³)	1·24	1·61	1·81	1·94	2·03(¹)	2·08	2·11
13	420·42(³)	0·90	1·24	1·42	1·54	1·62(¹)	1·67	1·69
14	419·99(²)(³)	0·47	0·77	0·92	1·03	1·10(¹)	1·14	1·17
15	419·60(²)(³)	420·06	420·33	420·46	420·56(¹)	420·63	420·66	420·68

(¹) Water-level above Bahr el Jebel left bank crest level.
(²) Water-level above invert level of large spill-channels.
(³) Water-level above average *toich* level east of River Aliab.

Water slopes at Mongalla mean discharge of 75 m/d:

	km. 0·0–km. 6·9	17·0 cm/km.
	km. 6·9–km. 21·2	10·4 "
	km. 21·2–km. 37·0	9·8 "
	km. 37·0–km. 57·2	9·0 "
Average ...	km. 0·0–km. 51·5	9·75 "

TABLE 376

ALIAB VALLEY

TOPOGRAPHICAL DETAILS—BANK

Cross-Section		Distance on Bank	Reduced Level of Bank	Bank Fall	Bank Slope	Average *Toich* Reduced Level		Invert Level Deepest Khors
Number	Bank km.	km.		m.	cm/km.	West of Aliab	East of Aliab	
1	4·4	—	425·60	—	—	425·00	—	423·70
2	8·3	3·9	5·25	0·35	9·0	4·00	423·50	—
3	10·8	2·5	4·70	0·55	22·0	3·75	3·25	2·50
4	13·0	2·2	4·70	—	—	3·25	2·75	2·20
5	16·6	3·6	4·15	0·55	15·3	3·00	3·00	2·80
6	19·2	2·6	4·00	0·15	5·8	2·50	2·75	2·65
7	22·2	3·0	3·77	0·23	7·7	—	1·90	1·90
8	24·4	2·2	3·50	0·27	12·3	1·75	1·50	2·70
9	26·6	2·2	3·30	0·20	9·1	1·50	1·00	—
10	31·0	4·4	2·85	0·45	10·2	0·50	0·50	421·25
11	33·5	2·5	2·40	0·45	18·0	420·00	420·00	—
12	37·0	3·5	2·00	0·40	11·4	419·75	419·75	419·75
13	41·2	4·2	1·60	0·40	9·5	9·50	9·00	—
14	46·5	5·3	1·05	0·55	10·4	—	8·50	420·20
15	51·5	5·0	420·50	0·55	11·0	418·25	418·00	415·28
Totals and Averages	—	47·1	—	5·1	10·8	—	—	—

TABLE 377

ALIAB VALLEY

TOPOGRAPHICAL DETAILS—*TOICH*

Cross-Section		Average *Toich* Reduced Level		West of Aliab		East of Aliab		Bank Height above *Toich*
Number	Straight Line km.	West of Aliab	East of Aliab	*Toich* Fall m.	*Toich* Slope cm/km.	*Toich* Fall m.	*Toich* Slope cm/km.	
1	—	425·00	—	—	—	—	—	0·60
2	1·0	4·00	423·50	1·00	10·0	—	—	1·75
3	3·0	3·75	3·25	0·25	12·5	0·25	12·5	1·45
4	5·0	3·25	2·75	0·50	25·0	0·50	25·0	1·95
5	7·0	3·00	3·00	0·25	12·5	—	—	1·15
6	9·0	2·50	2·75	0·50	25·0	—	—	1·25
7	11·0	—	2·90	—	—	—	—	1·87
8	13·0	1·75	1·50	0·75	18·75	1·25	15·6	2·00
9	15·5	1·50	1·00	0·25	10·0	0·50	20·0	2·30
10	19·5	0·50	0·50	1·00	25·0	0·50	12·5	2·35
11	21·9	420·00	420·00	0·50	20·8	0·50	20·8	2·40
12	25·8	419·75	419·75	0·25	6·4	0·25	6·4	2·25
13	29·5	9·50	9·00	0·25	6·75	0·75	20·3	2·60
14	33·2	—	8·50	—	—	0·50	13·5	2·55
15	37·2	418·25	418·00	1·25	16·2	0·50	12·5	2·50
Totals and Averages	37·2	—	—	6·75	18·2	5·50	15·2	1·93

TABLE 378

DURATION OF 10-DAY MEAN DISCHARGES AT MONGALLA

1946–50

In millions of cubic metres per day

Discharge above m/d	Duration in Each Year days								Average number of days per year
	1946	1947	1948	1949	1950	1950	Total	Cumulative	
120	10	20	10	—	—	—	40	40	7
110	10	10	50	10	—	—	80	120	20
100	10	30	50	10	—	—	100	220	37
90	10	40	30	50	40	40	210	430	71
80	10	50	50	30	40	40	220	650	108
70	50	80	140	80	20	20	390	1,040	173
60	60 +	30	30	160	20	20	320	1,360	227
50	70	70	—	20	120	120	400	1,760	293
40	50	30	—	—	120	120	320	2,080	347
30	80	—	—	—	—	—	80	2,160	360

TABLE 379

ALIAB VALLEY

(North-East of River Aliab)

AREAS FLOODED RELATED TO MONGALLA DISCHARGES AND AVERAGE DURATION

Mongalla Discharge m/d	Area Inundated sq. km.	Average Duration 1946–50 plus 1950 days
120	155·8 (Total)	7
110	155·8	20
100	152·3	37
90	140·6	71
80	109·5	108
70	94·2	173
60	56·7	227
50	29·8	293
40	—	347
30	—	360

SOILS

Combined with the survey work described above, an intensive soil survey was carried out in the Aliab Valley; 150 soil sample pits were sited at regular intervals of 0·5 km. or 1 km. along each cross-section and their positions are shown in Fig. H 2. These pits were dug to a depth of 6 ft., and, after two or three days' interval had allowed water to rise in the pit to the equilibrium position, the difference in height between this water-level and the nearest survey peg was measured. The height of this water-table has been marked on each section as a small horizontal line. The pit was then baled out, inspected, and samples taken over each foot; when stratification was pronounced, samples were collected according to strata. The site, vegetation, and root penetration were described, as well as the colour and texture of each sample. Thus 900 samples have been collected. So far only one line, C.S. 13, has been analysed in top 3 ft. composites; the results of this analysis are given below (see Table 380, p. 833). The remainder await analysis.

However, from the sample descriptions all the sites have been provisionally classified according to mechanical composition, as assessed in the field, the following categories being used:

Category	Abbreviation used in Fig. H 2
Sand with clay (sand predominant)	Sand+Clay
Sand and clay in alternating layers	Sand/Clay
Clay superimposed on sand (sand increasing with depth) ...	Clay→Sand
Clay with sand (clay predominant)	Clay+Sand
Clay with little sand (clay predominant)	Clay

Those sites with a surface organic horizon have also been noted. As a check, this classification from the descriptions has been compared with the analysis results received for C.S. 13 and has been found to correspond closely.

In spite of the fact that the sample pits were not alike in appearance, great variety of colouring being observed, it is found when each site on the location map (Fig. H 2) is marked according to the above categories that the proportions of sand and clay or the texture vary according to area. Each of the above categories tends to occupy definite zones, with few exceptions. A provisional map has therefore been compiled, showing soil texture, surface organic horizon, and underground water-table over the area surveyed. It should be emphasized that until all the samples have been analysed the distribution of soil texture must be regarded as provisional, though it agrees with the one line analysed. The distributions of the surface organic horizon and of the underground water-table, however, need no such qualification.

The map shows that sand predominates not only on the forested high ground to the west of the valley, but also along the bank of the Bahr el Jebel. In the two southern basins clay is found superimposed on sand, except for the lake into which the spill-water drains, where clay predominates. Clay and sand in stratified layers are found near the larger spill-channels—Khor Ker from its present head at Gukthon and the channels opposite Malek. To the north the predominance of clay increases according to the distance from the Bahr el Jebel. West of the River Aliab, where little spill from the Bahr el Jebel occurs, clay is predominant farther south than it is to the east of the River Aliab; near Yalakot and north of Khor Gwir, where some run-off from the high ground occurs, sand extends out into the flood-plain. This distribution is what one would expect from the alluvial origin of the area—the coarser particles being deposited by spill near the river and the finer particles being carried farther to the north from the source of the alluvium and farther to the west from the river; it also illustrates the account of *toich* soils given elsewhere (see Vol. I, pp. 121–2). It will be noted that the main spill-channels, which only carry large particles in years of high flood, have formed stratified layers of clay and sand near their courses.

The map shows an organic horizon in the areas where soils are permanently saturated and nearly always flooded, as described above; i.e. at the northern end of the small south-eastern basin surrounded by the banks of Khor Ker, and in the north-eastern area of backwater flooding, where papyrus and *Vossia cuspidata* are dominant. The flooding in soil pits, shown on the map in relation to the surface and on the cross-sections, indicates the underground water-table extending from the Bahr el Jebel in the sandy alluvial bank and near the chain of lakes where spill-water flows north.

The areas where an organic horizon is found are also characterized by a high water-table. The difference in flooding west of the River Aliab is also demonstrated. Partly because of the lack of residual flooding and partly because of the greater predominance of clay, no flooding of pits was found west of the River Aliab, even in a pit dug on the bank of Khor Akolo well below the water-level in the khor.

VEGETATION

From the survey of vegetation carried out in the field, a map showing distribution of species has been compiled (see Fig. H 3). From the cross-section traverse notes giving species and percentages of species found in association, the linear distribution along each section has been marked on the map. The distribution between cross-sections has been interpolated where the same association is found on adjacent lines by joining up boundaries with regard to topography. There is, however, no way of showing on this map the dominant grass in an association; also where grasses alternate on high and low ground they have to be shown as associated.

From this map a broad pattern of vegetation distribution over the area emerges. Comparing the vegetation map with the contour and flooding map, and taking first the largest basin north-east of the River Aliab dependent on backwater flooding, the relationship between duration of flooding and vegetation is evident. At the northern limit of the survey where flooding is permanent, open water and *Cyperus papyrus* predominate, the papyrus being found near the river, possibly because the water is less stagnant where Nyin Akujai flows in (see Vol. I, p. 142). As flooding decreases farther south, open water occurs only in the chain of lakes carrying the spill-water north, while papyrus gives place first to *Vossia cuspidata* and *Echinochloa pyramidalis*, the former in channels and the latter on the higher ground between channels, and then to *Vossia cuspidata*, *Echinochloa stagnina* and *Echinochloa pyramidalis*. A band of *Echinochloa stagnina* mixed with *Echinochloa pyramidalis*, parallel to the Bahr el Jebel on its alluvial bank, is produced by a combination of underground water-table, spill, and flooding. At Jerkwot an area near the river was banked off in 1949 to eliminate flooding and spill. In March 1952, after three years of irrigation by rainfall and seepage only, no difference in the grasses—*Echinochloa pyramidalis* and *Echinochloa stagnina*—inside and outside the bank was noticeable, while regrowth inside compared fairly well with that outside.

Near Mathiang a number of large spill-channels produce *Vossia cuspidata*, merging into *Echinochloa stagnina* which is confined to channels as the flooding drains north in Nyin Koriom. On the higher ground to the south and near the River Aliab *Echinochloa pyramidalis* is found alone, while the banks of the River Aliab and the Bahr el Jebel, which are seldom inundated, support *Phragmites communis* and *Echinochloa pyramidalis*. At the northern end of the valley where the banks are inundated for longer periods *Phragmites communis* is not present; nor is it found at the southern end of the valley at the areas of spilling near B.M. A 15 and B.M. A 18. The distribution of ant-hills was found to coincide with that of *Phragmites communis*.

The difference in the grass distribution on the two sides of the River Aliab is clearly demonstrated. To the west of this channel, in the basin irrigated by Khor Gwir, *Echinochloa pyramidalis* is found throughout, associated with *Oryza barthii* in a broad belt on the edge of the forest and with *Echinochloa stagnina* in the drainage system leading north from Lake Dijir. In the two southern basins, where spill over the bank and through channels is the main source of flooding, *Vossia cuspidata* is prevalent where spilling occurs, and gives place to *Echinochloa stagnina* where the water is ponded by the banks of the River Aliab and therefore more stagnant.

Table 381 (p. 834) gives areas in square kilometres of each species in each of the three divisions dealt with above. The areas where each vegetative association is found have been measured on the map, and these areas are divided between the associated species in the proportions of each species noted in the field. The total cover of each species has been deduced, and the percentages of each species in each basin and in the whole area surveyed have been tabulated. This table illustrates the way, already described, in which the different hydrological régimes in each basin produce different vegetation.

Having established the correlation between duration of flooding and vegetation, it is necessary to treat the relationship quantitatively. The basin north-east of the River Aliab, where flooding depends on backwater and the areas flooded at each discharge and therefore the duration of flooding are known, has been treated in isolation. A graph has been drawn for this basin (see Fig. H 22), showing the area in square kilometres flooded at each Mongalla discharge, and also the duration of flooding in days per year based on the years 1946–50, the last year being given double weight. On the same graph areas of open water and each vegetative association have been plotted, arranged in steps according to the order in which they occur from north to south, i.e. as duration of flooding decreases. The effect of plotting each association in steps is to make clear-cut transitions between associations which are in fact gradual, but should not alter the figure obtained for the optimum duration of flooding for each species, that at which it forms the highest proportion of the vegetative cover. These figures of optimum duration have been deduced from the graph, together with the limits of flooding duration, and are tabulated below (see Table 382, p. 834). This quantitative analysis does not distinguish between depth of flooding and duration, since these are closely related; nor does it take into consideration other ecological factors, such as soil, current speed, etc., which are dealt with elsewhere (see Vol. I, p. 152), but it provides figures applicable not only to the area surveyed but also to other areas under similar conditions.

This short account of the ecology of the Aliab Valley demonstrates how, in the small section of the riverain flood-plain under consideration, soil and vegetation are governed by topography and the hydrological régime. The economic utilization of the same area is described in the next section.

TABLE 380

ALIAB VALLEY CROSS-SECTION No. 13
RESULTS OF MECHANICAL AND CHEMICAL ANALYSIS OF SOIL SAMPLES

MECHANICAL ANALYSIS

Pit Number	Reduced Level of Surface m.	S.G. %	C.S. %	F.S. %	Clay and Silt %
1	424·09	1	37	23	40
2	422·14	1	49	20	32
3	418·81	0	48	21	31
4	419·33	0	65	18	17
5	418·68	0	6	28	66
6	420·01	0	1	24	75
7	418·77	0	9	29	62
8	419·02	0	12	24	63
9	419·35	0	21	25	54
10	418·91	0	33	29	37
11	419·42	1	10	21	69
12	419·70	0	1	23	75
13	419·78	0	1	16	83
14	418·87	0	1	21	77
15	419·33	0	1	22	78
16	419·65	0	7	42	51
17	419·52	0	1	31	67
18	419·34	0	2	28	69
19	420·07	0	1	27	72
20	420·72	0	4	37	59
21	421·51	0	1	57	42

NOTE: All samples were analysed in top 3 feet composites except Pits 3 and 4, where samples 2 and 3 were taken from a narrow layer of sand.

CHEMICAL ANALYSIS

Pit Number	Salts %	SO_4 %	NR Value	PH Exch. 1 ft. Steps			Nitrogen p.p.m.	C/N	Carbon %	Exch. Ca
				0–1	1–2	2–3				
1	0·07	—	4	7·35	8·30	8·60	350	—	0·36	7
2	0·06	0·01	5	8·05	8·55	8·70	260	—	0·25	6
3	0·02	—	2	5·80	5·75	6·30	510	9·4	0·64	2
4	0·01	—	2	6·00	6·60	6·60	700	10·4	0·97	1
5	0·05	—	2	5·20	4·50	6·10	1,060	9·8	1·38	7
6	0·10	0·01	5	6·20	6·60	6·20	760	8·8	0·89	10
7	0·08	—	3	5·10	6·20	6·70	910	11·1	1·34	8
8	0·11	—	4	5·70	6·20	6·65	880	8·6	1·01	19
9	0·05	—	3	5·90	6·55	7·00	820	9·0	0·99	—
10	0·05	—	3	4·45	6·60	6·50	260	8·5	0·26	17
11	0·49	0·40	8	4·95	5·10	6·45	1,150	8·5	1·32	15
12	0·08	—	4	5·30	5·20	4·50	1,460	9·9	1·92	24
13	0·10	—	3	6·50	6·85	6·45	1,200	10·7	1·69	23
14	0·13	—	3	5·65	5·25	—	2,320	10·8	3·34	9
15	0·14	0·05	4	5·95	6·90	7·30	810	8·8	0·96	10
16	0·10	—	3	6·80	7·20	7·30	840	8·9	1·00	12
17	0·21	0·12	3	4·75	4·80	4·50	1,390	9·9	1·84	5
18	0·07	—	3	4·70	6·00	7·00	1,160	10·2	1·58	7
19	0·09	—	4	5·80	6·05	5·90	860	8·8	1·01	10
20	0·05	—	7	6·40	6·80	6·75	650	10·5	0·90	7
21	0·03	—	2	6·30	6·65	6·60	640	8·7	0·75	6

TABLE 381

ALIAB VALLEY
PRESENT DISTRIBUTION OF VEGETATION SPECIES

Species	Areas Measured from North: From sq. km.	Areas Measured from North: To sq. km.	Area covered in association with other spp. sq. km.	Area covered sq. km.	Percentage
North-East of the River Aliab					
Open Water	0·0	19·5	19·5	19·5	12·5
Cyperus papyrus ...	19·5	33·2 (45·8)	13·7 (26·3)	11·2	7·2
Vossia cuspidata ...	31·1 (19·5)	80·0	48·9 (60·5)	20·1	12·9
Echinochloa stagnina ...	49·5	104·9	55·4	29·8	19·1
Echinochloa pyramidalis	31·1	155·8	124·7	71·5	45·9
Phragmites communis ...	145·3	155·8	10·5	3·7	2·4
			Total area ...	155·8	100·0
West of the River Aliab					
Echinochloa stagnina ...	—	—	21·0	11·1	16·7
Echinochloa pyramidalis	—	—	65·4	47·1	70·8
Oryza barthii	—	—	20·1	8·0	12·0
Phragmites communis ...	—	—	0·9	0·3	0·5
			Total area ...	66·5	100·0
Two Basins South of Yalakot					
Vossia cuspidata ...	—	—	8·3	3·9	14·4
Echinochloa stagnina ...	—	—	9·2	6·2	23·0
Echinochloa pyramidalis	—	—	24·9	16·4	60·7
Phragmites communis ...	—	—	1·4	0·5	1·9
			Total area ...	27·0	100·0
Total Area Surveyed					
Open Water	—	—	19·5	19·5	7·8
Cyperus papyrus ...	—	—	13·7 (26·3)	11·2	4·5
Vossia cuspidata ...	—	—	57·2 (68·8)	24·0	9·6
Echinochloa stagnina ...	—	—	85·6	47·1	18·9
Echinochloa pyramidalis	—	—	215·0	135·0	54·2
Oryza barthii	—	—	20·1	8·0	3·2
Phragmites communis ...	—	—	12·8	4·5	1·8
			Total area ...	249·3	100·0

Brackets refer to partial cover.

TABLE 382

ALIAB VALLEY
DURATION OF FLOODING OF VEGETATION SPECIES
(From Fig. H 22)

Species	Minimum Days	Maximum Days	Optimum Days
Open Water	360	360	360
Cyperus papyrus	281	360	329
Vossia cuspidata	198	300	260
Echinochloa stagnina ...	178	240	204
Echinochloa pyramidalis ...	25	287	126
Phragmites communis ...	25	58	44

LAND UTILIZATION

Except for a very small amount of maize grown by the Mandari during the dry season on the river bank near Tombe, the riverain flood-plain in the area covered by the survey is used exclusively for dry season grazing. As the flood-plain on the right bank of the Bahr el

Jebel is extremely limited in extent between the latitudes of Tombe and Bor, the Bor Gok Dinka as well as the Aliab Dinka are dependent on the Aliab Valley pasture (see Figs. E 5, E 6). Although the Bahr el Jebel forms the boundary between Upper Nile and Bahr el Ghazal Provinces, the Bor Dinka cross the river to dry season cattle-camps in the Aliab Valley; the River Aliab forms a rough boundary between Bor Dinka and Aliab Dinka camps, the former being to the east of its channel and the latter to the west, with a few camps on the east bank.

The period of utilization varies from year to year, depending on the rains and the fall and rise of the river. Before the cattle are moved on to the *toich*, a period of three weeks is allowed after flooding has receded for the ground to dry out and for the grass to be sufficiently dry for burning. Thus the time at which cattle-camps are first occupied may vary from early November to January and also varies according to the camp, but the end of November or beginning of December is considered normal. The time of the move away from the *toich* is more constant, and occurs generally at the end of April or the beginning of May.

The positions of all the cattle-camps in the area have been marked on the vegetation map (see Fig. H 3); altered conditions cause only minor variations in camp sites, which are limited to the highest ground, although the direction of pasture utilization may change each year. It will be noted that all camps are situated where *Echinochloa pyramidalis* and *Phragmites communis* indicate relatively high ground, generally on the sloping banks of the River Aliab or the Bahr el Jebel, where they are also within easy reach of water. Each cattle-camp was visited, and the cattle population was estimated by counting the number of cattle groups and estimating the average number in each group by counting a few typical ones. The figures obtained can be found on the map. The numbers of sheep and goats were also estimated, though with less accuracy. The total animal population belonging to each tribe over the area covered by the survey is tabulated below:

Tribe	Cattle	Sheep	Goats	Area (sq. km.)
Aliab Dinka ...	14,790	2,870	1,370	—
Bor Gok Dinka ...	22,860	3,920	2,080	—
Total ...	37,650	6,790	3,450	250 (including 20 open water)

The directions of grazing movements from each camp at the time of the survey—April 1951, towards the end of the dry season—have been indicated on the map by arrows. These show the concentration of cattle around the north-eastern basin, where flooding is governed by backwater and where the range of flooding and the areas successively exposed as the discharge decreases from 90 m/d to 50 m/d are greatest. Earlier in the dry season the grazing west of the River Aliab is used, but by April the lower areas, which are indicated by the presence of *Vossia cuspidata* and *Echinochloa stagnina* and which dry out last, are being grazed. The southern basins where flooding is produced by spill support relatively smaller populations, possibly because flooding is more constant and all parts of the area tend to dry out simultaneously.

To complete the picture some mention should be made of the game found in the area, although to the Dinka of this area it is of little economic importance except that it competes for pasture. Between December and April large herds of game migrate from the west and graze the western fringe of the flood-plain. Very many buffalo, estimated at about 3,000, and over 1,000 tiang are found between Tombe and Fadunyiel, concentrated between Lake Dijir and Minkaman where the River Aliab is set back to the east and leaves a wide belt accessible. Also to be seen in smaller numbers are elephant, giraffe, lion, waterbuck, reedbuck, bushbuck, Mrs. Gray's lechwe, and warthog.

FISHERIES

An account of the fish resources of the Jonglei Area and their importance as an item of diet is given elsewhere (Vol. I, p. 387 and p. 245). The statistics collected in the Aliab Valley give a measure of these resources in a small area.

During the period of the survey—13th March to 24th April 1951—the fish were concentrated in the Bahr el Jebel and a few khors. Two Shilluk fishermen, using small fine-mesh casting-nets, fished the Tombe channel, some spill-channels and, with the help of a Dinka guide, all the inland lagoons and drainage-channels in the area. The position of each fishing site is shown on the map by a letter. The species, weight, and size of each fish caught were recorded, and also the time spent fishing in each place.

These results have been tabulated in two ways, according to species and according to fishing sites (see Tables 383 and 384, pp. 836-7). The first table gives the totals caught in two years' fishing, the first (1950–51) in the Aliab Valley, and the second (1951–52) between Juba and Bor, only a small proportion being in the Aliab. This table also gives an indication of the relative frequency of each species over the area—*Tilapia*, *Heterotis*, and *Clarias* being by far the most common. It also shows the weight of fish generally caught in casting-nets and the large yield which can be obtained by this method. The total catch for 33 days' fishing by two men in 1950–51 was 662 kg., or 10 kg. of fish per man per day.

The second table shows for each fishing site, arranged approximately from south to north from Juba to Bor, total catches and the percentage of each species in the catch. Positions G to X are in the Aliab Valley. As the fishermen often fished a long way from camp, the total catch tended to be what they could carry back, so kg. per man-hour of fishing is the only objective basis for comparison. In spite of weather changes yields were very consistent at a given place on different days. Even so, it is not an absolute measure of distribution, as some areas are more suitable than others for the casting-net and bottom fish such as *Clarias* are less likely to be caught by this method.

However, the table, with the map, shows that catches were largest in the Bahr el Jebel, and especially at Khor Lalop head. Away from the river, they were very large in a pool near Yalakot in the nearly dry bed of the River Aliab, and fairly constant elsewhere over the whole valley, even in the isolated Khor Gwir system. The proportion of *Tilapia* caught was everywhere large; that of *Clarias* greatest near the Bahr el Jebel, and that of *Heterotis* largest away from the river. *Polypterus* were caught, in small quantities, only in inland khors.

At present, exploitation of these resources is limited in extent and methods. Monythany Dinka (see Vol. I, p. 384), who rely almost entirely on fishing, have permanent villages down the west side of the Aliab Valley at Akot, Ahou, Minkaman, Panabang, and Yalakot. All these villages are close to open water, in Lake Barnyieu, Khor Tetang, Lake Dijir, and Khor Ker at Yalakot, which they fish from canoes using harpoon and line. Monythany from the east bank also fish Lakes Majir and Guol. The majority of the population, however, rely on random spearing and occasional mass spearing in nearly dry khors or behind traps; when the river rises *Clarias* especially are caught on their way to the *toich*.

The amount caught by two men shows that although suitable khors are probably too scattered and inaccessible for commercial exploitation on any scale, improvement of present fishing methods would greatly increase local catches of fish, though there might be some danger of overfishing.

TABLE 383

TOTAL FISH CATCHES TABULATED BY SPECIES

Species	(1950–1951)			(1951–1952)		
	Number	Weight (kg.)	Average (kg.)	Number	Weight (kg.)	Average (kg.)
Tilapia sp.	443	423·1	0·960	413	430·6	1·040
Heterotis niloticus...	84	136·7	1·630	33	96·5	2·920
Clarias sp.	53	73·4	1·390	3	4·1	1·370
Citharinus sp.	25	6·2	0·250	39	48·8	1·250
Polypterus sp.	55	15·0	0·270	7	4·1	0·590
Hydrocyon lineatus	5	0·8	0·160	31	13·2	0·430
Sinodontis spp.	5	0·9	0·180	37	12·5	0·340
Labeo sp.	—	—	—	16	12·3	0·770
Alestes spp.	10	1·2	0·120	44	8·4	0·190
Lates niloticus	—	—	—	6	8·4	1·400
Auchenglanis sp.	1	0·1	0·100	12	6·0	0·500
Distichodus sp.	9	1·5	0·170	8	2·0	0·250
Gymnarchus niloticus	2	1·0	0·500	—	—	—
Mormyrus spp.	7	0·9	0·130	—	—	—
Eutropius niloticus or *Schilbe* sp.	4	0·5	0·120	1	0·1	0·100
Bagrus bayad	1	0·2	0·200	1	0·5	0·500
Clarotes laticeps	1	0·1	0·100	1	0·2	0·200
Anabas sp.	1	0·1	0·100	—	—	—
TOTAL	706	661·7	—	652	647·7	—

1950–1951	1951–1952
33 days' fishing by two fishermen (117 hours' fishing by two fishermen)	44 days' fishing by two fishermen (157·5 hours' fishing by two fishermen)
Average catch/day = 10·0 kg. Average catch/hour = 2·8 kg.	Average catch/day = 7·4 kg. Average catch/hour = 2·1 kg.

TABLE 384

FISH CATCHES TABULATED BY FISHING SITES

Fishing Site		Number of Days	Period	Percentage of Catch according to Species						Total Weight kg.	Hours (2 men)	Rate kg/hr.
Letter	Description			*Tilapia*	*Heterotis*	*Clarias*	*Citharinus*	*Polypterus*	Others			
A	Juba Channels	3	1/52	—	—	—	—	—	—	—	5·0	—
B	Khor Nyaraya	6	1/52	—	—	15	52	—	33	17·4	14·0	0·620
C	Mongalla Lake	8	12/51 & 4/52	51	15	3	9	7	15	53·2	26·0	1·020
D	Lake Buri	10	2/52	57	38	—	3	—	2	207·2	46·0	2·250
E	Lake Moni	9	3/52	86	—	—	2	—	12	231·2	38·0	3·040
F	Lake Pariak	2	4/52	81	4	—	11	1	3	39·0	7·5	2·600
G	Spill-channel near Mathiang	1	3/52	77	—	—	10	—	13	16·2	2·5	3·240
H	Tombe channel near B.M. A 22	3	3/52	55	—	—	25	—	20	49·0	11·0	2·230
I	Loop of Tombe channel	1	3/52	56	8	—	17	—	19	27·8	2·5	5·560
J	Mabiorager	2	4/51	80	—	14	5	—	1	49·3	5·0	4·930
K	Deep spill-channel near Mabiorager ...	1	3/52	—	100	—	—	—	—	6·2	3·5	0·890
L	Tombe channel north of Khor Lalop head	2	4/51	61	13	25	—	—	1	42·1	4·5	4·680
M	Tombe channel south of Khor Lalop head	3	3/51	72	4	22	—	—	2	52·8	11·0	2·400
N	Khor Lalop head	4	4/51	67	11	21	—	—	1	107·2	10·5	5·100
O	Khor Lalop	2	4/51	67	20	11	—	—	2	40·3	6·0	3·360
P	Lake Yango	4	4/51	93	—	7	—	—	—	57·3	17·0	1·690
Q	Khor Ker near Gukthon	2	3/51	61	30	6	—	2	1	30·4	5·0	3·040
R	Khor Ker near Yalakot	2	3/51	52	7	10	—	29	2	23·4	2·5	4·680
S	Khor Akolo	4	4/51	75	18	2	—	3	2	86·4	17·0	2·540
T	Khor Ker near Wundot	2	3/51	31	62	4	—	2	1	51·2	11·0	2·330
U	Khor Tetang	3	3/51	56	38	3	—	3	—	78·0	13·5	2·890
V	Khor Alek	1	3/51	62	31	—	—	3	4	16·9	5·5	1·540
W	Lake Barnyieu, southern end	1	3/51	—	73	19	—	3	5	17·7	3·5	2·530
X	Fadunyiel	1	3/51	24	38	—	37	—	1	8·0	3·5	1·140

TABLE 385

FISH CATCHES TABULATED BY REACHES

	Sites	Days	Weight kg.	Hours (2 men)	Rate kg./hr.
Juba-Mongalla	A-C	17	70·6	45	0·780
Mongalla-Tombe	D-E	19	438·4	84	2·610
Tombe-Bor (Bahr el Jebel and inlets)	F-N	19	389·6	58	3·360
Aliab Valley away from Bahr el Jebel	O-X	22	409·6	84·5	2·420
	—	77	1,308·2	271·5	2·410

EFFECTS OF THE EQUATORIAL NILE PROJECT

In the basin north-east of the River Aliab the hydrological effects of the Project, assuming that the Bahr el Jebel is banked to eliminate spill, are as follows:

From	To	Area (sq. km.)	Effects
0	24·9	24·9	360 days' seepage plus 180 days' rainfall
24·9	155·8	130·9	180 days' rainfall

By considering areas where conditions similar to these are found at present, and taking the present vegetation into account, the following distribution by areas of vegetation species under the Project has been estimated for each basin and the whole area surveyed as follows:

TABLE 386

ALIAB VALLEY

FUTURE DISTRIBUTION OF VEGETATION SPECIES

Area (sq. km.)	*Echinochloa stagnina*	*Echinochloa pyramidalis*	*Phragmites communis*	*Hyparrhenia* sp.	*Oryza barthii*
			North-East of River Aliab		
24·9	7·5	7·5	9·9	—	—
130·9	—	39·3	32·7	58·9	—
			West of River Aliab (Unchanged)		
66·5	11·1	47·1	0·3	—	8·0
			South of Yalakot		
27·0	2·7	13·5	6·8	4·0	—
Total 249·3	21·3	107·4	49·7	62·9	8·0
Percentages 100·0	8·5	43·2	19·9	25·2	3·2

These effects have been plotted in diagram form (see H 24). For easy comparison, present and future estimated distributions north-east of the River Aliab are shown in Table 387:

TABLE 387

ALIAB VALLEY (North-East of River Aliab)

PRESENT AND FUTURE DISTRIBUTION OF VEGETATION SPECIES

Species	Present Estimated Distribution		Future Estimated Distribution	
	sq. km.	%	sq. km.	%
Open Water	19·5	12·5	—	—
Cyperus papyrus	11·2	7·2	—	—
Vossia cuspidata	20·1	12·9	—	—
Echinochloa stagnina	29·8	19·1	7·5	4·8
Echinochloa pyramidalis	71·5	45·9	46·8	30·1
Phragmites communis	3·7	2·4	42·6	27·3
Intermediate spp. (*Hyparrhenia*) ...	—	—	58·9	37·8
Total	155·8	100·0	155·8	100·0

5. THE MONGALLA-GEMMEIZA *TOICH*

TOPOGRAPHY

After the Aliab Valley had been investigated in 1951, the survey was extended during the 1951–52 season to cover the Bahr el Jebel flood-plain between Juba and Bor, with concentration on the Mongalla–Gemmeiza *toich* as representative of conditions south of Tombe. The objectives of the Mongalla–Gemmeiza survey were the same as in the Aliab Valley survey and have already been defined. The techniques of the survey and of presenting data were the same in both areas, and have been described; the results were in many respects similar and are therefore recorded in less detail here. The main differences are stressed. The survey consists of twelve cross-sections from the high ground to the east to the right bank of the Bahr el Jebel, and a longitudinal section of the bank crest from north of Mongalla to Gemmeiza. The cross-sections, based on E.I.D. bench-marks near the road, are spaced approximately 4 km. apart; their lengths vary from 2·5 to 8 km. Three cross-sections of the forest to the east, 6, 10, and 15 km. long, were also completed. The positions of these sections are shown on a 1/50,000 air survey map, on which contours of general ground level and limits of flooding have been drawn (Fig. H 12).

The Mongalla–Gemmeiza *toich* is the area contained between the forest on the eastern side of the flood-plain and the Bahr el Jebel as it swings from that forest 5 km. north of Mongalla to the western side of the valley south of Terakeka, and back to the eastern forest south of Gemmeiza. It is therefore narrow at either end and broadest in the centre. It extends 48 km. from south to north, and has an area of 161 sq. km. The eastern limit of the flood-plain is the bank marking the boundary between afforested high ground and open *toich*. C.S. 1 to 12 (Figs. H 14–16) show that this bank rises initially 2 to 6 m. from the *toich*; it is most marked in the south, where C.S. X (Fig. A 10), 3 km. north of Mongalla, shows a fall towards the river of 25 m. in 6 km. Farther north the initial rise decreases to 2 m., but, as C.S. Y (Fig. A 11) shows, there is a second rise set back from the edge of the forest. Near Gemmeiza the bank is again 5 m. in height, and, as C.S. Z (Fig. A 12) indicates, the ground to the east of the road is flat. Thus for 20 km. north of Mongalla the road is crossed by a number of small khors, the run-off from which, during the rains, forms small lakes in several depressions. These lakes are connected by a small drainage-channel running north by the side of the forest.

The western limit of the area, the most easterly branch of the Bahr el Jebel, was followed by a longitudinal section of the alluvial bank crest, 57 km. long. The kilometrage along the bank and all main spill-channels are shown on the map. The section shows that few changes have occurred in the topography since the map was made in 1931. The large channels shown at the south of the *toich* near R.P. 149 have almost silted up at their heads, while minor changes have occurred through silting and scouring at 2, 19, 22, and 27 km., the old banks being shown by broken lines. Comparison of this section with the Tombe–Bor section shows fewer spill-channels—280 against 370—and, apart from Khor Nyarja at the northern end, few large channels. Between Mongalla and Gemmeiza, however, the Mandari do not dam spill-channels. It will be noted that most of the spill-channels are found where the section follows small branches of the Bahr el Jebel round islands, as from 5 to 17, 35 to 37, and 40 to 48 km., possibly because the bank is of more recent origin, or because cultivation elsewhere hinders the formation of channels. A number of the main spill-channels occur where a drainage-channel runs close to the river so that spill is carried north, but others are found on the upstream side of bends in the river, as at 29, 35, and 44 km., causing semi-permanent flooding in the basins formed by the curve of the river. Flooding at the northern end of the valley is governed by Khor Nyarja, the large channel connecting Lake Buri with the river. When C.S. 12 was surveyed, the water was level across the section and at the same height as at the head of Khor Nyarja.

The combined section of bank and water profiles (Figs. H 17–18) shows that, as in the Aliab Valley, the bank falls in relation to river level from south to north; the points of intersection at each discharge of water-level and effective bank level, and flooding contours, have been drawn in. The bank is relatively higher and therefore inundated at a higher discharge than between Tombe and Bor, and, because of the greater ground-slope, backwater effects do not penetrate so far south. With discharges up to 70 m/d at Mongalla, flooding occurs mainly through Khor Nyarja; at 80 m/d the bank is inundated north of B.M. 100. This is confirmed by field observations; C.S. 9, C.S. 10, and C.S. 12 were surveyed at about this discharge and spill-water was pouring over the bank at the time. At higher discharges, bank inundation and backwater flooding spread farther south, as shown on the map, until the whole area is flooded at a discharge of 120 m/d.

The *toich* itself is, as shown by the cross-sections, extremely broken and irregular. It is divided into a number of longitudinal basins by the alluvial ridges of watercourses, now silted up, which run parallel to the river. These ridges are almost as high as the bank of the Bahr el Jebel, except in the north where they tend to disappear as the flat bed of Lake Buri is reached. Thus at the southern end of the valley spill from the Bahr el Jebel through channels and seepage is limited to a fairly narrow belt beside the river, while run-off is confined to a small area near the forest. This is illustrated by C.S. 2, surveyed after the river had just risen. The water-level near the river was rising while the small drainage-channel near the forest was drying up, and the greater part of the section was dry, unaffected by spill or run-off. This is also illustrated by the vegetation, as will be shown later.

However, as these longitudinal channels do not form any separate basins like the Khor Gwir basin in the Aliab Valley, it has been assumed that once the bank crest is completely inundated backwater flooding will spread laterally as far as the forest, and the whole *toich* has been treated as a unit in the next section in assessing areas flooded.

HYDROLOGY

The Mongalla-Gemmeiza *toich* is 48 km. long and varies from 2·5 to 8·0 km. in width. Its total area is 161 sq. km. The valley is bounded by high ground on the east, from 2 to 6 m. above the average *toich* level in the first marked rise from it. On the west the area is bounded by channels of the Bahr el Jebel whose right bank is alluvial and whose level is on the average 1·67 m. above the average *toich* level. The *toich* is also divided into a number of longitudinal sections by the alluvial ridges of a number of modern and old watercourses which traverse it from south to north. Over most of the area these subsidiary ridges are roughly as high as the main river bank, but in the north they tend to disappear.

The following are the significant slopes from south to north:

Average water slope at Mongalla discharge 75 m/d	17·8 cm/km.
Average bank slope	19 cm/km.
Average *toich* slope	26 cm/km.

The following sections refer to the five different ways in which the flood-plains in the Southern Zone receive water. Details are given in Tables 388 to 390 (pp. 841-2), to which the reader should refer.

(1) Spill over the bank crest begins at Mongalla discharges of from 120 m/d at the southern end to 90 m/d at the northern end. Spill into the valley begins in the largest khors and spill-channels (over 1·0 m. deep), of which there are 14, at discharges varying from 70 m/d to 50 m/d, according to location. There are in addition 214 spill-channels less than 0·5 m. deep, and 52 between 0·5 m. and 1·0 m. in depth. There are also points on the banks 0·15 m. on the average lower than the levels given. Thus when water-level reaches the bank level given here it can be safely assumed that water is spilling over the crest of the bank in appreciable quantities. Owing to the ridges which divide the *toich* into strips longitudinally, even when the river spills over the crest of the bank water cannot spread very far eastwards, perhaps from 1 to 1·5 km., since the ridges form banks effectively barring the way. Only a narrow strip bordering the river is affected directly by river spill. Water pouring into the valley in deep khors is retained in them until the khors disappear in the lake at the northern end.

(2) Except for these watercourses, flooding from the river in the valley is almost entirely due to backwater from the northern end, when the bank is topped, and through the large channel just south of Gemmeiza.

(3) Another important source of flooding which affects the eastern edge of the valley is run-off from the valley side, and that brought in by some small watercourses of local origin.

(4) Since there is a larger percentage of coarse sand in the soil here than in that of the Aliab Valley, the effect of underground seepage both from the river and from the watercourses running through the valley must be borne in mind. The width of the alluvial bank east of the river varies from 200 to 500 m.

(5) The average annual rainfall at Mongalla is 929 mm.

On the basis of the above points, we have calculated areas of the valley inundated by the river at different discharges at Mongalla. Up to a discharge of 70 m/d only a small part of the flood-plain is inundated. At discharges from 70 m/d to 110 m/d the valley becomes submerged at a fairly steady rate, and at 120 m/d becomes almost fully inundated.

The relationship between pasture and flooding in the Mongalla–Gemmeiza *toich* is one of the most important features. On the hydrological side we have calculated the areas inundated related to Mongalla discharges and the duration of flooding which occurred in the 5-year period ending in 1950. As already stated, the Team has decided that the reasonable empirical rule to be applied for the duration of flooding of pasture examined should be the duration in the five previous years, i.e. from 1946–50, weighted in favour of the final year by including that year's flooding twice (see Vol. 1, p. 156). We have calculated the areas inundated on the assumption that flooding starts at the northern end and moves southwards.

When considering vegetation, due allowance must be made for run-off in small local khors, spill in channels, the underground water-tables which are mentioned in the above description, and the average annual rainfall of 929 mm. at Mongalla.

TABLE 388

MONGALLA-GEMMEIZA *TOICH*

HYDROLOGICAL DETAILS

Cross-Section Number	Water-Levels Corresponding to Mongalla Discharges millions of cubic metres per day							
	50	60	70	80	90	100	110	120
1	437·77	438·03	438·39(2)	438·68(3)	438·95	439·20	439·49	439·68(1)
2	6·84	7·18	7·49(3)	7·79	8·03	8·28	8·50	8·69(1)
3	5·89	6·24(3)	6·53	6·82(2)	7·08	7·32	7·53(1)	7·71
4	5·00	5·35(2)(3)	5·65	5·94	6·19	6·43	6·63	6·80(1)
5	4·17(3)	4·53	4·82	5·10	5·35	5·59	5·78(1)	5·93
6	3·59	3·95	4·24(2)	4·52	4·76	4·99	5·18(1)	5·32
7	2·40(2)	2·77	3·05	3·33	3·58	3·79(1)	3·97	4·10
8	1·73	2·09(2)	2·38	2·66	2·89	3·09(1)	3·27	3·39
9	0·97(3)	1·33	1·60	1·88	2·11	2·30(1)	2·46	2·58
10	0·25(2)	0·60	0·88	1·15	1·38(1)	1·56	1·70	1·80
11	429·50	429·85(2)	0·12	0·39	0·62(1)	0·78	0·90	1·00
12	8·85(2)	9·19	429·45	429·70	429·94(1)	430·10	430·20	430·30

(1) Bahr el Jebel right bank crest level.
(2) Invert level of large spill-channels.
(3) Average *toich* level.

Water slopes at Mongalla Mean Discharge of 75 m/d:

Mongalla to km. 13	...	19·7	cm/km.
km. 13 to km. 34	...	18·4	,,
km. 34 to km. 57·4	...	15·7	,,
Average Mongalla to km. 57·4		17·8	,,

TABLE 389

MONGALLA-GEMMEIZA *TOICH*

TOPOGRAPHICAL DETAILS—BANK

Cross-Section Number	Cross-Section Bank km.	Distance on Bank km.	R.L. of Bank	Bank Fall m.	Bank Slope cm/km.	Invert Level Deep Khors	Average *Toich* Level R.L.
1	1·7	—	439·70	—	—	438·30	438·50
2	6·1	4·4	8·62	1·08	24·5	—	7·50
3	10·6	4·5	7·52	1·10	24·4	7·10 6·70	6·00
4	15·3	4·7	6·70	0·82	17·5	5·30 5·80	5·25
5	20·0	4·7	5·68	1·02	21·7	—	4·00
6	23·3	3·3	5·06	0·62	18·8	4·00	3·00
7	30·0	6·7	3·65	1·41	21·0	2·35	2·00
8	33·8	3·8	3·00	0·65	17·1	1·90	1·00
9	38·8	5·0	2·15	0·85	17·0	1·50 430·35	430·50
10	43·5	4·7	1·28	0·87	18·5	429·85	429·50
11	48·4	4·9	430·50	0·78	15·9	9·75	8·80
12	52·7	4·3	429·90	0·60	14·0	8·60 425·75	427·50
Totals and Averages	—	51·0	—	9·80	19·2	—	—

TABLE 390

MONGALLA-GEMMEIZA *TOICH*
TOPOGRAPHICAL DETAILS—*TOICH*

Cross-Section		*Toich* Levels		Average *Toich* Fall m.	Average *Toich* Slope cm/km.	Height of Bank above Average *Toich*
Number	Straight Line Distance km.	Average R.L. m.	Lowest R.L. m.			
1	—	438·50	436·85	—	—	1·20
2	3·8	7·50	6·00	1·0	26·3	1·12
3	4·1	6·00	4·90	1·5	36·6	1·52
4	3·9	5·25	3·80	0·75	19·2	1·45
5	4·1	4·00	2·20	1·25	30·5	1·68
6	3·2	3·00	1·00	1·0	31·2	2·06
7	3·8	2·00	430·60	1·0	26·3	1·65
8	3·6	1·00	429·60	1·0	27·8	2·00
9	4·3	430·50	8·75	0·5	11·6	1·65
10	4·1	429·50	7·80	1·0	24·4	1·78
11	3·7	8·80	7·80	0·7	18·9	1·70
12	3·8	427·50	427·25	1·3	34·2	2·40
Total and Averages	42·4	11·00	—	—	25·9	1·68
1–8	26·5	7·50	—	—	28·3	—
8–12	15·9	3·50	—	—	22·0	—

TABLE 391

MONGALLA-GEMMEIZA *TOICH*
AREAS FLOODED RELATED TO MONGALLA
DISCHARGES AND AVERAGE DURATION

Mongalla Discharge m/d	Area Inundated sq. km.	Average Duration 1946–50 plus 1950 days
120	161·1 (Total)	7
110	157·7	20
100	127·3	37
90	67·9	71
80	38·2	108
70	17·7	173
60	11·5	227
50	8·4	293
40	5·0	347
30	2·5	360

SOILS

During 1951–52 the soil survey was extended to cover the reach from Juba to Tombe, 58 soil sample pits being dug on cross-sections A to L, as marked on the diagrams (Figs. A 2–7 and H 14–16). Of these, 19 pits were between Mongalla and Gemmeiza, as shown on the map (Fig. H 12); only 15 were actually on the *toich*, so the survey was far less detailed than in the Aliab Valley.

Without analysis, the descriptions of the samples on the *toich* do no more than indicate a greater proportion of sand than in the Aliab Valley, though the soils may still be classified as clayey; a number of holes contained stratified layers of sand and clay. In the drainage-channel carrying run-off north beside the forest, clay seems to predominate.

To the east of the Mongalla–Gemmeiza road on the afforested high ground, 31 pits were dug at 1 km. intervals along C.S. X, C.S. Y, and C.S. Z (Figs. A 10–12) and examined. 124 samples were collected from 22 pits. These samples have been sent for analysis in connection with the proposed sugar plantation scheme, and results are expected shortly but not in time for inclusion in this report.

The holes dug on C.S. X, 4 km. north of Mongalla, and the traverse notes show that ironstone soils extend from 3·150 to 1·850 km., and east of 0·970 km. on the section; sand predominates elsewhere. C.S. Y, east of B.M. 64, indicates a predominance of clay from the road to the rise 3 km. to the east, and a predominance of sand on slightly higher ground beyond.

1 and 2. Taking soil samples (Aliab Valley).

3. Deep pool with Nile Cabbage (*Pistia stratoides*).

1

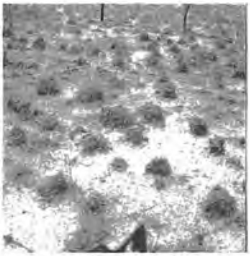
2

3

4

5

6



7

8

9

10

11

12

13

14

15

1. River flood-plain under water (near Bor). Nearly all the swamp grass is *Echinochloa stagnina*. Grass Sampling Unit No. I was sited by the near side of the large pool (December 1951).

2. Inlet on east bank of Bahr el Jebel near Bor. Flood-water in background has receded and the swamp grass has already been grazed flat (1951).

3. A close view of the edge of the flood-plain with flood season growth of *Echinochloa stagnina* recently exposed. It is already partly grazed and trampled. All this thick growth is edible (December 1951).

4. Exposed river flood-plain near Jonglei with coarse growth of *Echinochloa pyramidalis*. This is burnt and the subsequent regrowth grazed (November 1951).

5. A close view of regrowth of *Echinochloa pyramidalis* after burning. Note the very poor ground cover. A 2¼" film box indicates the height of the regrowth.

6. *Hyparrhenia rufa*. Coarse rains season growth being fired to encourage regrowth. Pengko grazing trials (December 1951).

7. *Hyparrhenia rufa*. The coarse rains season growth has been burnt, but no regrowth has yet occurred. Eastern Plain: Sampling Unit No. VI (May 1951).

8. Robust regrowth of *Hyparrhenia rufa* after burning of coarse growth. Eastern Plain: Sampling Unit No. IV (May 1951).

9. Nilotic cow grazing on deep-flooded pasture in Faddoi Pool, Central Nuer District (December 1951).

10. Dura (*Agono*) on 'Killifer' ridges: Nagdiar road near Malakal (December 1951).

11. Dura (*Agono*) on 'Killifer' ridges (left) and on the flat (right). Note the uneven spacing and indifferent growth of the latter (December 1951).

12. The effects of flooding. Dura sown on the flat. Note the tall, flourishing stand of dura (cf. No. 11) in the background.

13. The effects of drought. Feterita sown in October 1951, two months before the photo was taken. Germination, survival, and growth were very poor. Bor District (December 1951).

14. Castor sown 7.6.51 Bor District (December 1951).

15. Ploughing oxen (Nilotic), Bor District (December 1951).

C.S. Z, east of B.M. 72, shows a predominance of clay throughout. If the results of analysis confirm this, the three sections illustrate a transition from south to north in soil type as in topography.

VEGETATION

A vegetation map (Fig. H 13) of the Mongalla-Gemmeiza *toich* has been compiled from traverses along the cross-sections, notes taken during the survey of the bank section, and from air photographs. This map, like that of the Aliab Valley, illustrates the importance of hydrological conditions, mainly depth and duration of flooding, among the factors governing distribution of vegetation on the flood-plain. Comparing this map with the contour and flooding map, it will be noted that open water and *Cyperus papyrus* occur at the northern end of the valley, permanently flooded through the head of Lake Buri. A band of *Cyperus papyrus* and *Vossia cuspidata* is found between 40 and 48 km. on the bank section, where the bank is relatively low and therefore inundated at 80 m/d, and where permanent spilling occurs through channels. This spill flows north into Lake Buri on the eastern side of C.S. 11, where a combination of flooding, run-off, and spill produces a band of *Echinochloa stagnina*, mixed with *Vossia cuspidata* near the lake.

Large spill-channels at 30, 35, 37, and 40 km. on the bank section lead into areas with little drainage to the north; this spill combines with seasonal inundation of the bank to produce near the river a band of *Echinochloa stagnina*, *Vossia cuspidata*, and some *Cyperus papyrus*.

South of Terakeka, where backwater flooding occurs for a very short period, spill and seepage produce a belt, parallel to the river, of a little *Echinochloa stagnina* and *Vossia cuspidata* interspersed with *Echinochloa pyramidalis* and *Phragmites communis*. The large channel near the river, which carries this spill north, is blocked with *Echinochloa stagnina* and *Vossia cuspidata*. Near the forest, where run-off from the high ground collects in depressions, *Echinochloa stagnina* is found. South of the 80 m/d flooding line, in the centre of the valley where longitudinal banks eliminate the effects of spill or run-off, *Echinochloa pyramidalis* and *Phragmites communis* are predominant. These are also found on the bank of the Bahr el Jebel.

The areas in square kilometres over which each association is found, and the areas covered by each species, have been tabulated; these have also been given as percentages of the total area surveyed (see Table 392 below).

These distributions have been plotted on a graph (Fig. G 23) showing areas flooded at given Mongalla discharges, and for given durations in days. The grasses have been plotted in steps according to associations, those found in the north of the valley in the area of greatest flooding being plotted on the left of the graph, and the others in order from north to south. Exceptions to this are those areas where some *Echinochloa stagnina* and *Vossia cuspidata*, due to spill with little flooding, are found interspersed with *Phragmites communis* south of Terakeka. These have been plotted separately from other areas of the same species, as have the areas of *Echinochloa stagnina* caused by run-off in the south. This graph shows the optimum durations of flooding for each vegetative species tabulated below (see Table 393).

TABLE 392

MONGALLA-GEMMEIZA *TOICH*
PRESENT DISTRIBUTION OF VEGETATION SPECIES

	Area Measured from North		Area covered in association with other spp.	Area Covered	Total Area	Percentage
	from	to				
	sq. km.	sq. km.	sq. km.	sq. km.	sq. km.	
Open Water	—	2·3	2·3	2·3	2·3	1·4
Cyperus papyrus	2·3	10·9	8·6	4·8	4·8	3·0
Vossia cuspidata	3·6	13·5	9·9	3·0	3·9	2·4
Echinochloa stagnina	4·0	36·6	32·6	19·6	32·8	20·4
Echinochloa pyramidalis	20·6	155·3	134·7	84·7	84·7	52·6
Phragmites communis	56·7	155·3	98·6	32·6	32·6	20·2
Vossia cuspidata } spill and	56·7	65·4	8·7	0·9	—	—
Echinochloa stagnina } seepage	57·4	78·6	21·2	7·4	—	—
Echinochloa stagnina (run-off) ...	155·3	161·1	5·8	5·8	—	—
Total				161·1	161·1	100·0

TABLE 393

MONGALLA–GEMMEIZA *TOICH*
DURATION OF FLOODING OF VEGETATION SPECIES
(From Fig. H 23)

Species	Minimum Days	Maximum Days	Optimum Days
Open Water	360	360	360
Cyperus papyrus	256	360	320
Vossia cuspidata	216	360	256
Echinochloa stagnina	110	360	180
Echinochloa pyramidalis	10	160	98
Phragmites communis	10	82	42

LAND UTILIZATION

The Mongalla–Gemmeiza *toich* is used by Mandari from both east and west of the Bahr el Jebel. On the east bank the Mandari extend from north of Mongalla to about 20 km. north of Gemmeiza, and their permanent villages are grouped along the ridge near the Mongalla–Gemmeiza road. Where the Bahr el Jebel adjoins the forest south of Terakeka, the *toich* on the east of the river is used by Mandari from the west bank. On the east bank, crop husbandry plays a more important part in the economy than among the Dinka farther north, and it is possible to use the *toich* for this purpose as it is less frequently inundated than that in the Aliab Valley. Besides the millet and groundnuts grown in clearings in the forest, maize and some tobacco are grown on the banks of the Bahr el Jebel wherever these are easily accessible.

Cultivations are to be seen in a narrow strip extending up to 50 m. from the river between the following points on the bank section—from 0 to 3·2 km., easily reached from the east bank, from 14 to 26 km., accessible from the west bank, and from 53·6 to 56·2 km., near Gemmeiza. The total area on this one bank is estimated at 100 feddans. In April 1952 cultivations were prepared for planting in the south, and crops were well established near Gemmeiza.

The positions of villages and cattle-camps have been marked on the vegetation map (Fig. H 13), together with figures of cattle population. Permanent villages and their associated cattle-camps are joined by a broken line, while approximate grazing areas are marked by arrows. It will be seen that all cattle-camps are on the banks of the Bahr el Jebel. At the extreme south of the *toich* and north of Terakeka there is movement from permanent villages to cattle-camps, possibly because a number of drainage-channels separate the high ground from the grazing produced by spill near the river. For 8 km. south of Terakeka the grazing near the river is used by cattle-camps from the west bank, while on the east side the cattle are not moved away from the permanent villages, presumably because adequate grazing is accessible nearby. Cattle-camps are normally occupied from December or January to the middle of April, but, as permanent villages are near the *toich*, some use is made of the verge of the *toich* throughout the year.

The total number of cattle supported by the Mongalla–Gemmeiza *toich* (on the east bank) is given below, with estimated totals of sheep and goats:

Tribe	Cattle	Sheep and Goats	Area (sq. km.)
Mandari (E. Bank)	4,010	8,720	—
Mandari (W. Bank)...	1,220	1,710	—
Total	5,230	10,430	161

FISHERIES

A fishery survey, as carried out in the Aliab Valley, was continued during 1951–52 to the south as far as Juba. On the east bank between Mongalla and Gemmeiza only one stretch of open water suitable for the casting-net was found—Lake Buri, south of Gemmeiza—so it will be convenient to deal with the whole reach from Juba to Gemmeiza.

The results of the survey have been tabulated according to species and according to fishing sites in Tables 383 and 384 (pp. 836-7). The first, giving the total 1951–52 catch by species, includes some fishing in the Tombe channel, but shows that, as in the Aliab, *Tilapia* and *Heterotis* were most frequently caught; *Clarias* were seldom found, while *Citharinus* were more common than farther north.

Fishing sites A to E are south of Gemmeiza; sites D and E are marked on the map (Fig. H 13). In spite of extensive search and enquiry, no other sites were found on the east bank. As the second table shows, an attempt was made to use a casting-net in various channels near Juba, but failed because of the high banks, the depth of water, and the strength of the current. In Khor Nyaraya, near Gondokoro, catches were small. The lake south of Mongalla and also Lakes Buri and Moni were fished more successfully; over the whole reach, in fact, catches increased from south to north.

There is at present a commercial fishing camp on Lake Buri which sells dried fish to the south. Apart from this there is no permanent open water and there are few permanent khors. On the east bank at least, fishing seems to play a relatively unimportant part in the economy; there is no specialist fishing section like the Monythany among the Dinka, and the Mandari rely solely on somewhat haphazard methods of spearing fish, especially during the rains. Near Lake Buri, however, where one area of seasonally flooded *toich* is named ' The Lake of Fish ', fishing is carried on throughout the year.

South of Mongalla the Bari fish with hooks in the Bahr el Jebel, and also fish in pools during the rains. On the west bank, however, Lake Moni is one of several large lagoons where the Fisheries Section have shown that commercial fishing has greater possibilities (Vol. I, p. 387).

EFFECTS OF THE EQUATORIAL NILE PROJECT

In order to assess the effects of the Project on the Mongalla–Gemmeiza *toich* the area has had to be divided into three main sections: the portion flooded at a Mongalla discharge of 57 m/d; that exposed at 57 m/d but flooded at 90 m/d; and that not flooded at 90 m/d.

The second and third portions have each been sub-divided into three types of area: those affected at present respectively by spill and seepage from the river, by run-off from the forest, and by neither. The hydrological effects of the Project in the area may then be tabulated as follows:

Number	From	To	Area	Effects
1	0·0	10·5	10·5 sq. km.	360 days' flooding
2	10·5	33·5	23·0 ,, ,,	192 ,, flooding plus 168 ,, seepage and rainfall
3	33·5	39·6	6·1 ,, ,,	192 ,, flooding plus 168 ,, run-off and rainfall
4	39·6	67·9	28·3 ,, ,,	192 ,, flooding plus 168 ,, rainfall
5	67·9	87·6	19·7 ,, ,,	192 ,, seepage plus 180 ,, rainfall
6	87·6	93·4	5·9 ,, ,,	180 ,, run-off and rainfall
7	93·4	161·1	67·7 ,, ,,	180 ,, rainfall

By comparison with areas where similar conditions are found at present, and with the present vegetation in the area, the effects on vegetation under the Project have been estimated and are shown in Table 394.

These effects have also been plotted in diagram form (see Fig. H 25). For comparison, the present and future estimated distribution of species are given in Table 395.

TABLE 394
MONGALLA–GEMMEIZA *TOICH*
FUTURE DISTRIBUTION OF VEGETATION SPECIES

Number	Area sq. km.	Open Water	*Cyperus papyrus*	*Vossia cuspidata*	*Echinochloa stagnina*	*Echinochloa pyramidalis*	*Phragmites communis*	*Hyparrhenia* sp.	
1	10·5	7·3	3·2	—	—	—	—	—	flooded in dry season
2	23·0	—	11·5	6·9	4·6	—	—	—	
3	6·1	—	—	2·4	3·7	—	—	—	
4	28·3	—	—	8·5	14·2	5·6	—	—	
5	19·7	—	—	—	4·9	8·9	5·9	—	
6	5·8	—	—	—	5·8	—	—	—	
7	67·7	—	—	—	—	20·3	33·9	13·5	
Total ...	161·1	7·3	14·7	17·8	33·2	34·8	39·8	13·5	
Percentages	100·0	4·5	9·1	11·0	20·6	21·6	24·8	8·4	

TABLE 395

MONGALLA–GEMMEIZA *TOICH*

PRESENT AND FUTURE DISTRIBUTION OF VEGETATION SPECIES

Species	Present Estimated Distribution		Future Estimated Distribution	
	sq. km.	%	sq. km.	%
Open Water	2·3	1·4	7·3	4·5
Cyperus papyrus	4·8	3·0	14·7	9·1
Vossia cuspidata	3·9	2·4	17·8	11·0
Echinochloa stagnina	32·8	20·4	33·2	20·6
Echinochloa pyramidalis	84·7	52·6	34·8	21·6
Phragmites communis	32·6	20·2	39·8	24·8
Intermediate spp. (*Hyparrhenia*) ...	—	—	13·5	8·4
Total	161·1	100·0	161·1	100·0

6. CONCLUSIONS

The conclusions reached may best be summarized with reference to the objectives of the survey, defined earlier.

It has been shown how each unit of the flood-plain must be treated in isolation, and how a complete survey of the unit area, including the river bank, is required for the determination of flooding. The way in which flooding is mainly due to backwater has been demonstrated, and how it is caused by the fall in bank level relative to river level over the whole reach and along each section of the reach (see Fig. H 21). It has been pointed out that at the northern end of each *toich* there is a channel through which rainfall or spill from higher up drains into the river and through which flooding occurs as the river rises. This has been noted in the *Sudd* region farther north, and the hypothesis has been put forward that the Bahr el Jebel formed its bank when it flowed at a steeper gradient, and that the lagoons in this region were formed by spill-water forcing an exit at the northern end of each reach (see *The Nile Basin*, Vol. I, p. 78).

In the Juba-Bor reach analysis of the correlation between Rejaf, Juba, Mongalla, and Tombe gauges (see Vol. II, p. 534) has confirmed that the river water profile is tilting about a point between Juba and Mongalla because of the effects of silting or scouring. This explains the present inclination of water profile to bank profile and the inclination of both to the *toich* profile, brought out most clearly in Fig. H 21, and thus makes clear the way in which flooding is greatest at the northern end of the reach, and also at the northern end of each unit of flood-plain.

This process, if it has been continuous in the past, may explain the discrepancy between early descriptions of the large herds of cattle between Juba and Mongalla (see F. Werne, *The White Nile*, tr. C. W. O'Reilly, London, 1849; Vol. II, pp. 71, 95) and the present shortage of good *toich* grazing in this reach. It was claimed by a guide, who pointed out the erosion of the old post at Gondokoro, that there used to be far more flooding in this area than at present.

The relation between soil texture and surface organic horizon and the hydrological régime has been described, as has the relation between flooding and vegetation. The graphs showing areas flooded in the Aliab Valley and the Mongalla–Gemmeiza *toich* (see Figs. H 22 and H 23), when compared, illustrate the differences between the hydrological régimes in the two areas—widespread flooding occurring in the southern area at higher discharges and therefore for shorter periods than in the northern area.

The distribution of vegetation in the two areas may be compared by referring to the two vegetation maps (Figs. H 3 and H 13), Tables 381 and 392 (pp. 834, 843) showing areas of species, and the graphic representation of these tables on Figs. H 22 and H 23. Though other factors, including soil and slope, have to be considered, the dominant factor governing distribution of species has been shown to be depth and duration of flooding. Comparison of Tables 382 and 393 (pp. 834, 844) shows that the optimum duration of flooding for each species is found to be the same in the two areas. But the two areas have different hydrological régimes, and therefore, although species occur in the same order from north to south in both areas, the difference in duration of flooding produces a different proportion of vegetation species—more *Phragmites communis* and less open water, *Cyperus papyrus*, and *Vossia cuspidata* in the southern than in the northern area.

The dependence of the economy of the two areas on the hydrological régime and the resulting vegetation has been described. The adjustment of the economy to the differences between the two areas has also been brought out—the greater degree of reliance on animal husbandry in the Aliab, and on crop husbandry in the Mongalla-Gemmeiza area, and the greater importance of fishing in the Aliab Valley.

The effects of the Equatorial Nile Project in areas and duration of flooding and in vegetation changes have been described and shown in diagrammatic form. This has formed the basis for the estimate of losses in the Southern Zone.

Basic information for the design of banking of the Bahr el Jebel or canalization of the River Aliab in this reach, and also for the design of irrigation schemes in the Aliab Valley and Mongalla–Gemmeiza *toich*, has been obtained; the actual design of these schemes is described elsewhere (see Vol. II, p. 664).

To sum up, the intensive survey of all aspects of a small area has yielded basic information applicable not only in the area itself but also in similar areas elsewhere. It is therefore of exceptional significance in an investigation of the Equatorial Nile Project and its effects in the Sudan and demonstrates the value of intensive sample surveys.

CHAPTER 2. AN ANALYSIS OF THE WHITE NILE FLOOD BETWEEN MALAKAL AND RENK

by J. W. Wright, M.A., F.R.I.C.S.

INTRODUCTION

This analysis of the White Nile Flood, together with a preliminary note on the Sobat, was written in the summer of 1949, as the direct sequel to the determination of flood-plain areas along the White Nile which was described in Appendix IV of the *Third Interim Report* of the Jonglei Investigation Team. That appendix showed how the surface areas of the river at different stages could be calculated quite simply from its height above normal low level. These surface areas were then used to calculate the trough volume, the gains by rainfall, the losses by evaporation, and the losses by absorption during a number of floods on the White Nile. The results were compared with the differences between the observed discharges at Malakal and Renk, and this comparison gave figures for the amounts of water which had flowed into the river between those two points through tributary khors. Thus the shape of the river trough was used to calculate the main elements of its flood. In the preliminary note on the Sobat originally attached to this analysis an outline was given of how rather more complete observations of discharges on that river and on its tributaries might be used to derive from the elements of its flood cycle the shape of its trough. The whole of this thesis was produced in a limited ' edition ' of nine typed copies for study by members of the Jonglei Investigation Team and certain other people who took an interest in the subject.

Since the production of that ' edition ' several events have occurred which have led to modifications of the original thesis, which is now presented in a slightly different form. First of all the investigation of the Sobat flood has been carried out in much greater detail and the results have made the preliminary note no longer worth publishing. It is therefore omitted from this paper and a full account is given later in this volume (Chapter 3).

Secondly the calculations of the White Nile analysis have been checked by irrigation engineers of the Jonglei Investigation Team, with resulting minor corrections to the values given in the first ' edition '. None of these alterations is significant but they have been incorporated. Thirdly an error was found in the drawing of one of the cross-sections supplied by the Egyptian Irrigation Department on which the tables of surface areas, and thus practically all the other calculations, were based. The effects of this error are in most cases less than the probable errors of the tables themselves, and to take full account of it would necessitate completely re-computing them. This has therefore not been done, but a note is included in the present edition indicating the effects of this correction on the tables of both Appendix IV of the *Third Interim Report* and of this analysis. Fourthly I have had the opportunity of discussing this paper with Dr. H. E. Hurst of the Directorate of Nile Control, and sometime Director of the Egyptian Physical Department which was responsible for most of the data on which it is based. His main criticism was that I had not made sufficient allowance for the possibility of systematic errors in the observed discharges, and I have therefore added a note on this at the end of Section II which deals with the observed discharges in detail. Finally, the last section—on future conditions—has been omitted as the subject has been dealt with in Volume II, Chapter 11.

This brief note replaces the original summary of the analysis which formed the first paragraph of the introduction. Some other parts of this now seem redundant and have been omitted, but apart from this the original text of the paper has been retained with only minor alterations.

PRESENT CONDITIONS ON THE WHITE NILE

At the time this analysis was made there was available no detailed description of the White Nile between Malakal and Renk. In Volume I of *The Nile Basin* there is a brief account, comprising three and a half pages of text and illustrated by fourteen photographs. In spite of its brevity this included an outline of the main features of the river valley, drew attention to the unexpectedly small losses observed between Malakal and Khartoum, and suggested that there might be a considerable contribution from the many khors which join the river between these two places, particularly in the southern part of the reach. As will appear, this estimate, which I am able to confirm, was lost sight of by later investigators. Volume V of the same work described the Lake Plateau and the Bahr el Jebel, and included a chapter on the White Nile between Lake No and Sobat mouth; it ended with the hope that one more volume would complete the detailed account of the whole Nile Basin and its hydrology, and this was produced in 1950 as Volume VIII. Various proposals are made in Volume VII (' The Future Conservation of the Nile '); if these are carried out there will be profound changes in the régime of the White Nile north of Malakal. It therefore seems worth some trouble to analyse in more detail than has been done hitherto the hydrology of this reach, for only thus can the effects of the proposed changes be forecast with confidence.

At present the flow in this part of the Nile comes essentially from two sources, one almost constant, the other with a considerable annual fluctuation. These two sources are the main channel below the mouth of the Zeraf, and the River Sobat (see Map 1). The first has a discharge which remains practically constant throughout the year, the mean value being about 39 million cubic metres a day. (This unit of discharge will be referred to hereafter simply as ' millions a day ' or ' m/d '. It may be helpful in following the arguments below to think of a million as a square kilometre covered to a depth of one metre. The corresponding British unit is an acre-foot, which is self-explanatory; there are approximately 830 acre-feet in a million cubic metres.) The mean Sobat discharge, on the other hand, varies from about 7 millions a day in the dry season to 67 at the height of the flood. Thus at Malakal on the average the discharge of the White Nile, being the sum of these two, varies from 46 to 106 millions a day, the minimum being in March or April and the maximum in October or November.

EFFECTS OF PROJECTED CONTROL WORKS.

As is well known the Egyptian proposals include dams at Lakes Albert and Victoria and a canal through the *Sudd* from Jonglei, in latitude 6° 50′, to a point on the White Nile just upstream of the mouth of the Sobat. By this means it will be possible to vary the flow at this point considerably so as to counterbalance the varying discharge of the Sobat and cause a much more constant flow downstream of the junction in any one year. The discharge of a river is closely connected with the level which it occupies in its bed, and the effect of running the White Nile at a constant discharge would be to keep it at a correspondingly constant level. Under present conditions there is a variation in its level at Malakal which averages just over two metres each year. The river is low from February to April, rises slowly for six months till October or November when it holds its maximum level for about a month, and then falls fairly rapidly so that by February it has again almost returned to its lowest level.

Because its valley is very flat this small change in level is enough to flood and dry out a considerable area of land alongside the main channel, in what is here called the flood-plain. On this land, which is uncovered as the river falls in the driest part of the year, the pastoral tribes who live in this region depend for the only grazing which is then available to them. As explained elsewhere in this report, there may be grazing inland at this time but it cannot be used for lack of drinking-water or because it is unpalatable. In considering the Egyptian proposals for Nile control the Sudan Government has been greatly concerned at the possibility of losing this valuable natural grazing. To investigate the problem has therefore always been considered one of the most important tasks of the Jonglei Investigation Team. The first stage in this investigation was clearly to estimate the area of land flooded in a normal year under present conditions so that some idea could be obtained of how much was going to be lost. This could not be done by measurements from existing maps in the stretch south of Jebelein, because the best available maps were only on 1/250,000 scale and did not show contours near the river. In the *First Interim Report* of the Jonglei Investigation Team, published in 1946, an extremely ingenious attempt was made to estimate the area of the flooded land between Malakal and Renk by a consideration of the discharges which are measured at these two points. I shall describe this analysis in some detail because the present paper is based to a large extent on it. I have gone into more detail and used certain data about the river valley which were not fully appreciated at that time, and as a result I have been able to turn the analysis the other way round and work from the shape of the valley to the water account instead of using this to estimate some of the characteristics of the flood-plain. Nevertheless I owe to this analysis most of the fundamental idea of relating observed discharges to theoretical ones and so being able to analyse the water account.

ESTIMATES OF THE FLOOD-PLAIN AREA

The outlines of the analysis in the *First Interim Report* are briefly as follows. Study of the observed discharges at Malakal and Renk shows that when the river is rising those at Malakal are the greater, and when it is falling they are the smaller. This was thought to be due to water ' spilling ' over the banks of the main channel on to the flood-plain alongside when the river rises, and being returned when it falls. At the end of the flood there is a deficit because some of the water which has been 'spilt' has been lost by evaporation from its surface, and some was also lost when the water first covered the ground and was absorbed into it. If the total depth of water per unit area lost by these two agencies is estimated, the total area flooded can also be calculated; it is only necessary to divide the total deficit by the total average depth of water lost. By this method an estimate of 500 sq. km. was obtained for the maximum area flooded in an average year between Malakal and Renk, corresponding to a rise on the Malakal gauge of 2·26 m., which was the average for the years 1912–42. As will appear below, this estimate was to prove very close to that obtained by an entirely different method, in spite of the fact, as will also appear below in due course, that most of the data and factors on which the estimate were based were incorrect. It was realized at the time that since the total depths estimated for evaporation and absorption were necessarily very rough, the estimated area must be regarded as only an approximate figure, so that it could not be regarded as a final solution to the problem. It was suggested therefore at this time, and proposed again more strongly early in 1948, that several series of air photographs should be taken at different stages of the flood in order to obtain a more reliable result, and one which could be expressed in terms of different levels of the river and so be used for a detailed estimate of future losses due to alterations in these levels.

This proposal was fully discussed by me in Appendix IV of the *Third Interim Report*, which was published early in 1948. A modified version of this was also published in the *Geographical Journal* (Vol. CXIV, pp. 173–90). I showed that the proposed air survey might well prove disappointing, chiefly because of the masking effect of the long grass on the flood-plain; and I was also able to show that it was not really necessary. This was because the series of existing cross-sections which had been surveyed by the Egyptian Irrigation Department between Malakal and Jebelein could be used to give for any level of the river an average value of the flood-plain width on which considerable reliance could be placed. From internal evidence it appeared that the probable errors of these mean widths were in most cases below 15 per cent. of their value; and this was confirmed independently from air photographs taken at the height of the 1944 flood, whose levels were of course known. These photographs covered a stretch of river nearly 60 km. long south of Renk, and also nearly the whole of the reach between Malakal and Melut; and the differences in both these stretches between the 'observed' and predicted flood-plain areas were within the probable errors of the latter. In order to make these estimates I made use of a concept, which may be original, in the shape of an *idealized bank profile*. This and the development of an *idealized trough* from it are described in the next section. By this means the maximum area flooded in an average year between Malakal and Renk was estimated to be 470 sq. km.—only 6 per cent. less than that estimated in the analysis already described.

The immediate and practical part of the problem was in this way apparently solved, and it was clear that the effect of any proposed changes in the river régime could be turned into estimates of the flooded areas which would be lost, with a fairly small margin of error. The close agreement with the previous estimate, which was obtained by such very different methods, was very gratifying, especially in view of the scanty data by which it in particular had been obtained. Nevertheless this agreement in results was in fact largely fortuitous, because the earlier analysis was based on faulty grounds and did not present a true picture of the mechanism of the White Nile flood. To what extent the correct understanding of this is of practical importance at this juncture must be a matter of opinion; but since I believe that a true picture can now be presented it has seemed worth doing so, although it entails analysing the available records in considerable detail. Before I proceed to that part of the paper I feel it is worth outlining the theoretical grounds on which the analysis is based, and this is therefore done in the next section. I have been unable so far to trace any record of a similar approach to the subject by any previous student of it, and it seems therefore that my ideas may to a certain extent be original. Moreover they certainly differ considerably from the current conceptions of the hydrology of the White Nile and the Sobat held by the irrigation engineers of Egypt and the Sudan. There is therefore some excuse for describing them in detail, even though it means repeating some of the ideas expressed in the *Third Interim Report* in a slightly different form.

SECTION I. THE THEORY OF THE IDEALIZED TROUGH

IDEALIZATION OF A SINGLE CROSS-SECTION

As was clearly shown in Volume I of *The Nile Basin* by description and by the use of aerial photographs, the Sobat and the White Nile valleys have similar though rather unusual formations. On the White Nile this formation is confirmed by the measured cross-sections already mentioned, but unfortunately the Sobat valley above Abwong has never been surveyed on the ground and there are therefore no complete cross-sections of it. The typical cross-section of the White Nile valley is of the form shown in Fig. K 14 (i), the vertical scale being exaggerated some 200 times. (For some actual cross-sections reference may be made to Diagram 5 of Appendix IV of the *Third Interim Report* and to Fig. 2 of the paper in the *Geographical Journal.*) It will be seen to consist of a main channel with a number of subsidiary shallower channels or lagoons running parallel to it; these only communicate with it by cross-channels at infrequent intervals. The total width of the water surface at any level h above the low water-level is given by the sum of the widths of the separate channels, i.e., aa′ + bb′ + cc′ + dd′. The idea which I developed in the *Third Interim Report* for estimating the average widths of the flood-plain was that of a mean idealized bank profile. This time I want to make use of a mean idealized cross-section and so of an idealized trough. If the distances aa′, bb′, etc. are measured on the true cross-section for various values of h from zero up to the highest level, we can construct an idealized version of the cross-section in which the width at the corresponding height h above low level is always equal to the sum of these separate widths. This is one property of the idealized cross-section, the other being that both banks have the same profile so that the cross-section is symmetrical. This idealized version is shown on the right of the diagram, and it will be clear that

$$zz' = aa' + bb' + cc' + dd', \text{ for any value of h.}$$

APPLICATION TO SEVERAL CROSS-SECTIONS AND DERIVATION OF A MEAN

When this idealization is applied to a number of cross-sections on the White Nile it is found that their idealized versions have a remarkably close resemblance to each other, in spite of the dissimilarity of the cross-sections themselves. This is only apparent if the widths are compared at the same height above normal low level. This will of course be at a different height above sea level at each cross-section, owing to the longitudinal slope of the river bed. This is the first step in which I differ from current ideas, for the widths of the White Nile between Melut and Jebel Aulia have been worked out by the Egyptian Irrigation Department from their cross-sections, but it was all done in terms of reduced levels, or in other words in terms of heights above sea level. The differences between our methods are discussed more fully in Section III (p. 862), but this important difference may be noted here.

When a number of idealized cross-sections have been obtained in this way it is then possible to construct a mean idealized cross-section, by simply taking an arithmetical mean of the widths of the river valley in the different idealized cross-sections at the same height above low water level, and doing this for all the different heights from zero up to the highest flood level. This mean idealized cross-section has two properties of immediate practical value, and a third property which will be used in considering the Sobat. The first property is that it is simple and symmetrical and therefore its width at any height above low river level (or below it) can be expressed in terms of that height. The second property is rather unexpected: it is that the mean cross-section obtained in this way from several cross-sections distributed over a long stretch of river gives a more accurate value for the mean width at any level in a comparatively short stretch than one obtained from only one or two cross-sections. This is true even when these lie actually in the short stretch, so long as this is not less than 20 km. long. This second property of the long-term mean is due to the fact that there is a definite short-term variation of the total width of the cross-section of the valley at any given level above low river in terms of distance along the river. This short-term variation is almost periodic in character with a period of between 10 and 20 km. and an amplitude which is sometimes nearly as big as the average width. Over only a few kilometres the actual total width at any height may vary from about half to over twice the average value. This variation is brought out in Fig. J 1, which was compiled from measurements made during the writing of the Supplement to Appendix IV of the *Third Interim Report*. It shows the flood-plain width between Sobat mouth and Melut as taken off the new 1/100,000 map, which was compiled from photographs taken at the height of the 1944–45 flood, when the maximum extent of the flood could easily be seen by a change in the tone of the ground covered by it.

It will be clear from this diagram that the chances of one or two cross-sections in a short stretch being located at points where the actual width is close to the average are small. On the other hand, in spite of this local variation, it will also be seen that the long-term variation is small, and the mean of the whole reach from Sobat mouth to Melut gives a representative idea of the means of any shorter stretches, so long as these are not less than 20 km. long, and if allowance is made for the gradually decreasing rise of the flood downstream of Malakal. The practical consequences of these two characteristics of the mean—its short-term variation and its long-term uniformity—are that in estimating the average width at any level for a short stretch, it is better to use a mean derived from all the cross-sections in the reach rather than the one or two which happen to fall in or at the ends of the short stretch. The proofs of this were given in Appendix IV of the *Third Interim Report* and in the paper in the *Geographical Journal* already cited, where the means for several short stretches were derived both from one or two cross-sections in them and also from the long-term mean, and compared with mean widths (or with areas, which is the same thing) obtained either from large-scale contoured maps or from the water surface at a known level plotted from an air photograph. On the average the long-term mean gave a value twice as close to the true mean as the mean obtained from only two cross-sections.

It will be clear that this long-term mean must have some limits, and in fact it was found that the mean did change significantly if too long a stretch of river was considered. In fact three distinct means were found between Malakal and Jebel Aulia, with the boundaries between them approximately at Melut and Jebelein respectively. But within each of these stretches the mean idealized cross-section appeared to be comparatively uniform. By subtracting from each measured width the width of the low-level channel (or channels) at the same point, it was possible to get the shape of the idealized bank profile in terms of the height above low level. This disclosed the third property of the mean idealized cross-section, which is that its bank profiles, which are by definition symmetrical, are very approximately parabolas. This seemed to be true for all three reaches, and it was possible to express the differences between them simply by varying the constant of the parabola. In considering the White Nile, analytical treatment of the bank profiles in this way is quite unnecessary because they, and the mean idealized cross-sections of the different reaches, are obtained by direct arithmetical meaning of the widths measured on the different individual cross-sections. But in considering the upper Sobat, on which no cross-sections have been measured, it is necessary to consider the shape of the bank profile analytically and to derive a simple formula for it; it is for this reason that I have mentioned this aspect of it here.

THE IDEALIZED TROUGH

Once the concept of an idealized cross-section is understood there should be no difficulty in proceeding to the next step, which is to conceive of an idealized trough, since this merely represents a stretch of river in which the idealized cross-section is constant. Here again, however, I differ from current ideas since, in their published works at least, I think it is fair to say that the effect of studying the *Sudd* extensively has bred in those who have worked on the Nile an unnecessarily complex idea of conditions on the White Nile and on the Sobat. In the *Sudd* there is no doubt that the river valley—if one can call it that—is in two distinct parts: the low-stage channel, and the flood-plain over which this ' spills ' when the river has risen beyond a certain point and has overtopped its banks. In fact in the *Sudd* this plain is observed actually to slope away from the central channel and not towards it. Because the White Nile flood-plain is also flat and wide, and to a large extent is separated from the main channel by banks which rise above the main level of the plain, something of the same idea has persisted. Although in the actual working of the Jebel Aulia Reservoir, so far as I understand it, the whole valley seems to be thought of as one, on the Sobat certainly there is still a tendency to regard the valley as being in two parts. I believe that this is wrong, and that it is possible for a great many purposes, though not, as I shall explain, for all, to treat the river valley as one unified feature, and to think of its idealized form as a single trough of the shape I have described, with sides which slope comparatively steeply near the edges of the low-water channel but flatten out rapidly as they get farther away from it.

If this concept is being used the idea of ' spill ' must be abandoned. True ' spill ' is surely non-returnable water, and the difference between the ideas outlined here and those given in previous published works may be illustrated by a simple analogy. If a plate full of soup is tilted, some of the soup will lap over on to the flatter rim of the plate. But this soup is not spilt, for as soon as the plate is levelled it will return to the deeper central part. Only if the plate is tilted so far that the soup actually pours over the outer rim will it be truly spilt, in the sense of being unable to return. It may be argued that some of the water on the flood-plain, because of absorption and evaporation losses, will not return to the main river trough when the level of the river falls, and this is of course true. But I see no reason for distinguishing between this loss from the flood-plain and the loss which is taking place all the time from the surface of the main channel. As will be seen below, in Section V (p. 869), when the river is falling during the dry months this last source of loss may be at least as large as the loss from the outer parts of the trough, i.e., from the flood-plain. Thus another respect in which I differ from previous published work on the hydrology of the White Nile is that I prefer to think of the water as being held at all times in the trough of the river, and not as being ' spilt ' from it into a separate feature—the flood-plain—alongside. It will be seen below to what extent this concept can be justified, both by the ease with which it produces results and by the accuracy of them.

CHARACTERISTICS OF THE IDEALIZED TROUGH

It will be clear that the idealized trough is only equivalent to the actual river valley in some respects; in particular it cannot be applied when conditions of flow through the valley are being considered, since the irregular nature of the actual flood-plain and the grass which grows on it will prevent any but very small discharges over it. An estimate made by means of the idealized trough of the proportions of the discharge distributed between the main channel and the flood-plain would give a very misleading idea of the real conditions. Moreover, even when conditions of flow into and out of a section of river are being considered, as they are throughout this paper, the idealized trough must be used with care. When the river is rising or falling there will obviously be some sort of a lag between the water-level in the side-channels and the level recorded on the gauges, which are in the main channel. But this lag, as I shall show, is not very great except in the early stages of the flood, and it does not seriously invalidate the conception of the whole river valley as a single entity. On the other hand the idealized trough has several advantages in the way it makes possible a detailed analysis of the flood.

Before considering these I should like to note one more thing about it. It is definitely an ideal, and like most ideals, it is seldom if ever realized in actual fact. The only case I know of where an actual bank profile approximated to the parabolic shape of the ideal was not a natural one, but an incidental result of some experiments recently carried out in the United States. This experiment, described as ' A Laboratory Study of the Meandering of Alluvial Rivers ', was carried out during the war by the Mississippi River Commission and the results are described by J. F. Friedkin in a paper with this title which the Government Geologist kindly let me see. It was conducted with a scale model consisting of a gently sloping sand-table over which a regularly varying supply of water was poured, simulating the conditions of an annual flood. This water was started in a straight uniform channel and the main purpose of the experiments was to study how different conditions of flow and slope affected the meanders which tended to form. With these results we are not concerned here, but it was noticeable that when the experimenters tried to control the meanders by banking up one side of the channel with a hard substance to prevent further erosion of it, the other side did tend to take up a profile similar to that exhibited in the mean idealized cross-sections of the White Nile. In this case of course the characteristics of the relationship between rise above low level and width of surface were achieved by only one bank, the other being virtually vertical; and not by a symmetrical cross-section which has only been used in this paper because it is easier to imagine. The bank profile created in the experiments was naturally very much steeper than that observed on the White Nile, but this is expected to occur with models. Nevertheless, though under ideal conditions in the laboratory this profile was created it does not seem to be found in nature, where conditions are less uniform and where the forces concerned have been working for a longer time. It must be realized therefore that the near parabolic mean bank profile is only an idealized concept which has the advantages of being much simpler and yet equivalent in some respects to the many and varying channels of the actual river.

The fundamental advantage of this concept as compared with the older one of a main channel flanked by a fairly flat but irregular flood-plain is that the total width of the river at any level can be estimated easily. From this the surface area of any known length of river can be calculated, and by a process of integration the volume of the trough above low level can also be calculated for any given level of the river. Since the surface area is known, it is possible to estimate the loss by evaporation and the gain by rainfall once the depths of water abstracted or added by these have been assumed or recorded. Since the surface area of the newly flooded land is also known it is possible to estimate the loss by absorption once the depth of this has been assumed. But there is more to it than this. If the discharges at the two ends of a trough are measured regularly throughout several floods, these depths of evaporation and absorption can be calculated by comparing the observed and theoretical differences between the end discharges at different stages of each flood. Finally, I believe that by applying these estimated depths to another river flowing in similar conditions it is possible to turn the whole computation inside out and use the measured discharges on such a river to work backwards to its mean idealized cross-section, and so obtain an idea of the shape of its valley without the expense of an extensive ground survey. This has been attempted in the analysis of the Sobat flood (pp. 913–70).

OUTLINE OF THE METHOD OF ANALYSIS USED

After these preliminary general remarks, the practical details of the theory may be developed. In order to work out the theoretical losses for comparison with the observed differences between the discharges at the two ends of a section of river, it is necessary first of all to assume depths for the processes of evaporation and absorption of which the latter in particular is not at present very accurately determined. By a fortunate chance, on the White Nile these two sources of loss do not have their maximum effects at the same time; in fact each one's maximum coincides with the other's minimum. When the river rises it wets the ground and this absorbs water until it is saturated. This happens during the rainy season and so evaporation is small; in fact it is for a month or two more than counterbalanced by the amount of rain falling on the surface of the river. On the other hand, by the time the river has begun to fall the ground which it covers may be assumed with some confidence to have absorbed all it can take; rainfall has ceased, and evaporation is rapidly approaching its maximum value, which it maintains almost until the river has returned to its lowest level. Once the river has reached its highest or lowest level and remained there more or less stationary for about a month, it may be assumed that the delays in filling or emptying the minor channels and lagoons alongside the main channel will have been taken up, and that the volume contained in the actual river valley will therefore approximate very closely to that held in the idealized trough. During the periods between these two stages this will not be so, and since the amount of delay and the differences between the idealized and actual trough volumes at any time must be uncertain, the calculation of depths for absorption and evaporation must be done for the whole of the rising and falling stages respectively.

While the river is rising the discharges at the upper end of a given stretch will obviously be appreciably larger than those at the lower end. Normally these discharges are given on the White Nile at Malakal and Renk in the form of ten-day means, the last period of each month being sometimes eleven days or (in February) eight days. If the mean discharge for each period is multiplied by the number of days in it, the total discharge for that period is obtained. By summing cumulatively the differences between these totals at the two ends of the reach from the time when the river begins to rise until it begins to fall, the cumulative sum of the 'losses' during this stage is obtained. I have called these 'losses' though one of the items in the account—rainfall—is actually a gain, and another—the trough volume—is only a temporary loss because it is a form of storage. But, if this convention is followed, the equation below is immediately derived for the end of the rising stage of the flood:

Cumulative Sum of Differences of Observed Discharges (upper minus lower) or CUMULATIVE OBSERVED LOSS	=	Maximum Trough Volume minus Trough Volume at Start of Rise plus Total Absorption Loss plus Total Evaporation Loss minus Rainfall Gain

When the river is falling, as already explained, rainfall and absorption have virtually ceased, and the discharges at the lower end of the reach will be greater than those at the upper end because of the water being returned to the main channel from the side lagoons; in other words from the emptying of the trough. When the river has returned to its minimum level and remained there for a month, the following equation can therefore be derived:

Cumulative Sum of Differences of Observed Discharges (lower minus upper) or CUMULATIVE OBSERVED GAIN	=	Maximum Trough Volume minus Trough Volume at End of Fall minus Total Evaporation Loss during this stage

These equations have already been applied—in sum—in the analyses of the White Nile and Sobat floods carried out in the *First Interim Report* by H. A. W. Morrice and in *Sobat Hydraulics* by A. D. Butcher. It is only when the total volume of the river trough—not merely that of the main channel as used by Butcher—is estimated that it becomes possible to separate out the two stages of rise and fall and have some chance of estimating the size of the individual terms in the separate equations. Even when they have been separated out by doing this, it is still impossible to get reliable and consistent results in all years by considering each stage as a whole, and it is of no value therefore to take a mean of several years. The reason for this is that there is yet another term in the equations for which allowance has to be made, and it is one which cannot be estimated directly at all. This term is what I have called inflow, and its effects must now be discussed.

INFLOW

Inflow may be defined as water flowing into the river from a definitely outside source, that is to say it is quite distinct from water which may have been ' spilt ' from the river originally and which I consider, as explained above, to be still held in the trough. As was pointed out in Volume I of *The Nile Basin*, there is definitely inflow into this part of the Nile in some years, although there are practically speaking no measurements of its amount. Probably because there were no reliable data about it it has tended to be forgotten in more recent work, such as the *Interim Reports* of the Jonglei Investigation Team, and to be regarded as negligible; but in fact, as I shall show, with a value in some years of over a milliard, it is far from being so. Obviously, unless it can be allowed for in some way, it will completely invalidate the equations given above. It can only be allowed for by distinguishing the years in which it occurred, or in which it was present for part of the flood. In my opinion the only way in which this can be done is by making a preliminary study of each flood separately in great detail, comparing the observed and computed or theoretical losses all the way through the flood, and not just at the ends of the rising and falling stages in the way outlined above. It is this detailed analysis which makes the present paper so bulky, especially as regards the separate floods detailed in Tables 404–18 (pp. 885-900), and it has meant a great deal of work; but I do not see how this could have been avoided or the results achieved in any other shorter way. In order to get this close and continuous comparison of the observed and computed losses throughout the length of each flood it was necessary to calculate the values of each of the five terms of the equations—cumulative observed loss, trough volume, rainfall, evaporation, and absorption—for each of the ten-day periods of each flood. These formed the natural unit of time to use because it is for each of them that the mean discharges and the gauge-readings are given. It is clear that the equations will not hold true during these stages in the way that they will at their ends, when the lags have been taken up; but nevertheless I believe that it is possible by comparing the differences between observed and computed loss in one year with those in another to detect when inflow has occurred and to estimate its amount.

COMMENTS ON THE ANALYSIS IN THE *FIRST INTERIM REPORT*

Before I realized the necessity for individual treatment of each year in this way I tried to work from means, using the cumulative discharge differences and gauge-readings given in Table 16 of the *First Interim Report*, from which the first estimate of the flooded areas was calculated in the way I have already described in the introduction. It was very difficult to get any correlation between these which made sense, and for a long time I could not discover why, and I began to think that the whole theory of an idealized trough must have some fundamental fault. Later, however, I discovered why the gauge-readings and observed discharge differences did not agree, the reason being that this table had been constructed from means which were not strictly comparable. Discharges have been measured regularly at Malakal since 1912, but measurements started at Renk only in 1928. The means used in Table 16 of the *First Interim Report* were taken from the third supplement to Volume IV of *The Nile Basin*; those at Malakal being the averages for the years 1912–42, whereas those at Renk were of course averages for the years 1928–42 only. During this period the means had changed by about 2 per cent, which is less than the average error of a single discharge, and would in most hydrological work be regarded as unimportant. But in this particular investigation the very quantities being studied—the differences between the two sets of discharges—are themselves not much larger than this, and so a systematic change even of this small size in the means completely upsets the data. As is pointed out below, although the error of a single discharge may amount to a few per cent, the systematic errors in them are very much less than this, and over several years amount to only a fraction of one per cent. Thus the results obtained by comparing these means were actually quite erroneous, and it was only a series of accidents which made the resulting estimate of the maximum flooded area turn out to be very near that obtained by more direct means in the *Third Interim Report*.

In this earlier analysis an average value of 540 millions was found for the total loss during the year (February to February); but if the average discharges for 1928–42 are compared it will be found that the true average loss per year is very much less, in fact it is about 200 millions. (See Table 419, p. 901.) This difference is more than accounted for by an average value of 700 millions for inflow; and the true average losses by evaporation and absorption, less rainfall, I estimate to be nearly a milliard, as may also be seen from this table. The assumed depths on which the earlier analysis was based are admitted to have been very approximate, and these differences in the items of the water account from the figures obtained by a later more detailed estimate were only to be expected. The curious fact is that by a series of coincidences this earlier analysis should have arrived at practically the same value for the average maximum flood-plain area as I obtained last year by direct arithmetical averaging from the cross-sections. It can be seen from the above that the average value of the inflow makes it an item of some importance, but whereas the other items can be correlated with the height of the flood, and so their average values can be estimated from the average height, this is not true of inflow. So far it seems to have very little correlation with any obvious feature of the flood, and it is for this reason that each year has to be studied separately, since the average value of the inflow is no indication of the amount to be expected in a year like 1944–45, which in other respects may be regarded as average.

THE INDIVIDUAL ITEMS OF THE WATER ACCOUNT

In the next five sections each of the five measurable items of the water account is discussed in detail, and the way in which their values are calculated is described. In Section VII (p. 875) the analyses of sixteen years are given, the last one, for 1946–47, being given in complete detail in Table 403 (pp. 877-83) and the others in summary form in Tables 404–18 (pp. 885-900). In Table 403 the steps of the calculation are all shown and fully explained. In Tables 404–18 only the essential data and the different items of the account are shown. The intermediate steps can be worked out by anyone who wishes to do so, using the data provided and the auxiliary tables of surface areas and volumes (Tables 397 and 398, pp. 865-6) and following the procedure described and illustrated in Table 403.

The five items of the water account are placed in the order of directness of their derivation, which is not necessarily the order of accuracy. Thus the observed losses come first because they are obtained directly from the observed discharges by making the necessary allowance for the number of days in each ten-day period. Next come the trough volume and the rainfall gain, which are both obtained by direct calculation from measurements. The trough volumes are obtained from the direct means of the measured cross-sections, and so are the surface areas; and the depth of rainfall is deduced directly from the average of the available records. It is true that there is an element of uncertainty in this last factor, due to the variable nature of the rainfall and the small number of stations; nevertheless the calculation is a direct one and requires no estimated factor. This is not true of evaporation, since the relation between instrumental and actual evaporation is still uncertain, and I have therefore thought it worth while to make an independent estimate of this factor. As it turns out the value which I get is very near that which has been assumed previously and I do not therefore make use of it. For absorption, on the other hand, practically no reliable previous estimates seem to have been made, and I therefore have first to make an estimate of its depth before the losses which it causes can be calculated at all. Of these five items this is therefore clearly the one which is obtained most indirectly, and for that reason it is described last and shown last before the total computed losses in the individual analyses.

In calculating trough volumes and surface areas I assume all the time that the water surface across any given cross-section is horizontal. Obviously this is not true, for when the river is rising it will be higher in the main channel than at the sides, and when it is falling the level in the main channel will be lower. Nevertheless, until observations have been made of the amount of this difference of level—as they have in the *Sudd*—there is little point in trying to guess what it is. I feel that this source of uncertainty is better omitted from all the items which can otherwise be calculated directly, and for trough volume, rainfall, and evaporation the surface areas and volumes used are these theoretical ones. The effects of this uncertain difference between the theoretical and actual shapes of the transverse water profile have therefore been included in an item which I call apparent or mean absorption. This is explained more fully in Section VI (p. 872). I should like to make it quite clear, though, that I consider that I have allowed for the difference between the longitudinal profiles in the rising and falling stages, by breaking the stretch between Malakal and Renk into two parts separated by Melut, and obtaining for each of these at all times a mean gauge-reading derived from the gauges at its ends. There seems at times to be some confusion of thought about the effects of the reservoir. It does not ever cause backward flow at this point and I cannot see that it can invalidate measured discharges at Renk. What it does do of course is to lessen the water slope and so slow down the rate of discharge; and it also invalidates the normal gauge/discharge relationship. It is because of this last effect in particular that I am unwilling to analyse years in which the mean discharges at Renk or Melut are based only on gauge/discharge curves supported by few—if any—actual discharges. But when the analyses are based on measured discharges compared with measured levels of the water surface I am sure that the backwater effect is fully catered for, even when, as in later years, it is considerable. This may be checked by studying Tables 404–18 and Table 419 carefully.

The last item of the water account is inflow, and this is entirely incalculable except as a residual after all the others have been derived. I therefore feel that it should be left until after the analyses, since it contributes nothing to their calculation and is in fact obtained from them. There are virtually no measurements of this item—since the few recorded discharges of tributaries are not complete—but there is a certain amount of supporting evidence of a descriptive kind, which I have summarized after the analyses in Section VIII (p. 902). We may now proceed to discuss the individual items in detail, beginning with the observed losses.

SECTION II. CUMULATIVE OBSERVED LOSS

PERIOD COVERED BY THE OBSERVATIONS

The cumulative observed loss in a given period is the algebraic sum of the differences between the discharges at Malakal and Renk during the period. Discharges at Malakal have been measured regularly since 1912, but at Renk they only began in 1928 and there have been two quite long gaps since then. The first was from June 1930 to November 1932, and the second from March 1933 to June 1936. Discharges were then measured regularly at Renk until August 1947, when the discharge site was moved to Melut, where it has remained ever since. Thus for the floods of 1931–32, 1933–34, 1934–35, and 1935–36 there were no discharge measurements at all at Renk; and for the floods of 1930–31, 1932–33, and 1936–37 the measurements were not complete, though in the last flood only those of the first month and a half are missing. In the Supplements of Volume IV of *The Nile Basin* mean discharges are shown for the whole period from 1928 to 1942. In the years when no discharges at all were measured the ten-day means were obtained from a general gauge/discharge curve; in the years when only some measurements were made the means were obtained from a gauge/discharge curve fitted to these measurements. Means obtained from a general curve, as in the first case, and especially over such a long gap as the second mentioned above, seem to me too unreliable for the delicate balance required in estimating the losses, and I have therefore not thought it worth while to analyse the floods between 1933 and 1936.

I have analysed the floods of 1930–31 and 1931–32, though here also only a few measurements were made, because it was a shorter gap, and also because the floods were smaller so that the errors in the estimated discharges are probably less. I have not, however, used the figures obtained from these years in estimating the evaporation and absorption depths. Movement of the discharge site to Melut in 1947 alters all the items of the analysis and this makes comparison of the last two floods with the earlier ones impossible. Moreover discharge measurements at Melut were far from regular and there were gaps of several months during this period. I have therefore not included here any analysis of the last two floods (1947–48 and 1948–49), though I have made a preliminary analysis of the last one which is quoted below. A proper analysis of these two floods might be worth doing when the mean discharges at Melut have been published by the Directorate of Nile Control.

Thus the discharges at the lower end of the reach are the limiting factor in deciding what years should be analysed, and I have confined myself to those between 1928 and 1933, and between 1936 and 1947, giving a total of sixteen years to be analysed in the reach between Malakal and Renk. In each analysis I have worked not by calendar years but by floods, each flood being taken from when the river started to rise to when it stopped falling, which means normally from the beginning of May one year to the end of the following April. This practice makes it much easier to eliminate from any consideration of the whole flood the errors in the estimated trough volume, which is nearly at a maximum at the end of the calendar year. It also eliminates from the final totals of each flood any uncertainty about the delays in filling or emptying the side-channels and basins, which make exact correpondence between ideal and actual conditions impossible, especially when the river is changing its level as fast as it often is at the end of the calendar year.

METHOD OF COMPUTATION

The total discharge for each ten-day period in the following analyses has been computed by multiplying the mean for the period by the number of days in it. The means were either taken from the Supplements to Volume IV of *The Nile Basin* or were kindly supplied by the Egyptian Irrigation Department in Khartoum, to whom my grateful thanks are due. The differences between these ten-day totals for Malakal and Renk were derived and then summed cumulatively from the end of the ten-day period chosen as the start of each flood. The results are the cumulative observed losses. The final totals at the end of each flood are given in Table 396 (p. 861). In this table are also given the initial and maximum Malakal gauge-readings for each flood, the ten-day periods in which the rise began and ended and after which the fall began; and also the averages of the rainfall totals at Malakal, Melut, and Renk. This table shows therefore the data which were available when this analysis was started, and as such represents a preliminary summary of the floods.

METHODS OF MEASUREMENT OF THE DISCHARGES

Details of the methods of measuring the discharges are given in the introduction to Volume II of *The Nile Basin*, which also includes a discussion of their accuracy. It may be noted here that the probable error of an individual measurement is now assessed at about 3 per cent.,[1] and that the systematic error is thought to be very much less. Every precaution is taken to prevent systematic error; the current meters are used only for a limited number of measurements before being replaced, the original meters being sent to Egypt for checking. At Malakal and Renk tie banks have been built to constrict the river so that all the water has to pass through the cross-section used for the discharge measurements. So far this has not been done at Melut. It might be of interest to cut a channel there at right angles to the river across the flood-plain and take measurements across it at the height of the flood, since at present there are no figures for the proportion of the total flow which passes over this part of the river bed. There is little doubt that the proportion is small but it might be of value to know what it is.

PROBABLE ERRORS OF OBSERVED LOSSES (ASSUMING NO SYSTEMATIC ERRORS)

The frequency of measurement and the probable errors of the observed losses may now be considered. At Malakal the discharges are measured fairly regularly every five days, or twice in each ten-day period. At Renk the frequency was more variable, but it was never less than this, except for the occasional month which can be ignored. On the other hand over quite long periods the discharges at Renk were measured nearly every other day, and the assumption of the same frequency as at Malakal will not therefore give an over-optimistic idea of the accuracy of the means at Renk. The mean of two measurements each having a probable error of 3 per cent. may be taken as having a p.e. of 2 per cent. The probable error of the difference between two such means, provided they are approximately equal, may be taken as roughly equal to 3 per cent. of their mean. Thus the probable error of the observed loss during a single ten-day period may be taken as 3 per cent. of the mean of the total discharges at Malakal and Renk during that period. It should be noted that it is a function of the size of these discharges and not of the difference between them.

At low river these discharges average about 40 m/d, or 400 during a ten-day period; at high river they average about 1,000 m/d during a ten-day period. Thus the average probable errors of the observed losses in each ten-day period at these stages are 12 and 30 millions respectively, giving for both the rising and falling stages an approximate mean of 20 millions per ten-day period. The rise lasts as a rule for seven months (210 days) and the fall for about five months (150 days), so that the probable errors of the cumulative observed discharges during these periods (from which absorption and evaporation depths will be calculated) are roughly 90 and 75 millions respectively, assuming that there is no systematic effect. The probable error of the final cumulative observed loss in an average flood is about 120 millions, if the same assumption is made. Clearly this assumption will not hold in years when no discharges were measured, and no estimate of the probable errors of the observed discharges in these years can be made. It is almost certain that they will be greater than in years of regular discharge measurements; but how much greater I should not like to say.

THE POSSIBILITY AND EFFECTS OF SYSTEMATIC ERRORS

After this paper was completed in draft it was suggested to me that insufficient account had been taken of the possibility of systematic errors in the observed discharges. The following note has therefore been added and in it I try to assess these and outline what effects they would have on the analysis. I have preferred to deal with this question as a whole here rather than in parts under the various sections concerned. It may be found clearer, however, when these have been read, and so reference to this note is made in them where it is relevant.

There were said to be two principal ways in which systematic errors could arise. First the softness of the bottom could cause a systematic difference in the soundings taken by different engineers and so affect the area of the measured cross-section. Secondly the factor used in converting the velocity measured at half depth to the mean velocity of the corresponding part of the cross-section might be wrong. This factor is the mean of many years' observations and in the long run is probably very accurate; but changes in the conditions of the river bed in individual years may cause deviations from its mean value during any particular flood.

Opinions as to the possible size of these errors differ, but they may in theory amount to one or two per cent. with corresponding effects on the accuracy of the discharges.[2] There is, however, one piece of evidence which indicates that they may not be as large as this. I have outlined on p. 855 above and consider in more detail in Section V (p. 869) how in the falling stage the average evaporation depth can be obtained by comparing the difference between the observed discharges and the volume of water released by the emptying of the trough.

Varying values for this depth are obtained in different years, but it is noteworthy that none of them exceed by very much the average evaporation depth obtained from instrumental records and adopted by the Egyptian Irrigation Department. The absence of unusually large values for the evaporation depth calculated by this means is to me an indication of the comparative accuracy of the observed discharges when averaged over this falling stage, unless there have been errors which in all cases have been counterbalanced by inflow.

The effects of such errors on my results may now be considered. They are twofold. In the first place if larger errors are allowed for in the observed discharges then the values of evaporation and absorption depth obtained in Sections V and VI, by the methods indicated on pages 870 and 872, may be allowed a wider range. Since all the highest values are already included, this entails adding only smaller values and so decreasing the means obtained from them all. This is of little consequence in the case of evaporation because I do not use the means obtained in this way but rely on estimates observed from instrumental records; but in the case of absorption it would entail a decrease in the assumed depth. This is supported by other evidence and it seems likely in fact that the value of 80 cm. which I have obtained is actually too large and that 50 cm. may be a more reasonable figure.

The second effect of allowing for systematic errors in the observed discharges is to increase the probable errors of the deduced inflow. It will be observed that in some years, notably 1932–33, 1936–37, 1939–40, and 1943–44, this has a very steady value, as may be seen from the curves of Figs. J 5, 6, 7, 8, 9, which in these years have a steady rather than a sudden separation. It may well be that in these years this systematic decrease in the observed losses is not due to inflow counterbalancing the true losses by evaporation and absorption, but simply to systematic errors in the observed discharges causing these at Renk to appear relatively larger than they really are.

It has also been argued that there should be some correlation between the height of the White Nile and inflow into it, and that the poorness of this correlation with my figures for deduced inflow renders them very much open to question. I do not agree with this view, for the following reasons. In the first place there is unequivocal evidence of inflow in 1942–3 on the west bank (see Section VIII, p. 904) and yet in this year the maximum gauge-reading at Malakal was 12·38—only 12 cm. above the average. Secondly the arguments for this correlation seem to me much weaker than those in favour of correlation with the height of the Baro and Sobat which are explained in Section IX (p. 906); and in this case a fair degree of correlation does exist as is shown there. The maximum height of the White Nile in each flood is due to two factors: the height at which it begins the cycle, and the volume of water added to it by the Sobat. In other words a considerable part of its maximum height is due to the flow from the Great Lakes for a year or more beforehand and there is no reason why conditions there should be connected with inflow below Malakal, over six hundred miles farther north.

A third reason which inclines me to stand by my figures for deduced inflow, in spite of the possibility of their being invalidated by systematic discharge errors, is the correspondence between my maximum figures and the supporting evidence obtained from the few records available. I think it is quite possible that my totals for deduced inflow in each year may be wrong by 100% in years when it is small, and by 30 or 50% in years when it is large. Nevertheless it is worth noting that in three out of the four floods when I deduce maximum totals of inflow there is unequivocal evidence (given in Section VIII, p. 902) that it was larger than usual; for the fourth year—1929–30—no evidence either way is available since practically no records can be found. Moreover in the two months of 1947 when my deduced totals are very much larger than in any other month during the whole period considered, there is again plenty of evidence that inflow in the Paloich area was without precedent during the previous twenty years. Thus, though the possibility of systematic errors in the discharges cannot be excluded, there is a fair amount of evidence that they are not large enough to invalidate seriously the results which I have obtained by ignoring them.

TABLE 396

PRELIMINARY SUMMARY OF FLOODS ON THE WHITE NILE

BETWEEN MALAKAL AND RENK 1928-47

Year in which Flood began	Final Cumulative Observed Loss	Initial Malakal Gauge	Maximum Malakal Gauge	First Period Rise	Last Period Rise	Last Period of Peak	Average Total Rainfall
1928	625	9·78	12·30	Apr. (1)	Oct. (3)	Dec. (1)	727
1929	− 339	9·88	12·36	Apr. (2)	Nov. (1)	Dec. (1)	745
1930	571	9·97	11·84	Apr. (1)	Oct. (2)	Nov. (3)	522
1931	(287)	9·66	12·26	May (1)	Nov. (1)	Nov. (3)	690
1932	845	9·98	12·92	May (1)	Dec. (1)	Dec. (3)	573
1933	(20)	10·29	12·84	May (1)	Oct. (1)	Nov. (1)	645
1934	(− 190)	10·17	12·56	Apr. (1)	Nov. (1)	Dec. (2)	566
1935	(− 490)	10·19	12·36	May (1)	Oct. (3)	Dec. (1)	559
1936	551	10·12	12·17	May (1)	Oct. (3)	Nov. (3)	674
1937	− 111	9·87	12·44	May (1)	Oct. (3)	Nov. (2)	622
1938	− 201	10·09	12·63	Apr. (2)	Nov. (1)	Jan. (1)	601
1939	100	10·39	12·26	May (1)	Oct. (3)	Nov. (3)	692
1940	85	10·03	11·94	May (2)	Oct. (1)	Nov. (2)	520
1941	− 140	9·77	12·19	May (1)	Nov. (3)	Dec. (2)	633
1942	− 298	9·83	12·38	Apr. (3)	Oct. (1)	Nov. (2)	604
1943	− 1	10·04	12·17	Apr. (3)	Nov. (1)	Nov. (3)	514
1944	472	10·00	12·24	Apr. (3)	Oct. (2)	Nov. (2)	641
1945	805	9·44	12·37	Apr. (3)	Oct. (3)	Nov. (3)	865
1946	− 52	9·52	12·92	Apr. (3)	Nov. (2)	Jan. (2)	868

NOTES: Losses in millions, gauges in metres, rainfall in millimetres.
Observed losses in brackets are derived from general gauge/discharge curves only at Renk.
Fluctuations of under 3 cm. at the peak of the flood have been ignored in calculating its duration.

SECTION III. TROUGH VOLUME

As the river rises it fills the trough, and the trough extends from the bottom of the river to the highest flood limits without a break. This is the burden of my thesis, and the change of trough volume as the river rises and falls is the biggest factor in causing the differences which are observed between the discharges at Malakal and Renk during these stages. In calculating the theoretical differences this item in the account has two advantages: it can be calculated entirely from existing measurements without any assumptions having to be made or factors to be estimated, so long as no attempt is made to allow for lag; and it is cancelled out at the end of each flood when the river has returned virtually to the level it occupied at the beginning. This means that an estimate of the total loss during any one flood is not affected by any errors in the estimated trough volume.

PREVIOUS ESTIMATES

I have indicated in the introduction that I believe my approach to this question to be rather different from that used previously, and it may therefore be worth outlining what this previous approach was, and what I understand to be the current methods of working out the trough volume of this part of the river. It may be noted that previous estimates have not been concerned with the river above Melut (so far as I know) because they have been made in connection with the Jebel Aulia Reservoir whose effects are not felt above Melut. In Appendix IV of the *Third Interim Report* I gave an account of the tables, prepared originally by Topouzada Bey and revised by Dr. Amin, which are used in the working of the reservoir, and which the Egyptian Irrigation Department in Khartoum kindly let me see. The essence of this account will be repeated here for convenience. In these tables the river between Melut and Jebel Aulia is divided into 22 stretches of between 20 and 30 km. long, with a cross-section in the middle of each. The first part of the tables gives the widths of the water surface at each of these cross-sections corresponding to different reduced levels at it. That is to say the widths are given in terms of heights above sea level and not above the surface of the river; and so the different cross-sections are related to a series of horizontal planes instead of to a series of planes parallel to the low-level slope of the river. This system of reference makes impossible any comparison between successive cross-sections and so has prevented in the past any realization of the comparative uniformity of the cross-section or assessment of the probable errors of its mean width at various levels of the river.

Values for the surface areas and volumes of the different stretches were compiled in these Egyptian tables by assuming that the width of the surface at each cross-section was the mean for the width of the stretch in which it lay. As I have shown this gives on the average a less accurate value for each stretch than one derived from a large number of cross-sections taken over a much longer reach of the river, so long as this has reasonably uniform characteristics. Clearly, when such a long reach is being considered, the total surface area or volume will come out the same whether it is computed by summing the values obtained for the separate stretches of which it is composed, or whether it is done by taking a mean of the widths at the cross-sections and then multiplying this by the length of the reach. But it will also be clear that when a large number of volumes corresponding to many different states of the river are required the computations will be shortened considerably by taking the mean out first.

In estimating the volume of a long reach the first step must be to assume or predict a longitudinal profile for the water surface along it, and this is expressed in the first instance as a series of gauge-readings at various points along the reach. From these, in the Egyptian tables, the reduced level of the water surface at each of the cross-sections is interpolated, and the corresponding width of the section in which it lies is then deduced as described above. In my method, described below, the tables of volumes have already been prepared in terms of mean gauge-readings for each of the stretches into which the gauges divide the river. Thus the volume of the whole reach can be taken out directly once these gauge-readings have been assumed, and the volume of any shorter stretch can be obtained by reduction in the proportion of its length to that of the whole reach. In other words the whole reach between successive gauges is regarded as uniform and any shorter length required is chopped off like a sausage. The calculation of the trough volumes in any given conditions, even over so short a reach as that between Melut and Renk, must be a fairly lengthy calculation by the previous method; but it can be taken out from Table 398 (i), p. 866, in a few seconds once the gauge-readings at Melut and Renk have been assumed.

METHOD OF CALCULATION

The data for calculating the trough volumes which I have used were the 22 cross-sections surveyed between Malakal and Jebelein by the Egyptian Irrigation Department between 1928 and 1943. (These should not be confused with the 22 sections mentioned above into which the river between Melut and Jebel Aulia was divided quite arbitrarily in the Egyptian tables.) Following the principles outlined above I made use of separate means for the idealized bank profiles between Malakal and Melut and between Melut and Renk. Moreover in calculating the latter I did not omit from the mean the cross-sections below Renk because, as I have shown, there is no significant change in the cross-section at that point, and the more cross-sections used the better, even if they lie outside the stretch for which the mean is required.

To obtain the total width of the water surface at various gauges it is necessary to add to the flood-plain widths the mean width of the low-level channel. At mean gauges of 10·0 this is 400 m. between Malakal and Melut and 560 m. between Melut and Jebelein. I obtained the mean widths in this way because it made it possible to use the tables already compiled and published in the *Third Interim Report*; the means of the low-level widths were obtained from the individual values given in Table 24 and the mean flood-plain widths are taken directly from Table 26, with rises turned into gauge-readings by adding 10·0 to them.

The lengths of the two reaches Malakal to Melut and Melut to Renk are 141 and 182 km. respectively; if the total mean widths are multiplied by these the corresponding total surface areas are immediately obtained. It is thus possible to construct a table showing surface areas in terms of mean gauge-readings, and this has been done in Table 397 (p. 865). This table is used for calculating the volumes of water gained by rainfall and lost by evaporation, as is described in more detail in the next two sections. But it can also be used for calculating the volume of water held in the trough at any particular gauge-reading. For the present purposes we are concerned, not with the total volume of the trough, but with the extra volume caused by a rise above mean low level. If this is taken as corresponding to a mean gauge-reading of 9·80, the trough volume held at any particular height above it can be obtained by a process of integration. This is done in Table 398 (p. 865) which was calculated by adding successively the increments of volume corresponding to each decimetre rise, each increment being obtained by multiplying the mean surface area (taken from Table 397) during the rise by 0·1. Between the values for the separate decimetres direct interpolation could be used since the relationship between gauge and volume may be regarded as linear over such a short range.

COMPUTATION OF MEAN GAUGES (see Table 403 (i))

In order to make use of Table 398 it is necessary first of all to obtain the mean gauge-readings for each of the two reaches for each of the ten-day periods. The means for these at Malakal, Melut, and Renk were either obtained directly from Volume III of *The Nile Basin* and its Supplements or, for the years after 1942, from figures kindly supplied by the Egyptian Irrigation Department in Khartoum. The values at Kodok were not used because the profile between Malakal and Melut appeared to be substantially straight at all times; the values at Meteimer were also omitted because they were only available for part of the time. The mean gauge-readings for the two reaches were therefore obtained by a direct mean of those at Malakal and Melut, and at Melut and Renk respectively. In actual fact there is not quite the same correspondence between the rise at Renk and its gauge-reading as there is at Malakal and Melut, since the average low-level reading at Renk gauge is usually between one and two decimetres above those at the other two places. But the amount is small and uncertain, and to allow for it would have complicated the calculations, so I have not done so.

There is, however, one more step which has to be taken in order to achieve direct correspondence between the theoretical and the observed losses. This is to convert from the mean gauge-readings as derived above, which correspond to the middle of the ten-day period, to the mean gauge-readings corresponding to the end of the period, the moment for which each cumulative observed loss is given. When the river is rising or falling steeply this difference may amount to several decimetres over the whole length of the reach and cannot therefore be ignored. It may be argued that exact correspondence cannot exist between the theoretical and actual trough volumes, and this is of course true owing to the complex nature of the actual trough; nevertheless there is little point in confusing the analysis by introducing a large varying difference into the theoretical volume when a little extra computation will remove it.

It is necessary therefore first of all to mean the individual gauge-readings, and then to take out the mean of each ten-day period with that of the period immediately following it. When this has been done we are in a position to derive the theoretical 'loss' to the trough volume at the end of each ten-day period. We take first of all the mean gauge-reading at the end of the last ten-day period before the river begins to rise. This is our datum for the year, and we get from Table 398 the corresponding volumes held above (or below) the mean gauge-reading of 9·80 in each of the two reaches. This value is recorded, but of course the actual loss to the trough at this moment is nil. The trough volumes for all subsequent ten-day periods in this year are taken from Table 398 and corrected by subtraction of these datum values, which are of course given their correct signs. Thus we obtain for the end of each ten-day period the theoretical value of the trough volume held above the river surface at the start of the year, and this largest item in the computed losses is in direct correspondence with the observed losses. The value of 9·80 was chosen for the datum of the table because it gave the smallest initial value (either positive or negative) on the whole for the twenty years under consideration here and so made easier the correction of the volumes obtained from the table in order to convert them to 'losses'.

When this investigation was first started I calculated the cumulative loss to the trough volume by working out separately the change of volume for each ten-day period, and then summing these increments cumulatively. The advantages of tabulation over this method are obvious: the increments are chosen so as to be easily calculable and, once the basic table has been checked, the individual trough volumes taken from it are independent of each other. When they are obtained by cumulative summing of calculated increments any error in one of these or in the addition will affect all the cumulative sums which follow it. The years 1928–29, 1929–30, and 1930–31 had been worked out and checked by calculation of individual increments before I had fully realized the advantages of tabulation; I have not worked them out again and small differences may therefore be found in the trough volumes which would be obtained for these years if they were taken from Table 398.

PROBABLE ERRORS

Since the trough volume, even when it is taken from the table, is obtained by summing a succession of increments, its theoretical probable error at any level is obtained easily once we know the probable errors of the increments. This is done quite simply. Each increment may be thought of as a disc whose thickness equals the change of mean gauge-reading to which it corresponds. Its length is the length of the reach and its width the mean width of the reach corresponding to the height above low level at which it lies. Only this last factor has any appreciable error and we may therefore derive the probable error of the volume of the increment directly from it. In Table 26 of the *Third Interim Report* are shown the probable errors of the mean widths at various heights above low river level expressed as percentages of the widths of the flood-plain. Except at very low levels the variations in the width of the low-level channel are a small proportion of the flood-plain variations and will not seriously affect the probable errors of the means; in fact the main effect of adding the low-level width is to reduce the percentage error. We may therefore for practical purposes take these percentages as giving the corresponding percentage errors of the volumes of the increments. In Table 399 (p. 867) the calculation from these and from Table 398 of the probable errors of the trough volumes for each of the two reaches is shown, for each even decimetre of the gauge-readings up to the maximum values recorded during the years under consideration in this paper.

It will be seen that these probable errors are not large; in fact they are under ten per cent. for the upper reach and under five per cent. for the lower one, except at very low gauges. In a normal year, when the mean gauges in the two reaches attain maxima of 12·2 and 12·0 respectively the probable error of the whole trough volume between Malakal and Renk will be:

$$\sqrt{14^2 + 8^2} = 16.$$

For a high year such as 1946, when the mean gauges reached 12·8 and 12·6 respectively, the probable error of the total was:

$$\sqrt{20^2 + 13^2} = 24.$$

If therefore we assume that the probable errors of the totals in average and high years are 25 and 40 millions respectively it should not be an underestimate, even allowing for any systematic tendency there may be in the errors of the mean at different levels.

TRIBUTARY KHORS

It will be convenient at this point to deal with the subject of storage in the beds of the tributary khors, and also of their flood-plain areas. There are about a dozen of these khors on each side of the river between Malakal and Renk. From a study of the air photographs it is clear that few of them have a width, even when full, of more than two or three hundred metres. The opportunity of a surveyor's visit to Kodok in 1952 was taken to obtain a cross-section of the Khor Nyadwai, which enters there and is one of the biggest tributaries on the west bank in this reach. As will appear below it can on occasion provide a substantial portion of the inflow in some years. Nevertheless its capacity for storage is very small. The cross-section is triangular, with both banks sloping evenly upwards at an angle of about one in forty from a very narrow bed. The bed is at a level corresponding to Kodok gauge 11·4 so that no water would enter the khor until the gauges at Malakal and Melut reached this value. In an average year (maximum Malakal gauge 12·3) the khor would have under a metre of water in it even at the mouth. Its surface width there would be about 80 m. and its cross-sectional area about 40 sq. m. It is reported locally that in an average year the water reaches inland to a distance of about 10 km., so the stored volume would be only about a third of a million or less.

It will be clear therefore that even twenty of these khors are very unlikely to hold much more than 10 millions in an average year. This may be compared with the average maximum trough volume (as shown in Table 419, p. 901) of about 700 millions, of which it is only therefore just over one per cent. The Khor Adar, which goes back very much farther and obviously has a flatter slope—though not a much bigger cross-section—may hold a few millions when full; but even if it is included it will be clear that the storage in the tributary khors and the flooded areas which they provide for grazing must be almost negligible when compared with the same features on the main river along the whole stretch. The grazing areas on the tributary khors may assume a slightly greater degree of importance than is warranted by their size because of their relative accessibility; but even so it does not seem that they can be regarded as a serious proportion of the whole.

TABLE 397

SURFACE AREAS BETWEEN MALAKAL AND MELUT AND BETWEEN MELUT AND RENK, FOR VARIOUS MEAN GAUGE VALUES

(i) MALAKAL TO MELUT — (ii) MELUT TO RENK

Mean Gauge	Mean Width	Total Surface Area	Malakal–Melut Corrected Values after allowing for error in No. 4 cross-section		Mean Gauge	Mean Width	Total Surface Area
			Width	Area			
9·8	380	54	390	55	9·8	540	98
9·9	390	55	400	56	9·9	550	100
10·0	400	56	410	58	10·0	560	102
10·1	410	58	430	61	10·1	580	105
10·2	420	59	440	62	10·2	605	110
10·3	460	65	480	68	10·3	670	122
10·4	500	70	530	75	10·4	730	133
10·5	520	73	550	78	10·5	785	143
10·6	540	76	570	80	10·6	840	153
10·7	570	80	600	85	10·7	880	160
10·8	600	84	630	89	10·8	920	167
10·9	630	89	670	94	10·9	970	177
11·0	660	93	700	99	11·0	1,020	185
11·1	700	99	740	104	11·1	1,090	198
11·2	730	103	770	109	11·2	1,160	211
11·3	770	108	810	114	11·3	1,250	227
11·4	810	114	850	120	11·4	1,340	243
11·5	920	130	980	138	11·5	1,470	267
11·6	1,030	145	1,100	155	11·6	1,600	291
11·7	1,170	165	1,250	176	11·7	1,705	310
11·8	1,300	185	1,380	195	11·8	1,810	329
11·9	1,480	210	1,570	221	11·9	2,020	367
12·0	1,650	235	1,750	247	12·0	2,230	405
12·1	1,750	247	1,850	261	12·1	2,440	443
12·2	1,850	261	1,950	275	12·2	2,650	480
12·3	2,000	282	2,110	298	12·3	2,860	520
12·4	2,150	303	2,270	320	12·4	3,070	560
12·5	2,280	322	2,390	337	12·5	3,210	584
12·6	2,400	338	2,500	352	12·6	3,350	608
12·7	2,520	355	2,660	375	12·7	3,460	628
12·8	2,650	374	2,830	399	—	—	—

NOTES: These tables were computed from the mean widths given in the *Third Interim Report*, Appendix IV, Table 26, extrapolated to gauge 9·8. The mean widths of the low-level channels at gauge 10·0 are taken as 400 metres and 560 metres respectively, and the respective lengths of the two reaches as 141 and 182 kilometres.
Gauges and widths in metres, areas in square kilometres.

TABLE 398

TROUGH VOLUMES ABOVE MEAN GAUGE 9·80

(i) MALAKAL TO MELUT

Mean Gauge	0·00	0·01	0·02	0·03	0·04	0·05	0·06	0·07	0·08	0·09	Mean Gauge
9·8	0	1	1	2	2	3	3	4	4	5	9·8
9·9	5	6	6	7	7	8	8	9	9	10	9·9
10·0	11	11	12	12	13	13	14	14	15	16	10·0
10·1	17	18	18	19	19	20	20	21	22	23	10·1
10·2	23	24	24	25	26	26	27	27	28	29	10·2
10·3	29	30	31	32	32	33	34	35	35	35	10·3
10·4	36	36	37	38	38	39	40	40	41	42	10·4
10·5	43	44	44	45	46	47	47	48	49	49	10·5
10·6	50	51	52	52	53	54	55	56	56	57	10·6
10·7	58	59	60	60	61	62	62	63	64	65	10·7
10·8	66	67	68	68	69	70	71	72	73	74	10·8
10·9	75	76	77	79	79	80	81	82	83	83	10·9
11·0	84	85	86	87	88	89	90	91	92	93	11·0
11·1	94	95	96	97	98	99	100	101	102	103	11·1
11·2	104	105	106	107	108	110	111	112	113	114	11·2
11·3	115	116	117	118	119	121	122	123	124	125	11·3
11·4	126	127	128	129	130	132	133	134	135	137	11·4
11·5	138	139	141	142	144	145	146	148	149	151	11·5
11·6	152	154	155	157	158	160	162	163	165	166	11·6
11·7	168	170	172	173	175	177	179	181	182	184	11·7
11·8	186	188	190	192	194	196	198	200	202	204	11·8
11·9	206	208	210	212	215	217	219	222	224	226	11·9
12·0	228	230	233	235	238	240	243	245	247	250	12·0
12·1	252	254	257	259	262	264	267	269	272	274	12·1
12·2	277	280	283	285	288	291	293	296	299	301	12·2
12·3	304	307	310	313	316	318	321	324	327	330	12·3
12·4	333	336	339	342	345	349	352	355	358	361	12·4
12·5	364	367	371	374	377	380	384	387	391	394	12·5
12·6	397	400	404	407	411	414	418	421	425	428	12·6
12·7	431	434	438	441	445	449	452	456	459	463	12·7
12·8	467	471	476	480	485	489	494	499	503	508	12·8

NOTE: Gauges in metres and volumes in millions.

TABLE 398 (*continued*)

CORRECTED VALUES FOR EACH DECIMETRE ALLOWING FOR THE ERROR IN CROSS-SECTION No. 4

Mean Gauge	Trough Volume	Mean Gauge	Trough Volume	Mean Gauge	Trough Volume
9·8	0	—	—	—	—
9·9	6	—	—	—	—
10·0	12	11·0	89	12·0	240
10·1	18	11·1	99	12·1	265
10·2	24	11·2	110	12·2	292
10·3	30	11·3	121	12·3	321
10·4	37	11·4	133	12·4	352
10·5	45	11·5	146	12·5	385
10·6	53	11·6	161	12·6	419
10·7	61	11·7	177	12·7	455
10·8	70	11·8	196	12·8	494
10·9	79	11·9	217	12·9	534

TROUGH VOLUMES ABOVE MEAN GAUGE 9·80
(II) MELUT TO RENK

Mean Gauge	0·00	0·01	0·02	0·03	0·04	0·05	0·06	0·07	0·08	0·09	Mean Gauge
9·8	0	1	2	3	4	5	6	7	8	9	9·8
9·9	10	11	12	13	14	15	16	17	18	19	9·9
10·0	20	21	22	23	24	25	26	27	28	29	10·0
10·1	30	31	32	33	34	35	37	38	39	40	10·1
10·2	41	42	43	44	45	46	48	49	50	51	10·2
10·3	53	54	55	57	58	59	60	61	63	64	10·3
10·4	66	67	69	70	72	73	74	76	77	78	10·4
10·5	80	81	83	84	86	88	89	91	92	94	10·5
10·6	95	96	98	99	101	103	104	106	107	109	10·6
10·7	111	113	114	116	118	119	121	123	124	126	10·7
10·8	127	129	130	132	133	135	137	138	140	142	10·8
10·9	144	146	148	149	151	153	155	156	158	160	10·9
11·0	162	164	166	170	170	171	173	175	177	179	11·0
11·1	181	183	185	187	189	191	193	195	197	199	11·1
11·2	201	203	205	208	210	212	214	217	219	221	11·2
11·3	223	225	228	230	232	235	237	240	242	245	11·3
11·4	247	249	252	255	257	260	262	265	268	271	11·4
11·5	273	276	279	281	284	287	290	292	295	298	11·5
11·6	301	304	307	310	313	316	319	322	325	328	11·6
11·7	331	334	338	341	344	347	350	354	357	360	11·7
11·8	363	366	370	373	377	380	384	387	391	394	11·8
11·9	398	402	406	409	413	417	421	424	428	432	11·9
12·0	436	440	444	449	453	457	461	466	470	474	12·0
12·1	478	482	487	491	496	501	505	510	514	519	12·1
12·2	524	529	534	539	544	549	554	559	564	569	12·2
12·3	574	579	585	590	596	601	606	612	617	622	12·3
12·4	628	634	639	645	651	657	662	668	674	680	12·4
12·5	685	691	697	703	709	715	721	727	733	739	12·5
12·6	745	751	757	763	769	775	781	787	793	799	12·6

NOTE: Gauges in metres and volumes in millions.

TABLE 399

PROBABLE ERRORS OF TROUGH VOLUMES ABOVE MEAN GAUGE 9·80

(i) MALAKAL TO MELUT

Mean Gauge	Increment	Percentage Error	Probable Error	Square of Probable Error	Cumulative Sum of Squares	Probable Error of Trough Volume
(1)	(2)	(3)	(4)	(5)	(6)	(7)
9·8	0	0	0	0	0	0
10·0	11	25	3	9	9	3
10·2	12	25	3	9	18	4
10·4	13	25	3	9	27	5
10·6	14	21	3	9	36	6
10·8	16	17	3	9	45	7
11·0	18	17	3	9	54	7
11·2	20	17	3	9	63	8
11·4	22	16	4	16	79	9
11·6	26	14	4	16	95	10
11·8	34	13	4	16	111	11
12·0	42	14	6	36	147	12
12·2	49	14	7	49	196	14
12·4	56	13	7	49	245	16
12·6	64	13	8	64	309	18
12·8	70	13	9	81	390	20

(ii) MELUT TO RENK

Mean Gauge	Increment	Percentage Error	Probable Error	Square of Probable Error	Cumulative Sum of Squares	Probable Error of Trough Volume
9·8	0	0	0	0	0	0
10·0	20	11	2	4	4	2
10·2	21	11	2	4	8	3
10·4	25	12	3	9	17	4
10·6	29	9	3	9	26	5
10·8	32	7	2	4	30	5
11·0	35	5	2	4	34	6
11·2	39	3	1	1	35	6
11·4	46	3	1	1	36	6
11·6	54	4	2	4	40	6
11·8	62	4	2	4	44	7
12·0	73	5	4	16	60	8
12·2	88	5	4	16	76	9
12·4	104	6	6	36	112	10
12·6	117	6	7	49	161	13

NOTES: The increments in Col. (2) are taken from Table 398; the percentages in Col. (3) from Table 26 of the *Third Interim Report*. Col. (4) is the product of these two divided by 100 and is thus the p.e. of each increment. In Col. (5) these are squared and in Col. (6) the squares are summed cumulatively. Col. (7) shows the square roots of each cumulative sum and therefore gives the probable error of the volume held at the gauge-reading at the beginning of the line. The figures in Cols. (2), (4), and (7) are in millions.
The probable errors for the stretch between Malakal and Melut would be *decreased* by the correction to Cross-Section No. 4 since this now approximates very closely to the mean, whereas previously it was exceptionally far from it.

SECTION IV. RAINFALL

SOURCES OF ERROR

In a country where the rain falls gently and uniformly over a wide area the average depth of rain which has fallen on any area in a given period can be estimated with fair accuracy from a few rain-gauges evenly scattered over it. Unfortunately tropical rain is seldom gentle and nearly always localized; moreover in the Southern Sudan the rain-gauges are still too far apart to give a truly representative picture. This is shown by the fact that in the same year two adjacent stations may record totals which are well above and well below their respective averages. Nevertheless, in the present analysis I have placed the gains due to rainfall next after the change of trough volume because no estimate of a factor can or need be made. The relationship between the mean of the various rain-gauge records and the average depth over the whole area may be uncertain and variable; but there are no grounds for assuming any other relationship than equality between them. The gains due to rain falling on the surface of the river are therefore calculated very easily once the rainfall stations to be used have been selected and when the average surface area during the period concerned is known. This is derived in the manner already described. In this case, in calculating the rainfall gain for each ten-day period, we use of course the mean surface area for the period, and not the value at its end, and we therefore enter Table 397 (p. 865) with the mean gauge-readings corresponding to the middle of each period.

Apart from the major source of error described above, about which nothing can be done as far as past years are concerned, there are two further uncertainties which must be considered, though neither of them is serious. The first is the unknown time-lag between the theoretical and actual surface areas. I have neglected this altogether, as I did the lag between the theoretical and actual trough volumes, and as I do below the lag between theoretical and actual absorption. As is explained below, all these time-lags are combined in the apparent absorption which is derived empirically and only compared incidentally with its theoretical value. The second uncertainty is the amount of run-off from that part of the trough or valley not covered by the theoretical water surface. This does not seem to be a large item since there is no noticeable difference between the years when rainfall along the river has been high and those when it has been low. A possible exception to this is the year 1928, when unusually heavy rain in April coincided with an anomalous value of the apparent absorption; this is discussed in more detail in the next section but one, which deals with that subject. Run-off from areas outside the trough, entering by well-defined khors, is another matter altogether; as will appear later this is probably one of the most important sources of inflow and is therefore described in a special section which follows the analyses of the individual years. In general therefore the gains due to rainfall are obtained by direct multiplication of the mean of the readings at the selected stations during each ten-day period by the mean surface area during that period. Thus, though the results may be subject to error, they are obtained by direct calculation entirely from measured quantities.

DATA AND METHOD OF CALCULATION

The latest available maps of Sudan rainfall show that conditions are not the same inside and outside the river valley, and I have therefore made use only of records obtained from gauges sited on the river. From Malakal to Renk, during the twenty years considered here, continuous records have only been kept at Malakal, Kodok, Melut, and Renk. Although it reduces still further the number of stations from which the averages are derived, I have not used the records at Kodok. Conditions change fairly rapidly northwards from Malakal, and there is no corresponding station between Melut and Renk, so that I felt that to include the Kodok records in the mean would weight it unfairly. The total effect of the rainfall is not a large item in the analysis and it did not seem to warrant the complications of a weighted mean. It will be observed that in an average year the mean total surface area during the rainy season is about 400 sq. km.; with an average total fall of a little over 600 millimetres this gives a total gain of about 250 millions. Errors in the surface area will not be appreciable compared with the uncertainty in the amount of the rainfall, and if this is assumed to be 20 per cent. we arrive at a probable error in the total of the order of 50 millions.

For the years before 1937 the monthly totals at these three places are given in Volume VI of *The Nile Basin*, and I simply divided these by three to get the ten-day totals. For the later years, since monthly totals were not readily available, I went back to the original daily records which the Government Meteorologist was kind enough to lend me, and from which I derived the ten-day totals directly myself. Since the monthly totals were available for the earlier years this extra refinement did not seem to justify the extra labour involved for them. Even the heaviest falls occurring when the river surface was near its maximum (as for example in September 1939) caused only a minor effect on the curve of total computed loss.

SECTION V. EVAPORATION

RISING STAGE

Evaporation differs from rainfall in the very important fact that whereas it is possible to measure directly the amount of rain falling on a small known area, and to deduce from the result directly, if not accurately, the rainfall over a large area, there is as yet no really reliable method of relating instrumental observations of evaporation to the total over a large area of open water. There is no need here to discuss the various experiments which have been made and the various estimates given for the daily evaporation from an open water surface in these regions at different times of the year. I had hoped that this present investigation might add materially to the discussion of this problem, but it may as well be admitted at once that this has not happened, though I have obtained rough figures which agree with previous estimates for the conditions during the dry season surprisingly well. These are discussed below; at the moment I am concerned with the effect of evaporation during the rising stage of the river. Here we are on fairly sure ground, since by the time the surface area has become large enough for evaporation losses to become appreciable, evaporation itself has become so small that its effects are almost negligible; and this happy state of things persists nearly to the peak of the flood—or even beyond in low years. This is fortunate because it would be impossible from any consideration of the observed losses during this stage to make any distinction between those due to evaporation and those due to absorption. It is necessary therefore to rely entirely on previous estimates for evaporation during this stage; but on the other hand any errors in these estimates will not have a large effect on the losses.

In Volume I of *The Nile Basin* (pp. 57–61) the subject of evaporation is discussed thoroughly and a value of 1–2 mm. per day is estimated for this part of the river in the months June to October inclusive. I understand that the modern practice in the Egyptian Irrigation Department is to halve the readings of the Piche tube evaporimeters which are situated at various meteorological stations in the Jebel Aulia Reservoir; and I therefore give below the values obtained by halving the monthly means of these readings at Malakal and Renk during the years when records were taken:

TABLE 400

AVERAGE EVAPORATION FROM AN OPEN WATER SURFACE

(Piche Tube Readings(¹) × 0·5)

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April
Malakal (1915–47)	3·8	2·5	1·6	1·3	1·5	2·0	4·6	7·2	8·6	9·6	8·6	6·1
Renk (1938–48)	8·1	6·0	4·1	2·7	2·8	4·4	7·9	8·5	8·5	8·8	11·1	11·0
Mean	6·0	4·2	2·8	2·0	2·2	3·2	6·2	7·8	8·6	9·2	9·8	8·6

(¹) Supplied by the Sudan Government Meteorologist.
Evaporation in millimetres per day.

The average for the falling stage (December to April inclusive) may be noted as 8·8 mm. per day. Taking all these factors into consideration there seems to be little chance of serious error if a value of 2 mm. is accepted for the months of August and September, 2–4 mm. for July and October, and 5–8 mm. for May and November; with some allowance made for years which are abnormally dry or wet in the early or late stages of the season. All in all the total loss by evaporation during this stage, which amounts on the average to a little over 100 millions, may be estimated within 20 or 30 millions in an average year. The net gain or loss by evaporation minus rainfall during this stage may then be reckoned as being accurate to about 50 or 60 millions. It is worth noting before we leave the subject that the total net loss or gain from these factors up to the peak of the flood is very small and varies little from one year to another.

FALLING STAGE

During the rising stage therefore the net loss of evaporation minus rainfall can be estimated with a fair degree of accuracy and is a fairly small quantity; it is these facts which make it possible to estimate the absorption factor in years when there is apparently no inflow, as will be described in the next section. But as the river falls the situation is reversed: absorption may then be assumed with some confidence to have ceased, and therefore all the losses can be ascribed without serious error to evaporation. By making allowance for the volume of water released by the emptying of the trough it is possible to deduce from the observed differences between the discharges at the two ends how much has been lost from its surface. Unfortunately, however, it is in this part of the year that inflow most commonly occurs, and there are apparently very few years in which it is at all certain that there has been none. Thus, as will be seen below, only three determinations of the evaporation factor can be made from the data at present available. This is not enough to give one much confidence in the results (though they agree with each other and with previous estimates quite well), nor is it enough to determine whether the whole surface of the river should be treated as uniform or divided into two parts: the open channel and the flood-plain.

This requires a word of explanation. Surface conditions in these two areas are different after the peak of the flood, because on the flood-plain the grass has grown up enough to protect the water surface when it begins to fall, and so to produce conditions for evaporation very different from those on the main channel where the surface remains completely open the whole time. During the rising stage this difference probably does not occur, if the water rises faster than the grass can grow; and in any case evaporation at that time is so small that this difference will have little effect on the total. But in the falling stage, when evaporation from an open water surface is of the order of 10 mm. per day during one or two months, the difference between the evaporation from these two areas may be considerable. It has for example been estimated that evaporation from *sudd* is of the order of 4 mm. per day, and if this sort of value were assumed for the flood-plain it would affect the estimates for the total area considerably. If enough records were available from years of no inflow, condition equations could be derived from which the most probable values of the evaporation over both areas could be obtained. As it is at present, with only three years of no inflow in which discharges were fully recorded at Renk, we can only obtain an average value for the whole surface during the falling stage.

METHOD OF CALCULATION

In Table 401 (p. 871) the calculation of this average value is shown, using the only six years in which discharges were measured at Renk during this stage, and in which the losses during it have anything like reasonable values. Each of the six years has been allotted a column in the table, and the different lines, which are numbered, show the data and the successive stages in the calculation of the average evaporation depth. Line (1) gives the cumulative observed loss at the peak of each flood, just before the river began to fall. This level has usually been held for at least a month and all the delays in filling the side basins may be assumed to have been taken up, so that the theoretical and actual trough volumes should be equal. Line (2) shows the cumulative observed loss under similar conditions when the river has fallen to its low level and been more or less stationary for a month or so. The figures in both these lines are taken from the second parts of the relevant years of Table 404–18 (pp. 885–900). Line (3) gives the difference between them or the total amount of water, less that lost by evaporation, which has apparently been released by the decrease in volume of the trough. It is also the excess of the discharges at Renk over those at Malakal during this falling stage. This of course is assuming that there has been no inflow; the way in which I endeavour to eliminate this is shown below.

Lines (4) and (5) give the theoretical volumes of the trough at the same stages of the river, i.e. at the peak and at the end of the falling stage. They also are taken from the second parts of the relevant years in Tables 404–18. The difference between them is given in line (6), and it will be clear that this represents the whole of the theoretical amount of water released by the emptying of the trough. The difference between this and line (3) must therefore be the amount lost by evaporation, assuming that there has been no inflow. This difference is given in line (7). We thus have in this line the total observed loss due to evaporation, and in order to derive from this the average depth of evaporation in a given period of time it must be divided by the product of the average area of the water surface and the time during which the loss has taken place. This product is most easily derived by adding together the surface areas corresponding to each of the ten-day periods between the peak of the flood and its end, between which points both the theoretical and the observed losses obtained above have been taken. These cumulative totals of surface area are taken from the last column of the first parts of Tables 404–18. If the values in line (7)—the deduced loss by evaporation in millions—are multiplied by a hundred and then divided by this cumulative surface area the result will be the average evaporation in centimetres per ten-day period, or in millimetres per day.

DISCUSSION OF RESULTS

It is clear at once that only three years—1929, 1937, and 1946—give results which are at all consistent with each other and with the average of half the Piche tube readings quoted above. This was 8·8 mm., which may be compared with the mean of 7·8 mm. obtained from these three years. It will be seen that the general figures given by previous estimates are confirmed if inflow is assumed in small quantities in the other three years, as well as in large amounts in the remaining years excluded from the table. It may also be argued that the slightly low value which I have obtained is due to the presence of grass over part of the surface area, as already explained above. But are we justified in assuming that the calculation in the other three years shown in Table 399 (p. 867) is invalidated by inflow, and that the differences in the results are not merely due to errors in the other items of the account? This question can only be answered by a consideration of these errors in the year 1944–45 where the average depth comes closest to the mean without being accepted for it. (I have rejected the value obtained from 1932–33 because for two out of the four months no discharges were measured at Renk.)

In order to bring the evaporation depth in 1945 to the mean we must add over 250 millions to the value of the deduced loss by evaporation given in line (7), for there cannot be a serious error in the cumulative total of the surface areas. This deduced loss is obtained by the difference between the cumulative observed loss during the falling stage and the maximum trough volume minus the trough volume at the end of the falling stage. It can be shown from the arguments given on pages 859 and 864 that the theoretical probable error in the trough volume was less than a quarter of the probable error in the observed loss, and that this scarcely exceeded 100 millions during this period.[9] If therefore there was no inflow during this stage we should have to assume an unlikely combination of errors to account for the fact that the derived evaporation depth is so far from the mean. I see no reason for doing this when it seems at least possible that inflow has occurred, and I therefore feel justified in rejecting the value obtained in this year. This rejection, based entirely on a consideration of the internal errors of the account, is confirmed by the fact that the three concordant results agree also with the values which are used in the Jebel Aulia Reservoir as a result of many years' experience.

METHOD OF ESTIMATION IN THE ANALYSES

I have treated the preceding investigation purely as a confirmation of the previous estimates and of my theories, and for calculating the evaporation losses during the falling stage in all the years treated in Tables 403 and 404–18 I have used values based on the average of half the Piche tube readings as shown on page 869. These have been rounded off and some allowance has been made in abnormal years; but I have not scrupled to use 10 instead of 9 or 11 in order to ease the calculation of the losses. The effect on the total computed loss is negligible compared with the effects of the inevitable uncertainties in the values of the other items which go to make it up.

TABLE 401

CALCULATION OF EVAPORATION DEPTH

	1928–29	1932–33	1936–37	1937–38	1944–45	1945–46
Observed Loss at Flood Peak (1)	948	1,671	725	581	1,045	1,362
Final Observed Loss ... (2)	625	845	551	−111	472	805
Difference ... ... (3)	323	826	174	692	573	557
Maximum Trough Volume (4)	667	1,062	571	746	672	834
Final Trough Volume ... (5)	−2	52	−23	27	−59	4
Difference, equals water returned ... ... (6)	669	1,010	594	719	731	830
Deduced Loss by Evaporation (7)	346	184	420	27	158	273
Cumulative Total of Surface Area ... ... (8)	3,993	5,279	4,143	5,513	5,376	5,601
Average Evaporation in millimetres per day ... ... (9)	8·7	3·5	10	0·5	2·9	4·9

NOTES: All figures are in millions except those in lines (8) and (9) which are in square kilometres and millimetres respectively.

The figures in lines (1) and (2) are taken from the third column of the second parts of the relevant years in Tables 404–18. Line (3) is (1) minus (2). Lines (4) and (5) are taken from the fourth column of the second parts of Tables 404–18. Line (6) is (4) minus (5). Line (7) is (6) minus (3).

Line (8) is obtained by summing cumulatively the totals in the last column of the first parts of the relevant years in Tables 404–18. Line (9) is (7) multiplied by 100 and divided by (8).

SECTION VI. ABSORPTION

PREVIOUS ESTIMATES

As the river rises it covers land which has, apart from rain, been dry since the previous flood and which will therefore absorb a certain amount of water. I have not seen any previous published measurements or estimates of the average depth of absorption, apart from the estimate of 150 cm. given on page 31 of the *First Interim Report*, which is frankly described as "little more than a hopeful guess". This estimate was based on conditions in the Gezira, where a fortnightly watering of 10 cm. is made for a period of eight months. In my opinion this figure is too large for the conditions here, for two reasons. In the first place a series of shallow temporary floods will probably lead to more absorption than a single prolonged one, during which the ground will have no chance to dry out or to pass moisture up to the air through the plants rooted in it. In the second place the author of that section of the report has confirmed my suspicion that in thinking of these repeated shallow floods as being easily absorbed he forgot that they were also being dried up by evaporation, and he made no allowance for this, although over such a long period it forms a considerable proportion of the total loss. I understand that in the working of the Jebel Aulia Reservoir a very much smaller absorption depth—of the order of 25 to 50 cm.—is used; but in this case I believe no allowance has been made for inflow, which may quite possibly occur even north of Renk. Certainly one of the known and proven sources of inflow comes into the river only just above Renk, as will be shown in Section VIII (p. 902).

In the Gash, where conditions are perhaps not too dissimilar, the resident engineer Mr. H. Bell has informed me that the allowance for loss by both evaporation and absorption is 80 to 100 cm. This covers a period of about 30 days, in July or August, when the average evaporation may be taken as 5 mm. per day, or 15 cm. in all, and the average rainfall in a month is about 10 cm. Thus the assumed absorption depth there may be taken as between 75 and 95 cm., and it will be seen that although I learnt of this figure after my calculations for its value on the White Nile were complete, there is a surprisingly close agreement between the two results.

METHOD OF CALCULATION

In the following attempt to estimate absorption on the White Nile both the factors of evaporation and rainfall have been allowed for, and I have also done the best I can to eliminate the uncertainties due to inflow. The analysis is in three parts: first an attempt is made to distinguish the years in which during the rising stage inflow was either negligible or small enough to be allowed for; secondly from these years a mean value for the average absorption depth is derived so that the total absorption loss at the peak of the flood can be estimated in all years; and finally a rough and ready method is evolved for interpolating the apparent absorption losses throughout the rising stage in all years, so as to complete the running totals of the computed loss for comparison with those of the observed loss throughout this stage.

It must be clear that although we may derive a value for the total absorption loss, and so for the average depth, when the river has risen to its peak and been steady there for about a month, this depth cannot be used directly to estimate the absorption and total losses during the intermediate stages of the rise. The reason for this is that the actual absorption loss will be offset by an apparent gain due to the delays in filling the side basins and channels; delays which make the true trough volume at any stage and also the total and flood-plain surface areas less than their theoretical values. I have therefore included all these apparent gains, of which by far the largest must be the lag in the trough volume, in a term which I have called the 'apparent' absorption when I am calculating it, and the 'mean' absorption when I am using a mean derived from the apparent values. 'True' absorption can only be shown at and after the end of the flood peak, when all its lags have been taken up. In the individual ten-day periods of the rising stage, or rather at their ends, the apparent absorption can be obtained from the following equation, which is only that of page 855 of Section I expressed in a different form. The equation is:

Apparent Absorption (= True Absorption minus 'gains' due to delays in filling the side-channels)	=	Cumulative Observed Loss minus Theoretical Trough Volume minus Theoretical Evaporation Loss plus Theoretical Rainfall Gain

In using this equation it is clearly only worth while to work from years in which discharges at Renk have been actually measured and are not derived only from a gauge/discharge curve. The year 1930 can therefore not be used. In some of the remaining years, as will be seen from the second parts of Table 404–18, the apparent absorption as derived above is never large and is even negative; I have assumed that in these years the equations are invalidated by inflow, which is deliberately excluded from them. In yet other years it has a negative value to start with, or in the early stages, and in others again after a satisfactory start it suddenly begins to decrease, and becomes negative just when, by theory, it ought to be attaining a comparatively large value. In both these I assume inflow during part of the time, and in the first case I attempt to make an allowance for it. In only two years of recorded discharges at Renk—1944 and 1945—does the apparent absorption behave as theory predicts: starting slowly but steadily increasing at an increasing rate, and then tailing off to a maximum value which is held at the peak of the flood.

SELECTION OF YEARS OF NO INFLOW

After these general remarks we may proceed to the first step of selecting the years from which a mean value of the total average depth of absorption can be derived. In Table 402 (i), p. 874, and Fig. J 2 apparent absorption as derived above is shown for the only six years in which it has a reasonable value. It is compared with Malakal gauge since this can be roughly correlated with the area of the flood-plain, as was shown in Appendix IV of the *Third Interim Report*. The considerable differences in different years did not seem to make it worth while to compare actual computed flood-plain areas and apparent absorption directly, though this should ideally have been done. In Fig. J 2 the different characteristics of the different years can perhaps be distinguished more easily than in Table 402 (i), and reference should be made to it during the discussion which follows.

It will be observed that the curves fall into three different groups:

(a) 1928 and 1936, in which absorption is apparently negative for the first metre or so of the rise, but then increases rapidly so that its final value is quite large.

(b) 1944 and 1945, in which it increases steadily from a very small value to one which is quite large.

(c) 1940 and 1946, in which it starts steadily as in group (b), but suddenly begins to decrease before the river reaches its highest level, and finishes with a very small or even negative value. In both the table and the diagram I have stopped showing its values when it becomes negative.

There are, I think, some grounds for saying that one factor in the apparent absorption should be fairly constant from year to year, assuming a fairly constant rate of rise, and that is the total time-lag between theoretical and observed losses due to the delay in filling the side basins. The large differences which appear in apparent absorption in the early stage between different years can therefore be ascribed with some reason to inflow, assuming a small amount carried on from the previous year. Certainly negative apparent absorption seems to be found following years in which inflow was large, and not found after years when there was either none at all or not very much. Moreover in 1936, when the maximum negative value of the absorption nearly reached 100 millions, there were no actual measurements of the discharge at Renk until the middle of June, and I feel justified in ascribing part of this anomalous absorption at least to a systematic error in the estimated discharges.[4] In 1928, when the absorption seems to have been delayed rather than made permanently negative, there was an unprecedentedly large amount of rain during April (an average for the three stations of nearly 100 mm.), and this must have made conditions unusual if it did not actually arrive as inflow through the tributary khors. On the whole therefore there seems to be a reasonable correlation between the anomalous behaviour of apparent absorption in some years and the conditions in those years.

In postulating inflow in the later stages of the rising river, as in the years of group (c), I am on much firmer ground, for it is confirmed not only by the fact that the discrepancies are otherwise far too large to be accounted for, but also, as will be seen in Section VIII, by records of its actually having been observed in some years. Since in these years the total apparent absorption at the peak of the flood obviously bears no relation to the true absorption, they cannot be used for estimating the average total absorption depth. But the behaviour of their apparent absorption in the early stages before inflow began agrees well with what would be expected. These years therefore also support the general argument and can be used for estimating the mean apparent absorption in the early stages of other years when inflow was apparently present right from the start.

CALCULATION OF AVERAGE DEPTH

The total depth of absorption in each year of the two groups (a) and (b) is calculated in Table 402 (ii) by dividing the maximum value of the apparent absorption approximately one month after the peak of the flood by the maximum area which the flood-plain attains. Since I have assumed in the differentiation of the three groups of years that something in group (a)—either inflow or an error in the discharges—has invalidated the apparent absorption in the early stages, the total in these years is corrected by the addition to it of the maximum value of this inflow or error—in other words the maximum negative value which the apparent absorption attains. This means that the apparent absorption is assumed never to have been negative. This is of course only a rough rule, but it seems justified theoretically and also by the improvement which its application makes in the concordance of the results. By this means the four values shown in the last line of Table 402 (ii) were obtained. They have a mean of 82·5 cm., which may be rounded off to 80 cm., since even its theoretical probable error is of the order of a decimetre. This completes the second step of the analysis of absorption, and we have now to try to find a way of estimating the apparent absorption in the years when it cannot be obtained from the discharges owing to inflow.

CONDITIONS DURING THE RISING STAGE

In Fig. J 2 the dotted black curve was drawn by multiplying the flood-plain area corresponding to different Malakal gauge-readings by 0·8 m., the area having been taken from Diagram 8 of the *Third Interim Report*. It is clear that there is fair agreement with the curves of groups (b) and (c), allowing for a lag which starts at about one month and decreases gradually to zero. This is what one would expect, for as the river rises it overtops its immediate banks and so communicates more and more directly with the lagoons of the flood-plain, until at the highest level there is no barrier at all between it and them. This actual relationship can be seen from a study of the individual cross-sections, of which three were reproduced in Diagram 5 of the *Third Interim Report*.

From these results it would be possible to compute actual absorption and the combined lag of absorption, surface area, and trough volume due to the delay in filling these lagoons. But it would not be possible to distinguish between the different parts of the total. The main purpose of estimating the amount of absorption in the intermediate stages of the rising flood is to complete the items of the computed loss, and so arrive in all years at a computed or theoretical total cumulative loss for each ten-day period which can be compared with the corresponding cumulative observed loss obtained from the discharges. Only thus can the inflow be deduced and its characteristics studied. In short, by assuming that there is no inflow in some years, and that the delays and rate of absorption are the same in others, we arrive at the value and rate of inflow during them. I have therefore first of all computed for each year the total value of absorption during the rising stage, by multiplying the maximum value of the flood-plain area (total surface area at peak minus its value at the start) by 0·8 metre, expressing the result in millions. This gives the mean absorption at the peak, just as the river begins to drop. It may be noted that its theoretical probable error in an average year is something over ten per cent., or about 50 millions. The intermediate values for each ten-day period of the rise are obtained by interpolation, following what appears to be the ideal curve as obtained by a study of Fig. J 2. That is to say the apparent absorption is practically nothing for the first month, or till the Malakal gauge reaches about 10·5, whichever happens latest; and it then increases at an increasing rate for about a month, when the rate of increase remains fairly steady at about 4 millions a day, or more, or less, depending on the height of the flood. Finally, about a month or less before its maximum, the rate of increase tails off again fairly abruptly. This may sound complicated and approximate, but it was quite easy to apply in practice. As to its accuracy no quantitative estimate can be made, but study of the curves of Figs. J 4–9 shows a fair degree of correspondence between the total computed and total observed losses when they are not obviously invalidated by inflow.

In conclusion I should like to add that I fully realize the unsatisfactory nature of this analysis, and the extreme lengths to which the scanty data have been pushed; and I can only justify it by the extreme complexity of the subject and the fact that the results do appear to agree with such previous estimates as are based on similar conditions and where the uncertainty of inflow has either been allowed for or has not been present.

TABLE 402

(i) MALAKAL GAUGE AND APPARENT ABSORPTION IN SOME YEARS

1928–29		1936–37		1940–41		1944–45		1945–46		1946–47	
Malakal Gauge	Appar. Absorp.	Malakal Gauge	Appar. Absorp.	Malakal Gauge	Appar. Absorp.	Malakal Gauge	Appar. Absorp.	Malakal Gauge	Appar. Absorp.	Malakal Gauge	Appar. Absorp.
9·89	2	10·12	(− 33)	10·15	− 3	10·02	− 18	9·44	5	9·53	0
10·09	− 22	10·23	(− 54)	10·38	− 19	10·51	4	9·50	7	9·70	2
10·34	22	10·52	(− 83)	10·68	− 26	10·75	5	10·17	13	9·87	13
10·55	25	10·76	(− 74)	10·86	− 9	10·89	35	10·50	16	10·16	32
10·70	− 9	10·99	47	10·90	+ 5	11·10	46	10·63	29	10·48	27
10·83	+ 21	11·17	− 19	11·09	35	11·22	76	10·83	55	10·77	36
10·97	25	11·31	+ 10	11·30	59	11·34	117	10·99	84	10·97	68
11·12	18	11·43	35	11·46	62	11·48	151	11·14	126	11·11	100
11·26	19	11·54	55	11·55	56	11·64	180	11·27	162	11·23	152
11·40	31	11·65	62	11·69	65	11·70	204	11·42	196	11·56	203
11·53	47	11·75	62	11·81	49	11·77	226	11·60	205	11·83	172
11·70	57	11·83	75	11·85	19	11·86	246	11·72	236	12·37	140
11·90	53	11·91	83	11·89	2	11·99	290	11·79	241	12·61	80
11·94	32	11·97	96	11·92	+ 12	12·03	306	11·96	227	12·74	13
12·01	27	12·04	109	—	—	12·10	320	12·13	261	12·81	− 1
12·09	36	12·08	135	—	—	12·19	345	12·25	299	—	—
12·15	54	12·12	131	—	—	12·22	398	12·34	378	—	—
12·21	67	12·15	136	—	—	12·24	413	12·37	449	—	—
12·28	103	12·17	140	—	—	12·22	401	12·37	518	—	—
12·30	161	12·17	146	—	—	—	—	12·36	568	—	—
12·30	218	—	—	—	—	—	—	12·35	592	—	—
12·30	273	—	—	—	—	—	—	12·34	606	—	—
12·29	312	—	—	—	—	—	—	12·32	607	—	—
12·28	371	—	—	—	—	—	—	—	—	—	—

NOTE: The figures in brackets were not obtained from measured discharges at Renk. Gauges in metres and absorption losses in millions.

TABLE 402 (*continued*)

(ii) CALCULATION OF AVERAGE ABSORPTION DEPTH

	1928	1936	1944	1945
Apparent absorption at peak of flood	371	146	401	607
Correction for maximum negative value of apparent absorption	25	83	18	—
Corrected total absorption	396	229	419	607
Maximum area of flood-plain	484	419	507	601
Average depth of water absorbed in centimetres ...	82	55	83	110

NOTE: All figures are in millions except in the last line.

SECTION VII. ANALYSES OF INDIVIDUAL YEARS

INTRODUCTION

In each of the preceding sections the methods of calculation and estimation for each item have been explained. In Table 403 (pp. 877–83) the working out of one year, 1946–47, is shown in full detail, with a page of explanation opposite each of the three parts which go to make up the table.

In Tables 404–18 (pp. 885–900) summary analyses of the remaining fifteen years for which adequate discharge records exist are shown. These summaries are in two parts only: the first shows the rainfall data and gauge-readings from which the analysis was made, and the second shows the different items and totals of the computed loss. In this part are also shown the observed discharges at Malakal and Renk and the 'observed' losses derived from them. In the last two columns (sometimes one is omitted) are shown the apparent absorption and the inflow, which are both deduced by comparing the observed and computed losses. Table 419 (p. 901) summarizes all these items for the different floods, giving their maximum or final values.

It will be noticed that even the values of these last items have been left to the last figure and not rounded off, though I have tried to eliminate minor differences between the observed and computed totals which are too small to be certainly called inflow, and this is not shown till its cumulative value exceeds 100 millions. I thought that it might be easier for anyone who took the trouble to follow the construction of these tables if the figures were left just as they were obtained by calculation, though of course, particularly in a high flood, the values of the total losses at the end of the flood may have uncertainties of well over a hundred millions.

TABLE 403. COMPLETE ANALYSIS OF ONE YEAR (1946–47)

(i) GAUGE-READINGS AND TROUGH VOLUMES

(ii) RAINFALL AND EVAPORATION

(iii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

TABLE 403 (i). GAUGE-READINGS AND TROUGH VOLUMES

Explanatory Notes

This part of the table shows the gauge-readings and the trough volumes obtained from them. (See Section III).

Cols. (1) and (2) give the gauge-readings at Malakal and Melut respectively. Col. (3) is the direct mean of these, i.e., $\frac{1}{2}[(1) + (2)]$. Col. (4) is the mean of each value in Col. (3) with the one immediately following it in the same column. Thus it is the mean gauge-reading for the Malakal–Melut reach corresponding to the end of the ten-day period at the beginning of the line. Col. (5) is the gauge-reading at Renk for the middle of the ten-day period; and Col. (6) is the direct mean of this with the corresponding gauge-reading at Melut, i.e. $\frac{1}{2}[(5) + (2)]$.

Col. (7) is the mean of each value in Col. (6) with the one immediately following it in the same column; thus it is the mean gauge-reading for the Melut–Renk reach corresponding to the end of the ten-day period at the beginning of the line.

Cols. (8) and (9) are the trough volumes for each of the two reaches corresponding to the mean gauge-readings in Cols. (4) and (7) respectively; they are taken from Table 398, parts (i) and (ii) respectively. The top line, where the figures are in brackets, represents the volumes held above mean gauge-readings of 9·80 corresponding to the mean gauge-readings at the beginnings of Cols. (4) and (7). In this case these are below 9·80 and so the trough volumes are negative. The remaining values in these two columns are obtained by entering Table 398 with the corresponding mean gauge-readings in Cols. (4) and (7), and then adding to the results the figures in the brackets (i.e., 15 in Col. (8) and 12 in Col. (9)).

Col. (10) is the sum of Cols. (8) and (9). It is represented by the dotted line in Fig. J 3.

TABLE 403

COMPLETE ANALYSIS OF ONE YEAR (1946–47)

(i) GAUGE-READINGS AND TROUGH VOLUMES

Ten-day Period	Gauges		Malakal–Melut		Renk Gauge	Melut–Renk		Trough Volumes		
	Malakal	Melut	Direct Mean	At end 10 Days		Direct Mean	At end 10 Days	Malakal–Melut	Melut–Renk	Total
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) (− 15)	(9) (− 12)	(10) (− 27)
April	9·52	9·52	9·52	9·52	9·78	9·65	9·64	0	0	0
May	9·53	9·49	9·51	9·58	9·77	9·63	9·68	3	3	6
	9·70	9·61	9·66	9·74	9·83	9·72	9·78	11	10	21
	9·87	9·76	9·82	9·94	9·92	9·84	9·93	22	25	47
June	10·16	9·97	10·06	10·22	10·06	10·02	10·16	39	49	88
	10·48	10·30	10·39	10·52	10·30	10·30	10·41	59	79	138
	10·77	10·56	10·66	10·77	10·49	10·52	10·62	79	110	189
July	10·97	10·78	10·88	10·95	10·67	10·72	10·80	94	139	233
	11·11	10·94	11·02	11·08	10·83	10·88	10·93	107	161	268
	11·23	11·05	11·14	11·29	10·92	10·98	11·09	129	191	320
August	11·56	11·31	11·44	11·57	11·09	11·20	11·33	163	242	405
	11·83	11·58	11·70	11·95	11·35	11·46	11·65	232	328	560
	12·37	12·02	12·20	12·34	11·67	11·84	11·99	331	444	775
September	12·61	12·33	12·47	12·54	11·96	12·14	12·22	392	546	938
	12·74	12·50	12·62	12·66	12·12	12·31	12·38	433	629	1,062
	12·81	12·60	12·70	12·71	12·28	12·44	12·48	449	686	1,135
October	12·82	12·63	12·72	12·72	12·40	12·52	12·55	453	727	1,180
	12·81	12·64	12·72	12·74	12·51	12·58	12·60	460	757	1,217
	12·84	12·69	12·76	12·78	12·55	12·62	12·63	474	775	1,249
November	12·87	12·71	12·79	12·80	12·58	12·64	12·65	482	787	1,269
	12·90	12·73	12·82	12·82	12·60	12·66	12·66	491	793	1,284
	12·90	12·74	12·82	12·83	12·56	12·65	12·66	495	793	1,288
December	12·92	12·75	12·84	12·84	12·56	12·66	12·64	500	781	1,281
	12·92	12·74	12·83	12·83	12·52	12·63	12·62	495	769	1,264
	12·92	12·74	12·83	12·82	12·50	12·62	12·63	491	775	1,266
January	12·92	12·74	12·83	12·82	12·52	12·63	12·64	491	781	1,272
	12·90	12·74	12·82	12·80	12·53	12·64	12·64	482	781	1,273
	12·84	12·74	12·79	12·74	12·53	12·64	12·63	460	775	1,235
February	12·66	12·70	12·68	12·50	12·53	12·62	12·55	379	727	1,106
	12·12	12·49	12·30	12·00	12·48	12·48	12·32	243	597	840
	11·39	12·00	11·70	11·41	12·32	12·16	11·92	142	418	560
March	10·86	11·37	11·12	10·88	11·98	11·68	11·44	88	269	357
	10·46	10·81	10·64	10·50	11·58	11·19	11·28	58	231	289
	10·23	10·48	10·36	10·30	11·26	11·37	11·01	34	176	210
April	10·13	10·31	10·22	10·23	10·96	10·64	10·59	40	106	146
	10·23	10·26	10·24	10·28	10·82	10·54	10·52	43	95	138
	10·32	10·32	10·32	10·31	10·62	10·50	10·47	45	88	133
May	10·30	10·28	10·30	10·30	10·61	10·45	10·45	44	86	130

NOTES: Gauges are in metres and volumes in millions.
For explanation of the table see the opposite page.

TABLE 403 (ii). RAINFALL AND EVAPORATION

Explanatory Notes

This part of the table shows the basic rainfall data and assumed evaporation depths, and the calculation therefrom of the net evaporation loss. (See Section IV.)

Cols. (1), (2), and (3) show the recorded rainfall for each ten-day period at Malakal, Melut, and Renk respectively, in millimetres. Col. (4) shows the arithmetic mean, or $\frac{1}{3}[(1) + (2) + (3)]$.

Col. (5) is the assumed evaporation in millimetres per day, and Col. (6) is the net evaporation or $(5) - 1/10 \times (4)$. Col. (4) has to be divided by ten to bring it to millimetres per ten-day period.

Col. (7) and Col. (8) are the surface areas corresponding to the middles of the ten-day periods, and are taken from Table 397 using the mean gauges in Cols. (3) and (6) of part (i) of this table. Col. (9) is the sum of these, i.e. $(7) + (8)$. The flood-plain area at any time required for estimating the absorption is derived by subtracting the value in this column from the value at the head of it, which represents the surface area of the low-level channel. In this case it is 130.

Col. (10) is the net evaporation loss for each ten-day period in millions, and is obtained by multiplying the value in Col. (6) by that in Col. (9) and also by the number of days in the period (ten, eleven or eight) and then dividing by 1,000 to bring the result to millions of cubic metres, i.e.,

$$(10) = \frac{(6) \times (9) \times (10, 11 \text{ or } 8)}{1{,}000}$$

TABLE 403 (*continued*)

COMPLETE ANALYSIS OF ONE YEAR (1946–47)

(ii) RAINFALL AND EVAPORATION

Ten-Day Period	Rainfall				Evaporation		Areas			Net Evaporation Loss
	Malakal	Melut	Renk	Mean	Gross Evap.	Net Evap.	Malakal Melut	Melut Renk	Total	
	millimetres				millimetres per day		square kilometres			millions
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
May	3	24	1	9	6	5	50	80	130	6
	0	0	1	0	6	6	52	85	137	8
*	23	55	1	26	6	3	54	99	153	5
June	97	73	79	83	5	−3	57	103	160	− 5
	31	95	37	54	4	−1	70	122	192	− 2
	47	51	4	34	3	0	78	145	223	0
July	47	42	63	51	2	−3	88	161	249	− 8
	8	33	42	28	2	−1	94	175	269	− 3
*	119	59	134	104	2	−8	101	183	284	−25
August	142	41	98	94	2	−7	120	211	331	−24
	103	97	16	72	2	−5	165	257	422	−21
*	64	76	65	68	2	−5	261	345	606	−33
September	58	57	41	52	2	−3	317	458	775	−23
	42	38	41	40	2	−2	341	524	865	−17
	1	8	83	33	2	−1	355	570	925	− 9
October	44	7	35	29	3	0	359	589	948	0
	31	19	101	50	3	−2	359	603	962	−19
*	13	9	0	8	3	+2	367	613	980	+22
November	11	0	4	5	4	3	372	616	988	30
	—	—	—	—	4	4	378	620	998	40
	—	—	—	—	5	5	378	618	996	50
December	—	—	—	—	6	6	382	620	1,002	60
	—	—	—	—	7	7	380	615	995	70
*	—	—	—	—	8	8	380	613	993	88
January	—	—	—	—	8	8	378	618	996	80
	—	—	—	—	9	9	378	618	996	90
*	—	—	—	—	10	10	372	618	990	109
February	—	—	—	—	10	10	344	613	957	96
	—	—	—	—	10	10	269	584	853	85
*	—	—	—	—	10	10	131	477	608	49
March	—	—	—	—	10	10	98	306	404	40
	—	—	—	—	10	10	76	211	287	29
*	—	—	—	—	10	10	67	177	244	26
April	27	6	0	11	8	7	60	157	217	15
	0	0	0	0	8	8	63	147	210	17
	7	11	0	6	8	7	66	144	210	14
May (1)	1	0	0	0	6	6	64	139	203	12

NOTES: The periods marked * are not ten days.
For explanation of this table see the opposite page.

TABLE 403 (iii). CUMULATIVE OBSERVED AND COMPUTED LOSSES

Explanatory Notes

This part of the table shows the observed discharges, the observed losses deduced from them, the computed losses obtained from the previous parts of the table, and the calculation of apparent absorption and deduced inflow which are obtained from comparison of the observed and computed losses. (See Sections II and V.)

Cols. (1) and (2) show the mean observed discharges at Malakal and Renk respectively multiplied by the number of days in the period.

Col. (3) is the difference between them, or (1) − (2).

Col. (4) is the cumulative observed loss, or the cumulative sum of the differences in Col. (3). It is represented by a pecked line in Fig. J 3 and in Figs. J 4, 5, 6, 7, 8 and 9.

Col. (5) is the trough volume held above the mean gauge at the start of the flood, and merely repeats the last column of the first part of this table.

Col. (6) is the cumulative net evaporation and is obtained by summing cumulatively the values given in the last column of the second part of this table. It is represented by the dash and dot line in Fig. J 3.

Col. (7) is the mean absorption. Its maximum value is obtained by subtracting from the maximum area shown in Col. (9) of the second part of this table the area shown at the head of the column, and multiplying the result by 0·8. Intermediate values up to the maximum (of 700 millions reached at the end of November) are obtained by a form of interpolation as described in Section IV. It is represented by the line of crosses in Fig. J 3.

Col. (8) shows the computed total of the cumulative losses, or (5) + (6) + (7). It is represented by the continuous black line in Fig. J 3 and in all the parts of Figs. J 4–9.

Col. (9) shows the apparent absorption, or (4) − (5) − (6). It is not shown when it becomes negative.

Col. (10) shows the deduced inflow or (8) − (4). It is shown only when it exceeds 100 millions.

TABLE 403 (*continued*)

COMPLETE ANALYSIS OF ONE YEAR (1946–47)
(iii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Obser. Loss	Cumve. Obs. Loss	Trough Volume	Cumve. Net Evapor.	Mean Abs.	Cumve. Total	Appar. Abs.	Deduced Inflow
	Malakal	Renk								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
May	354	342	12	12	6	6	0	12	0	—
	390	365	25	37	21	14	0	35	2	—
*	477	435	42	79	47	19	0	66	13	—
June	496	441	55	134	88	14	0	102	32	—
	565	522	43	177	138	12	10	160	27	—
	636	576	60	237	189	12	30	231	36	—
July	690	622	68	305	233	4	50	351	68	—
	729	665	64	369	268	1	80	349	100	—
*	837	758	79	448	320	− 24	120	416	152	—
August	848	736	112	560	405	− 48	160	517	203	—
	924	821	103	663	560	− 69	200	691	172	—
*	1,190	1,040	150	813	775	−102	250	923	140	110
September	1,130	1,050	80	893	938	−125	300	1,113	80	220
	1,160	1,120	40	933	1,062	−142	360	1,280	13	347
	1,210	1,160	50	983	1,135	−151	420	1,404	—	421
October	1,220	1,180	40	1,023	1,180	−151	480	1,509	—	486
	1,200	1,200	0	1,023	1,217	−170	540	1,587	—	564
*	1,360	1,330	30	1,053	1,249	−148	590	1,691	—	638
November	1,240	1,220	20	1,073	1,269	−118	630	1,781	—	708
	1,240	1,210	30	1,103	1,284	− 78	670	1,876	—	773
	1,250	1,190	60	1,163	1,288	− 28	700	1,970	—	807
December	1,250	1,190	60	1,223	1,281	+ 32	700	2,013	—	790
	1,250	1,180	70	1,293	1,264	102	700	2,066	—	773
*	1,380	1,270	110	1,403	1,266	190	700	2,156	—	753
January	1,240	1,170	70	1,473	1,272	270	700	2,242	—	769
	1,200	1,160	40	1,513	1,273	360	700	2,333	—	820
*	1,310	1,270	40	1,553	1,235	469	700	2,404	—	851
February	1,000	1,160	−160	1,393	1,106	565	700	2,371	—	978
	767	1,130	−363	1,030	840	650	700	2,190	—	1,160
*	462	838	−376	654	560	699	700	1,959	—	1,305
March	517	838	−321	333	357	739	700	1,796	—	1,463
	448	641	−193	140	289	768	700	1,757	—	1,617
*	480	599	−119	21	210	794	700	1,704	—	1,683
April	439	496	− 57	− 36	146	809	700	1,655	—	1,691
	512	484	+ 28	− 8	138	826	700	1,664	—	1,672
	484	501	− 16	− 24	133	840	700	1,673	—	1,697
May (1)	482	510	− 28	− 52	130	852	700	1,682	—	1,744

NOTES: The periods marked * are not ten days.
For explanation of the table see the opposite page. All figures are in millions.

TABLES 404–18

SUMMARY ANALYSIS OF FIFTEEN FLOODS ON THE WHITE NILE BETWEEN MALAKAL AND RENK IN THE YEARS 1928 TO 1946

TABLE 404

SUMMARY ANALYSIS OF THE YEAR 1928–29

(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
April ...	9·78	9·76	9·94				6	—
	9·89	9·86	9·96	200	52	46	6	154
	10·09	10·00	10·06				6	162
May ...	10·34	10·18	10·16				6	170
	10·55	10·41	10·32	34	83	43	4	201
*	10·70	10·53	10·43				3	218
June ...	10·83	10·65	10·53				2	234
	10·97	10·78	10·64	115	76	78	2	249
	11·12	10·92	10·71				2	263
July ...	11·26	11·06	10·81				2	282
	11·40	11·19	10·92	195	98	66	2	298
*	11·53	11·32	11·04				2	325
August ...	11·70	11·49	11·18				2	378
	11·90	11·67	11·34	232	95	208	2	448
*	11·94	11·78	11·49				2	499
September	12·01	11·83	11·57				2	525
	12·09	11·90	11·59	156	87	63	2	553
	12·15	11·97	11·61				2	569
October ...	12·21	12·01	11·64				2	586
	12·28	12·08	11·67	94	95	32	2	618
*	12·30	12·11	11·71				2	632
November ...	12·30	12·11	11·73				2	636
	12·30	12·11	11·73	—	—	—	4	636
	12·29	12·11	11·73				6	636
December ...	12·28	12·11	11·74				7	638
	12·23	12·10	11·73	—	—	—	8	630
*	11·94	11·96	11·69				9	559
January ...	11·40	11·62	11·47				10	409
	10·92	11·04	11·10	—	—	—	10	287
*	10·63	10·64	10·74				10	238
February ...	10·43	10·42	10·49				10	209
	10·35	10·31	10·38	—	—	—	10	193
*	10·27	10·23	10·32				10	182
March ...	10·18	10·15	10·25				10	169
	10·10	10·09	10·18	—	—	—	10	166
*	10·01	10·01	10·11				10	159
April (1) ...	9·92	9·94	10·07				10	154

NOTES: Periods marked * are not ten days. Gauges are in metres, rainfall totals are in millimetres per month, evaporation is in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1928–29

(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses				Deduced	
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total	Apparent Absorption	Inflow
April ...	444	421	23	16	5	0	21	2	—
	479	473	29	41	10	0	51	−22	—
May ...	537	501	65	72	15	0	87	−22	—
	588	554	99	105	19	10	134	−25	—
*	692	647	144	132	21	20	173	− 9	—
June ...	658	601	201	161	19	30	210	+21	—
	689	656	234	192	17	50	259	25	—
	721	698	257	225	14	60	299	18	—
July ...	758	727	288	261	8	80	349	19	—
	802	759	331	298	2	110	410	31	—
*	926	869	388	345	− 4	130	471	47	—
August	886	829	445	408	− 20	160	548	57	103
	929	887	487	472	− 38	190	624	53	137
*	1,035	1,032	490	516	− 58	230	688	32	198
September	964	954	500	547	− 74	260	733	27	233
	997	975	522	577	− 91	290	776	36	254
	1,020	991	551	605	−108	320	817	54	266
October	1,040	1,010	581	633	−119	340	854	67	273
	1,070	1,010	641	657	−119	350	888	103	267
*	1,200	1,120	721	667	−107	360	920	161	199
November	1,090	1,020	791	667	− 94	370	943	218	152
	1,090	1,010	871	667	− 69	380	978	273	107
	1,060	983	948	667	− 31	390	1,026	312	—
December	1,060	968	1,040	662	+ 7	390	1,059	371	—
	1,020	980	1,080	609	57	390	1,056	414	—
*	969	1,039	1,010	474	113	390	977	423	—
January	701	868	843	306	153	390	849	—	—
	611	703	751	184	181	390	755	—	—
*	612	656	707	114	205	390	709	—	—
February	518	534	691	78	226	390	694	—	—
	502	522	671	62	245	390	697	—	—
*	390	400	661	49	263	390	702	—	—
March ...	470	486	645	36	280	390	700	—	—
	458	463	640	23	287	390	700	—	—
*	486	479	647	11	313	390	714	—	—
April (1)	429	451	625	− 2	328	390	716	—	—

NOTES: Periods marked * are not ten days. All figures are in millions. Apparent absorption is not shown after the peak of the flood, and deduced inflow is only shown when its cumulative value exceeds 100 millions.
Trough volumes are calculated and not taken from Table 398.

TABLE 405

SUMMARY ANALYSIS OF THE YEAR 1929–30

(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
April ...							7	—
	9·88	9·84	9·96	38	11	14	6	—
	10·19	10·03	10·06				5	156
May ...	10·60	10·42	10·32				5	203
	10·70	10·55	10·47	133	53	89	5	221
*	10·92	10·72	10·58				5	241
June ...	11·12	10·90	10·72				4	261
	11·28	11·06	10·85	180	98	25	4	283
	11·38	11·17	10·95				4	300
July ...	11·51	11·30	11·04				3	321
	11·62	11·43	11·16	224	153	222	3	330
*	11·80	11·64	11·31				3	341
August ...	11·89	11·76	11·44				2	480
	11·94	11·80	11·53	290	50	130	2	506
*	12·01	11·84	11·57				2	525
September ...	12·10	11·95	11·65				2	566
	12·16	12·01	11·71	76	124	52	2	598
	12·18	12·04	11·73				2	607
October ...	12·26	12·10	11·74				2	633
	12·33	12·14	11·75	106	62	63	3	650
*	12·34	12·17	11·77				4	665
November ...	12·36	12·18	11·76				5	667
	12·34	12·18	11·76	34	5	—	6	665
	12·33	12·16	11·75				7	659
December ...	12·33	12·16	11·73				8	652
	12·32	12·15	11·73	—	—	—	9	652
*	12·25	12·11	11·71				10	629
January ...	11·96	11·97	11·67				10	562
	11·43	11·58	11·47	—	—	—	10	402
*	10·98	11·01	11·06				10	283
February ...	10·74	10·70	10·72				10	243
	10·49	10·47	10·53	—	—	—	10	216
*	10·32	10·29*	10·37				10	190
March ...	10·30	10·22	10·26				10	179
	10·25	10·19	10·24	—	—	—	10	171
*	10·09	10·06	10·17				10	164
April (1) ...	9·97	9·94	10·09				8	158

NOTES: Periods marked * are not ten days. Gauges are in metres, rainfall totals are in millimetres per month, evaporation is in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1929–30

(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses				Deduced	
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total	Apparent Absorption	Inflow
April (3)	504	464	40	42	6	0	48		—
May ...	596	549	87	92	10	0	102		—
	619	611	95	124	14	10	148		—
*	742	690	147	164	19	20	203		—
June ...	728	670	205	208	22	30	260		—
	771	710	266	244	25	40	309	N	—
	800	743	323	276	28	60	364		—
July ...	838	778	383	308	15	80	403	E	—
	862	800	445	364	1	100	465		—
*	984	943	486	436	−16	120	540	V	—
August	913	902	497	477	−30	140	587		—
	922	957	462	502	−45	170	627	E	165
*	1,037	1,045	454	541	−61	200	680		226
September	976	981	449	586	−67	230	749	R	300
	998	1,000	447	610	−73	260	797		350
	1,010	1,010	447	633	−79	300	854	P	407
October	1,050	1,020	477	659	−85	330	904		427
	1,070	1,040	507	678	−85	360	953	O	446
*	1,190	1,160	537	691	−78	390	1,003		466
November	1,090	1,030	597	691	−45	400	1,046	S	449
	1,040	1,040	597	686	− 5	410	1,091		494
	1,020	1,030	587	675	+41	410	1,126	I	539
December	1,020	1,020	587	671	93	410	1,174		587
	1,010	1,010	587	655	152	410	1,217	T	630
*	1,050	1,090	547	597	215	410	1,222		675
January	854	966	435	438	271	410	1,134	I	699
	689	908	216	284	311	410	1,005	V	789
*	639	818	37	183	339	410	932		935
February	546	627	− 44	118	363	410	891	E	935
	503	566	−107	76	385	410	871		978
*	377	433	−163	52	404	410	866		1,029
March ...	466	507	−204	43	422	410	875		1,079
	458	499	−245	31	439	410	880		1,125
*	477	526	−294	12	445	410	867		1,161
April (1)	416	461	−339	4	467	410	881		1,220

NOTES: The periods marked * are not ten days. All figures are in millions. The volumes have been calculated and are not taken from Table 398. Apparent absorption is not shown because it is never positive; deduced inflow is only shown when its cumulative value exceeds 100 millions.

TABLE 406

SUMMARY ANALYSIS OF THE YEAR 1930-31

(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
April ...	9·97	9·94	10·09				—	—
	10·06	9·92	10·04	35	—	—	7	158
	10·08	10·00	10·10				7	161
May ...	10·19	10·10	10·13				6	164
	10·12	10·11	10·18	62	35	21	6	165
*	10·13	10·10	10·14				6	164
June ...	10·34	10·24	10·22				4	178
	10·69	10·53	10·41	99	60	71	4	216
	10·92	10·75	10·58				4	243
July ...	11·05	10·90	10·72				3	260
	11·16	11·00	10·81	92	99	86	3	275
*	11·31	11·13	10·90				3	291
August ...	11·40	11·24	11·01				2	309
	11·50	11·35	11·12	170	161	186	2	333
*	11·56	11·42	11·19				2	355
September ...	11·64	11·51	11·24				2	382
	11·71	11·57	11·28	70	44	91	2	401
	11·75	11·62	11·30				2	419
October ...	11·79	11·66	11·33				2	436
	11·82	11·68	11·35	76	54	30	2	447
*	11·82	11·69	11·34				2	449
November ...	11·84	11·70	11·36				2	453
	11·83	11·70	11·36	20	—	—	4	451
	11·72	11·64	11·34				5	426
December ...	11·40	11·42	11·25				6	348
	11·01	11·06	11·03	—	—	—	7	288
*	10·73	10·77	10·78				8	247
January ...	10·44	10·47	10·54				9	215
	10·24	10·26	10·35	—	—	—	10	184
*	10·13	10·14	10·21				10	167
February ...	10·00	10·02	10·13				10	160
	9·92	9·95	10·05	—	—	—	10	158
*	9·86	9·88	10·00				10	155
March ...	9·84	9·85	9·96				10	153
	9·74	9·79	9·93	—	—	—	10	151
*	9·71	9·74	9·90				10	150
April ...	9·71	9·75	9·92				10	150
	9·72	9·74	9·91	3	10	—	9	150
	9·71	9·74	9·91				8	150
May (1) ...	9·66	9·70	9·88	(18)	(5)	(15)	7	150

NOTES: Periods marked * are not ten days. Gauges are in metres, rainfall totals are in millimetres per month, but for May (1) 1931 one-third of the total is given (in brackets). Evaporation is in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1930-31

(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses			
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total
April ...	455	454†	1	4	14	0	18
	467	468†	−1	16	27	0	43
May ...	506	484†	21	22	39	0	61
	485	492†	14	21	47	0	68
*	540	533†	21	30	52	0	82
June ...	540	513	48	66	56	0	122
	617	573	92	118	58	10	186
	672	631	133	161	58	20	239
July ...	712	677	168	192	58	40	290
	750	708	210	222	58	60	340
*	883	811	282	255	58	80	393
August ...	829	772	339	288	46	100	434
	852	805	386	317	33	120	470
*	950	913	423	342	18	140	500
September	878	848	453	368	18	160	546
	890	858	485	385	18	180	583
	899	868	516	401	18	200	619
October ...	907	878	545	416	18	210	644
	915	883	577	422	18	220	660
*	1,007	969	615	424	18	230	672
November	919	886	648	424	27	240	691
	904	874	678	412	45	240	697
	845	809	714	357	67	240	664
December	734	772	676	268	88	240	596
	647	698	625	183	108	240	531
*	663	683	604	114	130	240	484
January ...	530	562	572	62	149	240	451
	497	517	552	33	167	240	440
*	523	529	546	14	186	240	440
February	439	459	526	− 1	203	240	442
	422	435	513	−12	220	240	448
*	340	334	519	−20	234	240	454
March ...	410	408	521	−27	249	240	462
	402	397	526	−34	264	240	470
*	438	423	541	−36	280	240	484
April ...	398	394	545	−36	295	240	499
	399	391	553	−37	309	240	512
	398	391	560	−39	321	240	522
May (1) ...	391	380	571	−41	330	240	529

NOTES: The periods marked * are not ten days. The discharges marked † are the only ones at Renk which are based on actual measurements. All figures are in millions. Apparent absorption is not shown in view of the lack of measured discharges at Renk. The same applies to deduced inflow which in any case does not exceed 100 millions. Trough volumes are calculated and not taken from Table 398.

TABLE 407

SUMMARY ANALYSIS OF THE YEAR 1931-32

(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
April (3) ...	9·71	9·74	9·90	—	—	—	—	—
May ...	9·66	9·70	9·88				7	151
	9·73	9·70	9·85	54	16	46	6	151
*	9·85	9·80	9·92				5	153
June ...	10·14	10·00	10·03				5	160
	10·37	10·23	10·21	59	71	94	4	177
	10·65	10·43	10·32				4	205
July ...	10·99	10·74	10·52				3	241
	11·19	10·97	10·74	112	141	290	3	271
*	11·35	11·15	10·89				3	293
August ...	11·48	11·30	11·02				2	320
	11·62	11·44	11·12	127	143	120	2	359
*	11·72	11·58	11·25				2	403
September ...	11·85	11·70	11·36				2	455
	12·00	11·86	11·45	277	146	104	2	521
	12·05	11·94	11·56				2	555
October ...	12·12	12·01	11·61				2	574
	12·19	12·06	11·64	92	72	78	2	596
*	12·22	12·10	11·67				2	612
November ...	12·28	12·13	11·70				4	632
	12·27	12·15	11·72	—	15	—	6	645
	12·26	12·16	11·73				8	645
December ...	12·23	12·14	11·73				8	640
	12·09	12·08	11·72	—	—	—	9	607
*	11·63	11·85	11·62				0	593
January ...	11·01	11·45	11·25				10	340
	10·58	10·84	10·82	—	—	—	10	250
*	10·38	10·41	10·49				10	208
February ...	10·27	10·27	10·33				10	185
	10·19	10·19	10·25	—	—	—	10	171
*	10·11	10·11	10·20				10	166
March ...	10·04	10·04	10·14				10	162
	9·99	9·98	10·09	—	—	—	10	159
*	9·96	9·97	10·08				10	158
April ...	9·94	9·94	10·07				10	158
	9·99	9·96	10·09	15	—	—	9	158
	9·98	9·97	10·08				8	158
May (1) ...	9·98	9·96	10·06	(9)	(14)	(7)	8	158

NOTES: Periods marked * are not ten days. Gauges are in metres. Rainfall totals are in millimetres per month, but for May (1) 1932 one-third of the total is given (in brackets). Evaporation is in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1931–32

(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses				Deduced Inflow
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total	
May ...	391	380	11	−2	9	0	7	—
	403	378	36	5	17	0	22	—
*	473	455	54	26	23	0	49	—
June ...	494	449	99	59	26	0	85	—
	560	511	148	95	30	0	125	—
	634	546	236	143	34	10	187	—
July ...	704	612	328	204	27	30	261	—
	746	683	391	256	19	50	325	—
*	859	806	444	301	10	70	381	—
August ...	815	774	485	343	4	100	447	—
	855	807	533	391	− 3	130	518	—
*	972	933	572	445	−11	160	594	—
September ...	921	888	605	504	−29	190	665	—
	967	918	654	555	−50	210	715	—
	982	964	672	597	−72	240	765	—
October ...	1,000	982	690	628	−78	280	830	140
	1,030	992	728	651	−84	320	887	159
*	1,140	1,100	768	675	−90	360	945	177
November ...	1,070	1,020	818	691	−71	380	1,000	182
	1,050	1,020	848	698	−39	390	1,049	201
	1,040	1,020	868	695	+ 6	400	1,101	233
December ...	1,020	979	909	670	57	400	1,127	218
	948	971	886	585	112	400	1,097	211
*	848	1,020	714	426	178	400	1,004	290
January ...	597	776	535	265	212	400	877	342
	553	633	455	153	237	400	790	335
*	554	605	404	100	260	400	760	356
February ...	482	513	373	78	278	400	756	383
	468	491	330	65	295	400	760	410
*	410	431	329	52	310	400	762	433
March ...	446	461	314	42	326	400	779	465
	440	447	307	37	342	400	779	472
*	479	486	300	34	360	400	794	494
April ...	432	441	291	34	376	400	810	519
	442	446	287	36	390	400	826	539
	439	444	282	36	402	400	838	556
May (1) ...	440	435	287	50	413	400	863	576

NOTES: The periods marked * are not ten days. No discharges were measured at Renk during this flood. Volumes were obtained from Table 398. All figures are in millions. The apparent absorption is not shown in view of the lack of measured discharges at Renk. The deduced inflow is shown only when it exceeds 100 millions; its value cannot be relied on for the same reason.

TABLE 408

SUMMARY ANALYSIS OF THE YEAR 1932–33

(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
April (3) ...	9·98	9·97	10·08	—	—	—	—	—
May ...	9·98	9·96	10·06				8	158
	10·13	10·02	10·06	26	42	20	6	161
*	10·44	10·28	10·21				5	183
June ...	10·84	10·60	10·42				4	225
	11·02	10·80	10·58	124	68	133	3	248
	11·14	10·93	10·71				2	266
July ...	11·25	11·04	10·81				2	280
	11·41	11·17	10·90	171	86	84	2	297
*	11·58	11·36	11·04				2	336
August ...	11·74	11·60	11·18				2	400
	11·87	11·78	11·31	118	142	74	2	443
*	11·97	11·90	11·42				2	523
September ...	12·09	11·94	11·49				2	552
	12·25	11·99	11·61	245	98	107	2	579
	12·47	12·11	11·70				2	647
October ...	12·59	12·20	11·79				2	708
	12·68	12·38	11·87	58	22	76	2	777
*	12·75	12·47	11·94				2	820
November ...	12·79	12·50	11·98				5	841
	12·83	12·52	12·01	—	—	2	6	856
	12·88	12·57	12·04				7	879
December ...	12·91	12·61	12·08				7	902
	12·92	12·65	12·12	—	—	—	8	922
*	12·91	12·67	12·14				9	932
January ...	12·87	12·68	12·16				10	935
	12·75	12·64	12·18	—	—	—	10	917
*	12·39	12·47	12·14				10	832
February ...	11·65	11·91	11·92				10	556
	11·06	11·30	11·41	—	—	—	10	339
*	10·76	10·84	10·94				10	260
March ...	10·62	10·64	10·65				10	228
	10·50	10·51	10·52	—	—	—	10	218
*	10·43	10·41	10·41				10	205
April ...	10·48	10·40	10·40				10	204
	10·45	10·40	10·40	—	—	—	9	204
	10·37	10·35	10·37				8	196
May (1) ...	10·29	10·27	10·31	(9)	(11)	(12)	7	185

NOTES: Periods marked * are not ten days. Gauges are in metres. Rainfall totals are in monthly totals of millimetres, but for May (1) 1933 one-third of the total is given (in brackets). Evaporation is in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1932–33

(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses				Deduced Inflow
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total	
May ...	440	435	5	3	11	0	14	—
	475	448	32	27	20	0	47	—
*	597	562	67	78	26	10	114	—
June ...	617	577	107	132	26	20	178	—
	670	631	146	172	24	40	236	—
	715	674	187	200	19	60	279	—
July ...	755	705	237	233	13	80	326	—
	795	736	296	278	7	100	385	—
*	915	858	353	340	0	130	470	117
August ...	880	826	407	406	− 8	160	558	151
	918	873	452	472	− 17	190	645	193
*	1,042	999	495	521	− 28	220	713	218
September ...	980	935	540	564	− 45	250	769	229
	1,030	979	590	626	− 62	280	844	254
	1,110	1,010	690	702	− 81	310	931	241
October ...	1,160	1,040	810	782	− 95	340	1,027	217
	1,190	1,070	930	861	− 95	380	1,146	216
*	1,330	1,229	1,031	907	− 69	420	1,258	227
November ...	1,230	1,110	1,151	936	− 27	460	1,369	218
	1,240	1,120	1,271	964	+ 24	500	1,488	217
	1,250	1,130†	1,391	999	85	540	1,625	234
December ...	1,260	1,140†	1,511	1,031	148	580	1,759	248
	1,260	1,160†	1,611	1,050	222	600	1,872	261
*	1,350	1,290†	1,671	1,062	314	610	1,986	315
January ...	1,190	1,170†	1,691	1,053	408	620	2,081	390
	1,130	1,180†	1,641	959	500	620	2,079	438
*	1,100	1,240†	1,501	703	591	620	1,914	413
February ...	729	944†	1,236	418	647	620	1,685	449
	627	819†	1,044	237	681	620	1,538	494
*	467	542†	969	150	703	620	1,473	504
March ...	558	600	927	108	726	620	1,454	527
	536	566	897	83	748	620	1,451	554
*	573	596	874	73	770	620	1,463	589
April ...	537	539	872	73	790	620	1,483	611
	537	539	870	67	808	620	1,495	625
	524	532	862	54	824	620	1,498	636
May (1) ...	505	522	845	52	835	620	1,507	662

NOTES: The periods marked * are not ten days. Only the discharges marked † are based on actual measurements at Renk. Since none of these were made during the rising stage no values are shown for apparent absorption. Deduced inflow is shown only when it exceeds 100 millions, and its value cannot be relied on for the above reason.

TABLE 409

SUMMARY ANALYSIS OF THE YEAR 1936–37
(i) THE DATA

Ten-Day Period	Gauges: Malakal	Gauges: Melut	Gauges: Renk	Rainfall: Malakal	Rainfall: Melut	Rainfall: Renk	Assumed Gross Evaporation	Total Surface Area
April (3) ...	10·09	10·00	10·06	—	—	—	—	—
May ...	10·12	10·06	10·13				6	163
	10·23	10·12	10·14	66	36	29	5	167
*	10·52	10·33	10·29				4	193
June ...	10·76	10·56	10·44				4	221
	10·99	10·76	10·58	90	140	142	3	243
	11·17	10·95	10·75				2	268
July ...	11·31	11·10	10·88				2	288
	11·43	11·23	10·99	174	216	84	2	309
*	11·54	11·35	11·09				2	336
August ...	11·65	11·47	11·19				2	369
	11·75	11·61	11·31	154	98	183	2	418
*	11·83	11·67	11·40				2	455
September ...	11·91	11·73	11·49				2	483
	11·97	11·80	11·56	86	86	137	2	511
	12·04	11·85	11·59				2	536
October ...	12·08	11·90	11·60				2	555
	12·12	11·93	11·61	57	40	98	3	563
*	12·15	11·95	11·61				4	567
November ...	12·17	11·98	11·64				5	582
	12·17	11·98	11·64	5	—	—	6	582
	12·15	11·98	11·64				7	579
December ...	12·06	11·94	11·64				8	563
	11·75	11·77	11·57	21	—	—	9	480
*	11·24	11·35	11·31				10	340
January ...	10·82	10·88	10·93				10	264
	10·59	10·58	10·63	—	—	—	10	229
*	10·40	10·37	10·43				10	203
February ...	10·30	10·26	10·33				10	187
	10·24	10·19	10·27	—	—	—	10	175
*	10·22	10·15	10·23				10	169
March ...	10·19	10·13	10·21				10	168
	10·11	10·07	10·20	—	—	—	10	164
*	9·98	9·97	10·18				10	159
April ...	9·89	9·88	10·10				9	157
	9·84	9·83	10·03	27	—	—	8	154
	9·87	9·82	10·02				7	152

NOTES: Periods marked * are not ten days. Gauges are in metres. Rainfall totals are in millimetres per month, evaporation is in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1936–37
(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges: Malakal	Discharges: Renk	Cumulative Observed Loss	Computed Losses: Trough Volume	Computed Losses: Net Evaporation	Computed Losses: Mean Absorption	Computed Losses: Total	Deduced: Apparent Absorption	Deduced: Inflow
May ...	467	483†	− 16	11	6	0	17	− 33	—
	492	487†	− 11	32	11	0	43	− 54	—
*	606	588†	+ 7	75	15	0	90	− 83	—
June ...	627	577†	57	116	13	10	141	− 74	—
	686	615	128	162	13	20	195	− 47	—
*	717	651	194	205	8	40	253	− 19	—
July ...	743	686	251	242	− 1	60	301	+ 10	—
	772	721	302	277	− 10	80	347	35	—
*	878	828	352	317	− 20	100	397	55	—
August	823	782	393	362	− 31	120	451	62	—
	847	817	423	405	− 44	140	501	62	—
*	954	923	454	437	− 58	160	539	75	—
September	892	857	489	469	− 63	180	586	83	—
	918	880	527	499	− 68	200	631	96	104
	938	906	559	523	− 73	230	680	109	121
October	952	911	600	538	− 73	260	725	135	125
	963	944	619	555	− 67	290	778	131	159
*	1,066	1,039	646	566	− 36	310	820	136	174
November	973	933	686	573	− 27	320	866	140	180
	968	929	725	571	+ 8	330	909	146	184
	935	929	731	558	49	340	947	124	216
December	883	916	698	503	94	340	937	—	239
	793	861	630	375	137	340	852	—	222
*	729	828	531	237	174	340	751	—	220
January	577	612	496	139	200	340	679	—	183
	525	534	487	81	223	340	644	—	157
*	542	545	484	50	245	340	635	—	151
February	482	473	493	34	264	340	638	—	145
	468	456	505	25	282	340	647	—	142
*	·370	353	522	20	296	340	656	—	134
March ...	449	436	535	15	313	340	668	—	133
	430	432	533	4	329	340	673	—	140
*	462	466	529	− 9	347	340	678	—	149
April ...	411	408	522	− 21	361	340	680	—	158
	405	403	534	− 26	373	340	687	—	153
	420	403	551	− 23	384	340	701	—	150

NOTES: The periods marked * are not ten days. Discharges at Renk marked † were not based on measurements. Apparent absorption is shown up to the peak of the flood, and inflow is shown only when it exceeds 100 millions. All figures are in millions.

TABLE 410

SUMMARY ANALYSIS OF THE YEAR 1937–38
(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
April (3) ...	9·87	9·82	10·02	—	—	—	—	—
May ...	9·94	9·87	10·00				6	155
	10·18	10·04	10·10	36	55	75	5	161
*	10·46	10·28	10·26				4	186
June ...	10·79	10·58	10·44				4	223
	10·95	10·74	10·39	141	129	33	4	243
	11·06	10·86	10·69				4	257
July ...	11·17	10·98	10·80				3	274
	11·30	11·09	10·91	200	127	88	3	288
*	11·46	11·23	11·02				3	311
August	11·86	11·54	11·20				2	403
	11·96	11·74	11·42	175	219	170	2	483
*	12·05	11·85	11·61				2	538
September ...	12·12	11·92	11·68				2	566
	12·20	11·99	11·70	90	71	61	2	591
	12·27	12·05	11·72				2	614
October ...	12·35	12·12	11·75				2	647
	12·39	12·16	11·82	47	94	34	3	671
*	12·44	12·21	11·82				4	699
November ...	12·43	12·22	11·85				5	706
	12·41	12·21	11·86	—	—	—	6	704
	12·38	12·20	11·86				7	697
December ...	12·33	12·17	11·85				8	673
	12·19	12·10	11·83	—	—	—	9	643
*	11·80	11·87	11·74				10	524
January ...	11·24	11·38	11·45				10	357
	10·81	10·89	11·04	—	—	—	10	268
*	10·57	10·53	10·68				10	227
February ...	10·45	10·40	10·50				10	208
	10·34	10·30	10·39	—	—	—	10	191
*	10·25	10·20	10·31				10	177
March ...	10·24	10·17	10·25				10	171
	10·25	10·16	10·22	—	—	—	10	169
*	10·30	10·22	10·26				10	177
April ...	10·11	10·11	10·23				8	166
	10·09	10·01	10·13	—	—	—	8	161

Notes: Periods marked * are not ten days. Gauges are in metres. Rainfall totals are in millimetres per month, evaporation is in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1937–38
(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses				Deduced	
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total	Apparent Absorption	Inflow
May ...	439	406	33	15	6	0	21	12	—
	492	446	79	47	11	0	58	21	—
*	610	552	137	92	15	0	107	30	—
June ...	626	569	194	139	17	10	166	38	—
	661	617	238	172	19	20	211	47	—
	689	648	279	202	22	40	264	55	—
July ...	715	689	305	232	17	60	309	56	—
	745	729	321	268	11	90	369	42	—
*	861	843	339	334	5	120	459	—	120
August	883	824	398	433	− 11	150	572	—	174
	909	892	415	508	− 30	180	658	—	243
*	1,029	1,031	413	557	− 52	210	715	—	302
September	959	957	415	596	− 52	240	784	—	369
	986	971	430	626	− 52	280	854	—	424
	1,020	999	451	662	− 52	320	930	—	479
October	1,060	1,020	491	697	− 52	350	995	—	504
	1,070	1,040	521	721	− 45	370	1,048	—	527
*	1,190	1,140	571	739	− 31	390	1,098	—	527
November	1,060	1,050	581	746	+ 4	410	1,160	—	579
	1,020	1,050	551	740	46	430	1,216	—	665
	994	1,030	515	719	95	440	1,254	—	739
December	966	1,020	461	688	149	440	1,277	—	816
	912	988	385	600	207	440	1,247	—	8C2
*	875	1,014	246	436	264	440	1,140	—	894
January	653	819	80	274	300	440	1,014	—	934
	565	658	− 13	174	327	440	941	—	954
*	577	604	− 40	109	352	440	901	—	941
February	505	513	− 48	84	372	440	896	—	944
	479	494	− 63	64	391	440	895	—	958
*	364	384	− 83	53	405	440	898	—	981
March ...	453	470	− 100	48	422	440	910	—	1,010
	459	467	− 108	52	439	440	931	—	1,039
*	524	520	− 104	47	457	440	944	—	1,048
April ...	451	467	− 120	32	470	440	942	—	1,063
	460	451	− 111	27	483	440	950	—	1,061

Notes: The periods marked * are not ten days. All figures are in millions. The apparent absorption is shown only as long as it remains positive, and the deduced inflow is not shown until it exceeds 100 millions.

TABLE 411

SUMMARY ANALYSIS OF THE YEAR 1938–39
(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
April ...	10·11	10·11	10·23	—	—	—	—	—
	10·09	10·01	10·13	—	—	—	8	160
	10·14	10·05	10·14	52	6	19	8	162
May ...	10·18	10·07	10·16	78	—	—	8	164
	10·31	10·18	10·24	38	—	12	7	172
*	10·34	10·21	10·26	33	4	1	6	180
June ...	10·57	10·35	10·33	25	18	—	5	198
	10·88	10·63	10·51	2	33	2	4	232
	11·10	10·83	10·66	31	7	22	3	254
July ...	11·30	11·04	10·82	44	70	12	2	282
	11·44	11·19	10·98	88	11	90	2	306
*	11·59	11·34	11·10	70	106	35	2	336
August ...	11·74	11·52	11·26	17	49	15	2	392
	11·83	11·63	11·40	11	90	69	2	443
*	11·96	11·74	11·51	45	72	37	2	492
September ...	12·06	11·86	11·66	230	62	70	1	547
	12·13	11·96	11·74	40	60	18	1	588
	12·23	12·04	11·83	14	11	38	1	635
October ...	12·34	12·12	11·90	66	54	—	2	676
	12·49	12·25	11·90	9	26	11	2	732
*	12·58	12·36	11·96	—	8	—	2	783
November ...	12·62	12·41	12·00	—	—	—	4	806
	12·62	12·41	12·03	—	—	—	6	814
*	12·61	12·41	12·04	—	—	—	8	810
December ...	12·60	12·40	12·05	—	—	—	9	810
	12·60	12·38	12·04	—	—	—	10	804
	12·62	12·39	12·03	—	—	—	10	810
January ...	12·63	12·41	12·04	—	—	—	10	814
	12·59	12·39	12·06	—	—	—	10	808
*	12·34	12·31	12·04	—	—	—	10	758
February ...	11·68	11·92	11·91	—	—	—	10	560
	11·09	11·24	11·48	—	—	—	10	337
*	10·74	10·78	11·02	—	—	—	10	259
March ...	10·57	10·50	10·75	—	—	—	10	229
	10·51	10·44	10·61	—	—	—	10	217
*	10·36	10·32	10·51	—	—	—	10	202
April ...	10·28	10·20	10·34	—	49	—	7	181

NOTES: The periods marked * are not ten days. Gauges are in metres. The rainfall totals are in millimetres for each ten-day period. Evaporation is in millimetres per day and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1938–39
(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses				Deduced	
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total	Apparent Absorption	Inflow
April ...	460	451	9	– 3	13	0	10	– 1	—
	472	454	27	+ 3	23	0	26	– 1	—
May ...	477	461	43	13	31	0	44	– 1	—
	497	490	50	24	39	0	63	– 13	
*	553	548	55	40	48	0	88	– 33	—
June ...	551	519	87	71	56	10	137	– 40	—
	640	581	146	129	63	30	222	– 46	—
	707	626	227	177	66	50	293	– 16	—
July ...	750	689	288	224	60	70	354	+ 4	—
	784	746	326	270	48	100	418	8	—
*	898	865	359	321	31	130	482	7	123
August	852	828	383	381	27	170	578	—	195
	871	863	391	430	9	210	649	—	258
*	989	983	397	488	– 6	250	732	—	335
September	923	938	382	545	– 66	290	769	—	387
	947	971	358	602	– 84	330	848	—	490
	988	1,020	326	654	– 90	370	934	—	608
October	1,030	1,040	316	711	– 103	410	1,018	—	702
	1,070	1,040	346	780	– 103	450	1,127	—	781
*	1,200	1,170	376	832	– 87	480	1,225	—	849
November	1,100	1,070	406	854	– 55	490	1,289	—	883
	1,100	1,080	426	859	– 22	500	1,337	—	911
	1,100	1,080	446	852	+ 42	510	1,404	—	958
December	1,090	1,080	456	852	115	520	1,487	—	1,031
	1,090	1,080	466	847	196	520	1,543	—	1,077
*	1,210	1,190	486	855	285	520	1,660	—	1,174
January	1,110	1,080	516	852	366	520	1,738	—	1,222
	1,060	1,070	506	811	447	520	1,778	—	1,272
*	1,005	1,150	361	654	530	520	1,704	—	1,343
February	724	961	124	403	586	520	1,509	—	1,385
	609	774	– 41	221	620	520	1,361	—	1,402
*	446	520	– 115	129	642	520	1,291	—	1,406
March	531	569	– 153	89	665	520	1,274	—	1,427
	523	534	– 164	66	687	520	1,273	—	1,437
*	541	565	– 188	42	709	520	1,271	—	1,459
April (1)	475	488	– 201	33	718	520	1,271	—	1,472

NOTES: The periods marked * are not ten days. All figures are in millions. The apparent absorption is not shown once it has become definitely negative with a fairly high gauge; and the deduced inflow is not shown until it exceeds 100 millions.

TABLE 412

SUMMARY ANALYSIS OF THE YEAR 1939–40

(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
April (3) ...	10·48	10·37	10·39	—	—	—	—	—
May ...	10·39	10·28	10·33	78	7	13	5	189
	10·60	10·40	10·37	37	—	9	5	204
*	10·93	10·66	10·56	33	57	8	5	238
June ...	11·12	10·89	10·74	28	59	3	4	262
	11·26	11·02	10·84	2	71	29	4	281
	11·39	11·15	10·95	31	58	52	4	297
July ...	11·51	11·27	11·05	44	61	5	3	319
	11·62	11·40	11·16	88	7	33	3	356
*	11·71	11·51	11·27	70	27	13	2	388
August ...	11·80	11·60	11·39	16	51	9	2	432
	11·88	11·69	11·54	12	35	45	3	477
*	11·96	11·76	11·64	45	22	89	2	510
September ...	12·05	11·85	11·68	232	58	56	2	544
	12·12	11·91	11·71	40	78	64	2	571
	12·16	11·94	11·70	13	22	1	2	578
October ...	12·18	11·97	11·72	66	7	3	2	589
	12·22	12·01	11·75	9	20	16	3	610
*	12·24	12·04	11·78	—	7	1	4	624
November ...	12·25	12·04	11·80	—	—	—	5	628
	12·26	12·05	11·81	—	—	—	6	633
	12·25	12·05	11·82	—	—	—	7	636
December ...	12·21	12·03	11·82	—	—	—	8	624
	12·03	11·94	11·79	—	—	—	9	570
*	11·50	11·59	11·65	—	—	—	10	431
January ...	10·97	11·06	11·25	—	—	—	10	300
	10·70	10·68	10·90	—	—	—	10	246
*	10·50	10·46	10·70	—	—	—	10	224
February ...	10·37	10·32	10·58	—	—	—	10	205
	10·35	10·27	10·48	—	—	—	10	196
*	10·32	10·25	10·39	—	—	—	10	188
March ...	10·29	10·20	10·30	—	—	—	10	178
	10·19	10·14	10·24	—	—	—	10	169
*	10·08	10·03	10·15	—	—	—	10	162
April ...	10·00	9·96	10·11	—	—	—	9	160
	9·96	9·89	10·05	—	—	—	9	158
	10·05	9·96	10·08	36	—	—	8	158
May ...	10·01	9·95	10·10	10	57	7	7	158
	10·03	9·94	10·08	27	5	9	6	158

NOTES: Periods marked * are not ten days. Gauges are in metres, rainfall totals are in millimetres per ten-day period, evaporation is in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1939–40

(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses				Deduced Inflow
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total	
May ...	494	506	− 12	2	4	0	6	—
	561	518	+ 31	41	10	0	51	—
*	696	653	74	85	15	20	120	—
June ...	683	658	99	137	18	40	195	—
	720	689	130	170	21	60	251	121
	757	722	165	205	18	80	303	138
July ...	794	753	206	243	15	100	358	152
	823	781	248	284	11	120	415	167
*	926	888	286	325	7	140	472	186
August ...	859	829	316	371	7	170	548	232
	874	857	333	415	2	200	617	284
*	979	970	342	453	− 13	230	670	328
September ...	912	896	358	487	− 67	260	680	322
	933	912	379	514	− 90	280	704	325
	947	908	418	522	− 84	300	738	320
October ...	961	918	461	542	− 84	320	778	317
	976	933	504	563	− 72	330	821	317
*	1,088	1,048	544	574	− 45	340	869	325
November ...	997	962	579	576	− 14	350	912	333
	1,000	965	614	586	+ 24	360	970	356
	995	931	678	577	68	360	1,005	327
December ...	938	931	685	544	118	360	1,022	337
	842	902	625	429	169	360	958	333
*	751	910	466	264	216	360	840	374
January ...	575	693	348	136	246	360	742	394
	529	582	295	63	271	360	694	399
*	543	586	252	27	295	360	682	430
February ...	471	497	226	6	315	360	681	455
	467	483	210	− 5	335	360	690	480
*	415	429	196	− 15	352	360	697	501
March ...	456	473	179	− 27	370	360	703	524
	442	468	151	− 41	387	360	706	555
*	473	494	132	− 55	403	360	708	576
April ...	425	439	118	− 65	417	360	712	594
	423	426	115	− 64	431	360	727	612
	436	438	113	− 62	442	360	740	627
May (1) ...	429	442	100	− 61	448	360	747	647

NOTES: The periods marked * are not ten days. All figures are in millions. Apparent absorption is not shown because it is never positive. Deduced inflow is shown only when it exceeds 100 millions.

TABLE 413

SUMMARY ANALYSIS OF THE YEAR 1940-41

(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
May ...	10·03	9·94	10·08	—	—	—	—	—
*	10·15	10·02	10·11	82	2	57	5	162
June ...	10·38	10·19	10·22	38	8	11	5	174
	10·68	10·45	10·38	77	14	2	5	210
	10·86	10·65	10·54	4	19	2	4	235
July ...	10·90	10·74	10·64	13	37	64	4	244
	11·09	10·88	10·74	77	61	40	3	260
*	11·30	11·08	10·90	73	61	95	2	287
August ...	11·46	11·25	11·04	10	29	21	2	314
	11·55	11·34	11·16	73	22	4	2	339
*	11·69	11·46	11·32	71	23	37	2	383
September ...	11·81	11·60	11·44	28	—	2	2	437
	11·85	11·67	11·57	41	9	12	2	472
	11·89	11·71	11·64	21	13	17	2	491
October ...	11·92	11·74	11·62	18	55	3	3	498
	11·93	11·76	11·61	1	28	—	4	501
*	11·93	11·77	11·62	—	—	—	6	507
November ...	11·94	11·78	11·65	11	—	5	7	514
	11·93	11·77	11·66	—	—	—	8	511
	11·77	11·70	11·64	—	—	—	9	477
December ...	11·43	11·46	11·55	—	—	—	10	387
	10·98	11·05	11·30	—	—	—	10	302
*	10·62	10·65	11·02	—	—	—	10	249
January ...	10·50	10·44	10·84	—	—	—	10	228
	10·34	10·31	10·71	—	—	—	10	210
*	10·21	10·19	10·62	—	—	—	10	192
February ...	10·12	10·07	10·46	—	—	—	10	175
	10·06	10·01	10·32	—	—	—	10	165
*	10·03	9·97	10·20	—	—	—	10	160
March ...	9·96	9·93	10·12	—	—	—	10	157
	9·88	9·85	10·03	—	—	—	10	154
*	9·81	9·78	9·97	—	—	—	10	153
April ...	9·78	9·74	9·94	—	—	—	9	150
	9·74	9·71	9·92	22	—	7	8	150
	9·75	9·70	9·90	—	—	—	7	150

NOTES: Periods marked * are not ten days. Gauges are in metres, rainfall totals in millimetres per ten-day period, evaporation in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1940-41

(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses				Deduced	
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total	Apparent Absorption	Inflow
May (3) *	504	489	15	18	0	0	18	− 3	—
June ...	511	486	40	54	5	0	59	− 19	—
	579	537	82	99	9	0	108	− 26	—
	636	582	136	129	16	10	155	− 9	—
July ...	651	610	177	156	16	20	192	+ 5	—
	705	641	241	198	8	40	246	35	—
*	829	772	298	248	− 9	60	299	59	—
August	782	736	344	291	− 9	80	362	62	—
	797	759	382	338	− 12	100	426	56	—
*	915	868	429	384	− 20	120	484	65	—
September	854	821	462	429	− 16	140	553	49	—
	862	839	465	462	− 16	170	616	19	151
	874	878	461	479	− 16	200	663	− 2	202
October	892	874	479	483	− 16	220	687	+ 12	208
	902	871	510	486	− 1	240	725	25	215
*	998	963	545	496	+ 32	260	788	17	243
November	911	879	577	500	63	270	833	14	256
	900	871	606	481	104	280	865	21	259
*	814	852	568	410	147	280	837	11	269
December	715	803	480	303	186	280	769	—	289
	604	696	388	197	216	280	693	—	305
*	582	639	331	130	243	280	653	—	322
January	504	530	305	93	266	280	639	—	334
	470	503	272	66	287	280	633	—	361
*	491	528	235	42	308	280	630	—	395
February	430	468	197	20	326	280	626	—	429
	423	453	167	7	342	280	629	—	462
*	335	348	154	− 3	356	280	633	—	479
March ...	410	423	141	− 14	372	280	638	—	497
	400	413	128	− 25	387	280	642	—	514
*	430	443	115	− 33	403	280	650	—	535
April ...	387	399	103	− 37	418	280	661	—	558
	384	396	91	− 40	433	280	673	—	582
	385	391	85	− 40	448	280	688	—	603

NOTES: The periods marked * are not ten days. All figures are in millions. Apparent absorption is shown until it becomes negative with a comparatively high gauge. Deduced inflow is shown only when it exceeds 100 millions.

TABLE 414

SUMMARY ANALYSIS OF THE YEAR 1941–42
(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
May ...	9·77	9·71	9·93	—	—	—	—	—
	9·84	9·74	9·92	68	73	32	5	151
*	10·25	10·04	10·09	65	98	57	4	162
June ...	10·61	10·36	10·33	39	—	38	4	198
	10·90	10·66	10·51	66	19	6	4	234
	11·14	10·89	10·69	57	18	16	4	260
July ...	11·27	11·04	10·83	10	78	15	3	281
	11·40	11·18	10·95	64	22	26	3	300
*	11·51	11·30	11·09	48	28	130	3	325
August ...	11·61	11·40	11·20	60	50	7	2	357
	11·73	11·49	11·34	60	25	36	2	395
*	11·84	11·62	11·48	32	100	79	2	450
September ...	11·91	11·72	11·57	49	35	3	2	487
	11·95	11·76	11·65	2	48	42	2	504
	11·98	11·81	11·74	50	13	22	2	535
October ...	12·02	11·85	11·77	33	4	11	2	553
	12·04	11·88	11·77	8	4	9	3	562
*	12·07	11·90	11·77	14	—	14	4	575
November ...	12·12	11·93	11·78	22	—	3	5	589
	12·14	11·95	11·81	—	—	—	6	599
	12·17	11·97	11·82	—	—	—	7	610
December ...	12·19	11·99	11·84	—	—	—	8	621
	12·19	12·00	11·86	—	—	—	9	626
*	12·13	11·99	11·88	—	—	—	10	624
January ...	11·84	11·85	11·85	—	—	—	10	543
	11·25	11·43	11·68	—	—	—	10	392
*	10·73	10·85	11·32	—	—	—	10	280
February ...	10·44	10·47	11·01	—	—	—	10	235
	10·27	10·26	10·79	—	—	—	10	208
*	10·21	10·18	10·63	—	—	—	10	192
March ...	10·17	10·11	10·46	—	—	—	10	178
	10·20	10·10	10·32	—	—	—	10	169
*	10·30	10·19	10·30	—	—	—	10	176
April ...	10·10	10·07	10·24	—	—	—	10	166
	9·91	9·88	10·09	—	—	—	10	157
	9·83	9·77	9·98	—	—	—	8	154

NOTES: Periods marked * are not ten days. Gauges are in metres, rainfall totals in millimetres per ten-day period, evaporation in millimetres per day, and the surface area in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1941–42
(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses				Deduced	
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total	Apparent Absorption	Inflow
May ...	404	395	9	24	− 2	0	22	− 13	—
*	550	489	70	72	− 7	0	65	+ 5	—
June ...	588	531	127	127	− 5	10	132	5	—
	655	598	184	182	− 3	20	199	5	—
	702	658	228	230	0	30	260	− 2	—
July ...	731	713	246	268	0	50	318	− 22	—
	762	760	248	306	− 3	70	373	—	126
*	870	871	247	344	− 17	90	417	—	170
August	816	809	254	383	− 24	110	469	—	215
	845	828	271	431	− 32	130	529	—	258
*	960	935	296	483	− 56	150	577	—	281
September	893	867	322	516	− 61	170	625	—	303
	904	885	341	546	− 66	190	670	—	329
	914	904	351	573	− 71	210	712	—	361
October	923	912	362	587	− 71	240	756	—	394
	928	912	378	595	− 60	270	805	—	427
*	1,030	1,003	405	608	− 41	290	857	—	452
November	943	915	433	622	− 17	310	916	—	482
	947	921	459	637	+ 19	330	986	—	527
	950	923	486	649	61	350	1,060	—	574
December	953	928	511	658	111	360	1,129	—	618
	952	933	530	660	167	370	1,197	—	667
*	1,003	1,027	506	615	235	380	1,230	—	724
January	802	918	390	582	289	380	1,251	—	861
	650	812	228	318	328	380	1,026	—	798
*	597	737	88	199	359	380	938	—	850
February	493	551	30	133	383	380	896	—	866
	467	507	− 10	100	404	380	884	—	894
*	366	389	− 33	80	419	380	879	—	912
March ...	453	467	− 47	66	437	380	883	—	930
	460	451	− 38	67	454	380	901	—	939
*	525	523	− 36	63	474	380	917	—	953
April ...	427	477	− 86	39	491	380	920	—	1,006
	398	433	− 121	16	507	380	903	—	1,024
	389	408	− 140	10	519	380	909	—	1,049

NOTES: The periods marked * are not ten days. All figures are in millions. The apparent absorption is not shown when it has a negative value with a high gauge at Malakal. Deduced inflow is shown only when its cumulative value exceeds 100 millions.

TABLE 415

SUMMARY ANALYSIS OF THE YEAR 1942-43
(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
April (3) ...	9·83	9·77	9·98	—	—	—	—	—
May ...	9·92	9·81	9·94	117	35	7	5	154
	10·09	9·95	10·05	40	72	10	5	158
*	10·56	10·31	10·27	37	98	37	5	192
June ...	10·81	10·61	10·50	10	—	3	4	229
	10·97	10·74	10·59	32	17	10	4	241
	11·16	10·92	10·74	2	19	14	4	266
July ...	11·30	11·08	10·90	39	78	66	2	287
	11·43	11·22	11·01	73	22	40	2	310
*	11·56	11·34	11·12	40	26	50	2	338
August ...	11·71	11·50	11·29	30	51	15	2	388
	11·84	11·62	11·43	44	25	25	2	443
*	12·00	11·76	11·54	112	100	41	2	506
September ...	12·20	11·94	11·66	38	35	114	2	573
	12·26	12·04	11·81	9	48	9	2	629
	12·29	12·09	11·89	56	13	3	2	661
October ...	12·37	12·14	11·95	7	3	4	2	693
	12·38	12·18	11·96	10	4	—	3	709
*	12·37	12·17	11·97	1	—	—	4	707
November ...	12·35	12·16	11·98	—	—	—	5	704
	12·35	12·14	11·98	—	—	—	6	696
	12·33	12·14	11·99	—	—	—	7	696
December ...	12·29	12·12	11·99	—	—	—	8	688
	12·18	12·07	11·97	—	—	—	9	663
*	11·78	11·85	11·90	—	—	—	10	547
January ...	11·11	11·31	11·65	—	—	—	10	365
	10·69	10·77	11·32	—	—	—	10	270
*	10·48	10·46	11·12	—	—	—	10	238
February ...	10·41	10·38	11·05	—	—	—	10	232
	10·32	10·29	10·89	—	—	—	10	217
*	10·23	10·19	10·71	—	—	—	10	197
March ...	10·16	10·11	10·52	—	—	—	10	182
	10·11	10·04	10·33	—	—	—	10	167
*	10·06	9·98	10·20	—	—	—	10	161
April ...	10·10	9·99	10·14	—	—	—	10	161
	10·08	9·99	10·14	—	—	—	8	161
	10·04	9·95	10·12	—	—	—	8	159

NOTES: The periods marked * are not ten days. Gauges are in metres, rainfall totals in millimetres per ten-day period, evaporation in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1942-43
(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses				Deduced Inflow
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total	
May ...	411	410	1	12	0	0	12	—
	451	446	6	50	2	0	52	—
*	613	562	57	109	0	0	109	—
June ...	604	581	7	151	9	10	170	—
	639	605	114	187	14	20	221	107
	696	658	152	232	22	40	294	142
July ...	742	721	173	274	13	60	347	174
	770	758	185	311	7	90	408	223
*	870	863	192	359	0	120	479	287
August ...	823	828	187	414	− 4	160	560	373
	859	861	185	471	− 8	180	643	458
*	1,005	976	214	552	− 41	210	721	507
September ...	975	921	268	628	− 64	240	804	536
	988	950	306	680	− 64	280	896	590
	996	962	340	717	− 64	320	973	633
October ...	1,020	971	389	747	− 50	360	1,057	668
	1,020	971	438	755	− 36	390	1,109	671
*	1,110	1,071	477	749	− 5	410	1,154	677
November ...	1,000	975	502	742	+ 30	420	1,192	690
	1,000	975	527	739	72	430	1,241	714
	992	976	543	734	121	430	1,285	742
December ...	976	976	543	710	176	430	1,316	773
	918	949	512	617	236	430	1,283	771
*	837	1,001	348	456	296	430	1,182	834
January ...	600	793	155	285	332	430	1,047	892
	520	638	37	189	359	430	978	941
*	523	584	− 24	151	385	430	966	990
February ...	460	515	− 79	128	408	430	966	1,043
	442	498	−135	101	430	430	961	1,096
*	342	380	−173	76	446	430	952	1,125
March ...	427	460	−206	56	464	430	950	1,156
	434	477	−249	39	481	430	950	1,199
*	483	506	−272	32	497	430	959	1,231
April ...	454	446	−264	30	513	430	973	1,237
	434	445	−275	28	526	430	984	1,259
	426	449	−298	27	539	430	996	1,294

NOTES: The periods marked * are not ten days. All figures are in millions. Apparent absorption is not shown because it is never positive, and deduced inflow is shown only when its cumulative value exceeds 100 millions.

TABLE 416

SUMMARY ANALYSIS OF THE YEAR 1943–44
(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
April (3) ...	10·04	9·95	10·12	—	—	—	—	—
May ...	10·10	9·97	10·12	12	—	—	7	160
	10·20	10·04	10·14	32	4	—	6	163
*	10·25	10·14	10·23	2	18	20	5	168
June ...	10·33	10·15	10·22	3	3	11	5	176
	10·61	10·39	10·34	23	16	17	5	201
	10·85	10·62	10·52	133	11	16	5	232
July ...	11·02	10·77	10·63	4	8	3	3	249
	11·19	10·94	10·78	53	27	16	3	269
*	11·39	11·12	10·93	19	22	107	3	294
August ...	11·52	11·28	11·07	33	93	9	2	322
	11·74	11·46	11·22	73	62	96	2	378
*	11·83	11·62	11·44	57	38	23	2	443
September ...	11·90	11·70	11·54	13	48	12	2	480
	11·96	11·76	11·65	50	87	35	2	510
	12·04	11·84	11·75	23	33	2	2	549
October ...	12·08	11·89	11·80	16	57	7	2	574
	12·10	11·91	11·82	10	32	27	3	587
*	12·13	11·93	11·86	2	—	8	4	606
November ...	12·16	11·96	11·90	—	—	—	5	622
	12·16	11·97	11·92	—	—	—	6	626
	12·17	11·97	11·94	—	—	—	7	633
December ...	12·14	11·97	11·96	—	—	—	8	632
	11·94	11·89	11·95	—	—	—	9	590
*	11·43	11·56	11·87	—	—	—	10	444
January ...	10·92	11·05	11·62	—	—	—	10	325
	10·60	10·76	11·44	—	—	—	10	277
*	10·41	10·43	11·35	—	—	—	10	247
February ...	10·37	10·35	11·29	—	—	—	10	237
	10·28	10·27	11·08	—	—	—	10	222
*	10·17	10·11	10·84	—	—	—	10	199
March ...	10·09	10·04	10·63	—	—	—	10	183
	10·02	9·95	10·40	—	—	—	10	165
*	9·95	9·87	10·19	—	—	—	10	158
April ...	10·14	9·98	10·15	—	—	—	10	161
	10·17	10·08	10·23	—	—	—	9	166
	10·00	9·94	10·14	—	—	—	8	159

NOTES: The periods marked * are not ten days. Gauges are in metres, rainfall totals in millimetres per ten-day period, evaporation in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1943–44
(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses				Deduced Inflow
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total	
May ...	461	456	5	6	10	0	16	—
	492	463	34	19	18	0	37	—
*	558	553	39	27	25	0	52	—
June ...	524	499	64	47	32	10	89	—
	582	537	109	90	39	20	149	—
	624	593	140	131	39	30	200	—
July ...	658	621	177	170	44	50	264	—
	708	660	225	215	44	70	329	104
*	841	778	288	263	38	90	391	103
August ...	796	755	329	316	32	110	458	129
	844	804	369	383	9	130	522	153
*	950	933	386	424	0	150	574	188
September ...	890	864	412	474	0	180	654	242
	916	890	438	517	−20	210	707	269
	942	907	473	553	−20	240	773	300
October ...	950	916	507	570	−26	270	814	307
	950	924	533	588	−20	300	868	335
*	1,055	1,017	571	607	+ 6	320	933	362
November ...	968	924	615	620	37	340	997	382
	968	924	659	626	75	360	1,061	402
	968	924	703	628	119	370	1,117	414
December ...	933	924	712	603	169	380	1,152	440
	844	890	666	504	222	380	1,106	440
*	756	909	513	353	270	380	1,003	490
January ...	570	721	362	238	302	380	920	558
	506	613	255	173	330	380	883	628
*	527	583	199	136	357	380	873	674
February ...	472	517	154	113	381	380	874	720
	454	484	124	80	403	380	863	739
*	394	428	90	58	421	380	859	769
March ...	430	449	71	24	439	380	843	772
	427	446	52	− 2	455	380	833	781
*	463	474	41	− 2	471	380	849	808
April ...	448	437	52	+11	487	380	878	826
	451	470	33	− 7	502	380	889	856
	426	460	− 1	− 6	510	380	884	883

NOTES: The periods marked * are not ten days. All figures are in millions. The apparent absorption is not shown because it is never positive. Deduced inflow is shown only when its cumulative value exceeds 100 millions.

TABLE 417

SUMMARY ANALYSIS OF THE YEAR 1944–45
(i) THE DATA

Ten-Day Period	Gauges: Malakal	Gauges: Melut	Gauges: Renk	Rainfall: Malakal	Rainfall: Melut	Rainfall: Renk	Assumed Gross Evaporation	Total Surface Area
April (3) ...	10·00	9·94	10·14	—	—	—	—	—
May ...	10·02	9·90	10·06	31	—	—	7	158
	10·51	10·22	10·23	—	3	—	7	178
*	10·75	10·53	10·49	32	—	—	7	222
June ...	10·89	10·66	10·58	39	6	20	5	237
	11·10	10·84	10·69	12	2	2	5	256
	11·22	10·97	10·80	14	1	34	5	274
July ...	11·34	11·09	10·88	6	32	72	2	287
	11·48	11·22	11·00	116	44	75	2	311
*	11·64	11·39	11·15	4	92	36	2	355
August ...	11·70	11·49	11·30	67	74	39	2	385
	11·77	11·56	11·39	22	87	27	2	419
*	11·86	11·64	11·47	98	6	38	2	457
September ...	11·99	11·75	11·56	28	112	52	2	505
	12·03	11·84	11·70	47	22	20	2	544
	12·10	11·90	11·79	52	31	5	2	579
October ...	12·19	11·98	11·85	14	27	17	2	620
	12·22	12·03	11·91	30	91	53	2	644
*	12·24	12·07	11·95	—	5	—	2	665
November ...	12·22	12·06	11·98	—	—	—	4	665
	12·18	12·04	12·00	—	—	—	7	662
	12·14	12·01	11·99	—	—	—	8	650
December ...	12·02	11·94	11·96	—	—	—	9	616
	11·72	11·76	11·91	—	—	—	10	517
*	11·30	11·39	11·78	—	—	—	10	397
January ...	10·98	11·03	11·61	—	—	—	10	323
	10·68	10·74	11·49	—	—	—	10	280
*	10·43	10·46	11·33	—	—	—	10	248
February ...	10·30	10·32	11·25	—	—	—	10	229
	10·23	10·22	11·04	—	—	—	10	214
*	10·17	10·14	10·87	—	—	—	10	202
March ...	10·08	10·05	10·63	—	—	—	10	183
	9·96	9·94	10·43	—	—	—	10	164
*	9·83	9·80	10·17	—	—	—	10	155
April ...	9·71	9·68	9·97	—	—	—	10	149
	9·63	9·61	9·91	—	—	—	9	146
	9·51	9·51	9·84	—	—	—	8	141

NOTES: The periods marked * are not ten days. Gauges are in metres, rainfall totals in millimetres per ten-day period, evaporation in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1944–45
(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges: Malakal	Discharges: Renk	Cumulative Observed Loss	Computed Losses: Trough Volume	Computed Losses: Net Evaporation	Computed Losses: Mean Absorption	Computed Losses: Total	Deduced: Apparent Absorption	Deduced: Inflow
May ...	436	423	13	21	10	0	31	−18	—
	551	467	97	72	21	0	93	+ 4	—
*	672	605	164	117	32	10	159	5	—
June ...	644	581	227	153	39	20	212	35	—
	684	617	294	189	49	40	278	56	—
	712	653	353	220	57	60	337	76	—
July ...	742	679	416	254	45	80	379	117	—
	779	717	478	301	26	100	427	151	—
*	903	837	544	345	19	120	484	180	—
August	840	793	591	383	4	140	527	204	—
	858	809	640	418	− 4	160	574	226	—
*	969	912	697	463	−12	180	631	246	—
September	924	848	773	515	−32	210	693	290	—
	933	881	825	556	−37	240	759	306	—
	959	907	877	600	−43	270	827	320	—
October	985	924	938	636	−43	300	893	345	—
	994	942	990	661	−69	330	922	398	—
*	1,102	1,055	1,037	679	−55	350	974	413	—
November	976	968	1,045	672	−28	380	1,024	401	—
	950	976	1,019	663	+18	400	1,081	—	—
	924	950	993	634	70	400	1,104	—	111
December	881	907	967	567	126	400	1,093	—	126
	783	873	877	449	178	400	1,027	—	150
*	738	867	748	332	222	400	954	—	206
January	602	676	674	247	254	400	901	—	227
	537	624	587	184	282	400	866	—	279
*	532	582	537	127	309	400	836	—	299
February	463	497	503	109	332	400	841	—	338
	453	468	488	83	353	400	836	—	348
*	357	369	476	58	369	400	827	—	351
March ...	437	448	465	30	387	400	817	—	352
	411	416	460	3	403	400	806	—	346
*	418	426	452	−21	419	400	798	—	346
April ...	366	362	456	−37	434	400	797	—	341
	359	352	463	−49	448	400	799	—	336
	346	337	472	−59	459	400	800	—	328

NOTES: The periods marked * are not ten days. All figures are in millions. The apparent absorption is shown only up to the peak of the flood and the deduced inflow is shown only when its cumulative value exceeds 100 millions.

TABLE 418

SUMMARY ANALYSIS OF THE YEAR 1945–46
(i) THE DATA

Ten-Day Period	Gauges			Rainfall			Assumed Gross Evaporation	Total Surface Area
	Malakal	Melut	Renk	Malakal	Melut	Renk		
April (3) ...	9·51	9·51	9·97	—	—	—	—	—
May ...	9·44	9·48	9·78	11	20	—	7	144
	9·50	9·47	9·76	74	69	12	6	144
*	10·17	9·90	10·03	6	17	—	5	157
June ...	10·50	10·31	10·34	73	74	104	4	194
	10·63	10·45	10·44	12	30	126	4	211
	10·83	10·62	10·34	10	4	8	4	232
July ...	10·99	10·77	10·66	54	—	13	3	249
	11·14	10·93	10·80	8	41	160	3	268
*	11·27	11·08	10·91	41	57	—	3	287
August ...	11·42	11·23	11·02	90	214	78	2	309
	11·60	11·41	11·20	36	17	106	2	357
*	11·72	11·33	11·39	54	75	145	2	407
September ...	11·79	11·61	11·52	35	35	85	2	447
	11·96	11·74	11·64	33	18	2	2	500
	12·13	11·91	11·80	115	53	—	2	589
October ...	12·25	12·06	11·92	6	56	21	2	654
	12·34	12·12	12·00	116	2	38	2	696
*	12·37	12·18	12·05	16	—	—	2	729
November ...	12·37	12·21	12·09	38	—	5	3	741
	12·36	12·22	12·10	—	—	—	4	745
	12·35	12·21	12·11	—	—	—	5	743
December ...	12·34	12·20	12·12	—	—	—	6	741
	12·32	12·19	12·12	—	—	—	7	738
*	12·28	12·16	12·13	—	—	—	9	723
January ...	12·12	12·09	12·11	—	—	—	10	690
	11·63	11·82	12·04	—	—	—	10	547
*	10·94	11·20	11·77	—	—	—	10	359
February ...	10·49	10·62	11·49	—	—	—	10	268
	10·27	10·32	11·26	—	—	—	10	231
*	10·15	10·18	11·18	—	—	—	10	217
March ...	10·02	10·04	10·92	—	—	—	10	198
	9·87	9·87	10·63	—	—	—	10	170
*	9·73	9·73	10·36	—	—	—	10	153
April ...	9·62	9·61	10·09	—	—	—	8	150
	9·58	9·56	9·90	—	—	—	8	146
	9·52	9·52	9·78	49	2	25	7	135
May (1) ...	9·53	9·49	9·77	3	24	1	6	135

NOTES: Periods marked * are not ten days. Gauges are in metres, rainfall totals in millimetres per ten-day period, evaporation in millimetres per day, and the surface area is in square kilometres.

SUMMARY ANALYSIS OF THE YEAR 1945–46
(ii) CUMULATIVE OBSERVED AND COMPUTED LOSSES

Ten-Day Period	Discharges		Cumulative Observed Loss	Computed Losses				Apparent Absorption
	Malakal	Renk		Trough Volume	Net Evaporation	Mean Absorption	Total	
May ...	334	325	9	− 4	8	0	4	5
	351	327	33	+17	9	0	26	7
*	546	463	116	88	15	0	103	13
June ...	559	519	156	133	7	10	150	16
	589	550	195	163	3	20	186	29
	658	589	264	199	10	30	239	55
July ...	689	621	332	236	12	50	298	84
	733	662	403	284	− 7	70	347	126
*	834	770	467	312	− 7	90	395	162
August ...	784	735	516	360	− 40	120	440	196
	831	778	569	418	− 54	150	514	205
*	950	904	615	468	− 89	190	569	236
September ...	890	847	658	519	−102	210	627	241
	933	864	727	602	−102	250	750	227
	985	890	822	686	−125	290	851	261
October ...	1,020	924	918	751	−132	330	949	299
	1,034	950	1,022	797	−153	370	1,014	378
*	1,170	1,064	1,128	825	−146	410	1,089	449
November ...	1,063	968	1,223	836	−131	430	1,135	518
	1,054	976	1,301	834	−101	450	1,183	568
	1,037	976	1,362	834	− 64	470	1,240	592
December ...	1,028	976	1,414	828	− 20	480	1,288	606
	1,020	976	1,458	819	32	480	1,331	607
*	1,093	1,064	1,487	784	103	480	1,367	600
January ...	907	950	1,444	682	172	480	1,334	—
	746	881	1,309	506	227	480	1,213	—
*	641	893	1,057	316	267	480	1,063	—
February ...	499	642	914	219	294	480	993	—
	461	517	858	174	317	480	971	—
*	352	392	818	146	335	480	961	—
March ...	420	451	787	99	355	480	934	—
	394	417	764	64	372	480	916	—
*	408	424	748	38	387	480	905	—
April ...	357	344	761	19	399	480	898	—
	352	334	779	6	411	480	897	—
	351	337	793	0	418	480	898	—
May (1) ...	354	342	805	4	426	480	910	—

NOTES: The periods marked * are not ten days. All figures are in millions. The apparent absorption is shown only up to the peak of the flood. Deduced inflow is not shown because its cumulative value never exceeds its probable error, and it seems quite likely that there was none in this flood.

TABLE 419

SUMMARY OF SIXTEEN FLOODS BETWEEN MALAKAL AND RENK DURING THE YEARS 1928 TO 1946

First Year of Flood	Period Flood Began	Period Flood Ended	Total Malakal Discharge	Final Computed Losses: Trough Volume (Max.)	Final Computed Losses: Net Evaporation	Final Computed Losses: Mean Absorption	Final Computed Losses: Computed Total	Cumulative Observed Loss	Cumulative Deduced Inflow
1928	April (2)	April (1)	27,900	667	328	390	716	625	Nil
1929	April (3)	April (1)	28,268	691	467	410	881	− 339	1,220
1930	April (2)	May (1)	25,045	424	330	240	529	571	Nil
1931	May (1)	May (1)	26,108	645	413	400	863	(287)	(576)
1932	May (1)	May (2)	32,748	1,062	835	620	1,507	845	662
1933 } 1934 } 1935 }	NOT ANALYSED								
1936	May (1)	April (3)	25,163	573	384	340	701	551	150
1937	May (1)	April (2)	26,261	746	483	440	950	− 111	1,061
1938	April (2)	April (1)	29,373	859	718	520	1,271	− 201	1,472
1939	May (1)	May (1)	27,600	586	448	360	747	100	647
1940	May (3)	April (3)	21,866	500	448	280	688	85	603
1941	May (2)	April (3)	25,250	660	519	390	909	− 140	1,049
1942	May (1)	April (3)	25,860	755	539	430	996	− 298	1,294
1943	May (1)	April (3)	24,746	628	510	380	884	− 1	883
1944	May (1)	April (3)	25,220	679	459	400	800	472	328
1945	May (1)	May (1)	26,447	836	426	480	910	805	Nil
1946	May (1)	May (1)	32,377	1,288	852	700	1,682	− 52	1,744
Sums: ...	—	—	430,592	11,599	8,159	6,770	15,034	3,199	11,691
MEANS: ...	May (1)	April (3)	26,912	725	510	423	939	200	730

NOTES: All figures except those in the first three columns are in millions.

In 1931 the figures in the last two columns are in brackets because they are approximate owing to lack of measured discharges at Renk in this year.

No deduced inflow is shown when its final value was less than 100 millions or, in 1945, than its probable error.

SECTION VIII. INFLOW AND THE EVIDENCE FOR IT

In Table 420 (p. 905) are shown the values attained by deduced inflow in individual months during the floods analysed in this paper. These are monthly totals, and they have been derived from Tables 403 and 404–18 by comparison of the cumulative totals of deduced inflow at the end of each month. The arbitrary lower limit of 40 m/d has been taken so that minor fluctuations or errors in the discharges may be eliminated as far as possible. Even with this limit there are some months—e.g. October 1936—when it may be doubted whether inflow has really occurred. In a few months there was a negative result with a value over 40 millions; these have been indicated in the table though the amounts are not shown. As will be seen one at least of these is confirmed by independent testimony, since when the river is really high it seems that the storage power of the Adar increases considerably and there may be a fair amount of flow back into it. In Table 420 averages have been derived for each month, and these repeat the tendency, which is well marked in the years of biggest inflow, towards a double peak in its values, the first peak occurring in August or September, and the second in January or February. The first peak is easily explained, for it corresponds to the peak of the rains; and there can be little doubt that it is due to the inflow brought by the steeper khors from a comparatively short distance away. The second peak is less easy to account for, and I discuss in the next section the most probable sources of supply at this time, particularly that of spill from the Baro travelling through the Machar Marshes. Before proceeding to discuss the inflow any further it will be as well to consider the evidence which, in my opinion, confirms beyond all doubt that inflow does exist, if the previous analysis by which it was deduced has not been sufficiently convincing.

MEASURED DISCHARGES OF TRIBUTARIES

The evidence for inflow takes two forms: actual measurements of the discharge of tributary khors, and observations of their flow and its effects which have been recorded in the province or district monthly diaries. Neither of these sources is anything like comprehensive, and reliable confirmation of deduced inflow goes only so far as agreement with the values deduced above in exceptional years. It must be remembered that the tributary khors, as was explained above in Section III (p. 864), take in a little water every year and pass it out again when the river drops. Thus they have water in them every year and it is only when this is higher than normal and flowing much faster than normal that it is likely to be observed or commented on specially, because it has caused damage. Actual measured discharges are very few. In 1930 a few measurements were made at the mouth of the Khor Adar, which joins the White Nile opposite a point upstream of Melut. Between September 21st and December 10th in that year the maximum flow into the Nile which was recorded in the Adar was under half a million a day; during some of the period of measurement the flow was the other way. Lately the discharges of this khor have been under constant observation, and they have been measured when they were at all large. They are described in more detail in the next section, but it may be noted here that the maximum ever recorded was 3 millions a day, in October 1947, and that in 1948 the maximum was under half a million a day, in August. In general the flow in this khor seems to coincide with the first peak of inflow mentioned above, and not to amount as a rule to more than a million a day.

The only other measurement of tributary discharge which I have been able to trace was in the Khor Doleib, which enters the White Nile just above Renk; it is a very significant one. The Egyptian Irrigation Department recorded of this khor in 1938:[6]

> " The khor began to rise on August 15th, reached its maximum from 29th September to 4th October, and then fell away fast. On September 30th a discharge of 108 m^3/sec. (9·3 millions a day) was recorded."

Comparison with Table 420 will show that in this year the deduced inflow began in July and reached its maximum in September and October, with an average daily inflow of nearly 10 m/d. As will be seen below, the Khor Doleib was not the only source of inflow at this time, so the correlation is quite good.

OBSERVED INFLOW

This completes the very meagre records of actual measured inflow, and we are left with the much more unsatisfactory evidence of administrative records; unsatisfactory because they must of necessity be purely qualitative and even accidental, and not even reliably objective. Administrative officers are changed frequently and each new man has a different standard; he must therefore rely at first entirely on local reports for the comparative size of what he sees or hears about. The available evidence is contained mainly in province and district diaries from which the extracts given below are quoted. A set of the Upper Nile Province diaries is held in the Civil Secretary's Office, and I went through these myself. But they only go back as far as 1937, and Mr. D. F. Ferguson of the Jonglei Investigation Team was kind enough to search through the Upper Nile archives, in which he found some valuable evidence from district diaries. Unfortunately so far no trace has been discovered of the records of 1929–30, which seems to have been an interesting year, since a large amount of inflow coincided with a low White Nile—or rather a not exceptionally high one—and also with a record high Baro. An attempt was made by the province staff to locate these records but without success.

From a study of Tables 419 and 420 and Fig. J 10 it will be clear that four floods stand out as pre-eminent as regards inflow: 1929–30, 1938–39, 1942–43, and 1946–47. From the preliminary analysis which I have made of the last flood—1948–49—between Malakal and Melut it appears that in this also there was an unusual amount of inflow, with maxima in August and September, and again in December. There was a fair amount of inflow also in 1937–38 and in 1941–42, amounting to just over a milliard, but I propose to confine myself here to a study of the four floods mentioned above, and to discuss them individually below.

1929–30 FLOOD

The deduced inflow in this flood totalled over 1,200 millions, with two maxima, in August and September 1929 and in January 1930. Up to the time of writing no evidence of inflow has been obtained, as described above, but it is worth mentioning that this year coincided with a record high Baro, and that the amount of water spilt from this into the Machar Marshes, as described fully below in the next section, was over six milliards, a milliard more than that recorded even in 1946. Thus the records of this year may be of considerable value in deciding the difficult question of what proportion of the second peak of inflow comes from this source. Since the White Nile was not particularly high in this year—the maximum Malakal gauge was 12·36—there would be more chance of distinguishing between flow from these marshes and general Nile flooding than there was in 1946.

1938–39 FLOOD

In this flood the deduced inflow was nearly 1,500 millions with maxima in September and December 1938. The measurement of the Khor Doleib discharge mentioned above is confirmed by the following extracts, which also reveal that the khors on the west bank flowed unusually hard that year. The first extract is from the Renk District diary, and the others from the province diary.

NOVEMBER 1938.

> " An embankment was erected at Khor Mario as well as at Khor Doleib, but unfortunately as the Khor Doleib flood was unusual this year the embankment was washed away."

NOVEMBER 1938 (Province Diary).

> " Of all the causeways between Kaka and Malakal there remain only those at Abaraoic, Thuor, and Famad. Three years' work has gone in as many months."

DECEMBER 1938.

> " The opening of the motor roads has been considerably delayed by the very high Nile and flooded rivers flowing from inland to the Nile. The most serious hold-up was the breaking of the causeway just north of Kodok which was cut in two places to let the flood-water escape which was coming from inland. These breaches are 5 and 15 metres wide. On 30th November, in spite of the high Nile, the water was still flowing hard from inland through these breaches. Usually the road is open as far as Melut in mid-November.
>
> " At the beginning of October the Khor Doleib was still flowing; it dried in the beginning of November and came down in spate in mid-November."

So big was this flow in the west bank khors that a special journey was made by the A.D.C. Kodok and Mr. H. Bell (at that time a member of the Egyptian Irrigation Department) to check on a Shilluk legend that this water came from the White Nile above Malakal, and that it was in fact a spill from near Tonga. They found that none of the tributary khors near Tonga went back any great distance and also that all the streams between here and the stretch north of Malakal were flowing southwards, and not northwards as this theory would require. They concluded that the water must come from the Nuba Mountains, though it must be remarked that neither on the existing maps nor on the recent American air photographs can any such connection be traced.

1942–43 FLOOD

In this year deduced inflow reached a total of nearly 1,300 millions, with the usual two maxima, one in August 1942, and the other in January and February 1943. The province monthly diary for October 1942 recorded:

" NORTHERN DISTRICT, SHILLUK SUB-DISTRICT, W. BANK

> " Heavy rains in the hinterland brought the watercourses down in a similar spate to that of 1938, when all the ramped culverts were destroyed. The brick bridges built after that have apparently been unable to cope with the volume of water and the earthworks at Akuinkual, Famad, Fadit, and Thuro have been washed away.
>
> " In October the spate subsided and repairs to bridged watercourses could be made sufficiently to allow of the passage of cars. The water in each place cut a channel for itself through the ramp of an average of 20 metres."

There is no mention in the diaries of an unusual inflow in the following January and February, either from this source or from any other.

1946–47 FLOOD

In this flood the deduced inflow reached the highest total and also—in February 1947—the highest monthly total during the period under review. The yearly total was over 1,700 millions and there were two well-marked peaks, with an actual negative value between them, in September 1946 and February and March 1947. The confirmatory evidence is considerable, and it has already been mentioned in the *Second Interim Report* (pp. 93–94). The following extracts from the Northern District monthly diaries, collected by Mr. Ferguson, do something to expand that account.

OCTOBER 1946

> " The timbers of the P.W.D. bridge over the Khor Adar have apparently been swept into the Nile."

JANUARY 1947

> " Lorries can now reach Paloich from Melut and Gelhak from Renk, but the khors to the south and east of Paloich rose during the month with overflows from the river and Adar."

This sounds more like simple flooding from the high river than true inflow, especially as it follows the negative inflow which may be seen from Table 420 to have occurred in December 1946.

FEBRUARY 1947

> " The six or seven khors between Paloich and Leweng were found by the Deputy-Governor when he walked this stretch to contain twice as much water as in the previous month. The Khor Lool (? Lul) which in December was ¾ mile wide, became some 6 miles wide by the middle of February and was still so at the end of the month."

Melut gauge had by then dropped to 12·0 from a maximum of 12·74 which it held throughout December and January; this effect must therefore have been due to inflow, and it confirms the record total of over 450 millions for this month shown in Table 420.

MARCH 1947

> " The khors in the Paloich area are still rising at the end of the month. From where the water is coming is a mystery."
>
> " The three miles of road which was under water from flooding by the Khor Wol on the south was dry by the end of the month, but water to a depth of two feet was still flowing over the bridge and there was a mile of water to the north of it." (Continuation of same diary.)

APRIL 1947

"The people compare this year to the great floods in the time of the Turkish Government (1878) and affirm that these present conditions will prevail throughout next year."

"The Khor Wol bridge appeared above water for the first time since Christmas."

"Work was begun on the ramps and bridges, many of which have been washed away completely, on the Tonga-Kodok road."

As already explained I have not included analyses of the floods of 1947–48 and 1948–49 in this paper because records were not made of the discharges at Renk after the middle of 1947; but it may be worth noting here that the summer of 1947 saw a continuation of these floods on the east side of the river, and it was not till early 1948 that the water there really began to dry out.

From these extracts it is clear that the last three exceptional floods—1938–39, 1942–43, and 1946–47—have the inflow which I deduced in their analyses well supported by independent testimony; and it is to be hoped that similar evidence will be found in due course for the first of these exceptional floods—in 1929–30. For the remaining floods when deduced inflow was under a milliard the evidence is unsatisfactory and fragmentary; and I do not propose to quote from it. It is clear that only exceptional inflow, particularly when it was in the form of a violent spate which caused damage, is likely to merit a special reference in the monthly diaries. Many of the tributary khors are bridged, and there is no reason why these should not take a fair amount of flow. This may be shown by quoting the Khor Nyadwai, near Kodok, of which the cross-section has already been described on page 864. In an average year this will have at maximum level a cross-section of about 40 square metres, and consequently if flowing at an average rate of half a metre per second would have a discharge of 20 cubic metres per second or nearly two millions a day. It is dangerous to generalize in this way, but this is sufficient to show that a few khors flowing in this manner could easily account for the monthly totals of inflow shown for 1941 in Table 420, and it is reasonable to suppose that flow of this sort of size might not cause damage or be remarkable enough to merit special mention in a district diary. Thus I do not think it is at all difficult to believe that inflow of the order of half a milliard or so could take place during the rainy season without causing remark; what cannot be denied is that the losses on this reach, as pointed out in Volume I of *The Nile Basin*, are very much less on the average than they should be by the most conservative estimates. It is less easy to feel sure that the deduced inflow shown in Table 420 for the early months of several years, when from all accounts the tributary khors are normally dry, has really occurred except in the obviously unusual years such as 1947. I have therefore devoted the next section entirely to a discussion of this problem, and have attempted to show that at any rate it does not seem to be due to overflow from the Machar Marshes caused by Baro spill, although this was given as the most likely explanation in the *Third Interim Report*, in the passage quoted above. (But see Chapter 4, pp. 976–7.)

TABLE 420†

DEDUCED INFLOW INTO THE WHITE NILE BETWEEN MALAKAL AND RENK IN THE MONTHS WHEN IT EXCEEDED 40 MILLIONS BETWEEN 1928 AND 1947

Flood	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April
28–29	—	—	52	72	68	– ve	– ve	—	—	—	—	—
29–30	—	—	—	172	181	61	73	136	220	134	133	98
30–31	Insufficient data but probably small or nil											
31–32	—	—	—	—	81*	80*	58*	58*	– ve*	77*	61*	62*
32–33	—	—	—	101*	—*	—*	—*	81	98	91	85*	47*
33–36	Insufficient Data											
36–37	—	—	—	—	—	53	—	—	—	—	—	—
37–38	—	—	120	182	168	48	216	51	47	40	67	—
38–39	—	—	57	212	273	241	109	216	169	63	33	—
39–40	46	92	48	142	—	—	—	57	46	71	75	51
40–41	—	—	—	54	147	41	—	53	73	84	56	68
41–42	—	—	138	111	80	91	122	150	126	62	41	96
42–43	51	90	145	220	126	44	65	92	156	135	106	63
43–44	—	—	43	85	112	62	52	76	184	95	—	75
44–45	—	—	—	—	—	—	174?	95	93	52	—	—
45–46	—	—	—	—	—	—	—	—	—	—	—	—
46–47	—	—	—	142	311	217	169	– ve	98	454	378	—
MEAN	6	13	39	93	97	59	64	72	89	82	66	31

NOTES: All figures except years are in millions. Figures marked * have been obtained from estimated and not measured discharges at Renk, and must be treated with reserve. The figures marked with a query in 1944 are also doubtful. (– ve means negative).
† Referred to as Table 10 in Fig. 3 10.

SECTION IX. DRY SEASON INFLOW AND POSSIBLE SOURCES

The second peak of inflow shown in many years in Table 420, coming usually in December or January, averages some two millions a day and in more than half the floods analysed appears to continue until May. This would appear to mean that as often as not one or more of the tributary khors between Malakal and Renk must be flowing at a time when, according to local information, they are normally dry—except of course in an unusual year such as 1947. It may be worth mentioning that the time when this phenomenon seems to have been most frequent was during the years 1939–43, when the administrative staff was reduced owing to the war, and this may account partly for the lack of records of its having been observed. But the questions of whether this delayed inflow does occur, and if so where it comes from, are of some importance. In the first place it is the only logical consequence of the preceding analyses which appears to run counter to the general evidence; and in the second this inflow is deduced as occurring in the timely season when it is of considerable practical interest. The inflow which occurs during the peaks both of the rains and the flood is unlikely to be denied and is unimportant; inflow coming in the dry months of January to April is neither. There are three possible causes for this deduced inflow: errors in the computed or observed losses; spill from the Baro or Sobat which has travelled through the marshes east of the Nile; or rain falling on these or other areas at a distance from the river and taking several months to reach it. Little can really be said about this last owing to the lack of rain-gauges in the areas concerned. The first of these possiblities may now be considered.

ERRORS IN THE OBSERVED OR COMPUTED LOSSES (see also the last part of Section II, p. 859)

At this time of the year absorption may be assumed to have ceased and rainfall has certainly done so; the only items from which the deduced inflow is derived are therefore the observed losses, trough volume, and evaporation. In the sections dealing with these I have made estimates of the probable errors which they have in an average year; in the first two they can be derived fairly directly, although this does not necessarily mean that they are correct. In Section V (p. 870) I show that they would appear to be too small to account for the low evaporation depths reached in two out of the six years considered in Table 401 (p. 871), and I therefore postulate inflow in those years. These were borderline cases, but the same arguments may be applied with more force to the years which were excluded from that table because they would have given actual negative values to the evaporation depth. For example in order to eliminate the deduced inflow in the early part of 1943, the three quantities from which it is derived would have to have a total error of 460 millions, whereas their probable errors are 130, 20, and about 40 millions, giving for the probable error of the deduced inflow a value of less than a third of this. I feel therefore that unless there is something seriously wrong with the observed discharges the only possible explanation is inflow. It is noticeable that it does behave much as one would expect if it were real and due to either of the two second causes given above: that is to say in general it follows years in which inflow during the rains has been above average; and it shows a steadier rate than this inflow, which would be expected if it had come from a long distance, probably through swamps. Only in 1947 does it show the characteristics of a spate, and 1947 was an exceptional year. It is arguable that if it is due to errors and not to real causes it would be much more variable and be unlikely to exhibit such a systematic tendency, not only in each year but in the several years in which it occurs.

BARO SPILL—METHOD OF CALCULATION[a]

The hydrology of the Baro has been discussed by A. D. Butcher in *Sobat Hydraulics* and by Dr. Mohammed Amin in ' River Baro Losses ' (unpublished), and also in the *Second Interim Report* (pp. 90–94). For the present purposes I have adopted the conclusion reached in the last named that when the monthly discharge at Gambela exceeds 1,500 millions the excess is spilt into the Machar Marshes, most of it being carried by the Khor Machar which leaves the Baro 57 km. upstream of its junction with the Sobat. This is true spill in the sense that it does not return to the Baro and apparently only a small proportion—if any—reaches the White Nile. A basic difficulty in assessing the contribution made by this spill to the White Nile is that it is difficult to distinguish its effects from those of rainfall in this eastern area. At first sight correlation between Baro spill and late inflow seems good, but it must be remembered that a large amount of spill on the Baro is due to a high flood and this is due in turn to heavy rains in its basin; these are likely to coincide with heavy rain farther north in the basins of the Yabus and Daga which are the likely alternative sources, or even with heavy rain actually on the marshes themselves. It is noticeable that even the Blue Nile flood shows a certain degree of correlation with this late inflow, though there is obviously no direct connection and the correspondence must be due to the chain of circumstances outlined above.

Because of this basic difficulty in distinguishing the sources of this inflow, a difficulty which is made almost insuperable by the lack of rainfall and discharge records in the areas concerned, I do not intend here to devote much space to discussing possible correlations, but will merely summarize the various factors and leave further discussion to others who are or will be better acquainted with the area. In Table 421 (below) are shown the values of Baro spill—calculated as described above—in the last twenty years, and I have also repeated for convenience the totals of inflow for the following dry season so that such correlation as there is may be seen at a glance. I think that the years 1931, 1937, 1943, and 1944 are indications that the Baro spill does not provide all of this inflow since in these years a low Baro flood was followed by an appreciable amount of dry season inflow, whereas the high floods of 1928 and 1945 were not followed by inflow.

POSSIBLE ROUTES

Here again local knowledge and some investigation of past records and memories may reveal evidence which at present is almost non-existent; and it would be premature at this stage to devote much space to a discussion of the routes by which this late inflow may have arrived. We may note only that the Egyptian engineers have never recorded a discharge of the Adar in these dry months, even in 1947, though I have been informed by Mr. Calder (then A.D.C. Renk) that in March of that year he saw this khor flowing strongly. In the preceding section it may be noted that the Khor Wol in 1947 showed signs of having flowed very strongly, and the bridge across it did not appear above water until April. No discharges of this khor have been measured, but it does not enter the Nile directly and may therefore easily have escaped observation since its waters would come into the river through the Khor Awilwil. This is one of the channels parallel to the main river and it would be emptying at this time naturally; inflow by this route would therefore lead only to an accentuation of this tendency. Nevertheless there might be some chance of obtaining confirmation from the missionaries who were at Rom on the banks of this khor. Once again records from the early months of 1930 would be of value since the inflow in that year was exceptionally large but the White Nile had not been anything like as high as in 1946. On the whole it seems unlikely that this dry season inflow can come from the west side of the river since even in 1946 the khors on that side seem to have finished their flow before the end of the flood peak. But this is as far as one can go at the present, and I suggest that if the question is considered of sufficient importance, a thorough search must be made through all province and district records; and that the missionaries who live on the east side of the river should also be consulted.

TABLE 421*

BARO SPILL AND DRY SEASON INFLOW

Year of Flood	Number of Months Spill	Total Gambela Discharge	Number of Months × 1,500	Difference equals Spill	Total Inflow in following Jan.–April inclusive
1928	5	12,140	7,500	4,640	nil
1929	5	13,630	7,500	6,130	545
1930	3	5,730	4,500	1,230	prob. nil
1931	4	8,960	6,000	2,960	266
1932	4	9,890	6,000	3,890	(321)
1933	4	9,550	6,000	3,550	no data available
1934	4	10,430	6,000	4,430	
1935	5	11,900	7,500	4,400	
1936	4	9,420	6,000	3,420	nil
1937	4	7,990	6,000	1,990	167
1938	4	10,800	6,000	4,800	298
1939	5	11,600	7,500	4,100	253
1940	No records owing to the war				281
1941	5	11,860	7,500	4,360	325
1942	3	8,590	4,500	4,090	460
1943	4	8,490	6,000	2,490	393
1944	3	6,790	4,500	2,290	122
1945	4	10,090	6,000	4,090	nil
1946	4	11,140	6,000	5,140	944
1947	4	9,960	6,000	3,960	not estimated
1948	4	10,730	6,000	4,730	(200)

NOTES: The total discharges at Gambela refer only to the months in which a total of 1,500 millions was exceeded. All figures except in the first two columns are in millions.
Figures are taken from *The Nile Basin*, Vol. IV and its Supplements, or from unpublished records kindly supplied by the Egyptian Irrigation Department in Khartoum.
Inflow shown in brackets is not based on continuous discharge records.
* Referred to as Table 11 in Fig. J 10.

APPENDIX

THE EFFECTS OF AN ERROR OF ONE METRE IN THE LEVELS OF CROSS-SECTION NO. 4 ON THE TABLES OF FLOOD-PLAIN AND SURFACE AREAS AND OF VOLUMES ON THE WHITE NILE

It has been established that the drawing of Cross-Section No. 4, 80 km. downstream of Malakal, showed values for the levels which were one metre too great. Thus in effect the datum used for measuring widths on this cross-section was one metre too low, and in consequence the widths are all much too small. The effects may be divided into those concerning the tables of Appendix IV of the *Third Interim Report* of the Jonglei Investigation Team, and those concerning the tables in this analysis of the White Nile flood.

EFFECTS ON FLOOD-PLAIN WIDTHS AND AREAS

The old and new values, the resulting differences in the widths obtained at Cross-Section No. 4, and the effects of these on the mean flood-plain widths for the reach Malakal to Melut, are shown in Table 422. It will be observed that the average flood-plain widths for this reach, and so the corresponding flood-plain areas at almost all rises, should be increased by between 4 and 10 per cent., with an average of about 6 per cent. Since for most stages of the river the flood-plain area of this reach is only about one-third of the total from Malakal to Jebelein, the effect of the error on these totals (given in Table 28 of the appendix quoted) is only about 2 per cent., and this is only about a third of the estimated probable error.

It may be noted, however, that the difference between predicted and ' observed ' flood-plain areas between Malakal and Melut, given in Table 33 of the supplement to that appendix, is now very much less, in fact only half its previous value. For the mean rise found there the new flood-plain width would be 1,520 m. instead of 1,430 m., and this reduces the difference between mean predicted and mean observed flood-plain widths from 170 to 80 m., and from 11 to under 6 per cent.

EFFECTS ON SURFACE AREAS AND TROUGH VOLUMES

The effects on total widths, and so on surface areas and volumes used in the White Nile flood analysis, are comparatively small if the whole reach from Malakal to Renk is being considered. From the last line of Table 422 it is clear that the effect of this error on the total mean widths between Malakal and Melut is very nearly constant for all rises of the river, the average being about 6 per cent. This will therefore be the proportional effect on the trough volumes of this reach also, both areas and volumes needing to be increased from the values previously given. But these quantities are only about two-fifths of the totals between Malakal and Renk, and the effect of this error on these totals is therefore only about 2 per cent., which is less than or equal to their estimated probable errors.

Since this error has therefore comparatively minor effects on these tables of volumes and surface areas, and so on the analyses themselves, and since it was not discovered until after they had been finally computed and typed, the analyses have not been corrected; but it will be possible from this note to carry out at any time such corrections as may be required. The corrected versions of the area and volume tables have been given with the original versions.

TABLE 422

THE EFFECTS ON FLOOD AND TOTAL SURFACE WIDTHS BETWEEN MALAKAL AND MELUT OF AN ERROR OF ONE METRE IN THE REDUCED LEVELS OF CROSS-SECTION No. 4

Rise above Datum	0·0	0·2	0·4	0·6	0·8	1·0	1·2	1·4	1·6	1·8	2·0	2·2	2·4	2·6	2·8	3·0
(1) New Total Width at Section No. 4	400	450	500	540	600	680	.790	850	1,080	1,220	1,460	1,620	1,800	1,920	2,620	2,800
(2) New Flood-Plain Width at Section No. 4	0	50	100	140	200	280	390	450	680	820	1,060	1,220	1,400	1,520	2,220	2,400
(3) Old Flood-Plain Width at Section No. 4	0	0	10	30	60	120	170	220	260	320	400	510	570	800	940	1,180
(4) Difference	0	50	90	110	140	160	220	230	420	500	660	710	830	720	1,280	1,220
(5) 1/8th of Difference	0	10	10	10	20	20	30	30	50	60	80	90	100	90	160	150
(6) Old Mean Flood-Plain Width (Malakal to Melut) ...	0	20	100	140	200	260	330	410	630	900	1,250	1,450	1,750	2,000	2,250	2,550
(7) 1/8th Difference as percentage of Old Mean Flood-Plain Width	0	50	10	7	10	8	9	7	8	7	6	6	6	4	7	6
(8) Old Total Width at Section No. 4	280	280	290	310	340	400	450	500	540	600	680	790	850	1,080	1,220	1,460
(9) Difference from New Total Width at Section No. 4	120	170	210	230	260	280	340	350	540	620	780	830	950	840	1,400	1,340
(10) 1/8th Difference of Total Widths at Section No. 4 ...	10	20	30	30	30	40	40	40	70	80	100	100	120	100	180	170
(11) Old Mean Total Width	400	420	500	540	600	660	730	810	1,030	1,300	1,650	1,850	2,150	2,400	2,650	2,950
(12) 1/8th Difference as Percentage of Old Mean Total Width	2	5	6	6	5	6	5	5	7	6	6	5	6	4	7	6

NOTES: All figures in metres except in the seventh and last lines which are percentages.

Line (1) is obtained by measurements from the correctly plotted cross-section; Line(3) from Table 24 of Appendix IV of the *Third Interim Report*; Line 4 is from Table 26 of the same publication.

NOTES AND REFERENCES

(1) Verbal communication by Mr. E. S. Waller. In the Introduction to Volume II of *The Nile Basin* the error of a single discharge was estimated to be 5%.

(2) Errors of this order were deduced from the analyses of five floods below average on the Sobat (see Chapter 3, p. 933); but in above average floods systematic errors up to 5% were found. A comparison of discharges above and below Khartoum also shows that errors up to 5% may occur, according to a private communication from Dr. H. E. Hurst.

(3) But see the last part of Section II (pp. 859–60).

(4) See also the last part of Section II (pp. 859–60).

(5) Private communication. But see Volume VIII of *The Nile Basin*, p. 77.

(6) A more detailed account of this and of possible routes is given later (see Chapter 4).

CHAPTER 3. AN ANALYSIS OF THE SOBAT FLOOD

by J. W. Wright, M.A., F.R.I.C.S.

INTRODUCTION

This paper describes a detailed analysis of the flood cycle of the River Sobat, derived almost entirely from the gauge-readings and discharges observed by the Egyptian Irrigation Department in the Sudan. From these records, and those of rainfall and evaporation kept by the Sudan Meteorological Service, an attempt has been made to analyse the flood and to estimate the average cross-section of the river valley by first assuming that it has a general form similar to that of the White Nile, then predicting the differences which should occur during the flood cycle between the discharges at the head and the mouth of the river, and finally comparing these with the differences actually observed.

This cycle of operations has been gone through more than once, so that the final results represent a series of successive approximations. This may appear to invalidate to some extent the extremely close resemblance which was finally obtained between the average predicted and observed differences in the discharges at the two ends of the river. Nevertheless it is hoped that in the main a more accurate picture has been drawn of the behaviour of the river in flood and of the shape of its trough than was available hitherto; and that the results may be of value in estimating the effects of any control schemes which may be projected either for the Sobat itself, its tributaries, or the Machar Marshes to the north.

The work was all done as a spare-time occupation and was made possible by a grant from the Leverhulme Trustees in 1950, followed by a second grant in 1952 when a reconsideration of the basic assumptions necessitated recomputation of most of the tables. Acknowledgment is also due to the Egyptian Irrigation Department in the Sudan, and the Sudan Meteorological Service for information supplied and for facilities to study original records, and to the Sudan Railways Accounts Department for calculating Tables 454–6 (pp. 961–2).

MAIN FEATURES OF THE SOBAT

For detailed accounts of the topography and hydrology of the Sobat and its tributaries, the Baro and Pibor, reference should be made to the relevant sections of *The Nile Basin*; only a brief outline will be given here. The Sobat is the principal tributary of the White Nile, and is responsible for the greater part of the fluctuations in level and discharge as far down as Jebelein. It contributes about 13 milliards annually, or just under half the total White Nile discharge. But whereas the White Nile discharge upstream of Sobat mouth varies only by a few per cent. throughout the year, the Sobat discharge varies from under 10 m/d in February and March to over 60 m/d during October, when it forms more than half the White Nile discharge below the junction.

The Sobat is formed by the junction of two streams, the Baro and the Pibor. The first rises and runs almost entirely in Ethiopia, and the second, though it runs in the Sudan, gets most of its water also from Ethiopia. From this junction, which is called Sobat Head, to its mouth the Sobat is 348 km. long. The water surface has a mean slope of between three and four centimetres per kilometre, but the lower third is rather flatter than this, particularly during the end of the flood, owing to the backwater effect of the White Nile. Apart from the Baro the Sobat has no tributaries which run during the whole year, and only two of the khors which join it have their discharges recorded every year. On the average these contribute about half a milliard, or less than a twentieth of the total annual discharge; but in very high years such as 1946 the amount may be very much larger.

There are a number of bends in the course of the river, and one of its characteristic features is the presence on the inside of these of marshy basins which have formed in the abandoned channels, and which are filled with water when the river is in flood. These therefore form a definite part of the river trough, and, though they are too overgrown to pass any appreciable portion of the discharge, the water which they absorb and store temporarily during the flood causes an appreciable lag in the passage of the flood down the river.

Apart from uncontoured air survey maps, a line of levels along the river, and four cross-sections in the lowest 100 km. of its course, there are no data about the shape of the valley. In this attempt to analyse the flood, therefore, use has had to be made of the concept of an average or *idealized* trough, with a form such that its filling and emptying during the passage of the flood cause differences in the discharges at the two ends which are, on the average, close to those actually observed. In each year these differences are very similar to those observed on the White Nile between Malakal and Renk, where cross-sections at intervals of 20 km. make possible a direct estimate of the shape of the trough. Similar differences would probably be found on the Baro between Gambela and Sobat Head were they not masked by the large amounts which that river spills over its banks. It is very noticeable from the air how the marshy basins on the Sobat, on the insides of its meanders, are continued in apparently exactly the same form up the Baro.

SUMMARY OF RESULTS

The first section of this paper is concerned with the shapes of the lower and upper Sobat troughs. The second comprises an analysis of the flood cycle, leading to comparisons between predicted and observed losses between the discharge sites at Sobat Head, and an estimate of the losses if the river were controlled. In the third section the régimes of the tributaries are discussed and the relationship of the Sobat with the Machar Marshes is investigated. The results may be briefly summarized as follows:

Section I. The Shape of the Sobat Valley

(i) Four cross-sections of the lower Sobat (from Hillet Doleib up to Abwong) show that its trough has a form such that the average width of its surface remains virtually unchanged for the first two metres of rise above mean low level. Thereafter the average width increases as the square of the extra rise above this.

(ii) The upper Sobat (from Abwong up to Sobat Head) is found to have a form such that its average total width increases as the square of the rise above mean low level, but only as far up as the average flood level. Above this the surface width is found to increase very much more rapidly, at the rate of something like 20,000 times the rise above average flood level. In other words the valley is found to be equivalent to a trough with sides of parabolic form, just large enough to contain the average flood, incised in a plain with a very gentle slope towards the river from both sides. (See Fig. K 4.)

(iii) The surface areas of the lower and upper Sobat troughs at the height of an average flood, computed from these results, are 5% less and 16% more respectively than the combined areas in each section of river channel and ' permanent swamp ' shown on the 1930–32 air survey maps.

(iv) The average absorption depth over the whole river is found, both in the trough and in the plain, to have a value of about 30 cm.

Section II. Analysis of the Flood

(i) Using these forms for the trough, and this value for the absorption depth, and allowing for losses and gains by evaporation and rainfall, the values of cumulative observed and cumulative predicted loss between Sobat Head and Hillet Doleib averaged from twelve floods are found to agree within 1% of the corresponding Sobat Head cumulative total of discharge throughout the rising stage of the flood, from May to November inclusive. Agreement in the falling stage of the flood is equally good for five floods below average height (i.e. contained within the incised trough), but not quite so good for seven floods above average, where observed losses by the end of February are less than those predicted, probably because of unrecorded inflow from tributaries.

(ii) This close agreement between observed and predicted losses means that apart from the measured exchanges of water through the Twalor and Wakau (which are regularly observed), the Sobat flood is in nearly all years virtually self-contained. The discharges observed at Sobat Head plus the water added to the actual flood surface by rainfall, less the loss from this by evaporation and the loss by absorption into the flood-plain, when corrected for the discharges of these two tributaries, account on the average entirely in low years, and almost entirely in high ones, for the discharges at Hillet Doleib throughout the flood cycle.

(iii) If the Sobat were kept at any constant discharge of between 10 and 50 m/d the losses during the timely season (January to June) would be of the order of 2 to 3%.

Section III. The Régimes of the Tributaries

(i) The Twalor is shown to act as a spill-channel from the Pibor in years when this is high.

(ii) The Wakau is shown to act as a simple spill-channel from the Sobat while this rises from 7·5 to 10·4 on Nasir gauge, taking out an average of 150 millions during this stage. After this the flow in the Wakau reverses, and it returns at least an equal amount and on the average contributes a further 250 millions to the Sobat during and after the peak of its flood. This behaviour is shown to be most probably due to an initial spill through the Wakau into the Tierbor system, which runs north of the Sobat and roughly parallel to it, this being later filled by spill from the north bank of the Baro to such a height that it is able to overflow through the Wakau back into the Sobat even at the height of its flood.

(iii) Reasons are given for the belief that apart from drainage from the southern plains in exceptional years none of the other tributaries takes from or contributes to the Sobat any appreciable amount. It is shown that the large losses and gains which occur at the peak of each high flood are unlikely to be due to spill through the northern tributaries followed either by sudden heavy inflow from the south, or by a return flow from the Tierbor system similar to that which takes place through the Wakau. The main reasons for this belief are the large size and rapidity of these losses and gains, the invariable close coincidence in time between the change from one to the other with the change from a rising to a falling river, and the lack of observed discharges in these tributary khors of the order of size required. It is shown that these losses and gains can most simply be explained by the assumption that they are due to the flooding and subsequent drainage of a wide area of plain above and immediately flanking the permanent swamps of the Sobat flood-plain.

HISTORY OF THE PRESENT INVESTIGATION

It has already been mentioned in the account of the White Nile Flood (Chapter 2, pp. 902–5 that heavy inflow on that river was deduced in four years and that in the three of these for which records were available there was ample confirmation in the administrative records of the area. This confirmation of the method of analysis led to the present paper, which attempts to apply it to the River Sobat, though in a somewhat different form. On the White Nile the form of the trough could be obtained from measured cross-sections, and the inflow of the tributaries had to be deduced from a comparison of the observed and computed losses. On the Sobat there are very few measured cross-sections, but on the other hand the flow in the tributaries appears to be measured fairly comprehensively, so that, except in very high years, a more reliable comparison can be made between the observed discharges at the two ends of the river than on the White Nile. Basically, therefore, the method used in this analysis was to start with the assumption that the total increase in the width of the river above low level was equal to a constant times the square of its average rise above that level, and then to calculate this constant from a comparison of the end discharges and the value of the rise in different years. This assumption made it possible to express the surface area, and hence the volume of the trough and the loss by absorption, in terms of the rise and the constant. By equating in several floods the losses computed from these to the losses derived from the differences between the discharges at the two ends of the river during the rising stage, an approximate value was obtained for the average constant of the whole river. This was the first step, taken before this paper was actually begun; and the close (though fortuitous) agreement between values of the constant derived from a number of floods was an encouragement to investigate the matter more closely, and to outline progress to date in a letter to *Nature* [1].

FIRST ANALYSIS OF THE SOBAT FLOOD

At this stage the author's attention was drawn to four cross-sections which had been measured of the lower Sobat. From these the average cross-section as far up as Abwong could be calculated directly as on the White Nile, leaving only the average cross-section of the upper two-thirds of the river to be derived indirectly. Thirteen floods were studied and twelve (excluding 1946–47) floods were found in which the records of main and tributary discharges were sufficiently complete for their differences to be used in estimating the shape of the average cross-section of the upper Sobat. From these a mean value for the constant already referred to was obtained, and used to compute tables of surface area and trough volume in terms of average rise above mean low level. Similar tables had been prepared for the lower Sobat from the measured cross-sections. Using these tables, as on the White Nile, it was possible to prepare detailed figures of the cumulative losses or gains due to evaporation, rainfall, change of trough volume, and absorption along the whole Sobat in thirteen floods. The total of these (total computed cumulative loss) for the end of each ten-day period was compared with that observed, and in the mean of the twelve floods whose records were reasonably complete the differences were not very great.

THE CONCEPT OF THE INCISED TROUGH

This was expected to complete the analysis; but the individual comparisons for each flood now available showed that they divided sharply into two groups. One group consisted of five 'low' floods where the maximum rise was below the average maximum of thirty years, and the other of seven 'high' floods where the maximum rise was above the average. In the first group the curve of observed loss had very much the predicted shape. In the high floods, on the other hand, once the water had risen above the average maximum flood level, the observed losses (except in 1946) increased very much faster than could be accounted for by the assumed average cross-section; and after the peak of the flood there were correspondingly large gains. The most obvious, and quite reasonable, explanation of this was that the assumed shape of the trough only extended up to the level of the average flood, and that beyond this the land surface stretched out in a flat or very gently sloping plain, over which the water spread and from which it returned, giving the large and rapid losses and subsequent gains deduced from the observed discharges. On the White Nile the trough is deep enough to contain all floods up to the highest recorded; but on the upper Sobat it seems that the trough has been incised by, and only just contains, the average flood.

RECONSIDERATION OF ABSORPTION DEPTH

This modification of the assumed shape of the trough necessitated complete recomputation of the basic tables of area and volume on the upper Sobat, and thereafter of the computed losses on the whole Sobat. The opportunity was also taken to review another of the basic assumptions—that regarding absorption. On the White Nile flood-plain an average absorption depth of 80 cm. had been deduced and used throughout the analysis, but there was some indication that this was probably an over-estimate. Nevertheless, for lack of any definite evidence the same value was originally assumed for the Sobat. The necessity of complete recomputation seemed to justify making a fresh estimate of absorption in the incised trough, using the five low floods. With approximate values for the maximum flooded area, and for evaporation losses and rainfall gains, these gave a mean value of only 30 cm., and this was therefore adopted. Investigations showed that no other value between 0 and 80 cm. appreciably affected the differences from the mean in the calculations of the slope of the surrounding plain, and so the same value was assumed for this.

This last stage of the analysis, which had been started in 1949, was carried out at Ed Damer in the Northern Sudan during 1952–53 without the earlier results having been discussed at all with the Jonglei Investigation Team, who were working in the Southern Sudan at Malakal. They had been studying the Machar Marshes and had available some information gained from ground and aerial reconnaissances of which I had had no knowledge. From these they had drawn independently their conclusions about conditions in and alongside the Sobat which did not differ very much from those which I had drawn. Such differences as existed were resolved during a visit to Malakal in June 1953 and the result is a general picture of the Sobat régime which seems likely to be as near the truth as can be hoped for until further information is available. It differs in some respects from the account given in Volume VIII of *The Nile Basin* by Dr. Hurst, but considering that virtually no reference was made to this either by the Jonglei Investigation Team or myself until our meeting in 1953 it is surprising how closely the results of the three independent investigations agree.

SECTION I. THE SHAPE OF THE SOBAT VALLEY

On the Sobat the regular discharge sites are at its head and at Hillet Doleib, 8 km. from its mouth; cross-sections are only available for the lower Sobat, as far up as Abwong. Above this there are no contoured maps or complete cross-sections at all, so that an indirect method of estimating the trough shape had to be used. It had been found on the White Nile, and also on the lower Sobat and for a part of the River Pibor which is a tributary of the Sobat, that the curve of the mean idealized bank profile was approximately parabolic; and it therefore seemed reasonable to assume a similar form for that of the upper Sobat. From this assumption, as will be shown below, the shape of the idealized trough can be calculated, using the rise from low to flood level, the difference between the discharges at the two ends of the trough, and measured or assumed depths for rainfall, evaporation, and absorption.

The method of deriving an idealized trough has already been outlined (see p. 853) and the calculations may now be considered in more detail. In the first place it was clearly advisable to divide the Sobat into two reaches, both because of the existence of cross-sections which did not extend very far up the river, and also because the backwater effects of the White Nile were likewise limited. Fortunately the limit in both cases was approximately at Abwong; and as this is a gauge site, it formed the obvious place to put the boundary between what for convenience may be called the upper and lower reaches of the Sobat.

THE LOWER SOBAT

On the lower Sobat four complete cross-sections have been measured[(4)]; they are shown in Figs. K 1 and K 2. In order to idealize them it was necessary first of all to establish at each the datum of normal low river level. This was done by plotting the longitudinal profile of the river surface from the mean gauge-readings converted to reduced levels as shown in Table 423 (p. 922). The profile is shown in Fig. K 3, and the positions of the cross-sections have been plotted on it, enabling their datums to be read off directly. On each cross-section the total width at each half metre of rise above the datum was then measured and the results are shown in Table 424. This table also gives, in the second line for each cross-section, the corresponding flood-plain widths, which are obtained by subtracting from each total width that of the low-level surface. The means were then abstracted, and it will be seen that they approximate closely to the formula:

$$\text{Width of Flood-Plain} = 210\,(\text{rise minus two metres})^2$$

or in other words the mean idealized bank profile of this reach is nearly a parabola which starts at two metres above normal low level. For calculation of the surface areas and volumes in the lower Sobat (Tables 425 and 426, pp. 923–4) this formula was used, assuming the length of the trough to be 116 km. This method was more convenient than using the actual mean profile, and introduced no appreciable inaccuracy into the results when these were combined with the same quantities on the upper Sobat, where the trough is not only twice as long but is filled to a higher level.

THE UPPER SOBAT

(I) THE INCISED TROUGH

For calculating the trough volumes and surface areas on the upper Sobat the shape of the incised trough has first to be found. At first it was assumed to have a form similar to that of the lower Sobat, with idealized bank profiles of parabolic form starting at some point above mean low level. This assumption had to be ruled out at an early stage because it failed completely to account for the considerable losses which invariably occurred each year during the early part of the rise, and which could only be accounted for by assuming that the incised trough began to widen as soon as its surface was above the mean low level. Thus the average width of the water surface was assumed to be related to the average rise above mean low level by the following formula:

$$W = W_o + 2.K.h^2 \qquad (1)$$

where W = average total width
W_o = average width of the low-level channel
h = average rise above mean low level
K = the constant of the parabola.

Clearly the area of the cross-section will be found by integrating this with respect to h, and we shall then get:

$$C = W_o h + \frac{2.K.h^3}{3} + C_o \qquad (2)$$

where C and C_o are respectively the areas of the whole cross-section and of the part below mean level. Assuming this average cross-section to hold for a length L of the river, we have at once that the trough volume is given by:

$$V = L(W_o h + \tfrac{2}{3}K.h^3) + V_o \qquad (3)$$

where V and V_o are respectively the total trough volume and the part held in the permanent channel below normal low level. It should be noted that of the terms in the bracket the first gives the increase in volume of the permanent channel and the second the volume held above the flood-plain.

The surface area will clearly be the product of the average width and the length, and so will be given by:

$$S = L(W_o + 2.Kh^2) \qquad (4)$$

where S is the total surface area. Here again the first term is the surface area of the permanent channel, and the second that of the flood-plain. In calculating absorption it has been assumed that all of it takes place in the flood-plain during the rising stage, and that after the ground has been wet for about a month it ceases to absorb any water at all. Thus the total absorption during any flood is given by the second term above multiplied by an assumed average depth. The net effects of evaporation and rainfall, on the other hand, have to be summed cumulatively over the course of the flood, since their depths and areas change by considerable amounts during it.

From the foregoing it is clear that we can obtain a value for $V-V_o$ (the increase in trough volume during the rising stage of the flood) which is in terms of the average rise of the water-level along the reach in question and of the constant of the assumed parabola, since values are known or can be assumed for the length and width of the low level-channel. But we also know that the increase in trough volume, plus the loss by absorption and by evaporation, less the gain by rainfall, must be equal to the total difference of the discharges at the upper and lower ends of the reach. If an average depth of absorption is assumed, the volume of water absorbed can also be expressed in terms of the parabolic constant and of the average rise; and the same applies to the volumes lost and gained by evaporation and rainfall, though in their case the relationship is much more complex. However, a fairly accurate result can be obtained for them by using an approximate value for the parabolic constant, and then calculating the amounts lost and gained during each ten-day period of each flood.

We can therefore write the following equation, in which values can be obtained, either from records or by approximation, for all the quantities except the parabolic constant K:

$$Q_u - Q_l = V - V_o + E - R + A \qquad (5)$$

$$= L(W_o h + \frac{2Kh^3}{3}) + E - R + 2K.L.D.h^2 \qquad (6)$$

where Q_u and Q_l are the total discharges at the upper and lower ends of the trough (corrected for tributary discharges), E is the loss by evaporation and R the gain by rainfall, and A is the loss by absorption and D its assumed average depth over the flood-plain. Re-arranging this equation we get the following expression for K in terms of the other quantities:

$$K = \frac{Q_u - Q_l - E + R - L.W_o h}{2L\frac{h^3}{3} + Dh^2)} \qquad (7)$$

This equation must of course be used with values for all the calculable quantities which are taken for the same period of time, and it will be clear that the best period for this is the rising stage of the flood, from when the river was steady at low level until it was again steady at the peak of the flood. This allows for any delays in filling the outer parts of the flood-plain to the same level as the main channel; and also for these to absorb their full amount of water up to the average depth assumed for D.

This formula is complicated enough even when the values E, R and D are known ; and when it is applicable to a single stretch of river assumed to be of uniform cross-section, without any tributaries, and terminated by the two discharge sites. Unfortunately none of these conditions is found on the Sobat, and a good deal of preliminary clearing away of corrections to the observed discharges is required before the formula can actually be applied. The main reason for this is of course that the formula is applied to the upper Sobat only, while the reach between the two discharge sites includes the lower Sobat as well. Before the formula can be applied we have therefore to do the following:

(*a*) Calculate and correct for losses on the lower Sobat (except evaporation).
(*b*) Calculate and correct for the observed discharges into and out of the tributaries along the whole river.
(*c*) Calculate approximate values for the net evaporation loss along the whole river.
(*d*) Calculate approximate values for the average absorption depth for the whole river. This of course can only be done by obtaining a preliminary approximate value of K.

(*a*) Losses on the Lower Sobat (see Fig. K 14)

The tables of volume and surface area for this reach have already been described. The losses in each flood can either be obtained from them or by direct calculation. The diagram shows those due to increased trough volume (P and F, F), and that due to absorption (A, A). The calculations of these are given in Table 429 (p. 926) following the calculation of the mean rises in Table 427 (p. 925), and the starting corrections in Table 428 (p. 925). The latter are required in order to allow for the fact that the water-level in the main channel at the start is not as a rule the same as that of the datum for the flood-plain. For convenience of calculation the mean rises and starting corrections for the upper Sobat have been included in the same tables.

(*b*) Gains from and Losses to Tributaries

These are straightforward, being taken directly from discharges observed at their mouths, and are shown in (ii) of Tables 441–53 (pp. 935–60) under ' observed inflow '.

(*c*) Net Evaporation Loss on the Whole Sobat

It was simpler, and more sensible because of the scarcity of rain-gauges, to calculate net evaporation loss (due to evaporation less rainfall) for the whole Sobat in one operation, rather than try to separate out the two parts of it. This is done exactly as described and illustrated in detail in the analysis of the White Nile flood (Chapter 2 of this volume). The mean surface area during each ten-day period (corresponding to the mean gauge) is multiplied by the evaporation depth minus the mean rainfall, if any. The losses from each ten-day period are then summed cumulatively, gains due to rainfall being of course counted as negative. The areas from the lower Sobat were taken from the mean of the gauges at Hillet Doleib and Abwong, be means of Table 425 (p. 923). Those for the upper Sobat were taken from the means of the gauges at Abwong, Nasir, and Sobat Head, using a preliminary version of Table 433 (p. 927) (computed from an approximate value of K). These calculations were straightforward but lengthy; they are not shown in this paper.

(*d*) Absorption Depth on the Whole Sobat

Originally this was simply assumed to be the same as that deduced for the White Nile (80 cm.); but subsequently, as already explained in the introduction (p. 915), a value was calculated from the five low floods which were assumed to have been contained entirely within the incised trough. When approximate values for all other quantities (including K) had been calculated, it was possible to eliminate from the observed losses at the end of each cycle those due to minor changes of trough volume between the starting and finishing levels, and to net evaporation throughout the cycle. The remaining losses could be assumed to be due entirely to absorption, and since the approximate maximum area inundated during the flood was known, a value could be obtained for the average absorption depth by dividing the residual observed loss by this maximum area. This area of course does not include that of the permanent channel, which is always covered by water and so assumed to be incapable of further absorption. The calculations for absorption depth are shown in Table 430 (p. 926), the mean being rounded off to 30 cm.

Method of Deriving Means

It will be observed that in this table, as also in Table 432 (p. 927) where the final value of K is calculated from equation (7), the value adopted is not the mean of the individual values, but is obtained by dividing the sum of the individual quotients by the sum of the dividends. The reason for this is that the main cause of divergencies from the mean is thought to be real or apparent errors in the observed discharges, which in both cases form the data from which the dividends (observed losses) are obtained. In a low year these losses are relatively small, and a given error in the observed discharges may have a disproportionate effect on the value of the depth or of K, whereas in a high year the effect of the same error would be very much less. It is therefore better to sum all the losses, and sum all the divisors first, and then divide one by the other. The differences of individual values from the mean obtained in this way are then converted into terms of observed loss, so that they may be expressed as errors in the observed discharges. This is done in the second parts of Tables 430 and 432. These errors may be real, or apparent, owing to the omission of discharges into or out of some tributary khors. When this has been done it will be seen that although widely different values are obtained for the absorption depth and for K they do not represent unusually high percentage errors in the observed discharges.

Calculation of Area and Volume Tables

Once the mean value of K has been obtained the calculation of the final table of surface areas is simply a matter of applying it to the formula given in equation (4) above and the result is Table 433. It will be noted that the rises above datum have been converted to mean gauge-readings for the reach, the means of Abwong, Nasir, and Sobat Head being used. The table shows the surface area for each decimetre of this mean gauge above normal low level. From this table the corresponding trough volumes above the low-level surface are easily obtained by integration, the average surface area for each rise of one decimetre being interpolated directly and then divided by ten to give the corresponding increment of volume. The values for each centimetre of rise were then interpolated between these. The cumulative values of the trough volume obtained in this way are shown in Table 434 (p. 928), and the values for each half metre rise were also calculated directly from formula (3) to give a check; these are shown in Table 435. The value of V_o was never obtained since it is not required for the study of the flood; moreover there are no data of the depth of the permanent channel.

Comparison with the Air Survey

The aerial survey maps on 1/50,000 scale made in 1930–32 show areas alongside the main channel marked as 'permanent swamp', most of them being on the insides of the river bends. These correspond to the basins already described in the introduction; during the dry season their bright green colour as compared with the general dun colour of the surrounding plain makes them stand out clearly from the air. The total area of these and the main channel together was scaled off these maps by means of squares with 500 metre sides, and the resulting areas for the upper and lower Sobat are shown below, together with the corresponding areas for the surface of the idealized trough at average flood height as given in Tables 425 and 433:

Section of River	Measured Area	Computed Area	Difference Computed—Measured	Difference as Percentage of Computed Area
Upper Sobat	278	333	+55	16
Lower Sobat	69	64	− 5	8
Whole Sobat	347	397	+50	13

(II) THE SURROUNDING PLAIN

The direct evidence of the measured cross-sections on the White Nile and the lower Sobat shows that their troughs are deep enough to contain even the highest recorded floods. It was natural therefore to assume at first the same general form for the upper Sobat valley, until the results of the individual flood analyses became available. Figs. K 5–11 show the curves of computed loss (dotted, and marked as 'First Computed') with those of the losses actually obtained. It is clear from these that in the exceptionally high floods of 1934, 1938, 1945, and 1947, once the river had risen above the average flood level, the observed losses became extremely large, and that in general they increased with the size of the flood. 1946, however, is an exception to this. It is also clear that there were correspondingly large gains as soon as the water-level began to drop after the peak of the flood.

These large losses and subsequent gains, coinciding very closely with the peak of the flood, could be accounted for most simply by assuming that the trough only contained floods of average height, and that it was incised in a plain which sloped towards the river, so that the observed rapid exchange of water could take place. They could also be accounted for in part by assuming either heavy spill to the north followed by heavy and sudden inflow from the south, or by supposing a heavy exchange of water with the marshes to the north where the water-level would be supposed to be initially below and subsequently above that in the Sobat. These two possibilities are discussed in some detail in Section III (p. 964) and it is shown there that they are unlikely to play any major part in causing this large and rapid change from loss to gain. It has therefore been assumed that the whole of this is caused by the flooding and subsequent drainage of a wide area flanking the incised trough.

The only data available for indicating the slope of this plain are a line of levels along the Khor Nyanding. These are summarized on page 34 of *The Nile Basin*, Volume VIII, where it is stated that this khor runs at a fairly constant depth below the plain with an average slope of 8 cm/km. To the north the Sobat trough or flood-plain is said to be bounded by a higher bank through which are cut a few khors such as the Loing and Banglai. For the purpose of calculating the areas and volumes held above this upper part of the 'trough', it has to be idealized in the same way as the main trough was idealized. The slope of this plain is therefore assumed to be uniform and the same on both sides of the river, although the scanty available evidence indicates that it is probably more gentle to the south. These assumptions make it possible to express the losses due to increase of 'trough' volume, net evaporation, and absorption in terms of only one unknown—the slope of this plain on both sides of the river. This is done for the period when the water is rising from the top of the incised trough to the maximum level it attained in each of these high floods. In this way the slope of the plain is calculated in very nearly the same way as the constant of the incised trough.

The losses which occur while the flood is filling the incised trough have of course to be calculated first, and the results obtained for the slope of the plain are likely to be less concordant than those of the parabolic constant of the incised trough for four reasons:

(*a*) The peaks of these high floods are sharper than those of low ones; i.e. there is a shorter period of stable conditions before the water-level begins to fall.

(*b*) The water has to travel farther and there is less likelihood therefore (especially as the time is short) of its surface being truly horizontal.

(*c*) The years of high floods are also years of heavy rainfall, and this may cause appreciable inflow through tributaries whose discharges are not measured. There is no doubt whatever that this happened in 1946–7, and it may well have happened to a less extent in other years.

(*d*) The percentage errors of discharge measurements tend to increase with the size of the discharge.

It will be seen both in the calculations of the slope of this assumed plain and in the computed losses of the high floods, that this expectation of less concordant results is justified; but in the writer's opinion the agreement of the observed and computed curves of loss throughout these high floods is good enough to confirm that the hypothesis of an incised trough in a gently sloping plain is worthy of serious consideration.

In order to overcome some of the errors due to (*a*) and (*b*) above, the calculations are applied up to the period ending with the largest value of cumulative observed loss, and the value of the excess height above the trough used is the mean of the value at this period with the maximum.

Derivation of Formulae

We may now proceed to derive the formulae based on this theory. Let the slope on each side be 1/1,000 p, let h′ be the excess height of the flood above the top of the incised trough (i.e. above average flood height) in metres, let the total surface width and area of this trough be W_t and S_t respectively, and let its volume above mean low level be V_t. We shall then have the following (see Fig. K 4):

$$\text{Total surface width in metres } W = W_t + 2{,}000p.h' \quad (8)$$
$$\text{Total surface area (km}^2\text{) } S = S_t + 2L.p.h' \quad (9)$$
$$\text{Total trough volume (millions) } V = V_t + h'S_t + L.p.h'^2 \quad (10)$$
$$\text{Absorption (millions) } A = D(S_t - W_aL + 2L.p.h') \quad (11)$$

We can obtain W_t, S_t, and V_t by the mean value of K derived from the five low floods as already described. We can therefore proceed to obtain p from each of the seven high floods by using formula (5), which was:

$$Q_u - Q_l = V - V_u + A + E - R \quad (5)$$
$$= V_t + h'S_t + L.p.h'^2 + D(S_t - W_aL + 2L.p.h') + E - R \quad (12)$$
$$\text{whence } p = \frac{Q_u - Q_l - V_t - S_t(h' + D) + D.W_aL - E + R}{L.h'^2 + 2L.D.h'} \quad (13)$$

using the same notation as in equations (6) and (7) above.

As was the case with the incised trough, we have to clear away a certain number of corrections in order to apply this formula to the upper Sobat plain. The volume and absorption losses on the lower Sobat, and the corrections for tributary discharges, are treated in high floods exactly as in low ones, in the manner already described on page 918. The calculations are not shown here. Net evaporation loss over the whole river is, however, more complicated in these high floods. It falls into three parts :

(*a*) Loss on the lower Sobat from the start up to the maximum height of the flood, i.e. for the whole period.

(*b*) Loss on the upper Sobat from the start until the flood reaches the average maximum height and overtops the trough.

(*c*) Loss on the upper Sobat from this stage until the flood reaches its maximum height.

The first is dealt with exactly as in low floods. The second is obtained from the preliminary calculations made when it was assumed that the incised trough contained all floods. Since the abandonment of this assumption did not, by good fortune, lead to any substantial change in the deduced value of K, the surface areas up to the top of the incised trough are virtually unchanged. The third stage fortunately occurs at a time when rainfall and evaporation nearly cancel out, so that net evaporation is very small. We can therefore obtain a reasonably accurate value for the net evaporation loss during this stage by multiplying the net evaporation depth during it by the mean of the surface areas at the beginning and the end. At the beginning this will be the surface area of the incised trough, and at the end the maximum area attained.

We may express this mathematically as follows :

$$\underset{\text{(for this stage only)}}{E - R} = \tfrac{1}{2}d(S_t + S_t + 2.L.p.h') = d(S_t + L.p.h') \qquad (14)$$

where d is the total net evaporation depth from when the flood overtops the incised trough until it reaches its maximum height. Substituting this in (12) we get :

$$p = \frac{Q_o \pm Q_t - V_t - S_t(h' + D + d) + D.W_a.L - E' + R'}{L.h'(h' + 2D + d)} \qquad (15)$$

where $E' - R'$ is the sum of the net evaporation losses as defined in (*a*) and (*b*) above. From this formula we can obtain a value for the average slope of the surrounding plain on each side of the incised trough, from any flood which overtops it, once we have computed the values of the surface width, area, and volume of the incised trough.

Calculation of Mean Plain Slope

From Table 423 (p. 922) we have the following gauge-readings for the average flood level corresponding to the top of the incised trough :

Sobat Head	9·57
Nasir	10·54
Abwong	14·70
Mean	11·60

The required quantities S_t and V_t can then be obtained as follows

$$S_t \text{ from Table 433} = 333 \text{ km}^2$$
$$V_t \text{ from Table 434} = 650 \text{ millions m}^3$$
$$\text{and } D.W_a.L = 0{\cdot}3 \times 0{\cdot}14 \times 231 = 10 \text{ millions.}$$

This last is the area of the permanent channel, multiplied by the absorption depth; it has to be subtracted from the loss by absorption because the bed of the permanent channel is assumed to be fully saturated and so incapable of further absorption. We can now proceed to apply equation (15) to the eight high floods, and this is done in Table 436 (p. 929). The differences from the mean in individual floods are expressed as percentage areas of the Sobat Head discharge in Table 437 (p. 929).

Discussion of Results

A preliminary mean slope was obtained by using the sums of the dividends and the divisors, as already explained on page 919 ; and the individual differences from this were expressed as errors in the discharge at Sobat Head. It was clear that in two years—1935 and 1946—the differences were considerably larger than in the remainder. Reasons are given below why it seemed justifiable to the author to omit these two values in calculating the final mean value of the slope, which was then used for computing the tables of volume and surface area.

1935–36 Flood

In Table 437 (p. 929) is shown the maximum mean gauge for each year, obtained by meaning the Sobat Head, Nasir, and Abwong gauges at the peak of the flood. The table also shows, in addition to the total Sobat Head discharge during the period of the rise, the total discharge there for the same period in each flood, namely from May 1st to October 31st. While this will not necessarily be related exactly to the maximum mean gauge in each flood, we may reasonably expect some sort of correlation between the two. It is therefore all the more remarkable that in 1935–36, though the maximum mean gauge was the lowest but one of the eight floods considered here, the total observed discharge during this period was the highest of them all, not even excepting the 1946–47 flood. From this it would seem that at a conservative estimate this discharge was over-estimated by at least 5 per cent., and probably by more. This being so, it seems justifiable to omit this flood from the final calculation of the mean.

1946–47 Flood

There is no reason to suppose any particular error in the Sobat Head discharges of this flood; but it is quite clear that the results obtained from it are invalidated by heavy inflow through tributaries whose discharges were not recorded, among which were very probably the Fullus and the Nyanding. Study of the observed discharges of this flood, which are shown in Table 452 (ii), p. 957, makes it quite clear that this heavy inflow began some time in August and continued right through till the end of January, when the total of the observed gain at Hillet Doleib amounted to something like three or four milliards. From the Second Supplement to Volume IV of *The Nile Basin* we know that the Khor Fullus in 1933 contributed something like 400 millions between May 1st and October 31st, so that it is evidently perfectly capable of flowing strongly in an exceptionally wet year such as we know 1946 to have been. With these two floods omitted the mean slope comes out to 1/10,800 or approximately 9 cm/km. Omitting the differences from this mean obtained for these two floods, if the whole of each of the other differences is supposed to be due to errors in the observed discharges at Sobat Head (which of course it is not), then the maximum percentage error is seen to be 4·9, and the average 3·1. As the gauge/discharge relationship at Hillet Doleib is complicated by the White Nile backwater effect, no attempt has been made to compare these divergencies with it. When, however, it is considered that there must also have been some errors there, and also a certain amount of unrecorded inflow in other years beside 1946, the agreement of the different values of the mean slope seems sufficiently good to justify the assumption of its existence.

Calculation of Surface Area and Volume Tables for High Floods

We may now proceed to calculate the values of the surface area and 'trough' volume of the valley, for the mean gauge-readings from 11·60 (the top of the incised trough) up to the highest recorded, which may be taken as 12·50. To do this p is rounded off to 11·0.

We have:

$$\begin{aligned} S &= S_t + 2.L.p.h' \\ &= 333 + 11 \times 462 \times h' \end{aligned} \qquad (9)$$

So for each centimetre on the mean gauge above 11·60, the surface area increases by 462 × 0·11 or 50·8 km². The table of surface areas, Table 438 (p. 930), is therefore easily constructed by simple addition.

For 'trough' volumes we have:

$$\begin{aligned} V &= V_t + h'S_t + L.p.h'^2 \\ &= 650 + 333h' + 231 \times 11 \times h'^2 \\ &= 650 + 333h' + 2{,}541h'^2 \end{aligned} \qquad (10)$$

This formula was used for calculating V for every decimetre of the excess rise; the results were then plotted on a graph, and the values for intermediate centimetres were then taken off the graph. The calculations are shown in Table 439, and the final results in Table 440 (p. 930).

TABLE 423

LONGITUDINAL PROFILES OF THE RIVER SOBAT

	Name of Gauge				
	Hillet Doleib	Abwong	Nyanding	Nasir	Sobat Head
Distance from Sobat Mouth (km.)	8	117	239	304	348
R.L. of Gauge Zero	371·49	373·61	380·72	385·99	388·93
Mean Low Level on Gauge (1912–42)	11·05	10·31	7·89	5·13	4·80
R.L. of Low Level (= Datum)	382·54	383·92	388·61	391·12	393·73
Mean Flood Level on Gauge (1912–42) ...	13·65	14·70	12·90	10·54	9·57
R.L. of Flood Level	385·14	388·31	393·63	396·63	398·50
Mean Rise (1912–42)	2·60	4·39	5·02	5·41	4·77

TABLE 424

MEASURED CROSS-SECTIONS ON THE LOWER SOBAT

Cross-Section No.	Km. from Mouth	R.L. of Datum	Low Level Width	Total and Flood-Plain Widths at heights above datum of:							
				1·5	2·0	2·5	3·0	3·5	4·0	4·5	5·0
1	26	382·7	90	90	90	110	230	800	1300	—	—
Flood-Plain Width			0	0	0	20	140	710	1210	—	—
2	40	382·9	100	115	140	260	560	850	1200 +	—	—
Flood-Plain Width			0	15	40	160	460	750	1100 +	—	—
3	61	383·2	90	90	100	100	220	450	520	580	—
Flood-Plain Width			0	0	10	10	130	360	430	490	—
4	81	383·4	160	160	170	180	270	520	790	900	950
Flood-Plain Width			0	0	10	20	110	360	630	740	790
Mean Flood-Plain Widths ...			0	4	15	52	210	545	860	—	—
Flood-Plain Widths from Formula: Width = 210(h-2)²			0	0	0	52	210	472	840	—	—
Difference			0	4	15	0	0	73	20	—	—
Mean Low Level Width ...			110	—	—	—	—	—	—	—	—

Widths and heights in metres.

TABLE 425

SURFACE AREAS ON THE LOWER SOBAT

This table is calculated by the formula:

Surface Area = W_o. L + 210.L. $(h - 2)^2$, where
L = length of reach, taken as 109 km.
W_o = mean low level width from Table 424 = 110 m.
h = mean rise above the mean of the low-level gauge-readings at Hillet Doleib and Abwong; this mean is 10·7.

Mean Gauge	Mean Rise h	$(h - 2)^2$	Flood-Plain Area 22·9 $(h - 2)^2$	Total Surface Area
10·7	0	0	0	12
12·7	2·0	0	0	12
12·9	2·2	0·04	0·9	13
13·0	2·3	0·09	2·1	14
13·1	2·4	0·16	3·7	16
13·2	2·5	0·25	5·8	18
13·3	2·6	0·36	8·2	20
13·4	2·7	0·49	11·4	23
13·5	2·8	0·64	14·7	27
13·6	2·9	0·81	18·5	30
13·7	3·0	1·00	22·9	35
13·8	3·1	1·21	27·7	40
13·9	3·2	1·44	32·9	45
14·0	3·3	1·69	38·7	51
14·1	3·4	1·96	44·9	57
14·2	3·5	2·25	51·5	64
14·3	3·6	2·56	57·6	70
14·4	3·7	2·89	66·2	78
14·5	3·8	3·24	74·2	86
14·6	3·9	3·61	82·7	95
14·7	4·0	4·00	91·6	104
14·8	4·1	4·41	101	113
14·9	4·2	4·84	111	123
15·0	4·3	5·29	122	134
15·1	4·4	5·76	132	144
15·2	4·5	6·25	143	155
15·3	4·6	6·76	154	166
15·4	4·7	7·29	167	179
15·5	4·8	7·84	179	191

Gauges and rises in metres, areas in square kilometres.

TABLE 426

TROUGH VOLUMES ON THE LOWER SOBAT

This table is calculated by the formula:

Trough Volume (above mean low level) = $W_o.L.h + 70.L.(h - 2)^2$, where
L = the length of the reach, taken as 109 km.
W_o = the mean low-level width, taken from Table 424 = 110 metres
h = the mean rise above the mean of the low-level readings at Hillet Doleib and Abwong; this mean is taken as 10·7.

(i) From 10·7 to 13·0 the second term in the above equation is zero or negligible and only the first term is required.

Mean Gauge	Trough Volume (12h)	Mean Gauge	Trough Volume (12h)	Mean Gauge	Trough Volume (12h)
10·7	0	11·5	10	12·3	19
10·8	1	11·6	11	12·4	20
10·9	2	11·7	12	12·5	22
11·0	4	11·8	13	12·6	23
11·1	5	11·9	14	12·7	24
11·2	6	12·0	16	12·8	25
11·3	7	12·1	17	12·9	26
11·4	8	12·2	18	13·0	28

(ii) From 13·01 onwards the volumes were calculated for each decimetre of the mean rise, and intermediate values were interpolated by estimation.

Mean Gauge	Channel Volume (12.h)	h − 2	$(h - 2)^2$	Flood-Plain Volume $7.6(h - 2)^2$	Total Trough Volume for each even centimetres: 0·00	0·02	0·04	0·06	0·08
13·1	28·8	0·4	0·06	0·4	29	29	30	30	30
13·2	30·0	0·5	0·12	0·9	31	31	31	32	32
13·3	31·2	0·6	0·22	1·6	33	33	33	34	34
13·4	32·4	0·7	0·34	2·6	35	35	36	36	37
13·5	33·6	0·8	0·51	3·9	37	38	39	39	40
13·6	34·8	0·9	0·73	5·5	40	41	42	42	43
13·7	36·0	1·0	1·00	7·6	44	45	46	46	47
13·8	37·2	1·1	1·33	10·1	48	49	50	50	51
13·9	38·4	1·2	1·73	13·2	52	53	54	54	55
14·0	39·6	1·3	2·20	16·8	56	57	58	60	61
14·1	40·8	1·4	2·74	20·8	62	63	64	66	67
14·2	42·0	1·5	3·38	25·7	68	69	70	72	73
14·3	43·2	1·6	4·10	31·2	74	75	77	78	80
14·4	44·4	1·7	4·91	37·4	82	84	86	87	89
14·5	45·6	1·8	5·83	44·3	90	92	94	95	97
14·6	46·8	1·9	6·86	52·3	99	101	103	105	107
14·7	48·0	2·0	8·00	60·8	109	111	113	116	118
14·8	49·2	2·1	9·26	70·3	120	122	124	127	129
14·9	50·4	2·2	10·65	81·0	131	133	136	139	141
15·0	51·6	2·3	12·17	92·5	144	147	150	152	155
15·1	52·8	2·4	13·82	105·0	158	161	164	167	170
15·2	54·0	2·5	15·62	118·7	173	176	180	183	186
15·3	55·2	2·6	17·58	133·6	189	192	196	199	203
15·4	56·4	2·7	19·68	149·6	206	210	213	217	221

Gauges and rises in metres, volumes in millions of cubic metres.

TABLE 427

COMPUTATION OF MEAN RISES ON THE SOBAT FOR FIVE LOW FLOODS

	1936	1939	1941	1943	1944
Ten-day Period with which Losses End	Oct. 3	Oct. 3	Nov. 1	Oct. 3	Oct. 2
Peak Gauge at Hillet Doleib	13·51	13·59	13·54	13·52	13·60
Low-Level Datum at Hillet Doleib	11·05	11·05	11·05	11·05	11·05
Peak Rise at Hillet Doleib	2·46	2·54	2·49	2·47	2·55
Peak Gauge at Abwong	14·49	14·52	14·59	14·33	14·24
Low-Level Datum at Abwong	10·31	10·31	10·31	10·31	10·31
Peak Rise at Abwong	4·18	4·21	4·28	4·02	3·93
Peak Gauge at Nasir	10·46	10·56	10·66	10·42	10·37
Low-Level Datum at Nasir	5·13	5·13	5·13	5·13	5·13
Peak Rise at Nasir	5·33	5·43	5·53	5·29	5·24
Peak Gauge at Sobat Head	9·48	9·48	9·50	9·46	9·42
Low-Level Datum at Sobat Head	4·80	4·80	4·80	4·80	4·80
Peak Rise at Sobat Head	4·68	4·68	4·70	4·66	4·62
MEAN RISE LOWER SOBAT (Mean of Hillet Doleib and Abwong = h_1)	3·32	3·38	3·38	3·24	3·24
MEAN RISE UPPER SOBAT (Mean of Abwong, Nasir, and Sobat Head = h_2)	4·73	4·77	4·84	4·66	4·60

TABLE 428

CORRECTIONS FOR ACTUAL STARTING GAUGES (DIFFERENCES OF THESE FROM MEAN LOW LEVEL DATUM) FOR FIVE LOW FLOODS

	1936	1939	1941	1943	1944
Ten-Day Period before Losses Begin	Apr. 1	Apr. 3	Apr. 3	Apr. 3	Apr. 3
Start Gauge at Hillet Doleib	11·02	11·50	10·78	11·11	11·06
Difference from Datum	−0·03	+0·45	−0·27	+0·06	+0·01
Starting Gauge at Abwong	10·27	10·89	10·12	10·33	10·28
Difference from Datum	−0·04	+0·58	−0·19	+0·02	−0·03
Starting Gauge at Nasir	5·12	5·80	5·08	5·34	5·43
Difference from Datum	−0·01	+0·67	−0·05	+0·21	+0·30
Start Gauge at Sobat Head	4·82	5·50	4·78	5·04	5·14
Difference from Datum	+0·02	+0·70	−0·02	+0·24	+0·34
MEAN DIFFERENCE LOWER SOBAT (Start minus Datum = d_1)	−0·04	+0·52	−0·23	+0·04	−0·01
MEAN DIFFERENCE UPPER SOBAT (Start minus Datum = d_2)	−0·01	+0·65	−0·09	+0·16	+0·20

TABLE 429

COMPUTATION OF LOSSES ON THE LOWER SOBAT IN FIVE LOW FLOODS

	1936	1939	1941	1943	1944
Mean Rise = h_1, from Table 427	3·32	3·38	3·38	3·24	3·24
$(h_1 - 2)^2$	1·74	1·90	1·90	1·54	1·54
$(h_1 - 2)^3$	2·30	2·63	2·63	1·91	1·91
$h_1 - d_1$	3·36	2·86	3·61	3·20	3·25
(d_1 from Table 428)					
Loss to Main Channel = $12(h_1 - d_1)$	40	34	43	38	38
Loss by Absorption to Flood-Plain = $6·9\ (h_1 - 2)^2$ ...	12	13	13	10	10
Loss to Volume above Flood-Plain = $7·63(h_1 - 2)^3$ ...	18	20	20	15	15
TOTAL	70	67	76	63	63

NOTE: Losses are in millions of cubic metres, all other figures are in metres.

TABLE 430

(i) DETERMINATION OF AVERAGE ABSORPTION DEPTH FROM FIVE LOW FLOODS

Year	Final Observed Loss	Approximate Evaporation Loss	Change in Trough Volume	Corrected Final Absorption Loss	Approximate Maximum Flood-Plain Area sq. km.	Deduced Absorption Depth cm.
1936–37	77	+10	+12	55	338	16
1939–40	493	+ 2	−15	506	320	158
1941–42	29	+85	+17	−73	350	−29
1943–44	−177	+ 5	− 8	−174	320	−54
1944–45	221	+ 5	− 5	221	309	72
Means	128	21	0	107	327	32·6

Mean absorption depth from ratio of sums in the last two columns = 30·6 cm.

(ii) DIFFERENCES OF DEDUCED ABSORPTION DEPTHS FROM 30 CM. EXPRESSED AS PERCENTAGE ERRORS OF SOBAT HEAD DISCHARGE

Year	Absorption Loss assuming Depth = 30 cm.	Difference Observed—Computed	Total Discharge Sobat Head	Difference as Percentage
1936–37	101	−46	11,480	−0·4
1939–40	96	+410	11,900	+3·4
1941–42	105	−178	10,920	−1·6
1943–44	96	−270	11,460	−2·3
1944–45	92	+129	11,800	+1·1
Mean (regardless of sign) ...				1·8

TABLE 431

COMPUTATION OF DIRECTLY CALCULABLE LOSSES ON THE UPPER AND LOWER SOBAT FOR FIVE LOW FLOODS

	1936	1939	1941	1943	1944
Mean Rise on Upper Sobat = h_2	4·73	4·77	4·84	4·66	4·60
h_2^2	22·4	22·8	23·4	21·7	21·2
h_2^3	105·8	108·5	113·4	101·2	97·3
Using d_2 from Table 428, $h_2 - d_2$	4·74	4·12	4·93	4·50	4·40
Total Loss on the Lower Sobat, less Evaporation (from Table 429)	70	67	76	63	63
Approximate Net Evaporation Loss for the Whole Sobat...	−85	−107	−32	−92	−108
Loss to Permanent Channel of Upper Sobat $= W_2L(h_2 - d_2)$	154	133	160	146	143
Sum of Calculable Losses	139	93	204	117	98

TABLE 432

COMPUTATION OF THE PARABOLIC CONSTANT OF THE UPPER SOBAT INCISED TROUGH FROM FIVE LOW FLOODS (EQUATION 7)

	1936	1939	1941	1943	1944
Observed Loss to Peak of Flood	639	966	792	609	830
Observed Inflow of Tributaries	−33	−44	−56	−226	−209
Corrected Observed Loss ($Q_a - Q_i$)	606	922	736	383	621
Sum of Calculable Losses ($R - E - L.W_o.h$)	139	93	204	117	98
Net Observed Loss = DIVIDEND	467	829	532	266	523
Upper Sobat: $\frac{2}{3}.L.h^2 = \frac{\text{Flood-Plain Loss}}{K}$	16·3	16·7	17·5	15·6	15·0
Upper Sobat: $2L.D.h^2 = \frac{\text{Absorption Loss}}{K}$	3·1	3·2	3·3	3·0	2·9
Sum = Coefficient of K = DIVISOR	19·4	19·9	20·8	18·6	17·9
QUOTIENT = K	24·1	41·7	25·6	14·3	29·3
Mean K (from Ratio of Sums)	27·1	27·1	27·1	27·1	27·1
Difference from Mean	−3·0	+14·6	−1·5	−12·8	+2·1
Difference × Divisor	−58	+291	−22	−238	+38
Total Discharge at Sobat Head	8,780	8,950	8,480	8,340	8,490
Difference as Percentage of Discharge	−0·7	+3·3	−0·3	−2·7	+0·4

TABLE 433

SURFACE AREAS OF THE INCISED TROUGH OF THE UPPER SOBAT, FOR MEAN GAUGE-READINGS FROM 6·6 TO 11·6

This table was calculated from the following formula:

Surface Area = $W_o L + 2K.L.h^2$, where
W_o = mean width at low level = 140 metres
L = length of reach = 231 km.
K = Parabolic Constant = 27·1 from Table 432
h = mean rise along the reach above the mean of the low-level gauge-readings at Abwong, Nasir, and Sobat Head, which is 6·7.

Mean Gauge	Rise Squared	Flood-Plain Area	Total Surface Area	Mean Gauge	Rise Squared	Flood-Plain Area	Total Surface Area
6·6	0·00	0·0	32	9·1	5·76	72·1	104
6·7	0·00	0·0	32	9·2	6·25	78·2	110
6·8	0·01	0·1	32	9·3	6·76	84·2	116
6·9	0·04	0·5	32	9·4	7·29	91·2	124
7·0	0·09	1·1	33	9·5	7·84	98·2	131
7·1	0·16	2·0	34	9·6	8·41	105·3	138
7·2	0·25	3·1	35	9·7	9·00	112·7	145
7·3	0·36	4·5	37	9·8	9·61	120·3	153
7·4	0·49	6·1	38	9·9	10·24	128·2	160
7·5	0·64	8·0	40	10·0	10·89	136·3	169
7·6	0·81	10·1	42	10·1	11·56	144·7	177
7·7	1·00	12·5	45	10·2	12·25	153·3	186
7·8	1·21	15·1	47	10·3	12·96	162·2	194
7·9	1·44	18·0	50	10·4	13·69	171·3	204
8·0	1·69	21·1	53	10·5	14·44	180·8	213
8·1	1·96	24·5	57	10·6	15·21	190·4	223
8·2	2·25	28·1	60	10·7	16·00	200·5	233
8·3	2·56	32·0	64	10·8	16·81	210·5	243
8·4	2·89	36·1	68	10·9	17·64	220·9	253
8·5	3·24	40·5	73	11·0	18·49	231·5	264
8·6	3·61	45·1	77	11·1	19·36	242·4	275
8·7	4·00	50·1	82	11·2	20·25	253·3	286
8·8	4·41	55·2	88	11·3	21·16	264·4	297
8·9	4·84	60·6	93	11·4	22·09	276·5	309
9·0	5·29	66·2	98	11·5	23·04	288·4	321
—	—	—	—	11·6	24·01	300·5	333

NOTES: Gauges in metres and areas in square kilometres.
When the upper discharge site is at Nasir, 190 km. from Hillet Doleib, the equivalent surface areas are obtained by multiplying values derived from this table by 190/231, which = 0·823.

TABLE 434

VOLUME OF THE INCISED TROUGH OF THE UPPER SOBAT ABOVE MEAN LOW LEVEL (FROM MEAN GAUGE 6·7 TO 11·6)

Mean Gauge	0·00	0·02	0·04	0·06	0·08	Mean Gauge	0·00	0·02	0·04	0·06	0·08
—	—	—	—	—	—	8·1	57	58	59	61	62
6·7	0	1	1	2	3	8·2	63	64	65	67	68
6·8	3	4	5	5	6	8·3	69	70	72	73	74
6·9	7	8	9	9	10	8·4	76	77	79	80	81
7·0	10	11	12	12	13	8·5	83	84	86	87	89
7·1	13	14	15	15	16	8·6	90	92	93	95	96
7·2	17	18	19	19	20	8·7	98	100	102	103	105
7·3	21	22	23	23	24	8·8	106	108	110	111	113
7·4	25	26	27	27	28	8·9	115	117	119	121	123
7·5	29	30	31	31	32	9·0	125	127	129	131	133
7·6	33	34	35	35	36	9·1	135	137	139	142	144
7·7	37	38	39	40	41	9·2	146	148	150	153	155
7·8	42	43	44	45	46	9·3	157	159	162	164	167
7·9	47	48	49	50	51	9·4	169	171	174	176	179
8·0	52	53	54	55	56	9·5	182	185	188	190	193
	0·00	0·01	0·02	0·03	0·04	0·05	0·06	0·07	0·08	0·09	
9·6	196	197	199	200	201	203	204	205	207	209	
9·7	210	211	213	214	216	217	219	220	222	223	
9·8	225	226	228	229	231	232	234	236	237	239	
9·9	241	242	244	246	247	249	250	252	254	256	
10·0	257	259	262	262	264	266	268	269	271	273	
10·1	274	276	277	279	281	283	284	286	288	290	
10·2	292	294	296	298	300	301	303	305	307	309	
10·3	311	313	315	317	319	321	323	325	327	329	
10·4	331	333	335	337	339	342	344	346	348	350	
10·5	352	354	356	358	360	363	365	367	370	372	
10·6	374	376	378	380	382	385	387	389	392	394	
10·7	397	399	402	404	406	409	411	414	416	418	
10·8	421	423	426	428	431	433	436	438	441	443	
10·9	446	448	451	453	456	458	461	463	466	469	
11·0	472	475	478	480	483	486	488	490	493	495	
11·1	498	501	504	507	509	511	514	517	520	523	
11·2	526	529	532	535	537	540	543	546	549	552	
11·3	555	558	561	564	567	570	573	576	579	582	
11·4	585	588	592	595	598	601	605	608	611	614	
11·5	617	620	623	626	629	632	636	639	642	646	
11·6	650										

NOTES: Volumes are in millions of cubic metres.
When the discharge site is at Nasir, 190 km. from Hillet Doleib, the equivalent trough volumes are obtained by multiplying values derived from this table by 190/231, or 0·823.

TABLE 435

CHECK CALCULATION OF THE VOLUME OF THE INCISED TROUGH OF THE UPPER SOBAT

This table was calculated from the following formula:

$$\text{Trough Volume} = W_o.L.h + \frac{2.K.L.h^3}{3} \text{ where}$$

W_o = width of the main channel = 140 metres
L = length of the reach = 231 km.
K = the parabolic constant = 27·1 from Table 432
h = mean rise along the reach above the mean of the low-level gauge-readings at Abwong, Nasir, and Sobat Head, which is 6·7.

Mean Gauge	h	h^3	$W_o.L.h$	$\frac{2}{3}.K.L.h^3$	Trough Volume
7·2	0·5	0·1	16·2	0·5	16·7
7·7	1·0	1·0	32·4	4·2	36·6
8·2	1·5	3·4	48·6	14·1	62·7
8·7	2·0	8·0	64·8	33·4	98·2
9·2	2·5	15·6	81·0	65·2	146·2
9·7	3·0	27·0	97·2	112·7	209·9
10·2	3·5	42·9	113·4	178·9	292·3
10·7	4·0	64·0	129·6	267·1	396·7
11·2	4·5	91·1	145·8	380·2	526·0
11·6	4·9	117·6	158·8	490·7	649·5

NOTE: The last three columns are in millions of cubic metres.

TABLE 436

CALCULATION OF THE SLOPE OF THE PLAIN TOWARDS THE UPPER SOBAT TROUGH

Item	1934–35	1935–36	1937–38	1938–39	1942–43	1945–46	1946–47	1947–48
(1) Period before Flood overtops Trough	Sep. (3)	Sep. (2)	Sep. (3)	Sep. (3)	Sep. (3)	Sep. (2)	Aug. (3)	Sep. (1)
(2) Period of Highest Observed Loss	Nov. (2)	Nov. (2)	Oct. (2)	Nov. (2)	Oct. (3)	Nov. (3)	Nov. (2)	Nov. (2)
(3) Mean Gauge at end of this Period	11·71	11·58	11·70	11·96	11·76	11·69	12·41	11·88
(4) Maximum Mean Gauge	11·86	11·75	11·70	11·98	11·76	11·87	12·46	12·02
(5) Mean of the two, minus 11·60 = h′ (centimetres)	18	6	10	37	16	18	84	35
(6) Lower Sobat Losses by Absorption and Trough Volume	118	91	91	118	91	105	245	116
(7) Evaporation on Whole Sobat, up to top of Trough	−78	−61	−122	−114	−106	−85	−77	−83
(8) Sum of Preliminary Losses (millions of m³)...	40	30	−31	4	−15	20	167	33
(9) Net Evaporation Depth from top of Trough to Peak (d)	5	6	−1	6	1	10	−1	5
(10) Sum of Height, Absorption and Evaporation Depths (h′ + d + D)	53	42	39	73	47	58	110	70
(11) $S_1(h' + D + d)$ (millions of m.³)	177	140	130	243	157	197	367	233
(12) $V_1 - D.W_o.L$	640	640	640	640	640	640	640	640
(13) Sum of (8), (11), and (12)	857	810	739	887	782	857	1,174	906
(14) Maximum Observed Loss (Corrected for Tributaries)	1,677	1,796	519	1,399	1,030	1,286	741	2,174
(15) Difference of (14) and (13) = Residual Loss = DIVIDEND	820	986	−220	512	248	429	−433	1,268
(16) h′ + 2D + d (metres)	0·83	0·72	0·69	1·03	0·77	0·88	1·40	1·00
(17) L(h′ + 2D + d) (L = 231)	192	166	159	238	178	203	323	231
(18) L.h′(h′ + 2D + d) = DIVISOR	34·5	8·0	15·9	88·1	28·5	36·5	271	80·8
(19) (15) divided by (18) = QUOTIENT = p	23·8	123·2	−13·8	5·8	8·7	11·8	−1·6	15·7

Mean Quotient (excluding 1935 and 1946) = 3057/284·3 = 10·8.

TABLE 437

DIFFERENCES FROM THE MEAN PLAIN SLOPE EXPRESSED AS DISCHARGE ERRORS AT SOBAT HEAD

Item	1934–35	1935–36	1937–38	1938–39	1942–43	1945–46	1946–47	1947–48
Difference of Individual Values of p from the Mean	+13·0	+112·4	−24·6	−5·0	−2·1	+1·0	−12·4	+4·9
Differences multiplied by Individual Divisors	+448	+889	−391	−440	−60	+36	−3,360	+396
Total Discharge at Sobat Head during the period	10,354	11,212	7,911	10,079	8,989	10,672	11,598	10,694
Difference as percentage of Discharge at Sobat Head	+4·3	+8·0	−4·9	−4·4	−0·7	+0·4	−29·0	+3·7
Total Sobat Head Discharge for May to October inclusive	8,866	9,986	8,613	8,733	8,989	8,724	9,978	9,405
Maximum Mean Gauge (mean of Abwong, Nasir, and Sobat Head)	11·86	11·75	11·70	11·98	11·76	11·87	12·46	12·02

TABLE 438

SURFACE AREAS ON THE UPPER SOBAT IN HIGH FLOODS

This table is calculated from the formula:

Surface Area = $S_t + 2.L.p.h'$, where
S_t = the surface area of the incised trough,
= 333 km.² from Table 433
L = length of the reach = 231 km.
p = one thousandth of the slope of the plain on each side of the trough = 11
h' = the rise above the top of the trough, which corresponds to mean gauge 11·60.

Mean Gauge	0·00	0·01	0·02	0·03	0·04	0·05	0·06	0·07	0·08	0·09
11·6	333	384	435	485	536	587	638	689	739	790
11·7	841	892	943	993	1,010	1,090	1,150	1,200	1,250	1,300
11·8	1,350	1,400	1,450	1,500	1,550	1,600	1,650	1,700	1,750	1,810
11·9	1,860	1,910	1,960	2,010	2,060	2,110	2,160	2,210	2,260	2,310
12·0	2,360	2,410	2,460	2,510	2,560	2,610	2,670	2,720	2,770	2,820
12·1	2,870	2,920	2,970	3,020	3,070	3,130	3,180	3,230	3,280	3,330
12·2	3,380	3,430	3,480	3,530	3,580	3,640	3,690	3,740	3,790	3,840
12·3	3,890	3,940	3,990	4,040	4,090	4,150	4,200	4,250	4,300	4,350
12·4	4,400	4,450	4,500	4,550	4,600	4,650	4,700	4,750	—	—

TABLE 439

CALCULATION OF 'TROUGH' VOLUMES ON THE UPPER SOBAT FOR EACH DECIMETRE ABOVE AVERAGE FLOOD LEVEL

This table is calculated from the formula:

'Trough' Volume = $V_t + S_t.h' + L.p.h'^2$, where
V_t = volume of the incised trough = 650 millions
S_t = surface area of the incised trough = 333 km²
L = the length of the reach = 231 km.
p = one thousandth of the slope of the plain on each side of the trough = 11
h' = the rise above the top of the incised trough, which corresponds to the mean gauge 11·60.

Mean Gauge	h' (cm.)	h'^2	333h'	$2541h'^2$	'Trough' Volume
11·60	0·0	0·0	0	0	650
11·70	0·1	0·01	33	25	708
11·80	0·2	0·04	67	102	819
11·90	0·3	0·09	100	229	979
12·00	0·4	0·16	133	406	1,189
12·10	0·5	0·25	167	635	1,452
12·20	0·6	0·36	200	915	1,765
12·30	0·7	0·49	233	1,245	2,128
12·40	0·8	0·64	267	1,626	2,543
12·50	0·9	0·81	300	2,058	3,008

Volumes in millions of m³.

TABLE 440

'TROUGH' VOLUMES ON THE UPPER SOBAT IN HIGH FLOODS

Mean Gauge	0·00	0·01	0·02	0·03	0·04	0·05	0·06	0·07	0·08	0·09
11·6	650	654	659	665	671	678	684	690	696	702
11·7	708	716	725	734	744	755	766	778	792	805
11·8	819	833	847	862	878	895	912	929	945	962
11·9	979	1,000	1,020	1,040	1,060	1,080	1,100	1,130	1,150	1,170
12·0	1,190	1,220	1,240	1,270	1,300	1,320	1,340	1,370	1,400	1,430
12·1	1,450	1,480	1,510	1,540	1,570	1,600	1,630	1,670	1,700	1,730
12·2	1,760	1,800	1,840	1,870	1,900	1,940	1,970	2,010	2,050	2,080
12·3	2,130	2,170	2,210	2,260	2,300	2,340	2,380	2,420	2,460	2,500
12·4	2,540	2,590	2,640	2,680	2,720	2,770	2,810	2,860	2,910	2,960
12·5	3,010	—	—	—	—	—	—	—	—	—

SECTION II. ANALYSIS OF THE SOBAT FLOOD

COMPUTED LOSSES

Once the tables of surface area and trough volume have been computed, calculating the individual items of loss in different years is a comparatively simple, though tedious, operation. The method used follows almost exactly that evolved in the analysis of the White Nile flood, of which a detailed account has already been given (pp. 861–75). The computed losses comprise the following :

(i) Increase of trough volume after the start of the cycle.

(ii) Net loss by evaporation minus rainfall.

(iii) Absorption in the newly wetted ground.

Trough Volume

For this the mean gauge-readings for each ten-day period at Hillet Doleib, Abwong, Nasir, and Sobat Head were used[(a)] ; they are given in (i) of Tables 441–53 (pp. 935–60). The mean gauge for the reach was first obtained for the ten-day period and then this was meaned with the mean of the ten-day period immediately following. This was necessary in order to obtain the increase in trough volume at the end, and not the middle, of each ten-day period, since this was the instant to which all other items of loss were referred. The mean of the first two gauges was used for the trough volume of the lower Sobat, by entering Table 426 (p. 924) ; and the mean of the last three for the upper Sobat, by entering Tables 434 and 440 (pp. 928 and 930).

It is the losses due to change of trough volume which are required, and so in each flood the trough volume at the start of the cycle has first to be calculated. This usually small quantity is then deducted from the actual quantities obtained directly from the tables. It will be noticed that in some years the trough volumes in February are negative. This is because the water surface had by then fallen below its level at the beginning of the cycle, and this level was the datum from which changes of trough volume were measured. This is shown in 1937–38 (Table 444, p. 941).

Rainfall and Evaporation

The volumes of water added to or taken from the Sobat between its head and Hillet Doleib by rainfall and evaporation during each flood were calculated by estimating the depths of these quantities during each ten-day period, and then multiplying the difference by the average surface area of the river during the same period. No allowance was made for rain falling on the flood-plain before it was covered by the river. Rainfall depths were obtained by taking the mean of the readings at Abwong, Nasir, and Doleib Hill up to 1939, and of the first two thereafter when observations at Doleib Hill had been stopped. The Sudan Government Meteorologist kindly lent the original records and the ten-day sums were made from these.

Evaporation depths were obtained by halving the average Piche tube readings at Malakal for each month, and then interpolating between the monthly averages for the first and third periods of each month. The results were rounded off to the nearest centimetre per ten-day period; they are shown in the first parts of Tables 441–53 (pp. 935–60) for each year. The differences between these and the corresponding mean rainfall (of which the data are also shown there) were then multiplied by the average surface area, which is also shown in the first part of the tables. These areas were obtained for the lower Sobat by entering Table 425 (p. 923) with the means of the gauge-readings at Hillet Doleib and Abwong, and for the upper Sobat by entering Tables 433 (p. 927) or 438 (p.930) with the means of the gauge-readings at Abwong, Nasir, and Sobat Head. In this calculation the direct means for each ten-day period were used, since they give the averages for the period.

It will be seen from Table 456 (p. 962) that the average net gain by rainfall minus evaporation during the rising stage of the Sobat flood is just over one hundred millions, as compared with an almost negligible quantity on the White Nile during its rising stage. There are two reasons for this. Firstly the Sobat basin is actually wetter, having more rainfall and less evaporation than that of the White Nile between Malakal and Renk ; and secondly, because its flood peak is earlier, its maximum surface area coincides rather with the immediate aftermath of the rains than with the drier conditions which come later.

Absorption

As on the White Nile, the losses by absorption are the least reliable of all, since they are subject to no measurement and the average depth on which they are based has been derived indirectly. The mean absorption depth of 30 cm. was obtained as already described on page 918 and Table 430 of Section I. For each flood this was then multiplied by the maximum area inundated, i.e. the maximum surface area less the surface area at the beginning. The result was then taken as having occurred approximately one month after the occurrence of this maximum inundation; and it was assumed that no further absorption occurred after that until the following year. The cumulative value of the loss during the early part of each cycle was interpolated from zero up to this maximum value roughly in accordance with the increase in the flooded area, with a lag behind it of about one month. The results cannot be claimed as accurate, but they follow what may be fairly presumed to be the characteristics of this form of loss.

Observed Losses

The data and the derivation of the observed losses in each year are shown in the second parts of Tables 441–53. The mean daily discharges for each ' ten-day period ', as published in Volume IV and its supplements of *The Nile Basin*, or as supplied by the Egyptian Irrigation Department, were multiplied by the number of days in each period. The difference between discharges at Sobat Head and Hillet Doleib during each period is then the uncorrected loss during that period, and these were summed cumulatively to give the uncorrected cumulative loss at the end of each period. The observed discharges of the tributaries were obtained in the same way, and also summed cumulatively. The difference is then the cumulative sum for each ten-day period of the corrected observed loss, and this is shown in the last column of the second parts of Tables 441–53, and transferred to the third parts of the tables for comparison with the computed losses.

The accuracy of these losses depends very much on the accuracy of the discharges, because they are obtained from the differences between them, and these differences are normally only about one-tenth of the discharges. Only during the three or four periods in November or December when the river is falling fast and the basins are returning their stored water to the main channel are these differences comparable in size with the discharges. In consequence of this it is particularly important to estimate the accuracy of measurement of the discharges as carefully as possible, and to take account of any movements of the discharge sites which may affect them.

Main River Discharges

On the main Sobat the discharges have been measured regularly since 1905 near its mouth at Hillet Doleib; and since 1929 they have been measured just below the junction of the Pibor and the Baro at Sobat Head. The latter is not easily reached except during the Sobat flood; during the low stages, therefore, the discharge site is moved to Nasir. On the average this site is used from January to April inclusive, but the exact dates are shown in the second parts of Tables 441–53. Because the river is fairly low at this time, this change of discharge site does not greatly affect the calculations of net evaporation; but it has been allowed for in computing the values of trough volume and surface area which are shown. An important effect of this change of site is that when the discharges are measured at Nasir no allowance has to be made for those of the Wakau, since the mouth of this lies between Nasir and Sobat Head. It is fortunate that this is so because their measurement usually ceases soon after the transfer of the main discharge measurements to Nasir, although the khor has not by any means always ceased flowing at that time.

Tributary Discharges

The discharges of the Wakau and of the other main tributary—the Torluar or Twalor—have only been measured regularly since 1934, and then only during the flood months. Because their contributions are sometimes quite large, even totalling over a milliard, they have an appreciable effect on the analyses, and these have therefore been confined to the years 1934–39 and 1941–47 inclusive in which these tributary discharges were measured. Since 1934 discharges of the main Sobat have been measured during the flood months downstream of the mouth of the Khor Nyanding, and the discharges of this khor and of the Khor Fullus have also been observed intermittently. As a rule neither of them contributes any appreciable amount, though in 1933 the Fullus discharged over 330 millions, in a year of heavy rainfall along the Sobat valley. It is probable that in 1946–47 also the flow in the Fullus was considerable though no discharges were measured.

The accuracy of observed discharges on the Nile and its tributaries was discussed in some detail in the analysis of the White Nile flood (p. 859). The probable error of any single discharge measurement was stated in Volume II of *The Nile Basin* to be 5 per cent.; but it was admitted that the error increases with the size of the discharge, and when the discharge site is not inspected very often. Systematic errors were stated to be unlikely to exceed 1 per cent. in any one year [4]; but, as has already been mentioned in Section 1 (p. 922), there are very strong reasons for suspecting a systematic over-estimate of the Sobat Head discharges in 1935 of at least 5 per cent. It is possible, however, that the accuracy of observation has been improved since that time, and that a systematic error of that size would not occur nowadays.

DISCUSSION OF RESULTS

By assuming a certain idealized form for the Sobat trough, and allowing for the effects of rainfall, evaporation, and absorption at all stages of the river, it has been possible to produce theoretical curves of cumulative loss between Sobat Head and mouth and to compare them with the curves of actual observed loss, after allowing for all observed discharges into and out of tributaries. The two curves for each flood are shown in Figs. K 5–11, and the averages for five low and seven high floods in Fig. K 12, together with the average of the twelve together. In both the last two cases the exceptional flood of 1946–47 has been omitted from the average.

LOW FLOODS

For the five low floods the two curves are remarkably close, even in individual years. The biggest differences occur in 1939–40 and 1943–44, when the computed losses are respectively smaller and greater than the observed ones. These divergencies do not amount at any stage to more than about 3% of the cumulative observed discharges at Sobat Head up to that stage, so that they could easily be accounted for entirely by relatively small systematic errors in the observed discharges at either or both Sobat Head and Hillet Doleib. Other probable contributing causes are errors in the assumed absorption and evaporation depths, and probably to a lesser extent, unrecorded discharges into and out of tributary khors. In all the five low years the observed contributions of the Twalor were under 100 millions, and it seems likely that with the exception of the Wakau there was no appreciable exchange of water between the Sobat and any other source of supply outside its flood-plain. The independent check on the theoretical shape of the idealized trough given by the observed area of 'permanent swamp' shown on the air survey maps makes it seem likely that in these low years only this is flooded, and that there is virtually no spilling through khors on the north side west of Nasir.

HIGH FLOODS

Reasons have already been given in Section 1 (p. 920) for expecting that the values obtained for the slope of the surrounding plain would be less concordant than those of the constant of the idealized trough, and clearly these also apply to the comparisons between computed and observed losses in high floods. It may also be expected that, where the water is presumed to spread thinly over a very wide area, comparatively small errors in the assumed absorption and evaporation depth will have a considerable effect on the losses computed from them. After 1946–47 the biggest divergencies between computed and observed loss occur in 1935–36 and 1938–39. Reasons have already been given (p. 922) for thinking that in 1935–36 the Sobat Head discharges may have been considerably over-estimated; and in 1938–39 the lack of observed discharges on the Twalor might account for as much as half the discrepancy.

There seems little doubt that in 1946–47 the divergence between computed and observed loss was due to unrecorded inflow. No discharges of the Fullus and Nyanding were measured, and those of the Twalor ceased at the end of December when it was still contributing over 15 millions a day. As shown in Fig. K 10 the inflow appears to have come in two waves, the first totalling about three and a half milliards in September and October, and the second about two milliards in December and January. It is impossible to say for certain what proportions of this inflow came from the south or from the north; but it seems likely that virtually all the first wave and most of the second came from the south.

If this flood is excluded, the average computed and observed losses of the remaining seven high floods (shown in Fig. K 12) are remarkably close up till the end of December. This is the time when the observed discharges of the Twalor and Wakau normally cease, although these khors are often still flowing. Since the upper discharge site on the main Sobat is then moved to Nasir, below the mouth of the Wakau, its discharges no longer affect the observed losses;

but those of the Twalor, which enters some 20 km. farther downstream, still do so. It can be seen from (ii) of Tables 441–53 that in several high floods the Twalor discharge was still considerable at the end of December, and it may be assumed to have contributed in some of them up to a further hundred millions after that time. In 1946–47 the amount was probably two or three times this.

CONCLUSIONS

The general picture which this analysis gives is therefore that of a river system which is almost entirely self-contained during the whole of its flood cycle. The two exceptions to this are the exchange of water through the Wakau, which occurs in all years; and the contributions of the Twalor, which are considerable only in high years and appear to be derived mainly from spill out of the Pibor. The régimes of these two tributaries are described in detail in the next section, where the possibility of similar exchanges through tributaries downstream of Nasir is also discussed. Like that of the White Nile the main Sobat channel is flanked by areas of semi-permanent swamp, which lie mainly on the insides of its meanders; and in floods of below average height the inundation and subsequent drainage of these seems adequate to account for the whole of the losses in the rising stage and the subsequent gains when the river falls, once the exchange of water through the Wakau has been allowed for.

What exactly happens in higher floods is less certain, but it is the author's belief that in these also the Sobat system still remains self-contained to a very large extent. Although its flood-water is then believed to overflow from the permanent swamps, it does not seem to ' spill ' out of the river valley and be lost as it does on the Bahr el Jebel and Baro, but to extend from the swamps over plains flanking them and sloping towards them in such a way that it can return to them and so to the main channel immediately the river drops. Only in 1946–47 is the divergence between losses calculated on this assumption and those actually observed too great to be accounted for by the sort of errors which may be expected in the observed or estimated data on which the calculations were based. Even in this year, as is shown in the next section, the losses behave at the peak of the flood exactly as would be expected from this assumption.

It should, however, be mentioned that this view differs from that of Dr. Hurst as given in Volume VIII of *The Nile Basin*. On page 63 he wrote: " To sum up, the gains on the Sobat after it has begun to fall at its head are due to drainage from the plains brought in by tributary khors, mostly from the south. They are indirectly related to the maximum height of the Sobat and to the discharge of the southern tributaries of the Pibor and more directly to the rainfall on the plains." It is clear that by this he definitely means that the gains are due to an independent supply of water draining into the Sobat valley from outside, and not, as this analysis has indicated, to the return of water which originally came from the Sobat itself.

FUTURE CONTROL OF THE SOBAT

In actual fact it seems unlikely that any extensive control scheme will be proposed for the Sobat in the near future. Nevertheless it may be of interest to study briefly the effects of running it at a constant level during the timely season (January to June inclusive) and to see what losses will result. If it is assumed that with no change of level there will be no loss by absorption, the only loss will be net evaporation from the upper surface. From January 1st till June 30th the gross evaporation is 120 cm., and the average rainfall in the same period is about 30 cm. The net evaporation depth may therefore be taken without serious error as one metre, so that the loss during this period in millions will be equal to the surface area in square kilometres.

We have next to establish a relationship between the discharge at Sobat Head and this area, for which we must first obtain the mean gauge-readings for the upper and lower stretches of the Sobat. From Table 427 (p. 925) it is clear that when the river is steady at average flood level the mean rise for the upper Sobat is equal to, and that for the lower Sobat is 0·7 times, the rise at Sobat Head. From Plate 27 of Volume VIII of *The Nile Basin* we can obtain a reasonably accurate mean gauge/discharge curve for Sobat Head, and so get the desired relationship between the discharges there and the mean gauge-readings for the upper and lower reaches. Using these values to enter Tables 425 (p. 923) and 433 (p. 927) we can obtain at once the total surface areas and so the losses between Sobat Head and Hillet Doleib corresponding to various discharges at Sobat Head. The results are shown in Table 457 (p. 962).

It would seem, therefore, that it is safe to assume a percentage loss at all stages of about 3 per cent., noting that the percentage is lowest when the Sobat is run steadily throughout this period at a Sobat Head discharge of 20 to 30 millions per day.

TABLE 441

SUMMARY ANALYSIS OF THE YEAR 1934–35

(i) GAUGES AND RAINFALL DATA

Ten-Day Period	Gauges				Rainfall (millimetres)				Total Area sq. km.
	Sobat Head	Nasir	Abwong	Hillet Doleib	Nasir	Abwong	Doleib Hill	Assumed Gross Evaporation	
March (3)	4·43	4·73	10·31	11·30	—	—	—	—	—
April ...	4·56	4·86	10·52	11·24	16	—	1	70	38
	4·95	5·24	10·69	11·28	19	—	4	60	39
	5·34	5·64	10·84	11·42	19	—	20	50	41
May ...	5·54	5·84	10·97	11·54	55	—	2	40	44
	5·35	5·65	10·86	11·56	96	59	45	40	42
*	5·82	6·13	11·13	11·63	94	13	20	40	49
June ...	6·44	6·78	11·66	11·89	21	—	22	40	62
	7·03	7·46	12·11	12·14	50	52	25	30	104
	7·54	8·05	12·54	12·39	61	38	12	20	135
July ...	8·14	8·61	12·89	12·63	57	118	99	20	171
	8·56	9·00	13·18	12·83	25	—	29	20	204
*	8·94	9·33	13·43	13·00	36	44	43	20	238
August	9·17	9·64	13·67	13·14	82	99	86	10	269
	9·36	9·87	13·98	13·31	76	163	19	10	305
*	9·55	10·18	14·26	13·51	29	103	52	10	339
September	9·60	10·43	14·46	13·65	15	28	30	10	373
	9·65	10·53	14·57	13·72	—	—	19	10	391
	9·69	10·61	14·69	13·81	2	—	5	10	1,056
October	9·75	10·68	14·80	13·89	35	18	105	10	1,114
	9·80	10·77	14·89	13·95	—	—	—	20	1,530
*	9·80	10·81	14·95	13·99	99	—	8	30	1,684
November	9·76	10·82	15·03	14·02	—	11	—	40	1,789
	9·55	10·74	15·07	14·04	12	—	—	50	1,392
	9·23	10·58	15·08	14·05	—	—	—	60	575
December	8·83	10·33	15·06	14·04	—	—	—	60	401
	8·30	9·88	14·90	14·00	—	—	—	70	350
*	7·74	9·14	14·48	13·87	—	—	—	80	270
January	6·92	7·81	13·44	13·52	—	—	—	80	150
	6·00	6·48	12·12	12·92	—	—	—	90	61
*	5·45	5·79	11·24	12·28	—	—	—	100	45
February	5·18	5·49	10·88	11·90	—	—	—	100	40
	5·17	5·47	10·79	11·74	—	—	—	100	39
*	4·98	5·26	10·63	11·66	—	—	—	100	39
March (1)	4·83	5·12	10·53	11·55	—	—	—	100	44

NOTE: The periods marked * are not ten days.

SUMMARY ANALYSIS OF THE YEAR 1934–35

(ii) OBSERVED DISCHARGES

Ten-Day Period	Discharges			Un-corrected Cumulative Loss	Observed Inflow			Cumulative Inflow Total	Corrected Cumulative Loss
	Sobat Head	Hillet Doleib	Difference		Nyanding	Twalor	Wakau		
April ...	42†	35	7	7	—	—	—	—	7
	72†	41	31	38	—	—	—	—	38
	107†	65	42	80	—	—	—	—	80
May ...	125†	97	28	108	—	—	—	—	108
	108†	102	6	114	—	—	—	—	114
*	174†	140	34	148	—	—	—	—	148
June ...	230†	193	37	185	—	—	—	—	185
	309	252	57	242	—	− 2	—	− 2	240
	382	313	69	311	− 2	− 3	1	− 6	305
July ...	459	370	89	400	− 3	− 4	− 6	− 19	381
	511	412	99	499	− 3	− 5	−10	− 37	462
*	607	488	119	618	− 3	− 5	−20	− 65	553
August	583	473	110	728	− 3	− 5	−27	−100	628
	601	517	84	812	− 1	− 3	−26	−130	682
*	686	626	60	872	+ 5	+ 2	−13	−136	736
September	645	598	47	919	5	12	+13	−106	813
	655	613	42	961	5	19	22	− 60	901
	664	632	32	993	6	28	27	+ 1	994
October	674	652	22	1,015	3	57	32	93	1,108
	688	669	19	1,034	−15	114	39	231	1,265
*	765	750	15	1,049	−27	146	47	397	1,416
November	667	696	− 29	1,020	−11	143	47	576	1,596
	600	700	−100	920	+10	131	40	757	1,677
	529	708	−199	741	12	104	27	900	1,641
December	456	702	−246	495	21	69	34	1,024	1,519
	375	679	−304	191	12	47	54	1,137	1,328
*	342	669	−327	− 136	24	34	56	1,251	1,115
January	261	441	−180	− 316	—	7	31	1,289	973
	164†	230	− 66	− 382	—	1	—	1,290	908
*	112†	151	− 39	− 421	—	—	—	1,290	869
February	82†	93	− 11	− 432	—	—	—	1,290	858
	80†	74	+ 6	− 426	—	—	—	1,290	864
*	54†	51	3	− 423	—	—	—	1,290	867

NOTES: All figures are millions of cubic metres.
Periods marked * are not ten days.
Discharges marked † were observed at Nasir, which is below the mouth of the Wakau.

TABLE 441 (*continued*)

SUMMARY ANALYSIS OF THE YEAR 1934–35 (HIGH FLOOD)

(iii) COMPARISON OF COMPUTED AND OBSERVED LOSSES

Ten-Day Period	Computed: Trough Volume	Computed: Net Evaporation	Computed: Absorption	Computed: TOTAL	Corrected Observed Loss	Difference Computed—Observed	
April ... ...†	7	2	0	9	7	+ 2	
†	17	4	0	21	38	− 17	
†	28	6	0	34	80	− 46	
May ... ...†	29	7	0	36	108	− 72	
†	33	6	0	39	114	− 75	
*†	54	6	0	60	148	− 88	
June ... ...†	89	8	0	97	185	− 88	
	159	7	0	166	240	− 74	
	226	6	10	242	305	− 63	
July	297	− 6	20	311	381	− 80	
	365	− 6	30	389	462	− 73	
*	433	− 11	40	462	553	− 91	
August	499	− 32	50	517	628	−111	
	575	− 57	60	578	682	−104	
*	649	− 74	70	645	736	− 91	
September ...	694	− 78	80	696	813	117	
	730	− 78	90	742	901	159	
	765	− 72	100	813	994	−181	
October	875	−116	130	889	1,108	−219	
	967	− 85	180	1,062	1,265	−203	
*	1,005	−102	300	1,203	1,446	−243	flood over-tops incised trough
November ...	959	− 30	400	1,329	1,596	−267	
	814	+ 26	470	1,310	1,677	−367	
	721	60	500	1,287	1,641	−354	
December ...	625	84	500	1,209	1,519	−310	
	484	108	500	1,092	1,328	−236	
*	297	130	500	927	1,115	−188	
January	131	142	500	773	973	−200	
†	55	148	500	703	908	−205	
*†	33	154	500	687	869	−182	
February... ...†	23	159	500	682	868	−186	
†	19	164	500	683	864	−181	
*†	13	169	500	682	867	−185	

NOTES: The periods marked * are not ten days.
For the periods marked † the upper discharge site was at Nasir, 190 km. from Hillet Doleib, and not at Sobat Head.
The figures for net evaporation, absorption, and corrected observed loss are cumulative.

TABLE 442

SUMMARY ANALYSIS OF THE YEAR 1935–36

(i) GAUGES AND RAINFALL DATA

Ten-Day Period	Gauges				Rainfall			Assumed Gross Evaporation	Total Surface Area sq. km.
	Sobat Head	Nasir	Abwong	Hillet Doleib	Nasir	Abwong	Doleib Hill		
					millimetres				
April ...	5·54	5·84	10·87	11·49	—	—	—	—	—
	5·42	5·72	10·83	11·54	—	—	—	—	—
	5·00	5·29	10·50	11·32	—	—	—	—	—
May ...	5·30	5·60	10·61	11·28	71	21	41	40	41
	6·33	6·67	11·44	11·58	10	17	4	40	70
*	6·89	7·31	11·99	11·92	81	23	4	40	96
June ...	7·75	8·18	12·49	12·21	15	46	41	40	141
	8·21	8·72	12·89	12·52	39	58	47	30	176
	8·62	9·10	13·19	12·74	39	35	18	20	208
July ...	8·96	9·41	13·43	12·88	17	3	21	20	240
	9·17	9·67	13·64	13·04	23	38	58	20	267
*	9·32	9·86	13·84	13·17	31	46	35	20	292
August	9·40	9·99	13·99	13·28	74	81	50	10	311
	9·45	10·08	14·10	13·38	2	12	17	10	324
*	9·50	10·23	14·20	13·44	56	34	45	10	339
September	9·60	10·40	14·33	13·51	10	16	6	10	359
	9·64	10·52	14·48	13·58	7	40	96	10	380
	9·70	10·60	14·60	13·65	39	32	24	10	543
October	9·72	10·66	14·71	13·71	4	39	102	10	914
	9·72	10·69	14·80	13·74	1	27	17	20	1,078
*	9·72	10·71	14·84	13·79	—	1	7	30	1,221
November	9·67	10·72	14·83	13·79	8	—	—	40	1,081
	9·49	10·66	14·86	13·80	—	—	—	50	761
	9·16	10·49	14·84	13·79	—	—	—	60	393
December	8·69	10·17	14·77	13·78	1	—	—	60	356
	8·03	9·51	14·52	13·71	—	—	—	70	294
*	7·06	8·05	13·59	13·41	—	—	14	80	138
January	6·00	6·48	12·03	12·69	—	—	—	80	60
	5·72	6·11	11·43	12·12	—	—	—	90	50
*	5·48	5·83	11·21	11·88	—	—	—	100	45
Feburary	5·46	5·82	10·99	11·69	—	—	—	100	43
	5·63	6·00	11·11	11·67	—	—	—	100	47
*	5·55	5·91	11·17	11·72	—	—	—	100	46
March(1)	5·10	5·40	11·00	11·48	—	—	—	—	—

NOTE: The periods marked * are not ten days.

SUMMARY ANALYSIS OF THE YEAR 1935–36

(ii) OBSERVED DISCHARGES

Ten-Day Period	Discharges			Un-corrected Cumulative Loss	Observed Inflow			Cumulative Inflow Total	Corrected Cumulative Loss
	Sobat Head	Hillet Doleib	Difference		Nyanding	Twalor	Wakau		
May ...	100†	68	32	32	not recorded	− 1	3	− 4	28
	209†	164	45	77		− 4	− 7	− 15	62
*	307	274	33	110		− 7	− 9	− 31	79
June ...	398	309	89	199		− 7	− 9	− 47	152
	475	376	99	298		− 6	− 9	− 62	236
	527	425	102	400		− 6	−14	− 82	318
July ...	565	454	111	511		− 5	−23	−110	401
	593	484	109	620		− 3	−32	−145	475
*	673	559	114	734		− 2	−37	−184	550
August	627	529	98	832		0	−27	−211	621
	636	545	91	923		+ 2	−20	−229	694
*	715	615	100	1,023		6	−11	−234	789
September	667	574	93	1,116		11	+ 4	−219	897
	676	591	85	1,201		15	18	−186	1,015
	683	612	71	1,272		27	26	−133	1,139
October	687	628	59	1,331		68	32	− 33	1,298
	689	643	46	1,377		81	35	+ 83	1,460
*	759	728	31	1,408		103	41	227	1,635
November	645	661	− 16	1,392		100	36	363	1,755
	581	664	− 83	1,309		95	29	487	1,796
	505	661	− 156	1,153		78	26	591	1,744
December	422	651	− 229	925		53	42	686	1,611
	382	619	− 237	687		32	64	782	1,469
*	334†	515	− 181	506		6	—	788	1,294
January	159†	223	− 64	442		—	—	788	1,230
	133†	143	− 10	432		—	—	788	1,220
*	121†	135	− 14	418		—	—	788	1,206
February	114†	111	+ 3	421		—	—	788	1,209
	135†	111	+ 24	445		—	—	788	1,233
*	110†	122	− 12	433		—	—	788	1,221
March ...	77†	90	− 13	420		—	—	788	1,208
	59†	67	− 8	412		—	—	788	1,200
*	46†	53	− 7	405		—	—	788	1,193

NOTES: Periods marked * are not ten days.
Discharges marked † were observed at Nasir, which is below the mouth of the Wakau.

TABLE 442 (*continued*)

SUMMARY ANALYSIS OF THE YEAR 1935–36 (HIGH FLOOD)

(iii) COMPARISON OF COMPUTED AND OBSERVED LOSSES

Ten-Day Period	Computed: Trough Volume	Computed: Net Evaporation	Computed: Absorption	Computed: Total	Corrected Observed Loss	Difference Computed—Observed	
May ... ...†	20	0	0	20	28	− 8	
†	75	2	0	77	62	+ 15	
*	138	2	0	140	79	61	
June	218	3	0	221	152	69	
	289	− 1	10	298	236	62	
	357	− 3	20	374	318	56	
July	420	− 1	30	449	401	48	
	472	− 6	40	508	475	23	
*	516	− 12	50	554	550	4	
August	562	− 31	60	591	621	− 30	
	576	− 31	70	615	694	− 79	
*	615	− 45	80	650	789	−139	
September ...	658	− 45	90	703	897	−194	
	693	60	100	733	1,015	−282	
	736	− 71	120	785	1,139	−354	flood
October	781	−108	150	829	1,298	−469	over-
	814	−108	190	896	1,460	−564	tops
*	815	− 71	240	984	1,635	−651	incised
November ...	769	− 27	300	1,042	1,755	−713	trough
	703	− 7	350	1,046	1,796	−750	
	633	+ 17	350	1,000	1,744	−744	
December ...	513	39	350	902	1,611	−709	
	322	50	350	722	1,469	−747	
*†	102	61	350	513	1,294	−761	
January ... ...†	45	67	350	462	1,230	−768	
†	26	72	350	448	1,220	−772	
*†	19	77	350	446	1,206	−760	
February ... ...†	20	82	350	452	1,209	−757	
†	23	87	350	460	1,233	−773	
*†	15	92	350	457	1,221	−764	

NOTES: The periods marked * are not ten days.
For the periods marked † the upper discharge site was at Nasir, 190 km. from Hillet Doleib, and not at Sobat Head.
The figures for net evaporation, absorption, and corrected observed loss are cumulative.

TABLE 443

SUMMARY ANALYSIS OF THE YEAR 1936–37

(i) GAUGES AND RAINFALL DATA

Ten-Day Period	Gauges				Rainfall (millimetres)			Assumed Gross Evaporation	Total Area sq. km.
	Sobat Head	Nasir	Abwong	Hillet Doleib	Nasir	Abwong	Doleib Hill		
April ...	4·66	4·95	10·13	11·01	—	—	—	—	—
	4·99	5·28	10·41	11·02	10	—	—	60	44
	5·39	5·68	10·70	11·14	28	4	23	50	49
May ...	5·36	5·67	10·72	11·18	11	12	7	40	48
	6·05	6·36	11·11	11·30	58	14	26	40	60
*	6·75	7·14	11·74	11·62	12	28	6	40	87
June ...	7·51	8·00	12·26	11·92	31	10	9	40	125
	7·84	8·45	12·65	12·22	26	14	48	30	154
	8·08	8·69	12·90	12·40	56	50	84	20	172
July ...	8·37	8·98	13·12	12·53	52	43	34	20	194
	8·60	9·20	13·30	12·65	16	25	67	20	215
*	8·83	9·43	13·48	12·79	42	12	60	20	238
August	8·98	9·61	13·66	12·93	19	53	62	10	258
	9·10	9·75	13·78	13·03	63	50	41	10	274
*	9·22	9·90	13·92	13·12	53	134	53	10	293
September	9·29	10·02	14·03	13·22	56	64	44	10	308
	9·34	10·18	14·15	13·30	129	26	24	10	326
	9·40	10·32	14·26	13·37	40	18	90	10	342
October	9·44	10·39	14·36	13·43	—	—	34	10	354
	9·47	10·42	14·43	13·48	1	6	14	20	362
*	9·51	10·46	14·47	13·50	—	21	29	30	369
November	9·45	10·46	14·51	13·52	—	—	3	40	376
	8·93	10·27	14·51	13·52	—	—	—	50	348
	8·24	9·72	14·38	13·59	—	—	—	60	289
December	7·51	8·81	13·94	13·33	12	1	14	60	209
	6·62	7·60	12·88	12·93	—	—	—	70	113
*	6·06	6·56	11·80	12·30	—	—	—	80	70
January	5·63	6·01	11·15	11·87	—	—	—	80	54
	5·36	5·68	10·91	11·64	—	—	—	90	49
*	5·13	5·43	10·73	11·44	—	—	—	100	46
February	5·04	5·33	10·59	11·35	—	—	—	100	46
	4·92	5·22	10·50	11·28	—	—	—	100	45
*	5·00	5·29	10·55	11·25	—	—	—	100	46

NOTE: The periods marked * are not ten days.

SUMMARY ANALYSIS OF THE YEAR 1936–37

(ii) OBSERVED DISCHARGES

Ten-Day Period	Discharges		Difference	Uncorrected Cumulative Loss	Observed Inflow		Cumulative Inflow Total	Corrected Cumulative Loss
	Sobat Head	Hillet Doleib			Twalor	Wakau		
April ...	71	46	25	25	—	—	—	25
	104	84	20	45	—	—	—	45
May ...	104	96	8	53	—	—	—	53
	168	131	37	90	—	—	—	90
*	273	237	36	126	—	—	—	126
June ...	337	289	48	174	—		—	174
	406	346	60	234	—	(−17)	—	234
	448	377	71	305	—		(− 17)	288
July ...	475	411	64	369	—		(− 31)	338
	499	453	46	415	—	(−42)	(− 45)	370
*	583	538	45	460	—		(− 59)	401
August ...	555	519	36	496	—		(− 76)	420
	570	541	29	525	—	(−51)	(− 93)	432
*	645	614	31	556	—		(−110)	446
September ...	596	573	23	579	−3	−13	−126	453
	601	586	15	594	+1	0	−125	469
	605	596	9	603	4	+11	−110	493
October ...	612	603	9	612	6	16	− 88	524
	618	608	10	622	7	19	− 62	570
*	689	672	17	639	8	21	− 33	606
November ...	601	612	− 11	628		23	− 10	618
	496	613	−117	511		45	+ 35	546
	391	592	−201	310		74	109	419
December ...	314	515	−201	109		65	174	283
	238	351	−113	− 4		33	207	203
*	178†	231	− 53	− 57		—	207	150
January ...	115†	149	− 34	− 91		—	207	116
	90†	114	− 24	−115	not measured	—	207	92
*	84†	97	− 13	−128		—	207	79
February ...	70†	75	− 5	−133		—	207	74
	64†	66	− 2	−135		—	207	72
*	55†	50	+ 5	−130		—	207	77
March ...	61†	59	2	−128		—	207	79
	42†	48	− 6	−134		—	207	73
*	36†	35	+ 1	−133		—	207	74

NOTES: Periods marked * are not ten days.
Discharges marked † were observed at Nasir, which is downstream the mouth of the Wakau.
Wakau discharges marked in brackets were estimated from a general gauge/discharge curve using Nasir gauge.

TABLE 443 (*continued*)

SUMMARY ANALYSIS OF THE YEAR 1936–37 (LOW FLOOD)

(iii) COMPARISON OF COMPUTED AND OBSERVED LOSSES

Ten-Day Period	Computed				Corrected Observed Loss	Difference Computed—Observed
	Trough Volume	Net Evaporation	Absorption	Total		
April	—	—	—	—	—	—
	13	2	0	15	25	−10
	26	3	0	29	45	−16
May	41	4	0	45	53	− 8
	76	5	0	81	90	− 9
*	134	7	0	141	126	+15
June	200	9	0	209	174	35
	247	9	0	256	234	22
	290	2	0	292	288	4
July	334	− 2	10	342	338	4
	381	− 6	10	385	370	15
*	423	−10	20	433	401	32
August	464	−20	20	464	420	44
	497	−31	30	496	432	74
*	532	−52	40	520	446	74
September ...	561	−68	50	543	453	90
	600	−85	60	575	469	106
	628	−99	70	599	493	106
October	651	−99	80	632	524	108
	664	−96	90	658	570	88
*	672	−93	90	669	606	63
November ...	635	−78	100	657	618	39
	535	−60	100	575	546	29
	392	−42	110	460	419	41
December ...	227	−31	110	306	283	23
	116	−23	110	203	203	0
*†	55	−17	110	148	150	− 2
January ... ...†	34	−13	110	131	116	+15
†	26	− 9	110	127	92	35
*†	18	− 4	110	124	79	45
February... ...†	14	+ 1	110	125	74	51
†	13	5	110	128	72	56
*†	12	10	110	132	77	55

NOTES: The periods marked * are not ten days.
For the periods marked † the upper discharge site was at Nasir, 190 km. from Hillet Doleib, and not at Sobat Head.
The figures for net evaporation, absorption, and corrected observed loss are cumulative.

TABLE 444

SUMMARY ANALYSIS OF THE YEAR 1937–38

(i) GAUGES AND RAINFALL DATA

Ten-Day Period	Gauges				Rainfall			Assumed Gross Evaporation	Total Surface Area sq. km.
	Sobat Head	Nasir	Abwong	Hillet Doleib	Nasir	Abwong	Doleib Hill		
					millimetres				
April (3)	4·87	5·16	10·30	10·90	—	—	—	—	—
May ...	5·23	5·53	10·47	10·98	48	12	1	40	40
	5·95	6·26	11·03	11·26	30	34	50	40	50
*	6·73	7·13	11·62	11·60	52	—	10	44	84
June ...	7·20	7·85	12·23	11·97	8	5	85	40	115
	7·28	7·96	12·43	12·10	125	98	48	30	123
	7·42	8·12	12·53	12·24	66	39	16	20	132
July ...	7·80	8·48	12·74	12·35	64	116	64	20	154
	8·21	8·85	13·00	12·51	73	27	46	20	183
*	8·77	9·32	13·33	12·68	40	45	125	22	224
August	9·10	9·68	13·69	13·16	57	43	90	10	269
	9·33	9·96	13·91	13·24	23	22	40	10	302
*	9·45	10·15	14·12	13·38	31	70	39	11	328
September	9·52	10·31	14·32	13·47	2	83	15	10	351
	9·57	10·44	14·43	13·53	53	65	56	10	369
	9·61	10·54	14·58	13·61	65	117	76	10	388
October	9·63	10·60	14·74	13·71	22	14	8	10	703
	9·65	10·64	14·79	13·75	14	52	14	20	858
*	9·62	10·64	14·83	13·80	—	—	6	33	913
November	9·49	10·59	14·82	13·78	6	—	—	40	555
	9·26	10·48	14·78	13·74	—	—	—	50	390
	8·93	10·26	14·69	13·70		—	—	60	360
December	8·18	9·65	14·50	13·63	—	—	—	60	295
	7·31	8·64	13·92	13·44	—	—	—	70	227
*	6·63	7·33	12·73	12·94	—	—	—	88	106
January	5·82	6·26	11·60	12·30	—	—	—	80	53
	5·44	5·77	11·02	11·85	—	—	—	90	43
*	5·22	5·54	10·77	11·61	—	—	—	110	41
February	5·02	5·31	10·60	11·49	—	—	—	100	39
	4·80	5·09	10·39	11·36	—	—	—	100	38
*	4·76	5·05	10·30	11·26	—	—	—	80	38

NOTE: The periods marked * are not ten days.

SUMMARY ANALYSIS OF THE YEAR 1937–38

(ii) OBSERVED DISCHARGES

Ten-Day Period	Discharges		Difference	Uncorrected Cumulative Loss	Observed Inflow		Cumulative Inflow Total	Corrected Cumulative Loss
	Sobat Head	Hillet Doleib			Twalor	Wakau		
May ...	89†	62	27	27	—	—	—	27
	154†	122	32	59	−1	—	− 1	58
*	269	230	39	98	0	− 5	− 6	92
June ...	318	285	33	131	−2	− 5	− 13	118
	328	304	24	155	−2	− 3	− 18	137
	344	325	19	174	0	0	− 18	136
July ...	389	347	42	216	−3	0	− 21	195
	448	392	56	272	−4	− 1	− 26	246
*	564	479	85	357	0	10	− 36	321
August ...	553	511	42	399	0	−22	− 58	341
	584	525	59	458	0	−26	− 84	374
*	664	612	52	510	0	−23	−107	403
September ...	621	579	42	552	0	−12	−119	433
	636	598	38	590	0	+ 3	−116	474
	646	629	17	607	0	15	−101	506
October ...	651	664	− 13	594	0	21	− 80	514
	653	673	− 20	574	0	25	− 55	519
*	702	748	− 46	528	0	27	− 28	500
November ...	596	672	− 76	472	0	20	− 8	464
	542	658	−116	336	5	18	+ 15	351
	482	641	−159	177	15	23	53	230
December ...	404	607	−203	− 26	15	60	128	102
	321	515	−194	−220	13	71	212	− 8
*	248	362	−114	−334	12	35	259	− 75
January ...	138†	183	− 45	−379	—	—	259	−120
	96†	128	− 32	−411	—	—	259	−152
*	89†	113	− 24	−435	—	—	259	−176
February ...	68†	86	− 18	−453	—	—	259	−194
	52†	68	− 16	−469	—	—	259	−210
*	39†	46	− 7	−476	—	—	259	−217

NOTES: The periods marked * are not ten days.
Discharges marked † were observed at Nasir, downstream the mouth of the Wakau.

TABLE 444 (*continued*)

SUMMARY ANALYSIS OF THE YEAR 1937–38 (HIGH FLOOD)

(iii) COMPARISON OF COMPUTED AND OBSERVED LOSSES

Ten-Day Period	Computed				Corrected Observed Loss	Difference Computed—Observed
	Trough Volume	Net Evaporation	Absorption	Total		
May ... ... †	18	1	0	19	27	− 8
†	50	1	0	51	58	− 7
*	112	3	0	115	92	+23
June	153	4	0	157	118	39
	168	− 4	0	164	137	27
	199	− 7	0	192	156	36
July	246	− 16	0	230	195	35
	319	− 21	10	288	246	42
*	406	− 32	20	394	321	73
August	486	− 46	30	410	341	69
	549	− 51	40	538	374	164
*	600	− 64	50	586	403	183
September ...	642	− 71	60	631	433	198
	677	− 90	70	657	474	183
	718	−122	80	676	506	270
October	759	−122	90	727	514	213 } flood overtops incised trough
	775	−131	120	764	519	245 }
*	751	−104	180	817	500	317 }
November ...	705	− 82	220	843	464	379 }
	648	− 62	260	846	351	495
*	540	− 40	260	760	230	530
December ...	403	− 22	260	641	102	539
	221	− 6	260	475	− 8	483
*	89	+ 3	260	352	− 75	427
January ... ... †	35	8	260	303	−120	423
†	19	13	260	291	−152	443
*†	10	18	260	288	−176	464
February... ... †	− 2	23	260	281	−194	475
†	− 4	27	260	283	−210	493
*†	− 4	31	260	287	−217	504

Notes: All losses are in millions of cubic metres.
The periods marked * are not ten days.
For the periods marked † the upper discharge site was at Nasir, 190 km. from Hillet Doleib, and not at Sobat Head.
The figures for net evaporation, absorption, and corrected observed loss are cumulative.

TABLE 445

SUMMARY ANALYSIS OF THE YEAR 1938–39
(i) GAUGES AND RAINFALL DATA

Ten-Day Period	Gauges				Rainfall				
	Sobat Head	Nasir	Abwong	Hillet Doleib	Nasir	Abwong	Doleib Hill	Assumed Gross Evaporation	Total Area sq. km.
					millimetres				
April (3)	5·02	5·31	10·44	11·71	—	—	—	—	—
May	5·44	5·74	10·67	11·23	29	—	16	40	42
	5·50	5·80	10·89	11·36	12	—	48	40	43
*	5·81	6·12	11·00	11·41	—	14	16	44	47
June	6·72	7·12	11·65	11·67	25	9	73	40	72
	7·27	7·83	12·21	12·03	114	86	48	30	116
	7·84	8·44	12·60	12·28	59	6	8	20	152
July	8·29	8·90	12·94	12·51	11	95	8	20	195
	8·57	9·18	13·20	12·67	23	41	22	20	206
*	8·84	9·45	13·42	12·84	54	80	137	22	237
August	8·98	9·66	13·63	13·01	27	27	57	10	260
	9·14	9·79	13·79	13·12	103	93	43	10	279
*	9·29	9·97	13·94	13·26	65	56	97	11	303
September	9·42	10·19	14·08	13·38	88	45	54	10	326
	9·52	10·47	14·28	13·47	132	18	12	10	355
	9·63	10·62	14·52	13·57	33	84	14	10	386
October	9·69	10·72	14·70	13·70	30	26	49	10	905
	9·75	10·81	14·89	13·86	67	36	14	20	1,527
*	9·80	10·88	14·99	13·94	3	7	2	33	1,893
November	9·87	10·93	15·08	13·98	1	16	10	40	2,250
	9·88	10·96	15·13	13·98	—	—	—	50	2,402
	9·85	10·93	15·17	13·98	—	—	—	60	1,040
December	9·70	10·80	15·22	13·99	—	—	—	60	958
	9·48	10·64	15·29	14·01	—	—	—	70	782
*	9·09	10·41	15·33	14·04	—	—	—	88	640
January	8·51	10·00	15·26	14·03	—	—	—	80	341
	7·80	9·23	14·89	13·94	—	—	—	90	267
*	6·83	7·67	13·62	13·54	—	—	—	110	130
February	5·84	6·26	11·93	12·74	—	—	—	10	56
	5·44	5·78	11·19	12·13	—	—	—	10	44
*	5·26	5·58	10·86	11·78	—	—	—	8	42
March	5·25	5·56	10·77	11·62	—	—	—	—	42
	5·26	5·57	10·81	11·57	—	—	—	10	42
*	4·88	5·16	10·41	11·40	—	—	—	9	—

NOTE: The periods marked * are not ten days.

SUMMARY ANALYSIS OF THE YEAR 1938–39
(ii) OBSERVED DISCHARGES

Ten-Day Period	Discharges		Difference	Un-corrected Cumulative Loss	Observed Inflow				Cumulative Inflow Total	Corrected Cumulative Loss
	Sobat Head	Hillet Doleib			Fullus	Nyanding	Wakau	Twalor		
May	103†	84	19	19	—	—	—	—	—	19
	109†	112	− 3	16	—	—	—	—	—	16
*	155†	135	20	36	—	—		—	—	36
June	242†	187	55	91	—	—	—	—	—	91
	331	269	62	153	—	—	− 3	−3	− 6	147
	416	332	84	237	—	−3	− 8	−5	− 22	215
July	473	381	92	329	—	—	−10	−4	− 36	293
	505	411	94	423	—	—	−10	−4	− 50	373
*	585	485	100	523	—	—	−20	−2	− 72	451
August	551	471	80	603	—	—	−25	0	− 97	506
	566	491	75	678	—	—	−27	0	−124	554
*	647	570	77	755	—	—	−25	0	−149	606
September	615	544	71	826	—	+1	−10	0	−158	668
	646	568	78	904	—	8	+12	0	−138	766
	663	594	69	973	2	8	26	0	−102	871
October	674	633	41	1,014	6	7	30	+1	− 58	956
	686	677	9	1,023	12	1	31	35	+ 21	1,044
*	766	771	− 5	1,018	11	—	35	82	149	1,167
November	705	714	− 9	1,009	8	—	32	115	304	1,313
	641	715	− 74	935	4	—	33	123	464	1,399
	557†	715	−158	777	2	—	(32)	122	588	1,365
December	520†	720	−200	577	0	—			588	1,165
	492†	731	−239	338	0	—			588	926
*	510†	829	−319	19	4	—			592	611
January	417†	748	−331	−312	7	—	no observations	no observations	599	287
	359†	683	−324	−636	6	—			605	− 31
*	260†	509	−249	−885	4	—			609	−276
February	128†	207	− 79	−964	3	—			612	−352
	92†	130	− 38	−1,002	1	—			613	389
*	62†	78	− 16	−1,018	0	—			613	−405
March	83†	86	− 3	−1,021	—	—			613	−438
	86†	81	+ 5	−1,016	—	—			613	−403
*	60†	64	− 4	−1,020	—	—			613	−407

NOTES: The periods marked * are not ten days.
Discharges marked † were taken below the mouth of the Wakau, at Nasir.
The figures in the last two columns are very unreliable after the end of November 1938, owing to lack of observed discharges in the Twalor.
The last Wakau discharge, marked in brackets, was not included in the inflow because the upper discharge site on the Sobat was then below Wakau mouth.

TABLE 445 (*continued*)

SUMMARY ANALYSIS OF THE YEAR 1938–39 (HIGH FLOOD)

(iii) COMPARISON OF COMPUTED AND OBSERVED LOSSES

Ten-Day Period	Computed				Corrected Observed Loss	Difference Computed-Observed	
	Trough Volume	Net Evaporation	Absorption	Total			
May ... ...†	10	1	0	11	19	− 8	
†	19	2	0	21	16	+ 5	
*†	43	3	0	46	36	10	
June ... ...†	91	3	0	94	91	3	
	170	− 3	0	167	147	20	
	242	− 3	0	239	215	24	
July	302	− 7	0	295	293	2	
	355	− 9	10	346	373	− 27	
*	406	− 26	20	400	451	− 51	
August	454	− 37	30	447	506	− 59	
	496	− 57	40	479	554	− 75	
*	541	− 75	50	516	606	− 90	
September ...	597	− 91	60	566	668	−102	
	659	−105	70	624	766	−142	
	722	−117	80	685	871	−186	
October	828	−144	90	774	956	−182	
	984	−175	100	909	1,044	−135	
*	1,098	−118	250	1,230	1,167	+ 63	
November ...	1,232	− 50	450	1,632	1,313	319	flood over-tops incised trough
	1,234	+ 70	560	1,864	1,399	465	
†	960	132	660	1,752	1,365	387	
December ...†	840	189	710	1,739	1,165	574	
†	705	244	710	1,659	926	733	
*†	587	295	710	1,592	611	981	
January ... ...†	460	322	710	1,492	287	1,205	
†	257	346	710	1,313	− 31	1,344	
*†	96	359	710	1,165	−276	1,441	
February ... ...†	38	365	710	1,113	−352	1,465	
†	18	369	710	1,097	−389	1,486	
*†	11	373	710	1,094	−405	1,499	

NOTES: The periods marked * are not ten days.
For the periods marked † the upper discharge site was at Nasir, 190 km. from Hillet Doleib, and not at Dobat Head.
The figures for net evaporation, absorption, and corrected observed loss are cumulative.

TABLE 446

SUMMARY ANALYSIS OF THE YEAR 1939–40

(i) GAUGES AND RAINFALL DATA

Ten-Day Period	Gauges				Rainfall (millimetres)			Assumed Gross Evaporation	Total Area sq. km.
	Sobat Head	Nasir	Abwong	Hillet Doleib	Nasir	Abwong	Doleib Hill		
April (3)	5·41	5·71	10·92	11·54	—	—	—	—	—
May ...	5·58	5·88	10·86	11·46	65	20	11	40	51
	6·52	6·89	11·55	11·69	54	8	61	40	87
*	7·16	7·63	12·15	12·07	46	13	71	44	109
June ...	7·41	7·97	12·40	12·29	15	8	42	40	125
	7·82	8·42	12·68	12·45	—	10	9	30	153
	8·14	8·77	12·94	12·59	48	18	6	20	177
July ...	8·46	9·04	13·14	12·72	21	41	60	20	200
	8·66	9·27	13·36	12·86	81	76	14	20	223
*	8·86	9·49	13·54	12·98	164	39	81	22	245
August	8·97	9·67	13·68	13·09	8	24	97	10	262
	9·04	9·75	13·80	13·18	8	55	20	10	276
*	9·16	9·86	13·88	13·26	44	23	76	11	291
September	9·27	10·00	13·98	13·37	98	52	66	10	307
	9·38	10·19	14·09	13·44	56	19	79	10	326
	9·48	10·38	14·22	13·49	64	12	119	10	348
October	9·50	10·49	14·32	13·50	11	13	53	10	360
	9·51	10·53	14·41	13·55	7	6	12	20	369
*	9·50	10·56	14·48	13·58	5	2	2	33	375
November	9·45	10·55	14·55	13·60	3	10	5	40	379
	9·22	10·47	14·55	13·60	—	—	—	50	366
	8·77	10·20	14·50	13·58	—	—	—	60	335
December	7·96	9·47	14·29	13·52	—	—	—	60	265
	7·13	8·18	13·55	13·27	—	—	—	70	163
*	6·12	6·64	12·03	12·60	—	—	—	88	63
January	5·76	6·17	11·36	12·04	—	—	—	80	50
	5·48	5·83	11·02	11·76	—	—	—	90	45
*	5·24	5·55	10·74	11·55	—	—	—	110	42
February	5·16	5·46	10·55	11·43	—	—	—	10	41
	5·19	5·49	10·62	11·41	—	—	—	10	41
*	5·14	5·44	10·57	11·37	—	—	—	9	41
March (1)	5·06	5·35	10·50	11·34	—	—	—	—	—

NOTE: The periods marked * are not ten days.

SUMMARY ANALYSIS OF THE YEAR 1939–40

(ii) OBSERVED DISCHARGES

Ten-Day Period	Discharges		Difference	Uncorrected Cumulative Loss	Observed Inflow		Cumulative Inflow Total	Corrected Cumulative Loss
	Sobat Head	Hillet Doleib			Twalor	Wakau		
May ...	123	98	25	25	—	—	—	25
	225	171	54	79	—	—	—	79
*	343	286	57	136	—	—	—	136
June ...	359	304	55	191	−3	− 8	− 11	180
	416	339	77	268	−3	− 8	− 22	246
	458	374	84	352	−4	− 7	− 33	319
July ...	487	408	79	431	−4	−10	− 47	384
	513	440	73	504	−2	−15	− 64	440
*	590	506	84	588	−2	−23	− 89	499
August ...	550	484	66	654	—	−20	−109	545
	556	501	55	709	—	−19	−128	380
*	618	568	50	759	—	−20	−148	611
September ...	572	538	34	793	—	−13	−161	632
	592	555	37	830	—	+ 2	−159	671
	613	571	42	872	—	13	−146	726
October ...	622	575	47	919	+3	21	−122	797
	626	594	32	951	11	24	− 87	864
*	689	674	15	966	14	29	− 44	922
November ...	614	619	− 5	961	13	27	− 4	957
	553	627	− 74	887	11	28	+ 35	922
	460	613	−153	734	9	38	82	816
December ...	346	562	−216	518	10	81	173	691
	273	437	−164	354	12	63	248	602
*	176†	257	− 81	273	0	(1)	248	521
January ...	128†	138	− 10	263	—	—	248	511
	100†	106	− 6	257	—	—	248	505
*	88†	90	− 2	255	—	—	248	503
February ...	73†	77	− 4	251	—	—	248	499
	75†	77	− 2	249	—	—	248	497
*	64†	68	− 4	245	—	—	248	493

NOTES: The periods marked * are not ten days.
Discharges marked † were taken at Nasir, below the mouth of the Wakau. The last discharge of this khor is therefore shown in brackets because it is not included in the inflow between the two discharge sites on the Sobat.

TABLE 446 (*continued*)

SUMMARY ANALYSIS OF THE YEAR 1939–40 (LOW FLOOD)

(iii) COMPARISON OF COMPUTED AND OBSERVED LOSSES

Ten-Day Period	Computed				Corrected Observed Loss	Difference Computed—Observed
	Trough Volume	Net Evaporation	Absorption	Total		
May	23	1	0	24	25	− 1
	76	1	0	77	79	− 2
*	123	1	0	124	136	− 12
June	164	4	0	168	180	− 12
	217	7	0	224	246	− 22
	265	7	0	272	319	− 47
July	311	3	10	324	384	− 60
	357	− 7	10	360	440	− 80
*	399	− 27	20	392	499	−107
August	430	− 35	20	415	545	−130
	457	− 41	30	446	580	−134
*	487	− 53	40	474	611	−137
September ...	521	− 72	50	499	632	−133
	568	− 86	60	542	671	−129
	604	−108	70	566	726	−160
October	627	−115	80	592	797	−205
	641	−111	90	620	864	−244
*	650	−100	90	640	922	−282
November ...	636	− 89	100	647	957	−310
	576	− 71	100	605	922	−317
	459	− 53	110	516	816	−300
December ...	284	− 40	110	354	691	−337
	113	− 32	110	191	602	−411
*†	32	− 26	110	116	521	−405
January ... ...†	9	− 22	110	97	511	−414
†	− 3	− 18	110	89	505	−416
*†	−10	− 13	110	87	503	−416
February... ...†	−12	− 8	110	90	499	−409
†	−12	− 3	110	95	497	−402
*†	−15	+ 2	110	97	493	−396

NOTES: The periods marked * are not ten days.
For the periods marked † the upper discharge site was at Nasir, 190 km. from Hillet Doleib, and not at Sobat Head.
The figures for net evaporation, absorption, and corrected observed loss are cumulative.

TABLE 447

SUMMARY ANALYSIS OF THE YEAR 1941–42

(i) GAUGES AND RAINFALL DATA

Ten-Day Period	Gauges				Rainfall			Assumed Gross Evaporation	Total Area sq. km.
	Sobat Head	Nasir	Abwong	Hillet Doleib	Nasir	Abwong	Doleib Hill		
					millimetres				
April (3)	4·74	5·03	10·02	10·77	—	—	No observations	—	—
May ...	4·83	5·12	10·21	10·79	8	1		40	44
	5·35	5·65	10·41	10·89	190	59		40	46
*	6·42	6·76	11·36	11·37	107	25		44	71
June ...	7·30	7·78	12·02	11·77	14	64		40	112
	7·96	8·53	12·55	12·12	10	103		30	155
	8·37	8·96	12·90	12·39	39	4		20	186
July ...	8·69	9·25	13·15	12·55	27	83		20	213
	8·92	9·51	13·34	12·68	21	16		20	236
*	9·08	9·71	13·51	12·82	16	15		22	257
August	9·17	9·84	13·67	12·94	79	11		10	272
	9·23	9·96	13·80	13·08	53	3		10	288
*	9·31	10·08	13·99	13·20	32	119		11	309
September	9·35	10·18	14·06	13·29	—	—		10	320
	9·36	10·23	14·11	13·34	1	61		10	325
	9·41	10·30	14·18	13·37	24	2		10	336
October	9·47	10·38	14·23	13·41	41	—		10	346
	9·53	10·50	14·30	13·43	12	40		20	357
*	9·57	10·58	14·39	13·48	6	5		33	369
November	9·59	10·63	14·47	13·50	42	—		40	374
	9·59	10·67	14·57	13·53	—	—		50	388
	9·42	10·64	14·61	13·55	—	—		60	384
December	9·02	10·47	14·62	13·58	—	—		60	363
	8·49	10·08	14·53	13·57	—	—		70	323
*	7·57	9·16	14·17	13·47	—	—		88	235
January	6·98	7·69	13·03	13·07	—	—		80	107
	6·00	6·47	11·72	12·34	—	—		90	57
*	5·76	5·93	11·06	11·80	—	—		110	46
February	5·30	5·63	10·77	11·51	—	—		100	41
	5·22	5·53	10·58	11·32	—	—		100	40
*	5·18	5·49	10·58	11·26	—	—		80	39
March (1)	5·32	5·64	10·64	11·24	—	—		—	—

NOTE: The periods marked * are not ten days.

SUMMARY ANALYSIS OF THE YEAR 1941–42

(ii) OBSERVED DISCHARGES

Ten-Day Period	Discharges		Difference	Uncorrected Cumulative Loss	Observed Inflow		Cumulative Inflow Total	Corrected Cumulative Loss
	Sobat Head	Hillet Doleib			Twalor	Wakau		
May ...	65	44	21	21	—	—	—	21
	111	68	43	64	—	—	—	64
*	245	186	59	123	—	—	—	123
June ...	332	259	73	196	0	0	0	196
	412	335	77	273	−2	− 4	− 6	266
	458	384	74	347	−3	−12	− 21	326
July ...	487	411	76	423	−4	−19	− 44	379
	513	436	77	500	−4	−26	− 74	426
*	584	511	73	573	−3	−32	−109	464
August ...	543	492	51	624	−2	−29	−140	484
	552	521	31	655	0	−26	−166	489
*	618	592	26	681	+2	−23	−187	494
September ...	569	547	22	703	+3	−17	−201	502
	572	553	19	722	4	−13	−210	512
	579	558	21	743	4	− 8	−214	529
October ...	584	567	17	760	5	− 1	−210	550
	597	576	21	781	9	+15	−186	595
*	667	655	12	793	12	28	−146	647
November ...	611	607	4	797	13	30	−103	694
	615	620	− 5	792	14	33	− 56	736
	562	630	− 68	724	14	33	− 9	715
December ...	466	635	−169	555	12	36	+ 39	594
	384	622	−238	317	10	57	106	423
*	327	605	−278	39	13	88	207	246
January ...	227†	382	−155	−116	—	—	207	91
	152†	202	− 50	−166	—	—	207	41
*	116†	125	− 9	−175	—	—	207	32
February ...	80†	84	− 4	−179	—	—	207	28
	73†	73	0	−179	—	—	207	28
*	57†	56	+ 1	−178	—	—	207	29

NOTES: The periods marked * are not ten days.
Discharges marked † were taken at Nasir, below the mouth of the Wakau.

TABLE 447 (*continued*)

SUMMARY ANALYSIS OF THE YEAR 1941–42 (LOW FLOOD)

(iii) COMPARISON OF COMPUTED AND OBSERVED LOSSES

Ten-Day Period	Computed				Corrected Observed Loss	Difference Computed—Observed
	Trough Volume	Net Evaporation	Absorption	Total		
May	10	1	0	11	21	−10
	41	− 3	0	38	64	−26
*	104	−12	0	92	123	−31
June	184	−12	0	172	196	−24
	262	−17	0	245	266	−21
	323	−17	0	306	326	−20
July	378	−26	0	352	379	−27
	424	−26	10	408	426	−18
*	463	−26	10	447	464	−17
August	493	−34	20	479	484	− 5
	529	−40	20	509	489	+20
*	559	−62	30	527	494	33
September ...	579	−59	40	560	502	58
	592	−66	50	576	512	64
	615	−66	60	608	529	79
October	638	−70	70	638	550	88
	666	−74	80	672	595	77
*	687	−67	80	700	647	53
November ...	704	−59	90	735	694	51
	707	−39	90	758	736	22
	470	−16	100	754	715	39
December ...	590	+ 6	100	696	594	102
	444	29	100	573	423	150
*	258	48	100	406	246	160
January ... ...†	100	58	100	258	91	167
†	48	65	100	213	41	172
*†	32	70	100	202	32	170
February... ...†	24	75	100	199	28	171
†	18	80	100	198	28	170
*†	17	85	100	202	29	173

NOTES: The periods marked * are not ten days.
For the periods marked † the upper discharge site was at Nasir, 190 km. from Hillet Doleib, and not at Sobat Head.
The figures for net evaporation, absorption, and corrected observed loss are cumulative.

TABLE 448

SUMMARY ANALYSIS OF THE YEAR 1942–43

(i) GAUGES AND RAINFALL DATA

Ten-Day Period	Gauges				Rainfall		Assumed Gross Evaporation	Total Area sq. km.
	Sobat Head	Nasir	Abwong	Hillet Doleib	Nasir	Abwong		
					millimetres			
April (3) ...	4·79	5·08	10·04	10·85	—	—	—	—
May ...	5·13	5·43	10·42	10·97	12	16	40	38
	5·94	6·24	10·86	11·16	88	23	40	49
*	7·04	7·49	11·88	11·72	50	13	44	100
June ...	7·18	7·81	12·21	11·99	49	3	40	114
	7·76	8·34	12·50	12·17	18	70	30	145
	8·16	8·81	12·83	12·40	105	44	20	175
July ...	8·42	9·09	13·09	12·56	51	36	20	199
	8·68	9·52	13·28	12·71	71	26	20	221
*	8·97	9·64	13·52	12·87	85	91	22	252
August ...	9·09	9·83	13·73	13·04	70	70	10	273
	9·23	10·02	13·89	13·19	81	70	10	298
*	9·38	10·21	14·11	13·37	23	95	11	326
September ...	9·52	10·40	14·32	13·57	41	46	10	358
	9·59	10·53	14·38	13·63	7	—	10	372
	9·63	10·64	14·48	13·67	8	33	10	387
October ...	9·68	10·74	14·63	13·75	63	17	10	802
	9·71	10·79	14·74	13·78	—	15	20	822
*	9·72	10·81	14·79	13·77	—	9	33	847
November ...	9·56	10·76	14·81	13·75	2	7	40	785
	9·18	10·61	14·81	13·74	—	1	50	393
	8·88	10·35	14·74	13·72	—	—	60	365
December ...	8·10	9·79	14·54	13·66	—	—	60	301
	7·36	8·85	14·01	13·49	—	—	70	211
*	6·34	7·10	12·63	12·94	—	—	88	80
January ...	5·70	6·09	11·39	12·18	—	—	80	50
	5·38	5·70	10·90	11·74	—	—	90	42
*	5·25	5·56	10·67	11·53	—	—	110	40
February ...	5·14	5·44	10·52	11·48	—	—	100	39
	4·97	5·26	10·44	11·38	—	—	100	38
*	4·75	5·04	10·21	11·28	—	—	80	38
March (1) ...	4·65	4·94	10·08	11·21	—	—	—	—

NOTES: The periods marked * are not ten days.
No rainfall observations were made at Doleib Hill during this flood.

SUMMARY ANALYSIS OF THE YEAR 1942–43 (LOW FLOOD)

(ii) OBSERVED DISCHARGES

Ten-Day Period	Discharges			Un-corrected Cumulative Loss	Observed Inflow			Cumulative Inflow Total	Corrected Cumulative Loss
	Sobat Head	Hillet Doleib	Difference		Nyanding	Wakau	Twalor		
May ...	71†	65	6	6	—	—	—	—	6
	147†	111	36	42	—	—	—	—	42
*	300	250	50	92	—	—	—	—	92
June ...	316	282	34	126	—	− 6	−3	− 9	117
	385	322	63	189	—	− 4	−3	−16	173
	443	371	72	261	—	0	−3	−19	242
July ...	480	403	77	338	1	− 7	−3	−28	310
	508	432	76	414	3	−16	−2	−43	371
*	591	507	84	498	4	−25	−2	−66	432
August	551	492	59	557	2	−22	−1	−87	470
	563	517	46	603	7	−15	−1	−96	507
*	647	603	44	647	21	− 6	+1	−80	567
September	625	581	44	691	8	+ 7	4	−61	630
	642	589	53	744	0	18	9	−34	710
	651	596	55	799	0	25	15	+ 6	805
October	664	627	37	836	0	31	19	56	892
	669	653	16	852	0	34	21	111	963
*	736	730	6	858	0	37	24	172	1,030
November	601	665	− 64	794	0	32	22	226	1,020
	494	666	−172	622	0	28	20	274	896
	416	657	−241	381	1	31	17	323	704
December	342	619	−277	104	7	58	24	412	516
	265	527	−262	−158	—	95	23	530	372
*	188†	353	−165	−323	—	(29)	4	534	211
January	125†	158	− 33	−356	—	—	—	534	178
	94†	96	− 2	−358	—	—	—	534	176
*	93†	89	+ 4	−354	—	—	—	534	180
February	75†	78	− 3	−357	—	—	—	534	177
	60†	67	− 7	−364	—	—	—	534	170
*	34†	41	− 7	−371	—	—	—	534	163

NOTES: The periods marked * are not ten days.
Discharges marked † were taken at Nasir, below the mouth of the Wakau. The last Wakau discharge is marked in brackets because it is therefore not included in the total inflow between the two discharge sites on the Sobat.

TABLE 448 (*continued*)

SUMMARY ANALYSIS OF THE YEAR 1942–43 (HIGH FLOOD)

(iii) COMPARISON OF COMPUTED AND OBSERVED LOSSES

Ten-Day Period		Computed				Corrected Observed Loss	Difference Computed-Observed	
		Trough Volume	Net Evaporation	Absorption	Total			
May ...	...†	17	1	0	18	6	12	
	†	38	0	0	38	42	4	
	*	122	1	0	123	92	+ 31	
June ...	...	172	2	0	174	117	57	
		232	1	0	233	173	60	
		289	− 8	0	281	242	39	
July ...	...	339	− 12	10	337	310	27	
		393	− 19	20	394	371	13	
	*	451	− 36	30	445	432	13	
August ...	...	494	− 53	40	481	470	11	
		548	− 74	50	524	507	17	
	*	608	− 91	60	577	567	10	
September	...	656	−102	70	624	630	− 6	
		684	−102	80	662	710	− 48	
		726	−106	90	710	805	− 95	flood over-tops incised trough
October ...	...	791	−131	100	760	892	−132	
		835	−123	170	882	963	− 81	
	*	814	− 98	220	936	1,030	− 94	
November	...	729	− 67	230	892	1,020	−128	
		661	− 47	240	854	896	− 42	
		551	− 25	240	766	704	+ 62	
December	...	389	− 7	240	622	516	106	
		196	+ 8	240	444	372	72	
	*†	66	16	240	322	211	111	
January ...	...†	32	21	240	294	178	116	
	†	20	25	240	285	176	109	
	*†	13	29	240	282	180	102	
February ...	...†	6	33	240	279	177	102	
	†	1	37	240	278	170	108	
	*†	−7	41	240	274	163	111	

NOTES: The periods marked * are not ten days.
For the periods marked † the upper discharge site was at Nasir, 190 km. from Hillet Doleib, and not at Sobat Head.
The figures of net evaporation, absorption, and corrected observed loss are cumulative.

TABLE 449

SUMMARY ANALYSIS OF THE YEAR 1943–44

(i) GAUGES AND RAINFALL DATA

Ten-Day Period	Gauges				Rainfall		Assumed Gross Evaporation	Total Area sq. km.
	Sobat Head	Nasir	Abwong	Hillet Doleib	Nasir	Abwong		
					millimetres			
April (3) ...	4·97	5·26	10·21	11·08	—	—	—	—
May ...	5·12	5·42	10·45	11·14	70	—	40	45
	5·54	5·84	10·79	11·27	55	77	40	50
*	5·45	5·75	10·72	11·31	33	—	44	49
June ...	6·28	6·60	11·19	11·43	3	—	40	66
	6·54	7·12	11·69	11·75	16	7	30	82
	7·05	7·64	12·06	12·01	19	67	20	106
July ...	7·58	8·22	12·40	12·21	2	62	20	136
	8·09	8·74	12·74	12·42	17	4	20	169
*	8·37	9·05	13·05	12·64	73	99	22	194
August ...	8·58	9·28	13·30	12·80	118	34	10	218
	8·81	9·55	13·60	13·07	68	113	10	249
*	9·02	9·74	13·74	13·17	28	52	11	271
September ...	9·14	9·87	13·83	13·24	29	35	10	287
	9·21	9·96	13·94	13·32	68	91	10	300
	9·32	10·08	14·03	13·42	35	37	10	315
October ...	9·38	10·19	14·12	13·46	17	3	10	329
	9·39	10·28	14·18	13·50	31	97	20	337
*	9·45	10·39	14·29	13·51	11	—	33	352
November ...	9·47	10·46	14·37	13·54	—	12	40	361
	9·14	10·41	14·41	13·56	—	—	50	350
	8·51	10·03	14·40	13·55	—	—	60	312
December ...	7·80	9·26	14·16	13·50	—	—	60	246
	7·01	7·96	13·31	13·21	—	—	70	145
*	6·20	6·75	12·08	12·56	—	—	88	78
January ...	5·66	6·05	11·24	11·96	—	—	80	56
	5·32	5·63	10·82	11·66	—	—	90	48
*	5·20	5·51	10·57	11·47	—	—	110	46
February ...	5·18	5·48	10·64	11·42	—	—	100	45
	5·00	5·28	10·44	11·34	—	—	100	44
*	4·64	5·06	10·20	11·22	—	—	90	44
March (1) ...	4·70	4·98	10·06	11·11	—	—	—	—

NOTES: The periods marked * are not ten days.
No rainfall observations were made at Doleib Hill during this flood.

SUMMARY ANALYSIS OF THE YEAR 1943–44

(ii) OBSERVED DISCHARGES

Ten-Day Period	Discharges		Difference	Uncorrected Cumulative Loss	Observed Inflow		Cumulative Inflow Total	Corrected Cumulative Loss
	Sobat Head	Hillet Doleib			Twalor	Wakau		
May ...	79†	74	5	5	—	—	—	5
	122†	109	13	18	—	—	—	18
*	123†	132	− 9	9	—	—	—	9
June ...	208†	150	+ 58	67	—	—	—	67
	246	234	12	79	—	—	—	79
	314	296	18	97	—	—	—	97
July ...	428	349	79	176	−5	− 7	− 12	164
	469	414	55	231	−6	− 8	− 26	205
*	546	509	37	268	−5	−12	− 43	225
August ...	532	492	40	308	−3	−16	− 63	245
	580	545	35	343	−1	−25	− 89	254
*	672	621	51	394	0	−33	−122	272
September ...	632	582	50	444	0	−29	−151	293
	644	599	45	489	0	−28	−179	310
	658	623	35	524	0	−24	−203	321
October ...	668	638	30	554	0	17	−220	334
	674	648	26	580	0	−10	−230	350
*	748	719	29	609	0	+ 4	−226	383
November ...	684	688	− 4	605	+3	22	−201	404
	588	698	−110	495	12	63	−126	369
	458	696	−238	257	12	78	− 36	221
December ...	368	646	−278	− 21	12	75	+ 51	+ 30
	291	490	−199	−220	19	63	133	− 87
*	222†	298	− 76	−296	—	—	133	−163
January ...	128†	148	− 20	−316	—	—	133	−183
	93†	100	7	−323	—	—	133	−190
*	92†	89	+ 3	−320	—	—	133	−187
February ...	81†	76	5	−315	—	—	133	−182
	66†	64	2	−313	—	—	133	−180
*	44†	41	3	−310	—	—	133	−177

NOTES: The periods marked * are not ten days.
The discharges marked † were taken at Nasir, below the mouth of the Wakau.

TABLE 449 (*continued*)

SUMMARY ANALYSIS OF THE YEAR 1943-44 (LOW FLOOD)

(iii) COMPARISON OF COMPUTED AND OBSERVED LOSSES

Ten-Day Period	Computed				Corrected Observed Loss	Difference Computed—Observed
	Trough Volume	Net Evaporation	Absorption	Total		
May ... †	10	0	0	10	5	5
†	17	− 2	0	15	18	− 3
*†	29	− 1	0	28	9	+19
June ... †	58	+ 2	0	60	67	− 7
	103	4	0	107	79	+28
	153	2	0	155	97	58
July ...	214	1	10	225	164	61
	276	3	10	289	205	84
*	327	− 13	20	334	225	109
August ...	380	− 28	20	372	245	127
	434	− 48	20	406	254	152
*	473	− 56	30	447	272	175
September	505	− 62	30	473	293	180
	531	− 83	40	488	310	178
	559	− 93	50	516	321	195
October	585	− 93	60	552	334	218
	607	−107	70	570	350	220
*†	632	−100	80	612	383	229
November ...	627	− 89	90	628	404	224
	559	− 71	90	578	369	209
	442	− 52	90	480	221	259
December ...	276	− 37	90	329	30	299
	131	− 27	90	194	− 87	281
*†	51	− 21	90	120	−163	283
January ... ...†	24	− 17	90	97	−183	280
†	12	− 13	90	89	−190	279
*†	9	− 8	90	91	−187	278
February ... †	5	− 3	90	92	−182	274
†	−4	+ 1	90	87	−180	267
*†	−8	5	90	87	−177	264

NOTES: The periods marked * are not ten days.
For the periods marked † the upper discharge site was at Nasir, 190 km. from Hillet Doleib, and not at Sobat Head.
The figures for net evaporation loss, absorption, and corrected observed loss are cumulative.

TABLE 450

SUMMARY ANALYSIS OF THE YEAR 1944-45

(i) GAUGES AND RAINFALL DATA

Ten-Day Period	Gauges				Rainfall		Assumed Gross Evaporation	Total Area sq. km.
	Sobat Head	Nasir	Abwong	Hillet Doleib	Nasir	Abwong		
					millimetres			
April (1) ...	4·79	5·08	10·12	11·03	—	—	—	—
May ...	5·48	5·78	10·43	11·08	35	27	40	47
	6·90	7·33	11·82	11·68	5	—	40	93
*	6·93	7·38	11·97	11·91	16	3	44	97
June ...	7·35	7·94	12·32	12·08	33	57	40	122
	7·86	8·48	12·67	12·32	14	5	30	155
	8·06	8·73	12·88	12·46	65	41	20	171
July ...	8·20	8·90	13·08	12·60	45	12	20	185
	8·47	9·11	13·25	12·76	86	76	20	206
*	8·68	9·31	13·44	12·95	33	54	22	229
August ...	8·87	9·48	13·55	13·02	18	39	10	246
	9·02	9·66	13·64	13·10	17	48	10	262
*	9·12	9·78	13·77	13·21	32	68	11	279
September ...	9·19	9·89	13·90	13·36	53	79	10	295
	9·26	9·98	13·98	13·40	88	56	10	307
	9·34	10·15	14·10	13·48	68	102	10	326
October ...	9·38	10·28	14·20	13·57	1	54	10	340
	9·41	10·34	14·22	13·60	6	22	20	344
*	9·42	10·39	14·26	13·61	20	42	33	352
November ...	9·14	10·35	14·28	13·58	—	—	40	341
	8·81	10·13	14·28	13·54	—	—	50	317
	8·33	9·66	14·13	13·49	—	—	60	274
December ...	7·66	8·86	13·74	13·32	—	—	60	204
	6·86	7·72	12·84	12·94	—	—	70	120
*	6·42	7·06	12·11	12·44	—	—	88	86
January ...	6·08	6·58	11·64	12·09	—	—	80	69
	5·60	5·94	11·07	11·73	—	—	90	33
*	5·26	5·58	10·68	11·50	—	—	110	47
February ...	5·10	5·38	10·50	11·36	—	—	100	45
	4·96	5·25	10·40	11·24	—	—	100	44
*	5·04	5·33	10·42	11·22	—	—	80	44
March (1) ...	4·77	5·06	10·11	11·11	—	—	—	—

NOTES: The periods marked * are not ten days.
No rainfall observations were made at Doleib Hill during this flood.

SUMMARY ANALYSIS OF THE YEAR 1944-45

(ii) OBSERVED DISCHARGES

Ten-Day Period	Discharges			Uncorrected Cumulative Loss	Observed Inflow			Cumulative Inflow Total	Corrected Cumulative Loss
	Sobat Head	Hillet Doleib	Difference		Nyanding	Twalor	Wakau		
May ...	104	63	41	41	—	—	—	—	41
	268	213	55	96	—	—	—	—	96
*	301	279	22	118	—	—	—	—	118
June ...	344	291	53	171	−5	−5	− 4	− 14	157
	411	344	67	238	−2	−3	− 2	− 21	217
	430	371	59	297	0	−2	− 5	− 28	269
July ...	444	394	50	347	+1	−2	− 7	− 36	311
	479	420	59	406	1	−2	−12	− 49	357
*	547	493	54	460	0	−3	−18	− 70	390
August	518	460	58	518	1	−3	−23	− 95	423
	544	472	72	590	3	−3	−29	+124	466
*	613	535	78	668	2	−2	−32	−156	512
September	567	512	55	723	1	1	−28	−184	539
	570	518	52	775	0	0	−26	−210	555
	574	536	38	813	0	0	−11	−221	592
October	571	558	13	826	0	0	+ 5	−216	610
	572	568	4	830	0	0	7	−209	621
*	632	634	− 2	828	0	0	10	−199	629
November	517	574	− 57	771	0	0	19	−180	591
	453	564	−111	660	0	0	34	−146	514
	396	546	−150	510	0	0	57	− 89	421
December	320	482	−162	348	—	—	61	− 28	320
	255	351	− 96	252	—	—	13	− 15	237
*	223†	255	− 32	220	—	—	0	− 15	205
January	162†	178	− 16	204	—	—	—	− 15	189
	107†	94	+ 13	217	—	—	—	− 15	202
*	85†	73	12	229	—	—	—	− 15	214
February	61†	56	5	234	—	—	—	− 15	219
	51†	49	2	236	—	—	—	− 15	221
*	46†	46	0	236	—	—	—	− 15	221

NOTES: The periods marked * are not ten days.
The observations marked † were taken at Nasir, downstream the mouth of the Wakau.

TABLE 450 (*continued*)

SUMMARY ANALYSIS OF THE YEAR 1944–45 (LOW FLOOD)

(iii) COMPARISON OF COMPUTED AND OBSERVED LOSSES

Ten-Day Period	Computed				Corrected Observed Loss	Difference Computed—Observed
	Trough Volume	Net Evaporation	Absorption	Total		
May	42	0	0	42	41	1
	92	4	0	96	96	0
*	131	7	0	138	118	20
June	185	6	0	191	157	34
	236	9	0	245	217	28
	269	4	0	273	269	4
July	304	2	10	316	311	5
	347	−11	10	346	357	− 11
*	388	−16	20	392	390	+ 2
August	421	−19	20	422	423	− 1
	455	−24	30	461	466	− 5
*	486	−36	40	490	512	− 22
September ...	513	−54	50	509	539	− 30
	546	−72	60	534	555	− 21
	578	−95	70	553	592	− 39
October	598	−102	70	576	610	− 44
	608	−98	80	590	621	− 31
*	603	−98	80	585	629	− 44
November ...	558	−84	90	564	591	− 27
	484	−68	90	506	514	− 8
	364	−51	90	403	421	− 18
December ...	221	−39	90	272	320	− 48
	124	−31	90	183	237	− 54
*†	66	−24	90	132	205	− 73
January ... ...†	39	−18	90	111	189	− 78
†	18	−13	90	95	202	−107
*†	7	− 8	90	89	214	−125
February ... ...†	2	− 3	90	89	219	−130
†	−1	+ 1	90	90	221	−131
*†	−5	5	90	90	221	−131

Notes: The periods marked * are not ten days.
For the periods marked † the upper discharge site was at Nasir, 190 km. from Hillet Doleib, and not at Sobat Head.
The figures for net evaporation, absorption, and corrected observed loss are cumulative.

TABLE 451

SUMMARY ANALYSIS OF THE YEAR 1945–46

(i) GAUGES AND RAINFALL DATA

Ten-Day Period	Gauges: Sobat Head	Gauges: Nasir	Gauges: Abwong	Gauges: Hillet Doleib	Rainfall: Nasir (millimetres)	Rainfall: Abwong (millimetres)	Assumed Gross Evaporation (millimetres)	Total Area sq. km.
April (3) ...	4·75	5·04	10·03	10·51	—	—	—	—
May ...	4·66	4·95	9·98	10·41	15	14	40	37
	5·48	5·78	10·35	10·51	94	43	40	40
*	6·98	7·38	11·76	11·31	38	10	44	80
June ...	6·44	7·29	11·95	11·65	56	16	40	74
	7·33	7·89	12·24	11·81	13	95	30	100
	7·65	8·28	12·53	12·03	37	14	20	122
July ...	7·99	8·64	12·77	12·22	22	98	20	175
	8·37	8·96	12·99	12·39	52	19	20	190
*	8·74	9·28	13·23	12·57	54	99	22	219
August ...	9·04	9·60	13·47	12·74	114	91	10	249
	9·31	9·92	13·78	12·98	20	81	10	286
*	9·45	10·10	13·91	13·10	22	42	11	309
September ...	9·56	10·37	14·07	13·20	62	47	10	333
	9·65	10·62	14·36	13·40	22	51	10	371
	9·80	10·74	14·58	13·52	54	35	10	946
October ...	9·83	10·82	14·74	13·65	36	28	10	1,414
	9·80	10·86	14·84	13·73	42	4	20	1,569
*	9·79	10·86	14·98	13·77	2	63	33	1,774
November ...	9·79	10·84	15·01	13·77	1	2	40	1,838
	9·74	10·82	15·02	13·76	—	3	50	1,728
	9·57	10·74	15·02	13·74	—	—	60	1,328
December ...	9·18	10·59	15·00	13·74	—	—	60	411
	8·70	10·32	14·96	13·72	—	—	70	374
*	7·79	9·70	14·70	13·65	—	—	88	299
January ...	7·15	8·54	13·97	13·45	—	—	80	165
	6·28	7·87	12·26	12·82	—	—	90	84
*	5·66	7·04	11·32	12·01	—	—	110	55
February ...	5·30	5·62	10·84	11·54	—	—	100	42
	5·14	5·44	10·62	11·31	—	—	100	40
*	4·98	5·26	10·45	11·19	—	—	80	38
March (1) ...	4·78	5·06	10·20	11·04	—	—	—	—

Notes: The periods marked * are not ten days.
No rainfall observations were made at Doleib Hill during this flood.

SUMMARY ANALYSIS OF THE YEAR 1945–46

(ii) OBSERVED DISCHARGES

Ten-Day Period	Discharges: Sobat Head	Discharges: Hillet Doleib	Difference	Cumulative Uncorrected Loss	Observed Inflow: Nyanding	Observed Inflow: Twalor	Observed Inflow: Wakau	Cumulative Inflow Total	Corrected Cumulative Loss
May ...	32†	34	− 2	− 2	—	—	—	—	− 2
	98†	55	+ 42	+ 42	—	—	—	—	+42
*	297†	212	85	125	—	—	—	—	125
June ...	257†	252	5	130	—	1	5	6	136
	338†	284	54	184	−11	−4	− 6	− 15	169
	373†	332	41	225	− 7	−4	− 4	− 30	195
July ...	416	369	47	272	0	−3	− 4	− 37	235
	473	397	76	348	− 1	−4	− 9	− 51	343
*	569	470	99	447	− 1	−5	−19	− 76	371
August	548	460	88	535	− 2	−4	−27	−109	426
	583	513	70	605	0	−2	−37	−148	457
*	668	596	72	677	0	0	−35	−183	494
September	619	563	56	733	+ 1	+5	−11	−188	545
	657	610	47	780	6	15	−16	−183	597
	675	637	38	818	10	27	+28	−118	644
October	683	665	18	836	6	45	33	− 34	802
	686	684	2	838	0	78	34	+ 78	916
*	752	763	− 11	827	0	110	37	225	1,052
November	677	702	− 25	802	0	100	34	359	1,161
	665	705	− 40	762	0	100	34	493	1,255
	606	704	− 98	664	0	98	31	622	1,286
December	505	703	−197	467	0	84	28	734	—
	408	698	−290	177	0	59	40	—	—
*	357	726	−369	−192	0	46	80	—	—
January	245†	522	−277	−469	—	—	—	—	—
	145†	292	−147	−616	—	—	—	—	—
*	106†	161	− 55	−671	—	—	—	—	—
February	71†	94	− 23	−694	—	—	—	—	—
	60†	68	− 8	−702	—	—	—	—	—
*	39†	45	− 6	−708	—	—	—	—	—

Notes: The periods marked * are not ten days.
The discharges marked † are assumed to have been taken at Nasir, downstream the mouth of the Wakau.

TABLE 451 (*continued*)

SUMMARY ANALYSIS OF THE YEAR 1945–46 (HIGH FLOOD)

(iii) COMPARISON OF COMPUTED AND OBSERVED LOSSES

Ten-Day Period		Computed				Corrected Observed Loss	Difference Computed—Observed	
		Trough Volume	Net Evaporation	Absorption	Total			
May	†	9	1	0	10	−2	12	
	†	48	0	0	48	42	6	
	*†	99	2	0	101	125	−24	
June	†	117	2	0	119	136	−17	
	†	160	− 1	10	169	169	0	
	†	197	− 3	10	204	195	+ 9	
July		284	− 10	20	294	235	59	
		339	− 14	20	345	343	2	
	*	404	− 22	30	412	371	41	
August		478	− 47	40	471	426	45	
		540	− 59	50	531	457	74	
	*	597	− 67	60	590	494	96	
September		655	− 82	70	643	545	98	
		730	− 93	80	717	597	120	flood over-tops incised trough (120–138)
		840	−122	100	818	644	174	
October		929	−150	160	939	802	137	
		982	−150	280	1,112	916	196	
	*	1,036	−150	400	1,286	1,052	234	
November		1,021	− 76	470	1,414	1,161	253	
		939	+ 10	510	1,459	1,255	204	
		794	90	540	1,424	1,286	138	
December		694	117	540	1,351	1,201	150	
		562	145	540	1,247	1,000	247	
	*	378	173	540	1,091	757	334	
January	†	172	189	540	901	480	421	
	†	89	199	540	828	333	495	
	*†	47	207	540	794	278	516	
February	†	26	212	540	778	255	523	
	†	20	217	540	777	247	530	
	*†	12	222	540	774	241	533	

NOTES: The periods marked * are not ten days.
For the periods marked † the upper discharge site is assumed to have been at Nasir, 190 km. from Hillet Doleib, and not at Sobat Head.
The figures for net evaporation, absorption, and corrected observed loss are cumulative.

TABLE 452

SUMMARY ANALYSIS OF THE YEAR 1946–47

(i) GAUGES AND RAINFALL DATA

Ten-Day Period	Gauges: Sobat Head	Gauges: Nasir	Gauges: Abwong	Gauges: Hillet Doleib	Rainfall (millimetres): Nasir	Rainfall (millimetres): Abwong	Assumed Gross Evaporation cm.	Total Area sq. km.
April (3) ...	4·67	4·95	10·03	10·49	—	—	—	—
May ...	5·09	5·39	10·25	10·54	28	16	40	44
	5·61	5·91	10·69	10·75	14	—	40	50
*	5·79	6·10	10·95	10·93	46	12	44	54
June ...	6·66	7·04	11·56	11·28	72	52	40	81
	7·08	7·60	11·96	11·64	61	26	30	104
	7·60	8·25	12·47	11·97	33	111	20	139
July ...	7·92	8·55	12·70	12·20	18	24	20	169
	8·24	8·85	12·91	12·35	39	—	20	181
*	8·59	9·19	13·14	12·50	59	69	22	208
August ...	8·96	9·56	13·53	12·86	50	30	10	249
	9·21	9·90	13·89	13·17	163	82	10	292
*	9·47	10·20	14·40	13·79	98	96	11	360
September ...	9·66	10·51	14·76	14·02	39	52	10	613
	9·82	10·78	15·17	14·20	42	72	10	2,063
	9·93	10·95	15·43	14·31	29	—	10	2,991
October ...	10·05	11·09	15·48	14·33	67	—	10	4,064
	10·17	11·23	15·60	14·34	25	29	20	4,172
*	10·15	11·30	15·86	14·40	6	6	33	4,748
November ...	10·03	11·28	16·10	14·45	—	—	40	4,916
	9·90	11·18	16·27	14·49	—	—	50	4,829
	9·72	11·03	16·37	14·50	—	—	60	4,436
December ...	9·46	10·86	16·40	14·52	—	—	60	3,768
	9·21	10·72	16·40	14·53	—	—	70	3,108
*	8·92	10·55	16·35	14·53	—	—	88	2,166
January ...	8·62	10·34	16·23	14·51	—	—	80	1,071
	8·21	10·01	15·99	14·46	—	—	90	467
*	7·63	9·38	15·55	14·33	—	—	110	378
February ...	—	8·09	14·46	13·98	—	—	100	(265)
	—	6·42	12·42	13·19	—	—	100	(112)
*	(5·54)	5·84	11·35	12·39	—	—	80	(55)
March ...	(5·26)	5·56	10·97	11·87	—	—	100	(49)
	(4·89)	5·19	10·55	11·46	—	—	90	(45)
*	(4·92)	5·22	10·45	11·24	—	—	88	(45)

NOTES: The periods marked * are not ten days.
The gauge readings at Sobat Head given in brackets, and the surface areas similarly enclosed, were obtained by estimation.
There were no rainfall readings at Doleib Hill during this flood.

SUMMARY ANALYSIS OF THE YEAR 1946–47

(ii) OBSERVED DISCHARGES

Ten-Day Period	Discharges: Sobat Head	Discharges: Hillet Doleib	Differences	Uncorrected Cumulative Loss	Observed Inflow: Twalor	Observed Inflow: Wakau	Cumulative Inflow Total	Corrected Cumulative Loss
May ...	72†	54	18	18	—	—	—	18
	124†	96	28	46	—	—	—	46
*	159†	147	12	58	—	—	—	58
June ...	258†	216	52	110	—	—	—	110
	346	294	52	162	—	—	—	162
	434	361	73	235	−1	2	1	236
July ...	476	406	70	305	−5	− 5	− 9	296
	519	438	81	386	−6	−10	− 25	361
*	627	516	111	497	−7	−15	− 47	450
August ...	616	542	74	571	−5	−24	− 76	495
	652	610	42	613	−1	−37	−114	499
*	759	812	− 53	560	+6	−39	−159	401
September ...	736	796	− 60	500	18	−23	−200	300
	784	884	−100	400	71	+17	−112	288
	812	938	−126	274	132	25	+ 45	319
October ...	828	950	−122	152	182	19	246	398
	837	956	−119	33	234	16	496	529
*	929	1,099	−170	− 137	286	20	802	665
November ...	820	1,040	−226	− 357	262	23	1,087	730
	800	1,070	−270	− 627	256	25	1,368	741
	756	1,080	−324	− 951	236	22	1,626	675
December ...	658	1,100	−442	−1,393	208	12	1,846	453
	580	1,100	−520	−1,913	183	− 7	2,022	109
*	575	1,210	−636	−2,548	170	− 3	2,189	− 359
January ...	460	1,090	−630	−3,178	—	—	2,189	− 989
	398	1,030	−632	−3,810	—	—	2,189	−1,621
*	361	1,033	−672	−4,482	—	—	2,189	−2,293
February ...	238	712	−474	−4,956	—	—	2,189	−2,767
	156†	323	−167	−5,123	—	—	2,189	−2,934
*	96†	127	− 31	−5,154	—	—	2,189	2,965
March ...	101†	110	− 9	−5,163	—	—	2,189	−2,974
	75†	75	0	−5,163	—	—	2,189	−2,974
*	84†	63	+ 21	−5,142	—	—	2,189	−2,593

NOTES: The periods marked * are not ten days.
The discharges marked † were taken at Nasir, below the mouth of the Wakau.
After the end of November 1946 the figures in the last two columns are unreliable owing to lack of complete records of inflow, and this becomes even more apparent after the cessation of discharge measurements on the Wakau and Twalor at the end of December.

TABLE 453 (*continued*)

SUMMARY ANALYSIS OF THE YEAR 1947–48 (HIGH FLOOD)

(iii) COMPARISON OF COMPUTED AND OBSERVED LOSSES

Ten-Day Period	Computed				Corrected Observed Loss	Difference Computed-Observed	
	Trough Volume	Net Evaporation	Absorption	Total			
May	no	1	0	—	−5	—	
	data	0	0	—	50	—	
*	—	− 1	0	—	67	—	
June	113	− 3	0	110	136	− 26	
	159	− 4	10	165	183	− 18	
	217	− 4	10	223	248	− 25	
July	280	− 15	20	285	319	− 34	
	340	− 13	30	357	402	− 45	
*	401	− 28	40	413	490	− 77	
August	460	− 33	50	477	559	− 80	
	529	− 45	60	544	639	− 95	
*	606	− 72	70	604	755	−151	
September	668	− 83	80	665	857	−192	
	770	− 83	90	777	1,005	−228	flood over-tops incised trough
	946	− 97	100	949	1,201	−252	
October	1,102	−137	240	1,205	1,430	−225	
	1,237	−160	400	1,477	1,664	−197	
*	1,290	−108	570	1,752	1,926	−174	
November	1,184	− 8	680	1,856	2,102	−246	
	1,002	+ 97	750	1,849	2,174	−325	
	837	189	750	1,776	2,155	−379	
December	746	251	750	1,747	2,044	−297	
	651	282	750	1,683	1,871	−188	
*	495	313	750	1,558	1,624	− 66	
January	187	336	750	1,273	1,256	+ 17	
	no data	352	750	—	937	—	
*	33	360	750	1,143	723	420	
February	− 4	365	750	1,111	682	429	
	no data	370	750	—	666	—	
*	−15	375	750	1,110	652	458	

NOTES: The periods marked * are not ten days.
For some periods no gauge-readings were available from Sobat Head, so that the trough volume could not be calculated.
The figures of net evaporation, absorption, and corrected observed loss are cumulative.

TABLE 454

COMPARISON OF COMPUTED AND OBSERVED LOSSES
AVERAGES FOR FIVE LOW FLOODS

Ten-Day Period	Computed				Corrected Observed Loss	Difference Computed -Observed	Approximate Percentage of Cumulative Discharge at Sobat Head
	Trough Volume	Net Evaporation	Absorption	Total			
May	25	1	0	26	29	− 3	3·0
	60	1	0	61	69	− 8	2·0
*	104	0	0	104	102	+ 2	0·3
June	158	2	0	160	155	5	0·5
	213	2	0	215	208	7	0·5
	260	0	0	260	260	0	0·0
July	308	− 4	8	312	315	− 3	0·2
	351	− 9	10	338	360	− 2	0·1
*	400	−18	18	400	396	+ 4	0·1
August	438	−28	20	430	423	7	0·2
	474	−37	26	463	444	19	0·4
*	507	−52	36	492	467	25	0·5
September ...	536	−63	44	517	484	33	0·6
	567	−78	54	543	503	40	0·7
	597	−93	64	568	532	36	0·5
October	620	−96	72	598	563	33	0·5
	637	−97	82	622	600	22	0·3
*	659	−92	84	641	637	4	0·0
November ...	632	−80	94	646	653	− 7	0·1
	572	−62	94	604	617	−13	0·1
	465	−43	100	522	518	+ 4	0·0
December... ...	319	−28	100	391	383	+ 8	0·1
	186	−17	100	269	276	− 7	0·1
*	92	− 8	100	184	192	− 8	0·1
January	41	− 2	100	139	145	− 6	0·1
	21	+ 2	100	123	130	− 7	0·1
*	11	+ 7	100	118	128	−10	0·1
February	6	12	100	118	128	−10	0·1
	3	17	100	120	128	− 8	0·1
*	1	21	100	122	129	− 7	0·1

NOTES: The periods marked * are not ten days.

TABLE 455

COMPARISON OF COMPUTED AND OBSERVED LOSSES
AVERAGES FOR SEVEN HIGH FLOODS (1946–47 EXCLUDED)

Ten-Day Period	Computed				Corrected Observed Loss	Difference Computed -Observed	Approximate Percentage of Cumulative Discharge at Sobat Head
	Trough Volume	Net Evaporation	Absorption	Total			
May	17	2	0	19	31	− 12	—
	44	2	0	46	55	− 9	—
*	95	2	0	97	95	+ 2	0·2
June	136	3	0	139	134	5	0·5
	191	− 1	4	194	183	11	0·8
	247	− 3	7	251	240	11	0·7
July	310	− 10	14	314	305	8	0·4
	369	− 14	23	378	382	− 4	0·2
*	431	− 24	33	440	452	− 12	0·4
August	491	− 40	43	494	507	− 13	0·4
	545	− 45	53	544	558	− 14	0·3
*	602	− 70	63	595	621	− 26	0·5
September ...	653	− 79	73	647	692	− 45	0·8
	706	− 87	83	702	781	− 79	1·2
	782	−101	96	777	880	−103	1·5
October	866	−129	137	874	1,000	−126	1·6
	942	−133	206	1,015	1,119	−104	1·2
*	973	−107	308	1,174	1,251	− 77	0·8
November ...	943	− 48	393	1,288	1,344	− 56	0·6
	857	− 12	448	1,317	1,364	− 47	0·5
	719	+ 60	472	1,251	1,303	− 52	0·5
December... ...	601	93	478	1,172	1,165	+ 7	0·0
	449	119	478	1,046	994	52	0·5
*	288	142	478	908	791	117	1·0
January	152	155	478	785	612	173	1·6
	77	165	478	720	484	236	2·0
*	36	172	478	686	400	286	2·4
February	15	178	478	671	378	293	2·5
	10	182	478	669	369	300	2·6
*	4	186	478	668	360	308	2·7

NOTES: The periods marked * are not ten days.
On the average the flood over-tops the incised trough between the end of September and the middle of November.

TABLE 456

COMPARISON OF COMPUTED AND OBSERVED LOSSES
AVERAGE OF TWELVE FLOODS (1946–47 EXCLUDED)

Ten-Day Period	Computed				Corrected Observed Loss	Difference Computed –Observed	Approximate Percentage of Cumulative Discharge at Sobat Head
	Trough Volume	Net Evaporation	Absorption	Total			
May	20	2	0	22	30	− 8	—
	51	2	0	53	62	− 9	—
*	99	2	0	101	99	+ 2	0·4
June	145	2	0	147	142	5	1·0
	200	1	2	203	194	9	0·8
	252	− 2	4	254	248	6	0·4
July	309	− 7	11	313	309	4	0·2
	364	− 11	17	370	372	− 2	0·1
*	418	− 22	27	423	429	− 6	0·2
August	468	− 34	33	467	472	− 5	0·1
	515	− 46	41	510	510	0	0·0
*	562	− 62	52	552	557	− 5	0·1
September	604	− 72	60	592	605	13	0·2
	648	− 83	70	635	664	− 29	0·5
	704	− 97	82	689	735	− 46	0·6
October	763	−115	110	758	818	− 60	0·8
	815	−118	154	851	903	− 52	0·6
*	838	−101	215	952	995	43	0·5
November	813	− 61	268	1,020	1,056	−36	0·4
	739	− 18	300	1,021	1,053	−32	0·3
	613	+ 9	321	943	977	−34	0·3
December	484	43	321	848	840	8	0·1
	339	62	321	722	695	27	0·3
*	206	79	321	606	541	65	0·6
January	106	89	321	516	417	99	0·9
	54	97	321	472	362	110	1·0
*	25	103	321	449	287	162	1·3
February	11	109	321	441	274	167	1·3
	6	113	321	440	269	171	1·3
*	2	117	321	440	264	176	1·3

NOTES: The periods marked * are not ten days.
The average flood over-tops the incised trough from about the beginning of October until the middle of November.

TABLE 457

PREDICTED LOSSES ON THE SOBAT DURING THE TIMELY SEASON
FOR VARIOUS DISCHARGES AT SOBAT HEAD

At Sobat Head		Corresponding Mean Gauges		Surface Areas (km²)		Total Loss (millions)	Loss as Percentage of Discharge
Daily Discharge	Total Discharge	Upper	Lower	Upper	Lower		
10	1,800	7·1	11·0	34	12	46	2·6
20	3,600	8·0	11·7	53	12	65	1·8
30	5,400	8·9	12·3	93	12	105	2·0
40	7,200	9·8	12·9	153	13	166	2·3
50	9,000	10·6	13·5	223	27	250	2·8

SECTION III. THE REGIMES OF THE TRIBUTARIES

Quite apart from their effect on the main Sobat flood these two tributaries of the Sobat present some features of interest which are worth describing in detail. The original account has been modified to include the comments of the Jonglei Investigation Team, which are based on field observations and other additional data.

(I) THE TWALOR

This enters the Sobat from the south just below Nasir. Unfortunately its upper reaches are not shown on the latest 1/100,000 maps; these were compiled from aerial photographs and this area was covered by cloud when the photographs were taken. There is, however, little doubt that the Twalor is connected to the Pibor downstream of the mouth of the Gila. Butcher suspected this in 1939 and suggested that the Twalor took water from the Pibor in years when this was high. The observations made since 1934 of the discharges in both rivers are shown in Table 458 (p. 966), and they confirm this suggestion.

From this table it can be seen that when the combined Pibor and Gila discharges are less than two milliards for the months August to December inclusive, the corresponding total discharge of the Twalor is normally under 100 millions. But when, as in 1934 and 1946, the total Pibor discharge in this period was over three milliards, in spite of the fact that it caused the Gila to flow backwards, then the corresponding recorded Twalor totals were a milliard and two milliards respectively. In the second case its discharge was only recorded till the end of December 1946 although it was then still flowing hard; and its actual total may have been considerably greater. It is probable that this khor contributed to the excess discharges at Hillet Doleib in January 1947 which have already been mentioned.

(II) THE WAKAU

GENERAL

The hydrology of the Wakau is more complex than that of the Twalor, and it presents some very interesting features for which only a tentative explanation can at present be given. Their main interest is the light which the behaviour of this khor appears to throw on conditions in the Machar Marshes, for which virtually no direct evidence is available. One of the striking and unusual features about the discharges of this khor is the fact that it both takes from and, later, discharges into the Sobat a considerable quantity of water. The amount taken averages about 150 millions, whereas no other tributary takes more that 40 millions as a rule during the rising stage. In Table 459 (p. 967) are shown the monthly negative discharges of the Wakau in June, July, and August in different years, during the rising stage of the Sobat. This table also shows the mean Nasir gauge-readings for the same periods, and the relationship between the two is shown also in Fig. K13. From this it is clear that while the Sobat is rising the Wakau begins to act as a simple spill-channel as soon as Nasir gauge reads about 7·5; and that its gauge/discharge curve is a fairly smooth and constant one. By the end of August, however, though the Sobat continues to rise, this relationship no longer holds good: the flow into the Wakau diminishes and eventually changes to a flow out of it into the Sobat some time between the beginning of September and the end of October. Details of this reversal are given in Table 460 (p. 967). It is noticeable from this that although the date of this reversal of flow varies from year to year, the level of the Sobat at which it occurs does not vary very much, since it occurs as a rule within a few centimetres of Nasir gauge-reading 10·4. It bears no relationship to the date of the maximum reading at Nasir gauge.

Up to this point the total discharge from the Sobat into the Wakau normally amounts to between 150 and 200 millions, as shown in Table 460. From then until the end of the year there is normally an uninterrupted discharge from the khor into the Sobat, as shown in Table 461 (p. 967). This discharge is fairly steady during the 'peak' of the flood (which may be defined as the part over 10·4 on Nasir gauge), but as the river drops below this gauge-reading it increases to a brief maximum, and indications are that it ceases by the time Nasir gauge is down to about 7·0.

Because the discharge measurements nearly always stop at the end of December, whatever the state of the river, the total amount of the Wakau discharge after the peak of the flood is only recorded in low years; but it appears likely that it amounts on the average to between 150 and 200 millions, or to much the same as the total discharge out of the river into the khor during the rise. During the peak of the flood the total discharge varies considerably from one year to another. On the whole it tends to be large when the river is high, and small when it is low; but this variation is due rather to the varying length of the peak than to any great variation in the rate of discharge during it. The table shows that in 1946, which was a record high year on the Sobat, the inflow from the Wakau during the peak was not particularly large; this fact will be referred to again below.

MAIN DEDUCTIONS

From these three tables certain definite conclusions were originally drawn, and they can now be amplified from data gathered by the Jonglei Investigation Team. In the first place it is clear that in order to cause this considerable initial outflow from the Sobat there must be a large area of ground, or length of channel, to the north of Nasir where the water surface lies below that of the Sobat during the first part of its rise. Since some 150 millions is spilt into this area annually via the Wakau while the Sobat rises three metres, the area can scarcely be less than 50 sq. km. In fact, some of the water probably spreads out much more than this, so that the area flooded from the Wakau may easily exceed a hundred square kilometres.

Secondly, since there is a reversal of flow and the Wakau begins to discharge into the Sobat as soon as Nasir gauge reads 10·4, it follows that at this stage the water-level in part of this area north of Nasir must have risen by at least three metres. The zero of Nasir gauge is at R.L. 386·0, so the levels of this water surface when flow in the Wakau begins and when it is reversed must be below 393·5 and above 396·4 respectively. Moreover, since flow into the river normally continues throughout the peak of the flood, this water surface must continue to rise in sympathy with that in the Sobat and so at the top of the flood be at a level equal to or above 386·0 plus the maximum reading on the Nasir gauge for the year. Thus during the rising stage of a high flood there may be a rise of about four metres in the level of the water surface over part of the area north east of Nasir.

Thirdly, since the discharge of the Wakau appears to cease when Nasir gauge has fallen below about 7·0, by this time the outside water surface must have fallen to below that of the Sobat. From these conclusions it is definite that there must be to the north of Nasir a separate water channel in which the water-level fluctuates more or less in sympathy with that of the main Sobat channel, but through a greater range. This much follows logically from the observations given in Tables 458 and 459. From the data collected by the Jonglei Investigation Team, which is included in the description on the Machar Marshes (see p. 979) there can be little doubt that this channel is that of the Machar-Tierbor system, which runs parallel to the Sobat about 30 km. away on the north side, from the Khor Machar right through to the Khor Wol; and that its fluctuations are caused by the passage down it of part of the spill from the north bank of the Baro.

Behaviour during 1946 Flood

A striking confirmation of this theory of the behaviour of the water in the Khor Tierbor can be obtained from a study of the 1946 records. In that year, though the Baro was high, the Pibor was also very high and its flood was prolonged after that of the Baro had passed, so that the Sobat was kept unusually high until after the end of December. As shown in Table 461, in the last ten days of December Nasir gauge averaged 10·55, instead of the normal 7·99. This high Sobat was accompanied by second reversal of flow in the Wakau, which took 10 millions out of the river during the last 20 days of December. Unfortunately the observations then stopped, so that there is no record of the discharge in January 1947 ; but it is clear that by the end of December 1946 the level north-east of Nasir had dropped below that in the Sobat. This is what would be expected if it were due to Baro spill, so long as the Sobat was still being kept high by the discharge of the Pibor. Moreover, as already mentioned, the total inflow from the Wakau during the peak of the flood was not above average in this year in spite of the very high total of Baro spill.

There are therefore good grounds for supposing that part at least of the spill from the Baro follows the western branch of the Khor Machar and travels down the Khor Tierbor parallel to the Sobat. It seems likely that all the spill west of Adura Tail will follow this route and, as may be seen from Table 464 (p. 973) in the description of the Machar Marshes, this would amount annually to at least a milliard on the average. Some 400 millions of this return via the Wakau to the Sobat during and after the peak of its flood. The remainder may be supposed to follow westwards the 150–200 millions which the Wakau had spilt out of the Sobat during the early stage of its rise, so that in all rather less than a milliard may be supposed to flow annually into the Tierbor marsh system west of Nasir from channels starting east of it. This quantity should be quite sufficient to flood and maintain these marshes without any substantial additions from spill downstream of Nasir.

(III) OTHER TRIBUTARIES

Proportions of High Losses and Gains Carried by Northern Tributaries

There are a number of north bank tributaries downstream of Nasir, but no cross-sections or discharges of them appear to have been measured. It has been suggested that these also have régimes similar to that of the Wakau, and the local inhabitants believe that the western part of the Tierbor system is flooded by Sobat spill passing through these tributaries. In the author's opinion any exchanges between the Tierbor and Sobat systems through these western tributaries are inconsiderable compared with the quantities of water which each receives from other sources—in the Sobat swamps and flanking plain from its main channel, and in the Tierbor system from Baro spill and from the Wakau. It has been shown in this analysis that in high floods each of these quantities may exceed a milliard, and it has been considered that less than a hundred millions is exchanged between them. Although hydrologically this is a relatively small proportion, it is of course sufficient to fill up all the channels connecting the two systems, and so account for the local view that the Tierbor system is supplied directly from the Sobat, since they may in fact be connected during the height of the flood.

This question of whether these tributaries are merely filled and emptied by the Sobat, or do pass appreciable quantities of water between it and the Tierbor system, is of some importance in the analysis of Sobat hydrology. Hitherto in this analysis it has been assumed that the large losses and subsequent gains observed in floods above average height are due almost entirely to the inundation and subsequent drainage of areas above and immediately flanking the permanent swamps which border its main channel and which form its main flood-plain. There are, however, two other possible mechanisms by which they could be caused, and these must be considered separately and in some detail to show why they have been rejected. These supposed mechanisms may be summarized as follows :

(a) The losses in the rising stage are caused by true spill, through channels in the north bank, over a plain sloping away from the river. The subsequent gains would then be supposedly due to a separate body of water arriving from the south, and flowing in through khors such as the Nyanding and Fullus.

(b) The losses and gains both take place through the northern channels, which communicate with the Tierbor system, in which the water-level is supposed to be initially below, and subsequently above, that in the Sobat.

Two noticeable features of these losses and gains in high floods are : first the change from loss to gain is very well marked, so long as the discharges of all recorded khors are allowed for ; and secondly it follows very soon after the river level begins to drop. These features are brought out in Table 462 (p. 968). This shows for each high flood the ten-day period in which the mean gauge on the upper Sobat (the mean of Sobat Head, Nasir, and Abwong) begins to drop, and the period in which the net losses (i.e. corrected for all observed tributary discharges) first turn to gains. It also shows the amounts of net loss and net gain during the 30 days preceding and following the change from loss to gain.

Arguments against Supposed Northern Spill and Southern Inflow

If the main cause of these large losses and gains is spill to the north, followed by subsequent inflow from the south, one would expect the change not to occur for some time after the first drop in level, because as long as the river is above the floors of the spill-channels it will continue to lose water through them, and the gains by inflow would have to counterbalance this in order to produce a net gain. Thus to produce the net gains shown the actual inflow through the southern tributaries would have to be of the order of half a milliard during the first month after the beginning of the fall. Moreover it would have to start at this time, and start suddenly, in order to produce such a sudden and large change in the observed net losses.

The available records of inflow from the southern plain do not correspond at all with this. As a result of their experience the Egyptian Irrigation Department have only found it worth while to measure the discharges of the Twalor, Nyanding, and Fullus, and of these only the first is measured every year. Study of the discharges of the other two shows that in most years they take a few millions during the rising stage and return it when the river drops, and these amounts may be taken as representing the volumes of Sobat water which they store in their valleys at high river. In a few years, however, there is superimposed on this a much larger discharge into the Sobat, which starts as early as July and reaches a peak in September or October. In December 1947 the Nyanding reached a maximum of 75 millions for the month, but in general, as with the White Nile tributaries the picture is of a flush of water arriving in August, September, or October, and not in November when the river starts to fall. These features are shown in Table 463 (p. 968) which summarizes the major recorded discharges of these two khors. There may be others entering from the south bank whose discharges the Egyptians have overlooked, but if so their behaviour would presumably be similar.

Arguments against Supposed Large Exchanges with Machar Marshes

The second suggested cause of these large losses and subsequent gains is an exchange of water with the marshes to the north, or with the Khor Tierbor, taking place over the bank or through the khors downstream of Nasir. This would be a continuation of the exchange which we do know takes place through the Khor Wakau, and it would presumably have similar characteristics. These have already been described, and it has been noted that the reversal of flow takes place on an average 45 days *before* the Sobat water-level at Nasir first starts to fall. Moreover the determining factor seems to be not so much the date of this first fall as the level of Nasir gauge when the reversal of flow takes place. On occasions the reversal of flow takes place as much as two months before the beginning of the fall and there is nothing like the close correspondence which is found in Table 462 (p. 968). The rate of flow both before and after the reversal is fairly regular, and averages about a hundred millions per month.

The passage of the flood wave down the Sobat would be a good deal more rapid than it would be down the Tierbor, so that it is possible that opposite Loing the two waves would on the average approximately coincide. Thus, on the average a heavy exchange of water through the Khor Loing could cause the sudden change from losses to gains at the time when it is observed. On the other hand, the longer the wave has to go the less likely it is to keep in time with the Sobat flood wave in individual years, and we should expect there to be marked differences between the two periods when losses turn to gains and when the Sobat level first begins to fall. Moreover the discharges required would be very large, about three times those observed in the Wakau; and it is difficult to believe that such large discharges could have been overlooked by the Egyptian Irrigation Department, who have never bothered to measure the discharge of the Khor Loing at all. On the air survey maps also it appears as very much smaller than the Wakau and Twalor, whose discharges we know.

CONCLUSIONS

The two main objections to these two supposed causes of large losses and gains in high floods are therefore much the same in both cases, namely that it is difficult to see how in every year they could have their effect so close to the time when the losses turn to gains ; and that the available records do not indicate discharges in the khors concerned of anything like the volume required. The hypothesis of flooding and subsequent draining of a wide area sloping gently towards the river and immediately adjacent to it presents neither of these difficulties. The coincidence in timing between the beginning of the fall and the change of losses to gains is inherent in the theory, and the fact that the large discharges required have not been observed is explained by their distribution over a considerable length of bank. In order to obtain figures for a mean slope it was necessary to assume that it was the same everywhere, and it was more reasonable to assume that it was the same on both banks. In fact such field observations as there are indicate that while the southern bank is a flat plain, on the north the Sobat appears to be bounded by a higher ridge, through which are cut the khors connecting with the marshes to the north. It seems probable therefore that either most of the flooding and return takes place over the southern plain (which would then have half the slope deduced in Section I, p. 920) or that only part takes place to the south and that on the north there are a number of basins, sloping towards the river, and filled and emptied by these khors. But what does seem to be firmly established is that although there are connections between the Tierbor and the Sobat, the amounts of water exchanged between them, except through the Wakau, are in all normal years relatively small, probably not exceeding 100 millions. Whatever flooding there is in the headwaters of the Khor Wol, it apparently does not come from the Sobat west of Nasir, but first from the Wakau and then from the Baro, both floods travelling via the Khor Tierbor.

TABLE 458

COMPARISON OF THE DISCHARGES IN THE PIBOR AND TWALOR

Year	Pibor U.S. Gila Mouth	Gila	Pibor D.S. Gila Mouth	Twalor	Remarks
	(1)	(2)	(3)	(4)	
1934	3,217	−115	3,102	898	—
1935	1,471	708	2,179	677	—
1936	566	999	1,565	(24)	Twalor not measured in November and December
1937	1,328	617	1,945	60	—
1938	Incomplete observations but both Pibor and Twalor high				
1939	628	765	1,393	83	—
1941	1,186	696	1,882	114	—
1942	2,163	50	2,213	202	—
1943	(591)	(654)	(1,245)	54	Gila and Pibor not measured in December
1944	(782)	(594)	(1,376)	−9	Gila and Pibor not measured in December
1945	No observations			761	—
1946	3,365	−354	3,011	2,238	—
1947	3,034	−263	2,771	1,366	—

NOTES: All discharges are in millions of cubic metres.
The first two and the last columns are taken from *The Nile Basin*, Vol. IV and Supplements, or privately furnished data. The third column is the algebraic sum of the first two.

TABLE 459

KHOR WAKAU DISCHARGES AND NASIR GAUGE BEFORE THE REVERSAL OF FLOW

Year	June		July		August	
	Wakau Discharge	Nasir Gauge	Wakau Discharge	Nasir Gauge	Wakau Discharge	Nasir Gauge
1934	—	—	−36	8·98	−66	9·90
1935	−32	8·66	−92	9·65	−58	10·10
1936	Not recorded					
1937	−8	7·98	−11	8·88	−71	9·93
1938	−11	7·80	−40	9·18	−77	9·81
1939	−23	8·29	−48	9·27	−59	9·76
1941	−16	8·46	−77	9·49	−82	9·96
1942	−10	8·32	−48	9·35	−43	10·02
1943	—	—	−27	8·67	−74	9·52
1944	−11	9·38	−37	9·11	−84	9·63
1945	−5	7·83	−32	8·96	−99	9·87
1946	—	—	−30	8·86	−100	9·89
1947	−17	8·05	−47	9·22	−92	10·02

TABLE 460

THE REVERSAL OF FLOW IN THE KHOR WAKAU

Year	Date of the Reversal	Corresponding Nasir Gauge	Difference from Mean	Date of Maximum Nasir Gauge	Total Negative Discharge
1934	August 31	10·30	−0·08	November 5	−101
1935	September 5	10·40	+0·02	November 5	−201
1936	September 15	10·18	−0·20	November 5	(−123)
1937	September 15	10·44	+0·06	October 5	(−107)
1938	September 10	10·32	−0·06	November 15	−138
1939	September 15	10·19	−0·19	November 5	−143
1941	October 5	10·38	0·00	November 15	−210
1942	August 31	10·30	−0·08	October 25	−197
1943	October 20	10·33	−0·05	November 5	−209
1944	October 5	10·28	−0·10	October 25	−197
1945	September 20	10·68	+0·30	October 25	−163
1946	September 10	10·64	+0·26	October 25	−151
1947	September 5	10·55	+0·17	October 25	−156
Means	September 15	10·38	0·12	November 1	−153

TABLE 461

DISCHARGES IN THE KHOR WAKAU AND GAUGE-READINGS AT NASIR DURING AND AFTER THE PEAK OF THE FLOOD

Year	Total Negative Discharge	Total during Peak	Total during Fall	Final net Discharge	Length of Peak	Maximum Nasir Gauge	Last Ten Days of Observed Wakau Discharge		
							Ten-Day Period	Observed Discharge	Nasir Gauge
	millions	millions	millions	millions	days				
1934	−101	301	(158)	(358)	90	10·82	Jan. (1)	31	7·81
1935	−201	247	(154)	(200)	85	10·72	Dec. (3)	48	8·05
1936	(−123)	88	(217)	(182)	35	10·46	Dec. (3)	7	7·60
1937	(−107)	129	(189)	(211)	70	10·64	Dec. (3)	35	7·33
1938	−138	incomplete records			110	10·96	Nov. (3)	32	10·93
1939	−143	163	(163)	(183)	55	10·56	Dec. (3)	1	6·64
1941	−210	106	(214)	(110)	65	10·67	Dec. (3)	88	9·16
1942	−197	103	101	7	80	10·81	Dec. (3)	29	7·10
1943	−209	128	(177)	(96)	30	10·46	Dec. (2)	63	7·96
1944	−197	22	184	9	10	10·39	Dec. (3)	0	7·06
1945	−163	279	(100)	(216)	100	10·86	Dec. (3)	80	9·70
1946	−151	179	(−10)	(18)	(125)	11·30	Dec. (3)	−3	10·55
1947	−156	177	(41)	(62)	110	11·03	Dec. (3)	41	10·13

Notes: Discharges shown in brackets were obtained from incomplete records. In most years observations ceased at the end of December, when the Wakau was still flowing.
The length of the peak is taken as the time during which Nasir gauge is above 10·38 it is given to the nearest five days only.

TABLE 462

LOSSES AND GAINS AT THE PEAK OF HIGH FLOODS

Year	First Ten-Day Period of Fall of Mean Gauge	First Ten-Day Period of Net Gain	Difference (days)	Net Loss in preceding 30 Days (millions)	Net gain in following 30 Days (millions)
1934	November (2)	November (3)	10	412	349
1935	November (1)	November (3)	20	336	327
1937	November (1)	October (3)	−10	45	168
1938	November (3)	November (3)	0	355	No Twalor records
1942	November (1)	November (1)	0	225	326
1945	November (2)	December (1)	20	234	529
1946	November (2)	November (3)*	10	212	632
1947	November (3)	November (3)	0	510	303
MEANS	November 19	November 25	6	282	362

* There was also a change from net loss to net gain in the third ten-day period of August.

TABLE 463

LARGE RECORDED DISCHARGES IN THE SOUTHERN TRIBUTARIES

Month	TOTAL MONTHLY DISCHARGES (millions)		
	Fullus 1933–34	Fullus 1938	Nyanding 1947
July	18	—	5
August	104	—	24
September	107	2	45
October	62	29	41
November	50	14	33
December	45	4	75
January	31	17	not
February	7	4	re-
March	6	0	corded
TOTALS	430	70	223

NOTES AND REFERENCES

(1) 'Some Characteristics of the White Nile and Sobat Flood Plains', *Nature*, Vol. 164 (1949), p. 926.

(2) *The Veveno-Pibor Scheme*, Egyptian Ministry of Public Works, Cairo, 1932. Plates 48–52.

(3) They were taken from Volume III and Supplements of *The Nile Basin* brought up to date by the E.I.D. to 1948.

(4) In a recent private communication Dr. Hurst considered that they might be as much as 5% in a single year. See note (2) in Chapter 2 of this volume.

CHAPTER 4. THE MACHAR MARSHES

1. INTRODUCTION

Anyone who visits Malakal in the dry season and sees from the motor roads the apparently endless expanses of dry, yellow grass, with only occasional parched acacia forests, will find it hard to believe that within 100 kilometres of it, inland and away from the rivers, there lies a vast area of swamp measuring at times some 20,000 sq. km. From time to time, when the Baro and local rainfall are higher than normal, the visitor is reminded of the existence of these swamps because the abundance of water forces its way north-west through grass-choked channels to the White Nile and cuts the motor road running northwards from Malakal.

With the prospect of losses of riverain grazing on the White Nile resulting from the Equatorial Nile Project, it was natural that early in the investigation our attention should have been drawn to these swamps, since their hydrology is independent of the White Nile and will not be affected by changes on it. Mention of the Machar Marshes was made in the Team's *First Interim Report*, which stressed the importance of a hydrological survey. In the *Second Interim Report* their boundaries were described; the hydrology of the Khor Machar, the major spill-channel from the Baro, was explained, and it was estimated that a total of 4 milliards of water reached the swamps in a normal year from the Baro and from the eastern torrents. It was also suggested that the swamps might be used for alternative livelihood on a large scale; major engineering works would be needed, including canalization of the Machar, Yabus, and Daga, banking of the Baro to reduce spill, and the construction of a dam and reservoir in the Ethiopian hills to control floods. At that time little was known about the marshes. They had been seen from the air in 1930, and, although the area had not been mapped, air photographs taken by the American Air Force in the winter of 1944–45 had reached Khartoum.

In the *Third Interim Report* the progress in the production of maps was recorded. The survey member had made sufficient astronomical fixes to control the maps, had circumnavigated the area while doing so, and had measured the channels of some twenty streams draining from the hilly catchment to the swamps. Some topographical features were made clearer as the result of field reconnaissances.

Because this preliminary work had been done, the Team was able to start its investigations in 1949–50 with a complete set of air survey maps. During our investigations we erected gauges on the Yabus and Daga, and have accumulated nearly three years' records on which to base a revised estimate of the contribution of the eastern torrents to the hydrology of the marshes. The Khor Adar was surveyed (*Progress Report* 1949–50) from its mouth south of Melut for a distance of 90 km. (71·5 km. in a straight line). A field reconnaissance on foot increased our knowledge of the maze of inland watercourses which go to make up the lower and upper Khor Wol system, related them to those shown on the air survey maps, and clarified the connection between the Wol and the Machar Marshes.

Other reconnaissances on foot covered a part of the northern fringe of the swamps from the end of the survey line for two days' march to Khor Daldal, the south-western approach by way of Khor Weikirr to Toich Malau, and the north-eastern swamps by the Yabus to Chidu; and the Assistant District Commissioner, Eastern Nuer, supplied a full account of a trek from Nasir to Buth some 110 km. north of the Sobat. We also reconnoitred the swamps from the air on 16th and 17th December 1949, and again on 7th April 1950. The vast area of swamp and open water seen then showed that it would have been impossible to cross the swamps on foot from north to south, as we had planned to do.

In May 1953 we received the draft of the very detailed attempt by Mr. J. W. Wright of the Survey Department to analyse the flood cycle of the River Sobat (Chapter 3 of this volume). His analysis, which has already been drawn on for the description of the River Sobat itself, is also relevant to the study of the Machar Marshes because it contains certain deductions about their relationship with the Sobat (as distinct from the Baro), and because it includes a detailed account of the curious and significant régime of the Khor Wakau. From the sum of this information, it has proved possible to draw a very much more comprehensive, detailed, and reliable picture of the marshes than ever before. The account included in Volume VIII of *The Nile Basin* comprises only three pages and does not add much to the information given in the earlier Jonglei reports, except to assess in more detail the hydrological balance of the area as a whole. Although our present description is a good deal more detailed than this, we have had neither the time nor the resources to do more than make a preliminary survey, and this has by no means reached the stage at which an engineering project could be designed in detail. Some suggestions for methods of drying up the swamps are made, however, and lines for future investigation are indicated.

2. HYDROLOGY

The information available about the periphery of this area is a good deal more detailed and reliable than the little we have been able to gather about the swamps themselves. For this reason we can describe how the water gets into the swamp, and how some of it gets away, and then deduce what happens to it in the swamps themselves. We therefore consider first all possible sources of supply, of which there are four; the first two are considerable, the third by far the greatest, and the fourth the least important.

WATER SUPPLIES

The four possible sources of water and their approximate annual total contributions are:

(i) Spill from the north bank of the River Baro, especially through the Khor Machar: 2·8 milliards.

(ii) Direct drainage from the Ethiopian plateau, via torrents such as the Yabus and Daga: 1·8 milliards.

(iii) Direct rainfall: 15 milliards.

(iv) Spill from the River Sobat downstream of the junction of the Pibor and the Baro, whose magnitude is as yet undetermined.

SPILL FROM THE BARO

The hydrology of the Baro has been described very fully on pages 7–24 of *The Nile Basin*, Volume VIII, and we may extract from this what we need, i.e. the amount and timing of the contribution to the Machar Marshes. We must make it clear that we are concerned only with losses downstream of the Jokau, since any spill upstream of the Jokau would have to cross it, and with those from the Baro proper and not from the southern branch called the Adura, since any spill from the Adura would have to cross the Baro before it could reach the swamps. Table 464 below shows the simple and approximate calculations used to get details of this contribution. There are four items: (1) the discharge of the Jokau, (2) the discharge of the Machar, (3) the differences between Baro discharges at Adura Head and Adura Tail after allowing for those of the Khor Machar, and (4) the differences between the discharges at Adura Tail and Baro mouth. All of the discharge of the first two enters the marsh; the same applies to ' most ' of the third, and ' more than half ' of the last. These proportions shown in inverted commas are quoted from *The Nile Basin*, Volume VIII, page 24, and are taken as ¾ and ⅗ respectively. Strictly speaking one should allow a little less in the third item owing to the fact that the Jokau cuts off all spill upstream of it, but this may be counterbalanced by spill from the Jokau itself. No data are available for this spill, but the equality of the discharges in the Jokau in August, September, and October indicates its existence. These proportions, as shown in the second part of the table, give an average annual total of 2·82 milliards, which agrees well enough with the estimate (on p. 25 of *The Nile Basin*, Vol. VIII) of ' 2½ to 3 milliards '.

From this table we can see that on the average any appreciable contribution does not begin till July, when the greater part comes from the section upstream of Adura Tail, under half of this being through the Khor Machar. In August the reach between Adura Tail and Baro mouth contributes one-fifth of the total (which is nearly double that of July) and by October it contributes nearly half. The total contribution in November from all four sources has dwindled to its value in June. It is important to describe this picture in some detail because we shall, below, study the effects of what is supposed to be the arrival of this water north of Nasir in September or October.

The total annual spill from the Baro obtained by taking the difference between Gambela and Baro mouth discharges may vary from just over a milliard to five or six milliards (see Table 421, p. 907), giving a maximum variation on either side of the normal equal to two-thirds of it. Assuming similar proportions for this part of the spill we get a possible variation from the normal annual total of just under 2 milliards.

TABLE 464

SPILL ON THE BARO

In millions of cubic metres

(a) TOTAL LOSSES DOWNSTREAM ADURA HEAD

Section of River	June	July	August	September	October	November	Total
1. K. Jokau[1]	10	40	50	50	50	20	220
2. K. Machar[2]	80	140	160	150	140	70	740
3. Between Adura Head and Tail (less K. Machar discharge)[3] ...	30	230	380	450	290	−60	1,320
4. Between Adura Tail and Baro Mouth[4]	10	10	190	430	510	170	1,320
Totals	130	420	780	1,080	990	200	3,600

(b) ESTIMATED CONTRIBUTIONS TO THE MACHAR MARSHES BY SPILL FROM THE BARO

Section of River	June	July	August	September	October	November	Total
All of K. Jokau	10	40	50	50	50	20	220
All of K. Machar	80	140	160	150	140	70	740
¾ of 3. (Upstream Adura Tail) ...	20	180	300	330	210	0	1,040
⅔ of 4. (Downstream Adura Tail)...	10	10	120	280	340	60	820
Totals	120	370	630	810	740	150	2,820

NOTES: (1) Calculated from table of means on page 17 of *The Nile Basin*, Vol. VIII.
(2) Calculated from table of means on page 18 of *The Nile Basin*, Vol. VIII.
(3) From Table 7 of *The Nile Basin*, Vol. VIII, after deducting (2).
(4) Directly from Table 10 of *The Nile Basin*, Vol. VIII.

THE EASTERN TORRENTS

The eastern torrents are those which debouch from the Ethiopian highlands in the east into the Machar Marshes. Our predecessors estimated their run-off as roughly 2·7 milliards from an effective catchment of 5,000 sq. km., which corresponds to the area on the Yabus and Daga upstream of the gauging points. When all the contributory khors, such as Khors Ahmar, Tombak, Lau, and minors, are included the gross effective catchment is 10,000 sq. km. and the latest estimate of run-off amounts to 1·75 milliards in a normal year. In *The Nile Basin* (Vol. VIII, p. 27) the estimated total run-off is given as 2·07 milliards. The details of our estimate are given in Table 465 below; it is based mainly on the records of gauges on the Yabus at Yabus Bridge and Khor Daga at Daga Post over a period of nearly three years. There is still a great deal of basic data wanting, and approximations have had to be made in arriving at this latest estimate. The percentage of run-off, 15%, compares reasonably with the 4% to 7% of the south-western area, where the slopes are much flatter, the country forested, and the upper reaches overgrown with swamp grasses. In *The Nile Basin*, Vol. VIII, a percentage run-off of 14% has been used.

Assuming that rainfall over the whole of the catchment areas varies by as much as 10% from the normal (though standard deviations of over 20% are the rule at individual stations) and that this is reflected in their contribution, it will be seen that this source of supply may vary from the normal by about 0·2 milliards. Some details of the main torrents are given below in Table 465.

A more descriptive account of the eastern torrents has been given in Volume I (pp. 31–2).

TABLE 465

THE EASTERN TORRENTS—NORTHERN AREA
ESTIMATE OF RUN-OFF

Name of Channel	Effective Catchment Area sq.km.	Approx. Average Annual Rainfall mm.[1]	Estimated Run-off	
			milliards	%[2]
Khor Ahmar	630	1,100	0·104	15·0
Khor Tombak	1,320	1,100	0·217	15·0
River Yabus Upstream Gauge ...	3,000	1,200	0·400[3]	11·1
Total	4,010	1,200	0·535	11·1
Khor Daga Upstream Gauge ...	2,000	1,200	0·450[4]	18·8
Total	2,940	1,200	0·660	18·8
Khor Lau	620	1,200	0·111	15·0
Others	780	1,000	0·117	15·0
Grand Total	10,300	1,130	1·744	15·0

NOTES: (1) Rainfall estimated from *The Nile Basin*, Vol. VI, plus consideration of the following average annual figures:

	mm.		mm.
Kurmuk	941	Saiyo	1,286
Ghali	872	Bure	1,396
Doro	807	Gore	2,029
Gambela	1,290		

(2) Run-off percentage estimated at 15%, being the average of Yabus and Daga.
(3) Two years' gauge-readings at Yabus Bridge. Provisional gauge-discharge curve based on two current meter and two float measurements.
(4) Gauge-readings at Daga Post from April 1950 to May 1952. Provisional gauge-discharge curve calculated from section and slope.

RAINFALL

There are no rainfall gauges actually in the swamp, but Table 466 shows the annual totals of the last few years at seven stations round it (see Map 3), two being on the Sobat, two on the White Nile, and three on the eastern side of the swamp. These give a long-term average of just under 800 mm., with a maximum variation from the normal in individual years of 100 mm. It is noticeable from this table that the five-year average for 1940–44 (though the records are incomplete) is less than that of the five years immediately following by over 100 mm. If we take the area lying between the other sources of supply and the drainage exits as 20,000 sq. km. (not all of which is necessarily permanent swamp) we see that rainfall contributes every year something of the order of 15 milliards, and that its annual variation from this normal may amount to as much as a milliard and a half. Thus rain falling directly on to the area contributes three times as much as all other sources of supply put together, but the possible variation in this contribution is roughly equal to the sum of those in the others. It should be noted that in most years the variations will all tend to be in the same direction.

TABLE 466

RAINFALL ON THE MACHAR MARSHES

In mm. per year

Year	Doro	Ghali	Nasir	Abwong	Malakal	Abaiat	Melut	Mean
1940	—	—	531	696	725	—	444	599
1941	—	—	755	839	825	—	520	735
1942	—	—	880	681	707	—	652	730
1943	—	—	685	800	569	—	583	659
1944	741	912	710	835	731	725	683	762
							Average	697
1945	710	973	789	923	899	1,013	792	871
1946	926	871	932	703	945	1,000	791	881
1947	867	959	742	834	744	735	747	804
1948	745	734	726	856	1,032	647	607	764
1949	757	990	619	879	1,176	759	651	833
							Average	830
1950	949	704	1,165	917	775	721	403	805
1951	?	693	756	873	793	667	533	719
1952	?	(1,045)	658	?	459	(640)	(550)	(670)
							Average	731
Annual ...	807	872	810	755	832	811	626	788 (all 7)
Average Rainfall ...	—	—	810	755	832	—	626	756 (4 only)

Malakal Maximum Gauge-Readings—Normal 12.30 m.
In metres

1940	11·94	1945	12·37
1941	12·19	1946	12·92
1942	12·38	1947	12·49
1943	12·17	1948	12·40
1944	12·24	1949	12·62
		1950	12·59
Average	12·18		
		Average	12·56
1951	11·99	1952	12·08

SPILL FROM THE SOBAT WEST OF THE BARO-PIBOR CONFLUENCE

The three previous sources of supply are undoubtedly large. Spill from the Sobat, west of the Baro-Pibor confluence, on the other hand is undoubtedly small, and in any case can only affect the south-westerly part of the swamps on the line of Khor Machar, the upper Wakau, Khors Tierbor, Malual, and Weikirr, to the Wol. The latter system stands out clearly on the map (Fig. K 15), almost paralleling the Sobat throughout its length. It has connections with the Sobat via Khors Wakau, Nyaiyin, Mairik, Loing, and Banglai. The Wakau is the largest and is the only one to have been gauged. The measurements show that on a rising flood water travels from the Sobat to the Machar (0·150 milliard), but that on a falling flood more water returns to the Sobat than ever left it (0·400 milliard). It is possible that similar interchanges occur in the other khors farther west, and in fact this two-way flow has been observed. The quantities of water involved, however, are not large compared with the other sources of supply. For instance if we assume that the channels of the Wol system total 500 km. in length, average 200 m. in width, and hold water to an average depth of one metre, then it would take 0.100 milliard of water to fill the system. This amount, while negligible in comparison with the Sobat discharge, is quite enough to have a big effect on the Wol system, the grasses growing in it, and the swamps surrounding it. Wright, in his examination of the Sobat flood, concludes that the spill from the Sobat west of Nasir is negligible. He puts forward the theory that the Sobat, from the Baro-Pibor confluence to its mouth, is a self-contained river in a normal year. When the flood is higher than normal, the losses increase rapidly while the river is rising. This is followed by a change to gains, correspondingly large, when the river falls. He concludes that the Sobat and its flood-plain trough are incised in a plain sloping gently towards the river. This is certainly true of the south bank, though the direction of watercourses and differences in level between the Sobat and the White Nile indicate that the slopes on the north bank are away from the river. Future investigators will be able to clarify this point by taking lines of levels, and to check the losses by spill from the Sobat by gauging more of the smaller channels west of Nasir.

LOSSES FROM THE SWAMP

There are two possible ways in which water may drain out of the area:

(i) Drainage to the White Nile.
(ii) Drainage to the Sobat.

Let us consider each of these in turn.

DRAINAGE TO THE WHITE NILE

In considering this we have for data our own measurements of the slope and cross-sections of the Khor Adar, and a field study of the Khor Wol system; we have also a few Egyptian observations of the discharge of the Adar; and finally we have the deductions, confirmed by reliable local reports, of the inflow into the White Nile in 1947 contained in the analysis of its flood.

The Khor Adar

From our experiences in the Aliab Valley during a year of heavy flooding, it appeared to us that one of the obvious and most important things to find out about a swamp was how it could be drained. To that end a close survey of the Khor Adar channel was made during the winter of 1949–50, and we have plotted and tabulated the following information obtained during the survey:

(1) Plan of the Khor Adar survey (Fig. K 23).
(2) Longitudinal section of the survey's base line (Fig. K 24).
(3) 8 cross-sections of the Khor Adar (Figs. K 25 and K 26).
(4) Typical cross-sections of the Khor Adar channel (Fig. K 27).
(5) Hydraulic details of the Khor Adar channel (Fig. K 28 and Table 467, p. 976).
(6) Hydraulic details of the Khor Adar flood-plain (Table 468, p. 977).

After referring to these diagrams and tables the reader will notice the striking resemblance of the Khor Adar to the White Nile, and, in fact, to many rivers and watercourses in the Flood Region of the Southern Sudan. The features to note are the relatively narrow deep-water channel, 2·5 m. deep by 100 m. wide, the much wider flood-plain which averages 830 m. in width and which is only covered at the highest levels, and the definite deltaic banks which contain the flood-plain with lower ground outside them. During his trek from Nasir to Buth, Mr. B. H. Dening (then Assistant District Commissioner, Eastern Nuer), noted a similar formation in a large well-defined watercourse which he crossed 13 km. south of Buth. He may have seen one of the southern branches of the Khor Adar.

The longitudinal section of the deep-water channel (Fig. K 28) of the Khor Adar shows the average slope to be 4.5 cm/km. in the upper portion, whereas the lower 33 km. is flatter and is obviously affected by backwater from the White Nile. In fact in January 1950 when the Nile was high there was only 35 cm. difference in water-level between the Malakal-Paloich road-bridge and the river over a distance of 37 km., whereas two months later when the White Nile level had dropped 2·05 m. the level at the road-bridge fell only 0·55 m. The hydraulic slope through the grass-choked khor near the river between it and Section No. 2 was about 9·5 cm/km., with a water width of 80 m. and a depth of 1·5 m. A float measurement of the discharge at the Malakal-Paloich road-bridge in January 1950 gave a figure of 3 cumecs. Assuming that it had fallen to 2 cumecs in March 1950, we have computed the value of ' n ' in Manning's Formula to be 0·12 for the grass-choked deep-water channel.

The capacity of the Khor Adar if cleared of grasses can be calculated theoretically if we make the following assumptions:

(i) The channel section is parabolic (see Fig. K 27).
(ii) The top width when full is 100 m.
(iii) The water depth when full is 2·5 m.
(iv) The value of ' n ' in Manning's Formula is 0·04 for the channel cleared of grass ($\frac{l}{h} = 25$).
(v) The water slope is 4·5 cm/km.

On these assumptions the discharge is estimated to be 39·2 cumecs. If we assume that the water depth is 3·25 m. when the flood-plain is covered to a depth of 0·75 m., the discharge is estimated to be 60 cumecs in the channel only. The discharges recorded at the mouth of the Khor Adar reached 28 and 36 cumecs in September and October 1947. We have been told of instances in which the flow of water in a ' southern ' type of watercourse (p. 30) has been sufficient to flatten the grasses which normally fill the waterway completely. The fact that the discharges of the Khor Adar, calculated on the assumption that the grasses have been removed, are of the same order as the discharges actually measured in 1947 is confirmation that this does happen. As a drainage-channel, the maximum capacity of the Khor Adar when cleared of grass is 60 cumecs, 5·2 m/d, or 1·9 milliards per year. This channel alone is insufficient to drain the marshes even if the difficulty of clearing the grass could be overcome. Under present conditions it appears to be capable of passing a maximum of about 5 millions a day or 150 millions a month.

TABLE 467
KHOR ADAR
HYDRAULIC DETAILS OF CHANNEL

Cross-Section		Water-Levels		Khor Adar Channel			
Number	Distance km.	R.L.	Date 1950	Bottom R.L.	Top R.L.	Depth metres	Width metres
White Nile	... ...	382·30	Jan.	—	—	—	—
	0	380·25	Mar. 3	—	—	—	—
1	4·8	380·60	Mar. 6	379·38	382·30	2·92	150
2	17·8	381·90	Mar. 7	379·90	382·85	2·95	135
3	26·8	382·05	Mar. 9	380·76	383·25	2·49	105
		382·65	Jan. 20	—	—	—	—
4	33·4	382·10	Mar. 18	380·74	383·25	2·51	95
5	39·4	382·32	Mar. 23	380·65	383·20	2·65	80
6	50·6	382·75	Apr. 1	381·05	383·30	2·25	90
7	70·6	383·66	Apr. 16	381·97	384·25	2·28	115
8	93·4	384·86	Apr. 19	383·12	384·90	1·78	100

TABLE 468

KHOR ADAR
DETAILS OF FLOOD-PLAIN

Cross-Section		Khor Adar Flood-Plain		
Number	Distance km.	Average Level R.L.	Width metres	Inundated at W.L.
1	4·8	382·25	620	382·50
2	17·8	383·00	Ill-defined	—
3	26·8	383·50	Ill-defined	—
4	33·4	383·75	975	384·00
5	39·4	383·35	900	383·75
6	50·6	383·50	1,185	384·00
7	70·6	384·40	550	384·50
8	93·4	385·25	780	385·50

THE KHOR WOL

As far as we know, no discharges of this khor have been measured by the Egyptian Irrigation Department, but it is possible that its rather indirect entry into the White Nile has caused them to overlook its importance. A detailed description of the system (Vol. I, pp. 29–30). has already been given, and it was mentioned there that a discharge of 2 cumecs was measured by us, as compared with one of 3 cumecs in the Adar. If these proportions hold good for higher discharges, it may pass as much as 3 millions per day or some 100 millions per month in exceptional conditions like those of 1946–47. Thus, from the very scanty evidence available about the two principal drainage-channels from the Machar Marshes to the White Nile, we are led to the same general conclusion as that given on page 27 of the *Nile Basin*, Volume VIII; that the total passed to the river in a normal year is certainly under half a milliard, while in 1946–47 these two channels alone could have passed 0·25 milliard per month.

DEDUCTIONS FROM THE WHITE NILE ANALYSIS

These conclusions lead us to regard with some reserve the figures of dry season inflow given in this analysis for most years, where it is estimated at an average of about 250 millions, and we are more inclined to put it at about 100 millions. These figures represent a small proportion of the Malakal and Renk discharges from which they were deduced and there is no supporting evidence. On the other hand the inflow deduced for the early months of 1947 reached a very much larger fraction of these discharges and is supported by reliable though only qualitative evidence. The Malakal and Renk discharges for February and March 1947 and the corresponding deduced values for inflow were as follows:

	February	March
Malakal discharge	3,750	2,229
Renk discharge	3,600	3,128
Mean	3,675	2,678
Deduced inflow (allowing for emptying of the trough, evaporation, etc.)	454	378
Deduced inflow as percentage of mean discharge	12%	14%

Even if we allow for a combined average error of 5 per cent. in the monthly discharges at Malakal and Renk over the whole two months, we are still left with a deduced inflow of about half a milliard; and it seems fairly certain that between Malakal and Renk the White Nile received in these two months a total amount of inflow somewhere between a half and one milliard. Local reports indicate that while the inflow deduced earlier in this and in other floods comes mostly from the west, or through khors such as the Doleib, this later inflow comes mostly from the khors between Malakal and Paloich. The local reports, by British administrators who personally walked over the area early in 1947, are given in the analysis of the White Nile flood (see Chapter 2, pp. 902–5). We may note here that although in February and March 1947 the Nile dropped over two metres, the khors near Paloich continued to rise;

that the Wol was three miles wide in February and one mile wide in March, when its bridge was still covered by flowing water; and that the Lul (another similar khor) was six miles wide in February. To sum up therefore, we believe with Dr. Hurst that in normal years the drainage from the marsh to the White Nile is certainly under half a milliard, and probably considerably less, but that in 1946–47 it may have amounted to as much as one milliard, and was almost certainly as much as half a milliard.

DRAINAGE TO THE SOBAT

We have seen already that on the average the Wakau takes out of the marshes a quarter of a milliard more than it contributes, and we have indicated that the exchange of water farther west is probably less than this in normal years. In 1946–47, however, the Sobat gained a net total of three milliards, after allowing for all the recorded discharges of its tributaries below Sobat Head. If we also allow for the effects of filling and emptying the supposed 'trough' of this river, and for losses by evaporation and absorption from this (which may well have been over-estimated in such a wet year), the deduced gains from sources outside the river reach a total of five and a half milliards, of which three and a half were supposed to arrive in August, September, and October 1946, and the other two in December 1946 and in January and the first half of February 1947. The recorded discharges of the southern tributaries in other years indicate that most of the earlier inflow came through them, and it may well be that all of the later inflow did too. We have no evidence either way and we can only note that some of this tremendous later inflow *may* have come from the Machar Marshes. As we shall see below, such a quantity of water could have come from the marshes, whereas we have seen that in fact the quantity contributed to the White Nile probably did not exceed a milliard.

Properly speaking, having included direct rainfall as one of the sources of supply, we should also include evaporation among the factors of loss since it is the major one. The difficulty is that we cannot make any proper estimate of evaporation except by considering the water balance of the swamps as a whole, and we may as well proceed at once to this; it forms the first part of an attempt to estimate conditions in the swamps themselves now that we have described what happens round them.

THE MACHAR MARSHES

EVAPORATION AND THE GENERAL WATER BALANCE

In view of the complete lack of quantitative information from inside the swamps, any estimate of evaporation loss and its variations from year to year must inevitably be bound up with the water account of the area as a whole. We may first conveniently summarize what we have so far estimated about the contributions to the area and their variations from the normal, these quantities being given in milliards:

Item	Normal Annual Total	Maximum Variation from Normal
Baro spill	2·8	± 2·0
Eastern torrents	1·8	± 0·2
Rainfall	15·0	± 1·5
Sobat spill	probably negligible	
Total gains ...	19·6	± 3·7

We may note that there is a tendency for all these variations to be of the same sign in any one year, since they all depend on rainfall either directly on the marsh or in the basins of rivers rising not far away; but the chances are against all of them reaching their maximum in the same year. Thus, as a rough average, we may take the maximum variation in supply in any one year as unlikely to exceed three and a half milliards.

From what we have said above it is clear that these variations are not normally reflected in the losses by drainage either to the White Nile or to the Sobat, since we have decided that these are only appreciable in exceptional years such as 1947. They must therefore either be counterbalanced by variations in the loss by evaporation, or cause changes in the volume of water held in the swamps, and so affect their level and extent. These effects are in fact inextricably linked together, since an increase in the area of the swamps will automatically increase the loss by evaporation from them; and to this extent the swamps are capable of absorbing these variations in supply without undergoing violent changes.

On the other hand a series of years with rainfall below or above the normal (such as 1940–44 and 1945–49 respectively) must inevitably cause a gradual change in the level and extent of the swamps, and these changes may well be considerable. These deductions are borne out by field observations both from the ground and the air. In May 1942 Mr. J. Longe (then District Commissioner, Northern District) described the Yabus swamps around Chidu as practically dry, and found that men, cattle, and wild animals were concentrated round the few pools and grazing areas which were left. In 1946 and 1947 on the other hand, as we have already seen, the swamp appears to have overflowed into the White Nile, and perhaps to the Sobat also, to a considerable extent. In 1949 and 1950 during our own flights over the area we saw an immense area of swamp and open water, even in April 1950 at the height of the dry season. This was confirmed by conditions at the end of the survey line along the Khor Adar, where, 71 km. from Melut, we found the water-level rising later in the same month. We may therefore sum up our conclusions about the general conditions in the swamps by saying that they vary considerably from one year to another owing to the large, and sometimes continued, variations in the annual supply, which are not counterbalanced by corresponding changes in the losses by drainage because these are in nearly all years practically negligible.

MOVEMENT OF WATER THROUGH THE SWAMPS

We have seen that the two main sources of supply, apart from rain falling on the swamps themselves, are the torrents in the east and the Baro spill in the south-east. We have three types of evidence showing by what routes, and at what rate, this water travels to the west and north-west; the air survey maps, ground reconnaissance, and the observed discharges of the Wakau and of the khors draining into the White Nile.

Air Survey

A number of air photographs was taken by the American Air Force in the winter of 1944–45 and used by the Sudan Survey Department for compiling a series of 1/100,000 maps. These photographs and the methods used have been described elsewhere (*Empire Survey Review* XI, pp. 2–14, and *Sudan Notes & Records* XXX (1949), p. 58), but we may note here that the photographs were taken from 23,000 feet and that only about a third of the area was covered by vertical photography, so that and detailed study of the whole of it was not possible, nor was any contouring attempted. Fig. K 15 is a reduction made from the 1/100,000 series, and it brings out clearly the two main lines of drainage—the Adar and the Wol. The first takes the discharge of the eastern torrents after they have reached the swamps, and the northern and eastern part of Baro spill; and the second takes the western part of this spill, which appears to travel through a belt of swamps about 30 km. north of, and running parallel to, the Sobat, with some connections through khors such as the Wakau, Loing, Banglai, etc. The 1/100,000 maps bring out the great complexity of these drainage-channels, and we have also seen this in our detailed survey of the Wol system, which may be regarded as typical.

Ground Reconnaissance

Our main source of information about the real interior of the swamps is a long trek made by Mr. B. H. Dening in December 1951, when he walked from Nasir to Buth, a point over 110 km. to the north, and returned to the Sobat at Loing. His account contains more details of the people than of the hydrology, and is used extensively in the next section, but we may note here that about 42 km. north of Nasir he crossed a large khor called the Tierbor which was said to be connected with the Wakau, from which its flooding was said to come. Farther north he reached an area where the water was said to drain northwards to the Adar. At about 100 km. from Nasir and 13 km. short of Buth he crossed another big khor with a wide, shallow flood-plain containing a deep water channel at one side; this watercourse was quite different from the others which he crossed. It was said never to dry up and to extend in both directions for a long way. The striking similarity between this khor and the lower reaches of the Adar (Figs. K 25 and K 26) leads to the conclusion that it is one of the main through channels connecting Khor Machar with the Adar. At such a distance from Nasir there is a main drainage line, flanked by swamp, shown in this locality on the air survey maps. The Khor Adar proper was reported to be 11 km. beyond Buth, but Mr. Dening was unable to visit it. On his way back south-westwards to Loing he crossed the Tierbor again and was again struck by its size.

Observed Discharge of the Wakau

The Wakau joins the Sobat 2 km. upstream of Nasir. We have already referred to its behaviour and this is described in detail in the analysis of the Sobat flood (see p. 932). We may note here that the Wakau has a steadily increasing discharge out of the Sobat from the time when the Nasir gauge reaches 7·5 until it reaches about 10·4; that in general this discharge is closely related to the height of the Nasir gauge; that the direction of flow is reversed each year on a date which varies from the beginning of September to the second half of October; and that this reversal usually occurs when the Nasir gauge is within a few centimetres of 10·4. After that the khor discharges steadily into the Sobat, even though this may rise another half metre or so; and it continues to do so at least until the end of December when the observations usually stop. In most years it is still flowing then, but in two low ones—1939 and 1944—it had virtually stopped, and in 1946 it had started to flow outwards again at a time when the Baro had dropped but the Pibor was still flowing hard and keeping up the level of the Sobat.

The deductions from this are given in detail in the analysis of the Sobat flood, and we may say here that the most likely explanation is the passage of a flood 'wave' from the western part of Baro spill down the Tierbor and through the marshes running parallel to the Sobat. We assume that this spill raises the level in the Tierbor by over 3 m. and that it passes the Wakau sometime in September or early October. Unfortunately we have not been able to obtain (though they may exist) enough detailed records of spill from the Baro to see whether its timing in early or late years corresponds with an early or late reversal of Wakau discharge. We have, however, noted that the main spill from the Baro between Adura Head and Tail does not start till July, and that it is doubled in August, while the average date of reversal in the Wakau is in mid-September. The straight line distance from the middle of this part of the Baro to the outer end of the Wakau is about 50 km., while the distance along the channel from Machar mouth to Wakau mouth is 85 km. Taking a mean we find that the water travels some 70 km. in about two months, giving an average rate of 1 km. a day.

Observed Discharges of White Nile Khors 1946–47

This was also approximately the average rate of travel for the same water from the Baro to Khor Wol in 1946–47, if it followed the Tierbor and arrived in the Wol—as the local accounts and deduced inflow indicate—in February 1947, since the distance was about 200 km. in a straight line (or say 300 km. by the channels), and the time seven months. From these accounts it appeared that the inflow in the northern khors—the Adar and those near Paloich—was a little later. If this came from the Yabus, Daga, and the other eastern torrents, and we assume that their floods arrived at Yabus bridge and Daga Post in July, we get roughly the same figure, as the straight line distance is again just over 200 km. In fact the discrepancies between the different rates of flow are under 10%. We may therefore take, with some confidence, an average rate of 1 km. per day for the rate of travel of the annual floods through the swamps. This may be compared with a rate of travel of about 10 km. a day for the flood wave passing down the Sobat, in spite of the large areas of flood-plain which it has to inundate and drain. From this we can deduce that by far the greater part of the flow through the Machar Marshes takes place on a wide front through vegetation, and in a form analogous to 'creeping flow' as described in Volume V of *The Nile Basin* (p. 120) and in the Team's *Second Interim Report* (p. 35), except that the rate of travel and the amount of rise and fall are considerably greater. Taken together these seem to indicate that over part of the width of its advance (i.e. down the main channels) the flood overtops the vegetation and so gets a freer and faster flow than would be possible if it were all seeping through marsh without any open surface. Between the Baro and the Wakau this may be achieved by the comparatively sudden arrival of such a large quantity of water, and farther west, in exceptional years like 1946–47 (and possibly 1949–50), by a high general level of the swamps, most of which would be saturated by rainfall before these eastern flood-waters reached them.

3. OTHER ASPECTS OF THE AREA

GENERAL INFORMATION (see Fig. K15)

Apart from the hydrological aspect of the Machar Marshes described above there is considerable information, obtained from many different sources, concerning the people, pasture and fisheries, drinking-water supplies, routes across the swamp, and so on, which is summarized here both because it fills in the background and increases our knowledge of the area, and because we hope it will be of use to future investigators.

The Nuer lay claim to the whole area bounded approximately by a line running from Khor Machar head, west of Daga Post, along the Daga-Adar line, south of the Maban pastures (occupied seasonally by the Rufa el Hoi Arabs), south of the Paloich (Nyiel) Dinka areas, described below, then southwards to a point north-east of Manetwom, through Malual to the

Sobat. This rough boundary encompasses the major part of the Machar Marshes, and, though this area is claimed by the Nuer, it should be noted that Dinka often enter the Nuer territory without trouble in search of grazing and fish. The Nuer do not by any means exploit the area to the full and most of them prefer to go to the Sobat and Baro *toiches*. Owing to the extremes in hydrological conditions to which the area is subject, i.e. heavy flooding or water shortage, its resources are not available as often as may be supposed. The northern side of the Machar proper is considered to be belong to the Thiang section of the Nuer and is used by people of Cieng Loing, whereas the southern side is used by the Garjok Nuer of the Jogiel–Ditchin area.

Reporting on a trek in June 1948 from Machar head on a line parallel to the khor and 5 km. from it, the District Commissioner, Nasir (Captain G. Rennie), noted that the rains had been exceptionally late and that the regrowth of grass was only a foot high. He found himself at the tail end of the migration of Nuer back from Ethiopia, via cattle-camps on the Machar, to their permanent settlements in the Thoij and Yom areas which are on comparatively high ground and are rarely inundated, except by phenomenally high floods. The effect of the late rains was to give the Nuer concerned a particularly plentiful supply of fish which had been trapped in small areas as the water evaporated. Watering cattle was not easy owing to the difficulty of getting to the water without becoming bogged in deep mud, a point which has been noted by more than one observer. Local informants described Khor Machar as a backwater which filled up on the rising Baro and flooded inland, and discharged back into the river when the level in it dropped. (This is not borne out by measured discharges at Machar head which show that Khor Machar spills as much as one milliard into the swamps in some years.) There is a considerable deposit of red silt which is apparent up to 10 or 15 km. from the Machar offtake. At the height of the flood the whole area is said to be flooded waist-deep on average ground and out of a man's depth in depressions.

As mentioned previously, Mr. Dening has also sent us a very interesting account of a journey made by him in December 1951, when he penetrated to the centre of the swamps to a village called Buth. From Nasir to Luakping is about 15 km., of which the last 10 km. south of Luakping was flooded to a depth of 50 cm. with short stretches of deeper water. He said that the flooding there was from the Wakau, or possibly spill from the Sobat west of Nasir in November. For the next 12 km. to Guum the country was dry, slightly wooded, and thickly populated, with regularly spaced villages and much cultivation. This part had not been flooded for the first time for many years, and the rains had been good (cf. Table 466, p. 974, Malakal maximum gauge and mean rainfall). From Guum to Kegh (south) the party passed through 15 km. of uninhabited dry *toich* where even the water-holes had ceased to yield water. Between Kegh (south) and Kegh (north) there was high ground with villages and extensive cultivations. In the Kegh area the channel of a large watercourse, Khor Tierbor, could be followed in many places, and is undoubtedly the one shown on the air survey maps. Mr. Dening said it was connected with the Wakau from which came the flooding. That year there had been no flooding and Khor Tierbor had drained off local rain-water. From this description there is little doubt that Khor Tierbor and the *toiches* through which it runs must be the major drainage line connecting a westerly branch of Khor Machar with the Wol system. (Note: This conclusion was reached from practical considerations, independently of Mr. Wright's analysis of the Sobat flood.)

From Kegh (north) to Ditchin (12·5 km.) *toich* was again crossed at a point where there were two villages on higher ground, both without water. Ditchin itself is a very big mound of a good height (by local standards) and must be a very old village site. The surrounding country had been flooded regularly in recent years (before 1951), and in 1950 was generally knee-deep in water. At the time of Mr. Dening's visit the nearest water was 2 km. away. Similar country was traversed in the next 13 km. to Jogiel. Ditchin and Jogiel had very large cultivations, particularly in 1951. Even in the previous years of bad flooding the people did not suffer from hunger. Flood-water was said to come from the Wakau and was drained in a northerly direction by Khor Manyang to the Adar. From Jogiel to Buth (35 km.) the party had to use buffalo tracks or force a way through tall grass. A short way north of Jogiel they crossed heavy *toich* land. There is a narrow ridge of high ground 11 km. north of Jogiel running north-west south-east which divides into two an area consisting of a confusion of khors. Those on the south side were mainly dry, whereas those on the north contained water with mud in between. Nowhere did the water exceed 75 cm. in depth, but the mud was deep in khors. Nearer to Buth the khors contained water, and were better defined and wider apart, with dry ground between.

As already stated, about 13 km. south of Buth the party crossed a big khor, consisting of a wide, shallow flood-plain with a deep water channel at one side, which was quite different from all the other khors crossed. It was said never to dry up and ran for a considerable distance in both directions. The striking similarity between this khor and the Khor Adar leads one to think that it may be one of the main through-channels connecting Khor Machar with Khor Adar, possibly a westerly branch. (The Khor Adar proper was reported to be 11 km. north of Buth.) North of this khor, about 8 km. from Buth, the ground became higher and thinly forested. Buth is the name applied both to a wide area and to a village on the banks of a khor of the same name. In 1951 only three sites were occupied; Buth itself by Nuer from Cieng Luol, and two other sites farther north by Nuer from Cieng Lang, Cieng Loing, and a few from Cieng Luol. Before that year all the area had been heavily flooded, though exactly to what extent is not known because the area had been evacuated by order since 1940 and permission to re-enter it had only just been given. Flood-water was said to come from the Machar and the Wakau, from the south-east and south-west respectively. The whole lot then drains northwards to the Adar which flows in a distinct channel 11 km. north of Buth. In years gone by the Nuer of Buth had their cattle-camps all along the Adar, where fishing and grazing were reported to be excellent; recently (before 1951), however, heavy flooding north of Buth had made it impossible to reach the Adar. On his return to Nasir Mr. Dening was told that the route from Buth to the Adar had been reopened. The people in Buth in 1951 preferred to take their cattle some 100 km. to Ajungmir at the junction of the Baro and Pibor, but this may have been due to their enforced exile from Buth. The Buth area is known as a sort of promised land, a wonderful country with plenty of grass, pasture, and fish. Its boundaries are roughly the Adar on the north, a permanent swamp 15 km. to the east, a wide band of low ground on the south-east which separates it from Cieng Loing, and the area of khors to the south which cut it off from the country round Ditchin and Jogiel. The western limits of the area are not known.

With Buth village as centre and a radius of 16 km., the sector from 20 to 110 degrees was permanent and impassable swamp with water knee-deep and more, even in dry years. In the direction 20 degrees east of north is a path through the Machar to the Maban country, which was not passable at that time.

Mr. Dening returned via Ditchin to the Sobat at Loing and has described the country seen en route. The area inland to the north of Nasir is known as Malou. It is a band of territory 15 km. wide running from Loing on the Sobat to Ditchin and beyond to Kegh and Jogiel. In previous years this area has been flooded to a depth of over 50 cm., but in 1951 it was quite dry and excellent crops were grown all over the area, though drinking-water could be found only in isolated pools. A big watercourse, Khor Taibor, runs from Palchanak (Palcieknak) to Biel and ties up with Khor Loing, and flood-water comes from Wakau and Loing and drains in both directions.

DINKA COUNTRY

We now turn to the western and northern parts of the Machar, which are largely within Dinka territory. Prior to 1946 these swamps dried out to a greater extent than when we saw them (in 1949–50) and movement within them was comparatively free.

The Dunjol Dinka, who have traditional prejudices against exploiting their part of the marshes, were forced to do so in 1941 owing to famine conditions and cattle plague which compelled a proportion of the population to move away from the White Nile in search of fish in the lakes and channels. Many died of thirst, and perhaps malnutrition, on the return journey over the watershed, which by then was dry. Since 1946 it has not been possible at any time to approach the Machar channel owing to wide areas of floods, but in 1951 and 1952 the Sobat flood was below normal, rainfall was light, and it is likely that the whole area was much more accessible in 1952 and 1953. The dry watershed between the Adar and Wol drainage lines is a real obstacle to the use of the Machar resources. Though pasture, fish, and drinking-water are available in the swamps, the danger is that the latter will be finished before the rains begin, in which case those who ventured into the interior would be faced with thirst and starvation and would be without a line of retreat. The *toiches* of the central Khor Wol are more easily reached since they are nearer to the Sobat, but the same difficulties are encountered.

Between Manyang and Adoich are several *toiches*, the largest known as Malau, Manetwom, and Thiangchor. Some of these are marked on the map of the Machar Marshes (Fig. K 15). They are drained by Khors Wabuit, Weikirr, etc., which join the Wol and are part of its system There is a khor joining the Weikirr which connects with the Khor Loing and which must be supplied from the Sobat when it rises, though later in the year (as late as May in 1950) the channels discharge back into the river. The Nuer say that these *toiches* are connected with the Machar; from the hydrology of the area this must be so, and Khor Tierbor (and its *toiches*), as we have deduced, is probably the connection, though future investigators would do well to confirm this or otherwise on the ground. All these *toiches* up to Manetwom are claimed by the Dunjol and by some of the Ngok Dinka. They are not fully exploited and are used only in years when the White Nile and Sobat *toiches* are abnormally dry. This is another instance of how the inhabitants are able to make use of alternative grazing areas according to the particular hydrological conditions prevailing. If the Sobat is high, it usually falls in January and February instead of in November and December, with the result that the main river *toiches* are wet enough to produce regrowth for grazing in March and April. At the same time the inland *toiches* are probably too heavily flooded to be usable. On the other hand if the Sobat flood is below normal, the main river *toiches* are burnt off early in the year and become relatively useless in March and April until the first rains bring up the fresh regrowth. In this case the inland *toiches* will have had less flooding and will be more accessible. The people say that drinking-water supplies often fail towards the end of the dry season, or are inaccessible owing to wide expanses of mud which the cattle would have to cross to reach them. In this connection the banking of the watercourses would appear to offer a better method of providing drinking-water supplies, pasture, and fish than the digging of hafirs. The *toiches*, Malau, Thiangchor and Manetwom, had not been used for many years prior to 1950 because they were too heavily flooded.

East of a line Loye–Akurweng is the Khor Daldal which connects with the Khor Adar and the surrounding marshes, known rather vaguely as Daldal. This area is not frequently used, though the Dunjol Dinka went there in 1941, with disastrous results. Immediately north of the Daldal is the Paloich Dinka area which the Dunjol refer to as Toich Nyiel, i.e. the territory of the Nyiel section of the Paloich Dinka. This area and the one east of it towards the junction of the Adar and the Machar are also partly used, depending on hydrological conditions. In March 1950 some Dinka from Akurweng were encountered at Abaj. It appeared that they were returning from the Daldal area via the Khor Adar. The reason for their return was a rise of water in the swamps, which we observed in the Khor Adar later in April. This was the tail end of the 1949 Sobat flood which had been highest some 8 or 9 months previously and had taken that time to traverse the Machar Marshes.

North of Toich Nyiel and to the east are the Adar *toiches*, which run out towards Jaimidh, south of Agor Dit, Wunkir, and Awaj el Bagar. These *toiches* must derive some water from Khors Tombak and Ahmar, from the Adar, and from the western branch of the Yabus in flood time.

Farther east are the Maban *toiches*. Though not shown clearly on the air survey maps, the Yabus does in fact split into two branches. One branch flowing south-west takes most of the flood flow, though carrying little in the dry season, and waters the *toiches* south of Awag el Bagar; the other branch (the Yir Pal) runs south, and carries practically all the dry season flow, to join Khor Adar after passing through the Moibar Swamp south-west of Chidu. The junction of the Yabus and Daga is said to be at a place called Ruol where there is an ancient village site set on high ground with forests of *dom* palms.

ROUTES INTO AND ACROSS THE MACHAR

There is a motorable track from Uriang through Thoij and Yom to Cieng Loing, but it is not much used because the villages are all deserted in the dry season. In some years one can motor from Boing to Chidu, but the way to Bar on the Daga is barred by a stretch of the Moibar Swamp which might be avoided by travelling farther east.

The following routes running parallel to or across the Machar Marshes are recorded even though many of the places have not been identified.

SOUTHERN ROUTES

The main focal point to which Nuer come when crossing from the Nasir areas to Dunjol direct is Ditchin; that is to say, a Nuer starting from the east would almost certainly pass through or near to this village, unless he followed the motor road along the Sobat.

From this point there are several possible routes, of which two are recorded here:

(1) Ditchin—Jogiel—Buth—Daldal—Akurweng

At Jogiel there are permanent habitations and cultivations. Beyond this there are none until Dunjol country is reached. From Jogiel to Ayuth or Yut, which is uninhabited but said to be on higher ground and is described as being on the edge of the main channel of the Khor Machar, one moves along the Machar channel, which is crossed near to a point called Mading, and the route passes through Buth, where there is forest.

Farther north-west, at Baragoth, the Machar channel is re-crossed to Cieng Gun (Achwoth) which is recognized as being the boundary between Nuer and Dunjol Dinka. The traveller then proceeds through Barakoich, from which the forests of the Daldal area (clearly seen on the air survey maps) can be seen. In most years the route is swampy and in recent years it has probably been impassable owing to heavy flooding. From this point onwards the crossing of the catchment between the Machar and the first Dunjol villages is difficult in the dry season owing to lack of water. Akurweng and Jogiel are both marked on the map of the Machar (Fig. K 15). The position of the other places mentioned is a matter for conjecture, but given that the route does not deviate more than ten miles on either side of a straight line between these two points, the general direction can be seen.

(2) Ditchin—Wanekwach—Malual—Guil

This route runs south of that described above and is more or less parallel to the Sobat. The route described by local informants is as follows: Ditchin, Riang or Bor, Palcieknak, Biel, Jueny, Manakwach. This brings the traveller to one branch of the headwaters of the Khor Wol, and thence the routes, though hazardous in some years owing to scarcity of water, are well known:

Rotik – Mangar – Malual (lat. 9° 18′, long. 32° 27′) – Abiel – Manowak (lat. 9° 19′, long. 32° 23′) – Rom – Dola (lat. 9° 26′, long. 32° 21′) to Guil and Adoich (lat. 9° 30′, long. 32° 15′).

Dik – Apach – Domong – Banychuk (lat. 9° 25′, long. 32° 24′) – Anguchah (lat. 9° 30′, long. 32° 22′) – Pamiaker – Loye – Akurweng.

In all cases any attempt to follow these routes should be preceded by careful investigation of the water position, and reliable guides (both Nuer and Dinka) from all regions should be engaged.

NORTHERN ROUTES

The focal point north of the Machar proper is Cieng Loing. Information from this area is limited, but having reached Cieng Loing from Nasir (a long and arduous trek but quite feasible) there appear to be two routes:

(1) Cieng Loing—Ruol—Gukror—Nuri Begh—Kiu—Nokdura

Ruol is said to be somewhere near the junction of the Yabus (Yir Pal in Nuer) and the Daga (Bar in Nuer) and might, by a fairly circuitous route, be reached from Chidu in Maban country. The intervening places are not known, but it is assumed that the route runs well north of the Machar channel and emerges somewhere near Abaj (marked) on the lower Adar.

(2) Cieng Loing—Buth—Daldal

This route goes directly across the Machar proper and joins the southern routes. From Cieng Loing the traveller walks, or wades, to Mangok and then wades to Pamiabil. This place, surrounded on all sides by swamp, is probably the isolated village which we observed from the air at approximately lat. 9° 17′, long. 32° 56′. Another day's wading brings the traveller to Keich (marked Kegh on 1/250,000 maps), where this route is linked with the Ditchin–Jogiel route.

Only parts of these routes have been attempted so far by the Jonglei Investigation Team, but the information recorded, though it may not be wholly accurate, is sufficient to give some idea of the general routes possible across this almost unknown region. The amount of time spent in collecting the information was considerable and it is recorded here for use in future investigations, further details being reserved for our own files.

PART II
EXPERIMENTAL DATA

TABLE 469

SUMMARY OF RESULTS OF SORGHUM VARIETY TRIALS IN UPPER NILE PROVINCE, 1933–49

Variety	Yield in kg.p.f.			Number of Trials
	lowest	highest	average	
Agono type	225	500	260	6
Luali type	F[1]	675	315	8
Feterita	F	500	203	4
Wad Aker	F	750	277	4
Hegeiri	—	—	109	1
Milo Dwarf	25	112	83	3
Korgi	F	250	106	5
Kordofan White ...	—	—	15	1
Nagad	F	750	313	3
Culum ...	F	373	219	5
McCoy	—	—	225	1
Kiddaka	F	238	119	2
Nili Nili	—	—	202	1
Kau	—	—	F	1

Yields converted on the basis of 1 ardeb = 150 kg.
1 keila = 12½ kg.

(1) F in this and subsequent tables signifies crop failure.

Maize

Records of seven years' trials at Kodok with ' Secatoon ' variety show yields from failure to 750 kg., with an average of 260 kg.p.f.

Bulrush Millet

Tried in 1940–41 season, yielded at Kodok 213 kg.p.f. and at Kongor 195 kg.p.f.

OIL CROPS

Sesame

Records of 11 trials at Kodok show yields varying from failure to 171 kg.p.f., with an average of 62 kg.p.f.

Sunflower

Tried in Kodok in 1949, reported successful.

LEGUMINOUS CROPS

Groundnuts

Experiments at Kodok have shown the following results:

TABLE 470

GROUNDNUT YIELDS AT KODOK, 1935–45

Variety	Yield in kg.p.f.			Number of Trials
	lowest	highest	average	
Local	20	540	327	7
American (Virginia)...	150	396	298	5
Central African ...	579	112	296	7
Trinidad	166	427	293	3
Barberton	—	—	104	1
Kalande	—	—	86	1

In the 1935–36 season an experiment at Selim Banga showed the following results:

TABLE 471

GROUNDNUT YIELDS AT SELIM BANGA, 1935–36

Variety	Yield in kg.p.f.	
	sandy soil	clay soil
Local	389	444
American	297	142
Central African ...	172	116
Average	286	234

In the 1935–36 season American and Central African varieties were tried at Yirol, both yielding 720 kg.p.f. In 1936–37 a local variety was tried at Bor, yielding 324 kg.p.f., and on Zeraf Island, yielding 180 kg.p.f. In the 1939–40 season in a trial at Kongor, a local variety yielded 337 kg.p.f., an American yielded 227 kg.p.f., and a Central African 231 kg.p.f. In the 1936–37 season it was noted at Kodok that ploughing did not increase yields, but halved the cost of harvesting the groundnuts.

Other Legumes

The results of trials with other legumes can be summarized as follows:

Cowpeas tried at Kodok—moderately good.
Dolichos lablab—failed to flower.
Babun—reported successful throughout the Province.
Pigeon peas—reported moderately successful throughout the Province.
Chick peas—failure throughout the Province (planted too early).
Soya bean—in 1944 at Kodok yielded 329 kg.p.f.

FIBRE CROPS

Cotton

Experiments included the effect of ploughing trials, which gave the following results:

TABLE 472

EFFECT OF PLOUGHING ON YIELDS OF COTTON

Variety	Year	Yield in kg.p.f.		Response %
		ploughed	unploughed	
Webber	1933	270	247	9
Webber	1936	302	256	18
Webber	1937	369	295	25
Pump Scheme ...	1937	461	378	22
Average		350	294	

These experiments also included, in 1937, a spacing experiment with Webber variety, with the following results:

TABLE 473

EFFECT OF SPACING ON YIELDS OF COTTON

Variety	Spacing	Yield in kg.p.f.
Webber	100 cm. × 100 cm.	458
	100 cm. × 50 cm.	574
	50 cm. × 50 cm.	494
	75 cm. × 75 cm.	345

Finally, between 1939 and 1946 the observation plots at Kodok showed yields between 132 kg.p.f. and 288 kg.p.f., with an average of 210 kg.p.f., i.e. 4·7 kantars (100).

OTHER FIBRE CROPS

Jute: tried at Kodok in 1943, results very poor.
Dom palm fibre sample was found unsuitable for the manufacture of bags.

3. MALAKAL EXPERIMENTAL FARM

ENVIRONMENT

Malakal offers special opportunities for investigation, as all three types of land found in the Flood Region are represented in the vicinity of the town. Two farms were organized; one, some three miles south of the town on the east bank, includes high and intermediate land; and the other, opposite the town on the west bank, is used mainly for experiments in the utilization of the riverain flood-plain (*toich*). An area of approximately 150 feddans of the latter was banked-off at the beginning of the 1952–53 season, permitting control of flooding. Unfortunately in the 1952–53 season the river did not reach its mean maximum and some pumping of water on to the land was necessary. The *toich* is here very uneven, and therefore there are difficulties in its cultivation and its use for experimental purposes.

SOILS

The soils in all parts are heavy clays. On the east bank on the high and intermediate land calcium carbonate nodules are abundant. The soil pH is generally high, and sodium values comparatively high.

The results of analysis of samples collected on the high and intermediate land on the east bank farm are given in Table 474:

TABLE 474

SOILS OF THE EAST BANK FARM (3' COMPOSITE SAMPLES)

Mechanical Analysis				Chemical Analysis			Type of land
Coarse sand %	Fine sand %	Silt %	Clay %	pH	Salts %	Sodium value	
11	23	10	56	9·19	0·055	14	high land
17	23	11	49	9·09	0·043	13	high land
13	24	10	53	9·07	0·048	12	intermediate land
9	24	11	55	9·00	0·052	14	intermediate land
10	23	10	56	9·05	0·050	13	intermediate land

Table 475 gives the analytical results of the *toich* soils of the west bank farm:

TABLE 475

SOILS OF THE WEST BANK FARM (3' COMPOSITE SAMPLES)

Mechanical Analysis				Chemical Analysis			Type of land
Coarse sand %	Fine sand %	Silt %	Clay %	pH	Salts %	Carbon %	
0	27	9	64	8·03	0·081	0·820	*toich*
0	18	11	70	7·28	0·056	2·612	*toich*

CLIMATE

The rainfall for the three years in which experiments were carried out is given in Table 476. It should be noted that the rain-gauge on the east bank farm was not installed until July 1950; therefore for this year we give also the rainfall recorded at Malakal aerodrome gauge, some 5 miles away. In the last column we give the average rainfall at Malakal for comparison. It should be noted that while the rainfall in 1950 and in 1951 was near the average, in 1952 it was some 300 mm. below average.

TABLE 476

RAINFALL 1950-52
(in millimetres)

Month	Malakal Aerodrome 1950	East Bank Farm 1950	East Bank Farm 1951	East Bank Farm 1952	West Bank Farm 1952	Malakal Average Rainfall
January	—		—	—		—
February	—	not	—	—	not	—
March	—		—	—		5
April	62	recorded	—	51	recorded	29
May	136		31	87		86
June	70		72	45		127
July...	152	198	229	100	161	169
August	189	220	203	81	81	181
September	95	136	262	102	121	139
October	69	37	62	72	20	71
November	1	—	—	—	6	9
December	—	—	—	—	—	1
Total	774		359	538		817

UTILIZATION OF HIGH LAND

EXPERIMENTS IN IMPROVEMENT OF HUSBANDRY

Manurial and Spacing Experiments

The aim of these experiments was not to investigate the possibilities of the application of artificial fertilizers to local crops such as sorghum, but to find out the plant nutrient status of local soils and whether this or soil moisture was the main limiting factor.

In the 1950–51 season the effect of the application of gypsum (rate 3 tons p.f.) and nitrogen (ammonium sulphate, 100 kg.p.f.) on sorghum crops planted at different spacings was tested. Nitrogen depressed yields of grain significantly, while differences due to manure on yields of straw were not significant. The effect of spacing on the yield of grain was not significant, while the yield of straw increased significantly with the close spacings.

TABLE 477

EFFECT OF FERTILIZERS AND SPACING ON YIELDS OF SORGHUM, 1950–51

Main effect of fertilizers	Yield in kg./plot(¹) Grain	Yield in kg./plot(¹) Straw
Control	4·7	49·2
Ammonium nitrate	3·6	48·9
Gypsum	5·0	51·1
Significant difference ($p = 0·05$) ...	1·2	NS

Main effect of spacing	Yield in kg./plot(¹) Grain	Yield in kg./plot(¹) Straw
40 cm. × 40 cm.	4·5	64·9
80 cm. × 80 cm.	4·5	50·3
120 cm. × 120 cm.	4·4	34·1
Significant difference ($p = 0·05$) ...	NS	10·4
Coefficient of variability %	24·8	18·6

(¹) Size of plots = 1/40th feddan.

In the 1951–52 season a larger trial with a sorghum crop was carried out. The crop was planted at spacings similar to those of the previous year and manured with nitrogen (ammonium sulphate at 150 lb.p.f.), phosphorus (super phosphate at 100 lb.p.f.), and potash (muriate of potash at 100 lb.p.f.), as well as dung (5 tons p.f.). The experiment showed a significant difference between spacing treatments, in both grain and straw, but no significant effect with manuring and no significant interaction between spacing and manuring.

TABLE 478

EFFECT OF FERTILIZERS AND SPACING ON YIELDS OF SORGHUM, 1951–52

Main effect of fertilizers	Yield in kg./plot[1]	
	Grain	Straw
Control	7·46	34·9
Ammonium sulphate	7·97	34·9
Superphosphate	9·44	36·2
Muriate of potash	8·49	35·7
Farmyard manure	9·44	33·9
Significant difference ($p = 0·05$) ...	NS	NS

Main effect of spacing	Yield in kg./plot[1]	
	Grain	Straw
40 cm. × 40 cm.	6·88	46·2
80 cm. × 80 cm.	11·27	37·9
120 cm. × 120 cm.	7·53	21·3
Significant difference ($p = 0·05$) ...	1·76	9·1
Coefficient of variability (manures)	27·8	21·4
Coefficient of variability (spacing)...	11·9	14·9

(1) Size of plots = 1/20th feddan.

In the 1952–53 season a manurial trial was again arranged with sorghum as an indicator crop, but owing to drought and very bad infestation with stem-borer, the yields on all plots were practically nil.

In the same season a manurial trial, involving unreplicated observation plots (4/5th feddan), was carried out with irrigated rice.[3] Nitrogen and potash alone depressed the yields, while phosphorus alone slightly increased them. The application of all three combined more than doubled the yields. Rates of application were very heavy and the appearance of the crop on the phosphorus fertilized plot suggested that application at this rate interfered with the absorption of iron or magnesium. The nitrogen manured plot and the plot receiving complete manure suffered a heavy attack of *Helminthosporium oryzae*.

TABLE 479

EFFECT OF FERTILIZERS ON YIELDS OF RICE, 1952–53

Treatment	Rate of application lb.p.f.	Yield in kg./plot
Control	—	457
Ammonium sulphate ...	300	367
Superphosphate (triple) ...	400	529
Potassium sulphate ...	300	252
Complete	1,000	1,060

The results of these experiments suggest that a heavy application of nitrogenous manure might actually depress the yields, while the application of other plant nutrients without irrigation is unlikely to lead to yield increase, as moisture is probably the main limiting factor. On the other hand, when moisture ceases to be a limiting factor, as when irrigation water is applied, phosphorus is probably the main limiting factor among the plant nutrients, while additional response can be achieved by the application of all three main elements.

In the 1952–53 season a small experiment on the application of minor elements was carried out. The only significant response was due to the application of zinc (zinc sulphate at 20 lb. p.f.). Response to manganese, boron, copper and iron was not significant.

In the 1950–51 season a small experiment on observation plots only was carried out to enquire into the value of the native practice of pegging cattle at night on the fields to be sown. The manured plots received the manure of 400 cattle-nights each. Local *luali* type sorghum was used as an indicator crop. The yields of both grain and straw were increased on the manured plots.

TABLE 480

EFFECT OF CATTLE-PEGGING ON YIELDS OF SORGHUM, 1950–51

Treatment	Yield in kg.p.f.	
	Grain	Straw
Control	301	2,215
Manured	345	3,123

In the 1952–53 season a similar but replicated experiment was carried out, involving pegging of cattle and burning of grass (*path*: Shilluk practice). The results, given in Table 481, showed no statistically significant differences due to these forms of manuring. The light rainfall and high stem-borer infestation during this season should be noted.

TABLE 481

EFFECT OF CATTLE-PEGGING AND GRASS BURNING ON YIELDS OF SORGHUM AGONO, 1952–53

Treatment	Yield in kg.p.f.	
	Grain	Straw
Control	100	2,228
Grass-burning	89	2,131
Cattle-pegging	55	2,158
Significant difference (p = 0·05)	NS	NS

EXPERIMENTS IN DATES OF PLANTING AND WEEDING OF RAIN-GROWN COTTON

Cotton is the most important cash crop in the area, but local standards of cultivation are generally low. It has been noticed by the officers responsible for the supervision of its cultivation that late planting and late weeding are often responsible for bad yields. In the 1952–53 season a replicated experiment was laid down to ascertain the effect of date of planting on yield of cotton, to confirm these observations.

TABLE 482

EFFECT OF DATE OF PLANTING ON YIELDS OF COTTON, 1952–53

Variety	Date of planting	Yield in kg.p.f.	Yield in kantars (100) p.f.
SP 84	28.6.52	420	9·3
SP 84	23.7.52	390	8·7
SP 84	18.8.52	70	1·5
Significant difference (p = 0·05)		82	1·8

As may be seen from the above table, the late planting of cotton gave a highly significant reduction of yield, though the difference between the second and third date of planting was only 26 days. The importance of early weeding was indicated by the observation plots trial carried out in the same season. The early weeded plots gave yields equal to those weeded continuously.

TABLE 483

EFFECT OF DATE OF WEEDING ON YIELDS OF COTTON, 1952–53

Variety	Treatment: Number of weedings	Treatment: Months after planting	Yield in kg.p.f.	Yield in kantars (100) p.f.
SP 84	1	1	235	5·2
SP 84	1	2	300	6·7
SP 84	2	1 & 2	325	7·2
SP 84	2	2 & 3	275	6·0
SP 84	3	1, 2 & 3	270	6·0
SP 84	Continuous	—	310	6·9
SP 84	Control	—	22	0·5

MIXED CROPPING EXPERIMENTS

Mixed cropping is the general native practice. In the 1951–52 season an observation plot trial was laid down to compare the yields of pure stands with those of mixed stands. These trials indicated that sorghum benefits from interplanting with legumes such as cowpeas, but not with groundnuts, the harvesting of which takes place earlier than that of sorghum, causing disturbance to the soil round the sorghum roots at a critical moment. The legumes suffered from interplanting with sorghum. Infestation with *Striga hermonthica* seemed to be reduced in mixed stands.

TABLE 484

EFFECT OF INTERPLANTING SORGHUM WITH LEGUMES, 1951–52

Crop	Interplanted with	Yield in kg.p.f.
Sorghum	Pure stand ...	490
Sorghum	Groundnuts ...	324
Sorghum	Cowpeas	704
Groundnuts ...	Pure stand ...	860
Groundnuts ...	Sorghum	300
Cowpeas	Pure stand ...	280
Cowpeas	Sorghum	130

EXPERIMENTS IN THE CONTROL OF *STRIGA HERMONTHICA*

Striga hermonthica is definitely one of the most important adverse factors in local agriculture; for example, in the 1951–52 season the weight of grain in 100 plants of sorghum affected with this parasite was 2·4 kg., while the weight of grain of 100 plants not affected was 5·3 kg., i.e. *Striga hermonthica* caused a 53% reduction in yield.

In the 1952–53 season experiments on the possibility of controlling this parasite by spraying with 2–4D (Sodium dichloro-phenoxy-acetate) were laid down. Unfortunately drought and very serious infestation with stem-borer reduced the yields of sorghum, which was used as an indicator crop, to practically nothing. However, the yield of straw was significantly higher on both the sprayed plots and plots from which *Striga hermonthica* was hand-pulled.

TABLE 485

EFFECT OF SPRAYING AND HAND-PULLING OF *STRIGA HERMONTHICA* ON YIELDS OF SORGHUM, 1952–53

Variety	Treatment	Yield of straw kg.p.f.
Agono	Control	512
Agono	2-4D at 1 lb.p.f. ...	782
Agono	Hand-pulling ...	960
Significant difference ($p = 0·05$)		266

An experiment on the control of *Striga hermonthica* by spraying and hand-pulling in maize was carried out in the same season. The plot was only lightly infested, and increases in yield were not significant. Pre-germination spraying at the rate of 1 lb.p.f. and 2½ lb.p.f. of 2–4D was done.

TABLE 486

EFFECT OF SPRAYING AND HAND-PULLING OF *STRIGA HERMONTHICA* ON YIELDS OF MAIZE, 1952–53

Variety	Treatment	Yield of grain kg.p.f.
Local	Control	416
Local	2-4D at 1 lb.p.f. ...	436
Local	2-4D at 2½ lb.p.f....	516
Local	Hand-pulling ...	534
Significant difference ($p = 0.05$)		NS

EXPERIMENTS IN CROP INTRODUCTION

For both agronomic and economic reasons, the extension of the range of crops and varieties grown in this area is desirable. A series of experiments was carried out to that end, and the following is a summary of the results. All new crops and varieties can be classified, on the basis of these results, as 'probable', 'possible', 'improbable', 'impossible'.

CEREALS

SORGHUM

Twenty-two varieties of sorghum, local and introduced, were tried, with the following results. It should be noted that the local mixed *agono* and *luali* types, as well as a selection thereof, have given generally better and less variable yields than any of the introduced varieties.

TABLE 487

YIELDS OF SORGHUM VARIETIES, 1950–53

Variety	Yield 1950–51 kg.p.f.	Yield 1951–52 kg.p.f.	Yield 1952–53 kg.p.f.	Yield Average kg.p.f.	Number of Years	Number of Trials
LOCAL VARIETIES						
Agono type (mixed) ...	498	408	123	369	3	1
Luali type (mixed)	(143)	290	—	290	2	1
Adwel (Agono type) ...	—	840	72	456	2	1
Alal (Agono type)	—	550	284	417	2	1
Awet (Agono type) ...	—	940	16	478	2	1
Challa (Agono type) ...	—	290	77	183	2	1
Boweng (Agono type) ...	—	150	100	125	2	1
Lual Deng (Luali type) ...	—	400	83	241	2	1
Average	—	483	108	320	—	—
NORTHERN VARIETIES						
Feterita 1931	(152)	170	98	130	3	1
Feterita Managil	—	205	70	137	2	1
Feterita Matuk	—	315	36	175	2	1
Feterita Suki	—	40	72	56	2	1
Wad Aker	—	350	90	220	2	1
Wad Fahal	(70)	300	35	167	3	1
Hegeiri	(210)	200	130	215	3	1
Milo Dwarf	—	325	117	221	2	1
Mugud Red	(F)	256	75	110	3	1
Korgi	—	620	27	323	2	1
Abu Sabain	—	120	145	132	2	1
Average	—	264	81	171	—	—
OTHER VARIETIES						
Martin Combine	(129)	90	56	72	2	1
Lafon	—	150	90	120	2	1
Olosingo	—	120	50	85	2	1
Average	—	120	65	92	—	—
Over-all average	—	324	88	215	—	—

Figures in brackets are of 'ratoon' harvest only.

MAIZE

Seven varieties of maize were tried; some introduced varieties were rather better than local varieties. On the whole yields are not inferior to those of sorghum, provided the maize can be protected from pests. Nearly all the 1950–51 crop was lost for this reason.

TABLE 488

YIELDS OF MAIZE VARIETIES, 1951–53

Variety	Yield in kg.p.f.			Number of years
	1951–52	1952–53	Average	
ECR/741	450	190	320	2
ECR/744	450	180	315	2
ECR/490	340	185	262	2
ECR/490 (ex Shendi) ...	560	—	560	1
ECR/320 Peruvian Yellow ...	760	80	420	2
ECR/321 Mexican June ...	420	105	262	2
Local (Control)	490	416	453	2
Average	496	193	370	—

BULRUSH MILLET

Three varieties of bulrush millet were tried. Yields were generally superior to those of sorghum, partly because the awned varieties are bird-resistant.

TABLE 489

YIELDS OF BULRUSH MILLET VARIETIES, 1950–53

Variety	Yield in kg.p.f.				Number of years
	1950–51	1951–52	1952–53	Average	
ECR/344	698	770	144	537	3
ECR/205 A Yellow awned ...	—	418	236	327	2
ECR/205 B Black awned	—	450	164	307	2
Average	—	546	181	390	—

FINGER MILLET

Nine varieties of finger millet were tried. Some of them gave yields at least as good as those of sorghum, although Malakal must be considered the northern limit for this crop when grown without irrigation. The introduction of this crop is worth considering because of its superior storage qualities.

TABLE 490

YIELDS OF FINGER MILLET VARIETIES, 1950–53

Variety	Yield in kg.p.f.				Number of years
	1950–51	1951–52	1952–53	Average	
ECR/377	544	320	168	344	3
ECR/380	363	490	114	322	3
ECR/401	123	210	76	136	3
ECR/707	103	310	40	151	3
ECR/929	—	220	114	167	2
AG 21	—	110	56	83	2
AG 22	—	105	52	78	2
AG 23	—	220	93	156	2
AG 24	—	140	83	111	2
Average	283	236	88	172	—

MISCELLANEOUS CEREALS

Yellow manna (*Setaria italica*) and pearl millet (*Pennisetum glaucum*) are worth considering. It should be noted that *Setaria*, mainly *Setaria pallidifusca*, is a naturally dominant species on this type of land in the Flood Region. Buckwheat was tried twice without success, Job's tears flowered but failed to produce grain, and crown millet failed.

TABLE 491

YIELDS OF MISCELLANEOUS CEREALS, 1950–53

Variety	Yield in kg.p.f.				Number of years
	1950–51	1951–52	1952–53	Average	
Yellow Manna, ECR/1100 (*Setaria italica*) ...	—	160	100	130	2
Pearl Millet, ECR/1209 (*Pennisetum glaucum*)	—	180	24	102	2
Crown Millet	—	F	—	—	1
Buckwheat	F	F	—	—	2
Job's Tears (*Coix lachryma jobi*)	F	F	—	—	2

OIL CROPS[4]

SESAME

Two introduced varieties have given better yields than local varieties. In the 1952–53 season, when rainfall was similar to that of the Semi-Arid Region, yields were much better than in the 1951–52 season of average rainfall. This indicates that in years of normal rainfall sesame is not a promising crop for the heavy soils of the Flood Region.

TABLE 492

YIELDS OF SESAME VARIETIES, 1951–53

Variety	Yield in kg.p.f.			Number of years	Oil %	Oil kg.p.f.
	1951–52	1952–53	Average			
ECR/951	71	294	182	2	50·6	92
ECR/991	27	140	83	2	45·1	37
Local	20	154	87	2	45·2	39
Average	39	196	117	—	—	56

SUNFLOWER

Ten varieties of sunflower were tried in Malakal, and this crop, easy to grow, can be classified as promising.

TABLE 493

YIELDS OF SUNFLOWER VARIETIES, 1950–53

Variety	Yield in kg.p.f.				Number of years	Oil %	Oil kg.p.f.
	1950–51	1951–52	1952–53	Average			
Dwarf Manchurian	338	83	305	242	3	30·6	74
Striped Grey ...	546	75	120	247	3	29·6	73
Ex Kodok ...	398	130	395	308	3	27·2	84
ECR/616	—	520	310	415	2	30·4	126
ECR/618	—	400	225	312	2	28·7	90
ECR/623	—	300	225	262	2	32·0	84
ECR/827	—	200	260	230	2	30·8	71
ECR/834	—	440	290	365	2	30·5	111
ECR/841	—	400	270	335	2	28·8	96
ECR/1059 ...	—	660	88	374	2	26·3	98
Average	427	321	249	309	—	—	91

HYPTIS SPICIGERA

This crop, popular in the Ironstone Region, was tried in Malakal but gave disappointing yields. It should be classified as improbable.

TABLE 494

YIELDS OF HYPTIS VARIETIES, 1951–53

Variety	Yield in kg.p.f.			Number of years	Oil %	Oil kg.p.f.
	1951–52	1952–53	Average			
ECR/1188... ...	50	40	45	2	24·0	11
ECR/1189... ...	45	120	82	2	24·4	20
EB 2	120	110	115	2	17·0	20
EB 4	45	30	37	2	24·0	9
Average	65	75	70	—	—	15

SAFFLOWER

This crop was tried with two different dates of sowing. The early sowing resulted in almost complete failure. As can be seen from Table 495, the yields of this crop, even when it is sown late (September), are disappointing. It might, however, be useful as a catch crop grown after rice or as a post-flood cash crop on intermediate land.

TABLE 495

YIELDS OF SAFFLOWER VARIETIES (LATE SOWN) 1950–52

Variety	Yield in kg.p.f.			Number of years	Oil %	Oil kg.p.f.
	1950–51	1951–52	Average			
Debeira ECR/601	91	80	85	2	31·6	27
American spineless ECR/866 ...	64	10	37	2	23·0	8
Average	77	45	—	—	—	18

CASTOR

This crop can be classified as improbable. In addition to giving very low yields, it does not survive the dry season. However, trials with other varieties should be continued.

TABLE 496

YIELDS OF CASTOR VARIETIES, 1950–52

Variety	Yield in kg.p.f.			Number of years
	1950–51	1951–52	Average	
ECR/278...	35	35	35	2

LEGUMINOUS CROPS

GROUNDNUTS

Experiments with groundnuts make it clear that though this crop is very laborious to harvest in these heavy soils, provided drainage is reasonable it yields very well and must be regarded as one of the most promising crops. Experiments also suggest that to obtain the best yields close spacing is essential, especially for the bunch type varieties. Response to ridging requires further investigation. The crop probably benefits from ridging in years of heavier, rather than in years of average, rainfall. On the other hand if the field is ridged this crop suffers at harvest time from increased damage by birds.

TABLE 497

YIELDS OF GROUNDNUT VARIETIES, 1950–53

Variety	Yield in kg.p.f. 1950–51	1951–52			1952–53							Number of years tried	Kernels kg.p.f.	Oil Content	
	On flat 50 cm. × 50 cm.	On flat 70 cm. × 30 cm.	On ridges 70 cm. × 30 cm.	Average	On flat 30 cm. × 80 cm.	On flat 30 cm. × 60 cm.	On flat 30 cm. × 40 cm.	On flat 30 cm. × 20 cm.	On ridges 30 cm. × 80 cm.	Average	Over-all Average			Oil %	Oil kg.p.f.
Local	400	730	655	692	328	372	424	408	200	346	436	3	368	47·9	176
American erect	310	805	1,125	965	596	572	504	728	265	533	614	3	524	47·1	247
Barberton	—	900	1,123	1,011	600	748	712	904	340	661	761	2	630	50·7	319
Medani erect	—	815	980	897	640	644	688	668	160	560	656	2	488	50·3	245
KCA	—	440	—	440	—	—	721	—	—	721	580	2	391	50·5	197
Average	355	738	971	801	541	584	610	677	241	564	609	—	480	49·3	237

SOYA BEAN

The yields of this crop, though comparable to yields of local cowpeas, were not high enough to classify it as more than an improbable cash crop. It might, however, be considered as a promising crop for local consumption.

TABLE 498

YIELDS OF SOYA BEAN VARIETIES, 1950-53

Variety	Yields in kg.p.f.				Number of years	Oil %	Oil kg.p.f.
	1950-51	1951-52	1952-53	Average			
ECR/124	—	100	90	95	2	11·5	11
ECR/262	—	180	F	90	2	13·4	12
ECR/299	—	110	80	95	2	16·3	15
ECR/759	—	10	—	10	1	17·5	2
ECR/973	243	90	400	244	3	18·7	46
ECR/998	—	140	300	220	2	16·4	36
ECR/999	—	180	250	215	2	16·8	36
ECR/1001 ...	—	30	—	30	1	18·6	6
Average	—	105	187	125	—	—	20

COWPEAS

Six introduced varieties were tried. None of them was outstandingly better than local varieties.

TABLE 499

YIELDS OF COWPEA VARIETIES, 1950-53

Variety	Yield in kg.p.f.				Number of years
	1950-51	1951-52	1952-53	Average	
Local	122	260	80	154	3
ECR/77	69	180	90	113	3
ECR/78	150	210	20	127	3
ECR/169	—	189	140	165	2
ECR/939	—	150	200	175	2
ECR/940	—	135	170	152	2
BA 13	—	60	60	60	2
Average	114	169	109	135	—

MISCELLANEOUS LEGUMINOUS CROPS

Of the introductions, velvet beans, green gram, black gram and tepary bean must be considered the most promising. Cluster bean and *babun* (*Vigna vexillata*) gave yields at least as good as cowpeas, and must therefore be classified as probable. Chick peas and pigeon peas (the latter do not normally survive the dry season) should be considered as possible. The value of the former as a catch crop after rice, possibly without additional irrigation, should be taken into account. Haricot beans and tick beans were failures.

TABLE 500

YIELDS OF MISCELLANEOUS LEGUMINOUS CROPS, 1950–53

Crop	Yield in kg.p.f.				Number of years
	1950–51	1951–52	1952–53	Average	
Bambara groundnuts ...	—	285	12	148	2
Tepary bean	349	140	260	249	3
Green gram ECR/65 ...	171	210	220	200	3
Black gram	—	350	230	290	2
Cluster bean	281	45	—	163	2
Babun	—	250	100	175	2
Haricot bean	—	F	—	—	1
Tick bean	—	F	—	—	1
Chick pea	—	80	—	80	1
Pigeon pea	78	65	—	72	2
Velvet bean	281	520	—	400	2

FIBRE CROPS

COTTON

Seven varieties of cotton, both long staple Egyptian type and short staple American type, were tried, with and without irrigation, and the results are given in Table 501. It should be noted that these varieties were grown in a badly drained field, and therefore suffered considerably from waterlogging.

In the 1951–52 season the irrigated plots received approximately 3,000 m^3. of water per feddan between 21st November 1951 and 5th March 1952. In the 1952–53 season approximately 2,500 m^3. of irrigation water was given, but irrigation was stopped at the end of December.

One of the main objects of these trials was to find out the blackarm resistance of these varieties under Flood Region conditions. In the 1951–52 season of average rainfall, only the varieties with B2 and B3 gene proved resistant (BAR 73, BAR 78, BAR 12/3, BAR 14/25 and BAR 4/16) while the other varieties, including SP 84, BAR XL, BAR XA and BAR NT 96, were all heavily infested. In the dry 1952–53 season blackarm infestation was absent.

TABLE 501

YIELDS OF COTTON VARIETIES (YIELDS OF SEED COTTON), 1950–53

Variety	Non-irrigated: Yield in kg.p.f. 1950–51	1951–52	1952–53	Average	Average kantars (100) p.f.	Number of years	Irrigated: Yield in kg.p.f. 1951–52	1952–53	Average	Average kantars (100) p.f.	Number of years
American Varieties											
SP 84	347	—	116	231	5·1	2	—	482	482	10·7	1
BAR NT 96	—	230	30	130	2·9	2	128	562	345	7·7	2
BAR 73	—	—	—	—	—	—	106	—	106	2·4	1
BAR 78	—	196	109	152	3·4	2	176	518	347	7·7	2
BAR 12/3	—	—	—	—	—	—	186	—	186	4·1	1
Average	347	213	85	171	3·9	—	149	521	293	6·5	—
					Average kantars (315) p.f.					Average kantars (315) p.f.	
Egyptian Varieties											
Domains sakel	—	—	—	—	—	—	162	—	162	1·1	1
BAR XL	—	35	—	35	0·3	1	108	—	108	0·8	1
BAR XA	—	—	—	—	—	—	298	—	298	2·1	1
BAR 14/25	—	—	17	17	0·1	1	166	654	410	2·9	2
BAR 4/16	—	39	F	19	0·1	2	—	719	719	5·1	1
Average	—	37	8	23	0·2	—	183	686	339	2·4	—

Jute

Jute was tried in the 1950–51 and 1951–52 seasons on the high land. In the 1950–51 season variety ECR/576 yielded only 118 kg.p.f. of clean fibre, and in the 1951–52 season the three varieties tried (ECR/584, ECR/585 and ECR/612) did not grow tall enough to be worth harvesting for fibre. The yields were better on intermediate land with subsidiary irrigation (see p. 1012).

Deccan Hemp

In the 1950–51 season Deccan hemp was a complete failure mainly owing to heavy infestation with flea beetle. In the 1951–52 season the variety ECR/985 yielded 210 kg.p.f. clean fibre.

Forage Crops

Though there is no immediate need for forage crops in this part of the Jonglei Area, the need may arise when, as the result of the Equatorial Nile Project, the area of riverain grazing is considerably reduced. A number of forage crops were therefore tried in the 1950–51 and 1951–52 seasons.

The crops were cut at the stage most suitable for fodder (generally the seed formation stage). They were weighed after cutting and after they had dried out in the field. Losses of fine tissue (leaves, etc.) in handling the dry crop are unavoidable, and therefore the difference between fresh and dry weight represents loss not only of moisture but also of part of the plant tissue.

In the 1951–52 season it was found impossible to ascertain the dry weight of some fodder crops as, owing to late rains and high humidity, they rotted before they dried out.

Sudan grass and sweet sorghum, the two most promising fodder cereals, gave yields as shown in Table 502.

TABLE 502

YIELDS OF SWEET SORGHUM AND SUDAN GRASS, 1950–52

Variety	Yield in kg.p.f. 1950–51		Number of cuts	Yield in kg.p.f. 1951–52		Number of cuts	Average kg.p.f.	
	fresh	dry		fresh	dry		fresh	dry
Sweet Sorghum								
Swaziland ...	4,905	2,860	1	5,342	2,690	2	5,123	2,775
Island	4,420	2,843	1	4,990	2,019	2	4,705	2,431
Red Amber ...	—	—	—	4,180	1,710	2	4,180	1,710
Columbus... ...	—	—	—	4,400	1,800	2	4,440	1,800
Minnesota ...	—	—	—	4,780	2,320	2	4,780	2,320
Medani	—	—	—	5,200	2,800	2	5,200	2,800
Evelyns	—	—	—	5,600	2,780	2	5,600	2,780
Fadasi	—	—	—	5,260	2,880	2	5,260	2,880
Abu Hegtein ...	—	—	—	3,640	1,816	2	3,640	1,816
Sudaniensis ...	—	—	—	1,100	400	2	1,100	400
Verticutiflorum ...	—	—	—	2,620	1,040	2	2,620	1,040
Average	4,662	2,851	—	4,283	2,023	—	4,241	2,068
Sudan Grass								
ECR/1013 ...	3,000	1,930	2	3,220	1,320	2	3,110	1,625
ECR/1201 ...	—	—	—	2,740	1,410	2	2,740	1,410
Yellow	—	—	—	3,490	1,420	2	3,490	1,420
Red ...	—	—	—	4,480	1,880	2	4,480	1,880
Brown	—	—	—	4,860	2,340	2	4,860	2,340
Average	3,000	1,930	—	3,758	1,674	—	3,736	1,735

Table 503 lists the yields of leguminous crops harvested for forage, i.e. at the seed-forming stage. It shows that some legumes can compete with sweet sorghum and Sudan grass for soiling, but on drying out lose not only moisture but a good deal of the finer plant tissue, which in fact is the most nutritious part of the crop.

TABLE 503

YIELDS OF LEGUMINOUS FORAGE CROPS, 1950-53

Crop	Yield in kg.p.f. 1950-51		Yield in kg.p.f. 1951-52	Yield in kg.p.f. 1952-53		Average	No. of Observations
	fresh	dry	fresh	fresh	dry	fresh	
Cowpeas	—	—	3,540	3,079	1,295	3,310	2
Soya bean	3,680	1,060	—	—	—	3,680	1
Tepary bean	1,450	644	187	1,336	360	991	3
Green gram	3,148	1,258	7,350	2,000	940	4,166	3
Cluster bean	608	283	640	—	—	624	2
Phillipisara	1,644	797	—	—	—	1,644	1
Babun	—	—	1,960	1,400	360	1,680	2
Sword bean	—	—	3,920	—	—	3,920	1
Velvet bean	—	—	3,920	—	—	3,920	1
Dolichos lablab ...	—	—	3,840	—	—	3,840	1

In the 1951-52 season an experiment was laid down to investigate the possibilities of growing sweet sorghum and ordinary local sorghum together with leguminous crops as a forage mixture. The sweet sorghum mixture was cut when the sorghum was forming seed, while the ordinary sorghum mixture was cut after the sorghum grain had been harvested separately. It is interesting to note that yields of sorghum grain were generally above average.

TABLE 504

YIELDS OF FORAGE MIXTURES, 1951-52

Crop	Yield in kg.p.f.			No. of Cuts
	Grain	Fodder fresh	Fodder dry	
Sweet sorghum and Phillipisara	—	13,620	8,700	2
Sweet sorghum and Dolichos lablab	—	9,480	3,660	2
Average	—	11,550	6,180	—
Sorghum Agono and Cowpeas	285	2,060	1,260	1
Sorghum Agono and Green gram	645	2,820	1,860	1
Sorghum Agono and Cluster bean	390	3,480	2,220	1
Sorghum Agono and Velvet bean	335	3,960	2,370	1
Sorghum Agono and Phillipisara	480	7,050	4,980	1
Sorghum Agono and Dolichos lablab	540	3,120	2,880	1
Average	446	3,748	2,595	—

Besides specially grown fodder crops, stovers of numerous crops have a value as animal fodder. In Table 505 we give the yields of stovers, averaged over three years and over all experiments of the main crops tried.

TABLE 505

YIELDS OF STOVERS, 1950-53

Crop	Average dry weight of stover kg.p.f.	Number of Observations
Sorghum Agono ...	1,905	13
Sorghum Luali	1,586	4
Maize	1,506	2
Groundnuts	775	20
Cowpeas	384	15

Samples of the main forage crops and stovers were sent for analysis to the Faculty of Agriculture, U.C.K. Table 506 gives the average analytical results. Unfortunately no digestibility trials could be performed and therefore these figures are of only limited value.

TABLE 506

RESULTS OF CHEMICAL ANALYSIS OF FODDER CROPS AND MIXTURES

Crop or Mixture	No. of Samples Averaged	Moisture %	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash	Silica
Sweet sorghum ...	10	7·66	11·52	1·88	27·49	48·30	10·08	6·09
Sudan grass	2	5·21	11·03	1·61	31·99	43·34	12·02	4·56
Cowpeas	5	5·54	13·81	2·01	36·18	38·19	9·82	2·51
Soya bean	1	5·95	15·08	2·68	31·79	44·40	5·99	0·27
Tepary bean	1	6·08	13·32	1·44	21·03	55·00	9·21	3·89
Green gram	2	3·60	9·66	1·31	38·06	42·90	9·06	2·06
Cluster bean	2	5·43	9·50	1·36	42·62	38·45	9·05	0·92
Phillipisara	1	5·08	10·97	2·87	29·64	47·67	8·85	1·05
Babun	1	4·70	10·75	1·68	48·14	27·94	11·49	2·26
Sword bean	1	6·05	9·49	1·44	40·93	39·22	8·92	1·33
Velvet bean	1	6·33	14·44	2·38	27·85	40·20	15·11	8·66
Dolichos lablab ...	1	5·53	10·98	1·83	41·02	34·85	11·33	4·60
FORAGE MIXTURES								
Sweet sorghum and								
Phillipisara ...	1	4·80	14·34	1·55	34·33	32·82	16·93	10·03
Dolichos lablab ...	1	7·10	11·87	1·32	30·68	44·61	11·52	5·95
Sorghum Agono and								
Cowpeas	1	4·80	10·53	1·89	33·51	43·91	10·08	4·34
Green gram ...	1	3·88	6·36	1·51	31·21	43·47	17·35	12·78
Cluster bean ...	1	4·70	10·13	1·76	31·11	46·03	10·94	4·60
Velvet bean ...	1	4·28	7·45	2·38	33·93	48·11	8·13	4·52
Phillipisara ...	1	5·50	11·25	1·69	30·61	43·77	12·68	6·03

UTILIZATION OF INTERMEDIATE LAND

DRAINAGE EXPERIMENTS

Intermediate land is subject to both flood and drought and consequently it can be utilized for a range of crops only if drainage is provided; it can be used without drainage for crops resistant to flood but not to drought, such as rice, if subsidiary irrigation is provided. The slope of the land is generally insufficient for an 'orthodox' drainage system, and so in 1951–52 experiments with 'drainage' by Killifer ridging were started. A Killifer plough (or ditcher) can make ridges of various shapes and sizes, as shown in Fig. G 8, the object of ridging being to raise the crop above the flood level. Yields of crops grown on Killifer ridges were generally disappointing. The volume of soil above the flood level which plant roots can utilize freely is too small for good development and yields; moreover, only half of the unit area can be utilized, the other half being flooded furrow.

However, Killifer ridging, as shown by these experiments, allows some yields to be obtained where otherwise there would be none.

UTILIZATION OF KILLIFER RIDGED LAND EXPERIMENTS

In the 1951–52 season the suitability of two different types of Killifer ridge for sorghum and maize was tried. This experiment has shown that the single ridge type (see Fig. G 8) is best, especially for a crop like maize. It has also shown that, with a wide-spaced crop such as sorghum, the number of ears produced per unit area can be higher on ridged than on unridged land, and therefore with such a crop the ridged area can be fully utilized.

TABLE 507

YIELDS OF SORGHUM AND MAIZE ON DIFFERENT TYPES OF KILLIFER RIDGES, 1951–52

Type of Ridging [1]	MAIZE (LOCAL)	SORGHUM (AGONO TYPE)	
	Yield in kg.p.f.	Yield in kg.p.f.	No. of ears per feddan
Control (unridged)	33	25	5,780
Double ridge	106	202	7,390
Single ridge	319	216	8,844

[1] See Fig. G 8.

In the 1951–52 and 1952–53 seasons experiments to ascertain the possibility of growing late-planted, quick-maturing crops in the furrows were carried out. Chick peas, in 1951–52, gave a promising yield of 105 kg.p.f. In the dry season of 1952–53, Feterita 1931 and chick peas failed because they were sown too late in this dry year.

In the 1951–52 season an experiment on the possibility of utilizing Killifer ridges with a mixed stand (native practice in this area) was carried out. This experiment suggested that sorghum benefited from interplanting with legumes; cowpeas were not affected, while the yield of *babun* (*Vigna vexillata*) was depressed by interplanting with sorghum. These results are comparable with those obtained on high land (see p. 994).

TABLE 508

EFFECT OF INTERPLANTING OF CROPS GROWN ON KILLIFER RIDGES, 1951–52

Crop	Interplanted with	Yield in kg.p.f.
Sorghum Agono ...	Pure stand	170
Sorghum Agono ...	Cowpeas	220
Sorghum Agono ...	Babun	270
Cowpeas	Pure Stand	75
Cowpeas	Sorghum	100
Babun	Pure stand	22
Babun	Sorghum	40

EXPERIMENTS ON THE INTRODUCTION OF NEW CROPS AND VARIETIES ON KILLIFER RIDGES

A series of crops and varieties, tried on high land, was also tried on Killifer ridges. The yields were generally lower than on the high land, but almost without exception the yields on unridged intermediate land were a complete failure.

CEREALS

Of the cereals, local types of sorghum are the most promising crops for Killifer ridged land. The yields of bulrush millet and finger millet showed little promise. Yields of maize were very erratic.

TABLE 509

YIELDS OF SORGHUM VARIETIES ON KILLIFER RIDGES, 1951–53

Variety	Yield in kg.p.f.			Number of years
	1951–52	1952–53	Average	
LOCAL VARIETIES				
Agono type mixed ...	170	110	140	2
Luali type mixed ...	105	70	87	2
Awet	360	—	360	1
Boweng	70	—	70	1
Challa	340	—	340	1
Average	209	90	199	—
NORTHERN VARIETIES				
Feterita 1931	85	—	85	1
Feterita Managil ...	40	—	40	1
Feterita Matuk	60	—	60	1
Feterita Suki	41	—	41	1
Wad Aker	85	—	85	1
Wad Fahal	340	—	340	1
Hegeiri	65	—	65	1
Milo Dwarf	75	—	75	1
Mugud Red	140	—	140	1
Korgi	240	—	240	1
Abu Sabain	20	—	20	1
Average	108	—	108	—
OTHER VARIETIES				
Martin Combine	65	—	65	1
Lafon	40	—	40	1
Olosingo	53	—	53	1
Average	53	—	53	1
Over-all average	126	90	123	—

TABLE 510

YIELDS OF CEREALS ON KILLIFER RIDGES, 1951-53

Crop	Variety	Yield in kg.p.f.			Number of years
		1951-52	1952-53	Average	
Maize ...	ECR/344	42	F	21	2
Bulrush Millet	ECR/205A Yellow awned	—	75	75	1
	ECR/205B Black awned	—	69	69	1
	ECR/344	87	81	84	2
Average ...	—	87	75	76	—
Finger Millet	ECR/377	—	110	110	1
	ECR/380	—	85	85	1
	ECR/401	—	35	35	1
	ECR/707	—	55	55	1
Average ...	—	—	71	71	—

OIL CROPS

Yields of oil crops tried in the 1951-52 season showed little promise, with the possible exception of sunflower.

TABLE 511

YIELDS OF OIL CROPS ON KILLIFER RIDGES, 1951-52

Crop	Variety	Yield kg.p.f.	Oil %	Oil kg.p.f.
Sunflower	Striped Grey	280	29·6	83
Sesame	Local	40	45·2	18
Hyptis	ECR/1188	140	24·0	33
	EB 2	80	17·0	14
Hyptis average ...	—	110	—	—
Safflower	Debeira	60	31·6	19
	American spineless	60	23·0	14
Safflower average	—	60	—	—
Castor	ECR 278	—	—	—

LEGUMINOUS CROPS

Groundnuts and soya beans showed little promise on Killifer ridges. The yields of other legumes on Killifer ridges were approximately half those of the high land, which is to be expected since only half the ridged area is actually under crop even when the crop is closely spaced.

TABLE 512

YIELDS OF LEGUMINOUS CROPS ON KILLIFER RIDGES, 1951-53

Crop	Variety	Yield in kg.p.f.		Average yield	Oil kg. p.f.
		1951-52	1952-53		
Groundnuts	Barberton	50	37	43	17
	American erect	70	110	90	30
Groundnuts average	—	60	73	66	23
Soya bean	ECR/124	50	—	—	6
	ECR/759	5	—	—	6
	ECR/973	60	—	—	11
	ECR/998	25	—	—	4
	ECR/999	30	—	—	5
Soya bean average	—	34	—	—	6
Cowpeas	ECR/77	60	—	60	—
	ECR/78	80	—	80	—
	Local	75	65	70	—
Cowpeas average	—	71	65	70	—
Tepary bean	—	45	—	—	—
Babun	ECR/174	85	—	—	—
Green gram	—	120	—	—	—
Velvet bean	ECR/1184	165	—	—	—

FIBRE CROPS

Yields of cotton on Killifer ridges were disappointing, but it should be remembered that in the 1951–52 season cotton suffered very badly from blackarm (neither variety planted was blackarm resistant) while in the 1952–53 season it suffered from drought.

TABLE 513

YIELDS OF COTTON ON KILLIFER RIDGES, 1951–53

Variety	Yield in kg.p.f. 1951–52	Yield in kg.p.f. 1952–53	Yield in kg.p.f. Average	Average Yield kantars (100) p.f.	Remarks
AMERICAN VARIETIES					
SP 84 ...	137	113	125	2·8	—
BAR NT/96 ...	—	104	104	2·3	—
BAR 7/8 ...	—	120	120	2·7	—
Average ...	137	112	116	2·6	—
EGYPTIAN VARIETIES				Kantars (315) p.f.	
BAR 14/25 ...	—	36	36	0·3	not irrigated
BAR 4/16 ...	—	32	32	0·2	not irrigated
BAR XL ...	139	—	139	1·0	irrigated Dec. & Jan. approx. 1,500 m³.
Average ...	139	34	69	0·5	—

Jute and Deccan hemp were also tried on Killifer ridged land but growth was so poor that they can be considered as failures.

FORAGE CROPS

The possibility of growing fodder crops on Killifer ridges was investigated in the 1951–52 season. Yields, as shown in Tables 514 and 515, were only approximately half those of high land. The yields of forage mixtures were rather better than those of crops planted in pure stands. All crops were cut at the seed-forming stage, before the nutritive value started decreasing.

TABLE 514

YIELDS OF FORAGE CROPS ON KILLIFER RIDGES, 1951–52

Crop	Variety	Yield in kg.p.f. fresh	Yield in kg.p.f. dry	No. of Cuts
CEREALS				
Sweet sorghum ...	ECR/337 Black top	2,260	1,135	2
	ECR/338 Red amber	2,100	1,130	2
Average ...	—	2,180	1,132	—
Sudan grass ...	ECR/1013	780	405	2
LEGUMINOUS CROPS				
Cowpeas ...	ECR/78	480	230	1
	ECR/79	1,070	560	1
	Local	390	200	1
Average ...	—	647	330	1
Green gram ...	ECR/65	1,805	810	1
Babun (*Vigna vexillata*) ...	ECR/174	220	160	1
Sword bean ...	ECR/757	2,360	1,560	1
Velvet bean ...	ECR/1184	1,670	1,280	1
Dolichos lablab ...	—	1,200	810	1

TABLE 515

YIELDS OF FORAGE MIXTURES ON KILLIFER RIDGES, 1951-52

Forage mixture	Yield in kg.p.f. fresh	Yield in kg.p.f. dry	No. of Cuts
Sorghum Agono and Cowpeas	3,225	1,190	2
Green gram	2,700	1,035	2
Babun	2,440	1,189	2
Velvet bean	2,664	1,107	2
Dolichos lablab	3,153	1,395	1
Phillipisara	2,553	1,070	2
Cluster bean	3,727	1,680	2
Tepary bean	3,213	1,150	2
Soya bean	3,325	1,378	2

In Table 516 the yields of stovers of local varieties of sorghum and of groundnuts collected from all experiments carried out on Killifer ridged land are summarized.

TABLE 516

YIELDS OF STOVERS OF LOCAL SORGHUM AND OF GROUNDNUTS, 1951-53

Crop	Average Yield for all Experiments in kg.p.f. fresh	Average Yield for all Experiments in kg.p.f. dry	Number of Records
Sorghum, Agono type	979	653	7
Sorghum, Luali type	800	520	3
Groundnuts, different varieties	499	244	5

EXPERIMENTS ON SUBSIDIARY IRRIGATION OF CROPS

These experiments were started in the 1951-52 season, when an area of 80 feddans, extended in the following year to 120 feddans, was canalized for irrigation. The experiments were carried out mainly by the Development Officer, Ministry of Agriculture, with the co-operation of the Team.[6]

RICE

During the first two seasons rice experiments were carried out on large observation plots only. Sowing was done by drill or by hand-broadcasting. As well as sowing into a normal 'dry' seed-bed, in 1951-52 and in 1952-53 an attempt was made to sow by broadcasting the seed, both dry and pre-soaked, on standing water. This method resulted in very poor stands, and the plots were abandoned. The explanation of this almost certainly lies in the lack of drainage facilities which would permit the draining-off of the water at the right time. This method of sowing, practised in the United States, is therefore unsuitable for rice cultivation on intermediate land unless drainage is provided.

In the 1952-53 season combine harvesting of rice was tried. The two main difficulties encountered were uneven maturation of rice varieties, and fields that were too wet at the time of harvesting. On the plots harvested by combine harvester, loss by shedding was estimated at 10%. A small 'plantation' type huller and polisher was tried; it was found to crack a large proportion of the seed. Consequently, the hulling percentages and yields of edible rice shown in Table 519 probably do not give a true picture.

Irrigation water in all experiments, with the exception of a water-duty experiment in the 1952-53 season, was applied as and when it was judged necessary. Analysis of the water application records shows that enough water must be given in the first two applications to saturate the soil thoroughly. A particularly large amount is necessary on fields where no irrigated rice has been grown in the previous season. For subsequent applications there is a general lessening in the quantity of water required to produce desirable moisture conditions. It is evident, however, that fields not irrigated and cultivated in the previous year require a larger quantity of water throughout the season (see Fig. L 1).

Analysis of the water application records also shows that the maximum quantity of water is required in the middle of the growing season, even though the quantity of rainfall is greatest at that time. Fields on which irrigated rice has not been grown during the previous season require a considerably larger quantity of irrigation water (see Fig. L 2). The total quantity of irrigation water which must be applied obviously depends on the rainfall. The average quantities supplied in the last two years are shown in Table 517.

TABLE 517

IRRIGATION AND TOTAL QUANTITY OF WATER SUPPLIED TO RICE IN GROWING SEASON, 1951–53(1)

Average Water	1951–52 Fields not previously irrigated m³.	1952–53	
		Fields not previously irrigated m³.	Fields previously irrigated m³.
Irrigation	1,815	3,346	2,357
Effective rainfall ...	3,175	1,198	1,198
Total	4,990	4,544	3,555

(1) The irrigation water supplied to different varieties is shown in Table 491.

In the 1952–53 season a simple trial of large plots (4-feddan observation plots) was carried out to investigate the water-duties of rice. Two types of rice were used on two plots each, and results indicate that, under local conditions and for the varieties tried, there is no advantage in renewing the water at weekly intervals and it is sufficient to make good by irrigation the losses from evaporation and seepage. They also indicate that after flooding from the sixth to the twelfth week after planting, it might be sufficient merely to keep the soil well moistened until maturation. Finally these results suggest that prolonged flooding, while beneficial to the swamp type of rice like the Fellata variety, may be harmful to upland rice. On the other hand upland rice seems to respond to initial flooding between the sixth and twelfth weeks of its growth.

TABLE 518

YIELDS OF RICE IN THE IRRIGATION TREATMENT TRIAL, 1952–53

Treatment	Average irrigation water m³.p.f.	Yield in kg.p.f.		
		Congo and Maridi varieties	Fellata variety	Average
Soil kept well moist	3,045	426	516	471
Flooded to 6" then level held	3,250	261	508	384
Flooded to 6" every 7 days, water drained off after 4 days	3,480	316	585	451
Flooded to 6" for 4 weeks then soil kept well moist ...	2,815	492	700	596

The manurial experiments carried out on rice are described on p. 992.

Small samples of numerous varieties of rice from different countries were received in 1951–52, and were then bulked up on nursery plots. During these first two seasons they were too small to permit assessment of yields. Eight varieties available locally in the Sudan were tried on large plots. The following belong to the upland type and came originally from the Belgian Congo:

Maridi
Congo
Congo 035
Congo 065
Congo 0110

The Yebani Pearl variety was supplied from Egypt. The Fellata variety was collected from Fellata tribesmen who cultivate it near El Jebelein. It proved the heaviest yielder, but it contains a large proportion of husks, sheds very badly and matures very unevenly. It is also pigmented, and is unsuitable for mechanical cultivation. The Yebani Pearl has given very poor yields. The varieties from the Congo have also given generally disappointing yields, but a lot has obviously to be learnt about their cultivation under local conditions, for which they may not be suitable. The results of variety trials are given in Table 519. Response to manuring with ammonium sulphate should be noted.

The low yields of rice on intermediate land are at least partly due to its very uneven fertility. Reasons for this patchy fertility have still to be found.

TABLE 519

YIELDS OF RICE VARIETIES, 1951–53

Variety	Non-manured Plots				Manured Plots					Over-all Averages			
	Season	Number of plots	Total area feddans	Yield unhusked rice kg.p.f.	Season	Number of plots	Total area feddans	Ammonium sulphate lb.p.f.	Yield unhusked rice kg.p.f.	Average irrigation water m^3.p.f.	Average yield unhusked rice kg.p.f.	Hulling %	Average yield edible rice kg.p.f.
Maridi	1951–52	2	5·0	345	1952–53	2	8	150	459	—	—	—	—
	1952–53	1	1·0	457	—	—	—	—	—	3,335	—	—	—
	Average	—	—	401	—	—	—	—	—	—	430	62	266
Yambio	1951–52	2	2·16	225	1952–53	1	4	400	460	1,550	341	70	239
Congo	1951–52	1	2·46	210	1952–53	2	8	150	288	2,427	249	59	147
Congo 035	1951–52	1	0·52	270	1952–53	1	4	100	589	1,770	430	57	245
Congo 065	1951–52	1	0·51	314	1952–53	1	4	100	193	2,055	253	61	154
Congo 0110	1951–52	1	0·53	290	1952–53	1	4	100	363	1,928	326	59	192
Yebani Pearl	—	—	—	—	1951–52	4	12	100	237	—	—	—	—
	—	—	—	—	1952–53	2	8	100	32	2,927	—	—	—
	—	—	—	—	Average	—	—	—	135	—	135	70	94
Fellata	1951–52	2	7·0	375	1951–52	1	4	100	600	—	—	—	—
	—	—	—	—	1952–53	4	16	150	578	3,142	—	—	—
	—	—	—	—	Average	—	—	—	589	—	517	40	207
Over-all mean	—	—	—	312	—	—	—	—	380	—	335	—	193

Coarse Fibres

Jute

In the 1951–52 season jute, planted on intermediate land, did not grow taller than 80–100 cm. and therefore was not worth harvesting for fibre. Four varieties were tried, and three (ECR/584, ECR/585 and ECR/612) were found to branch very badly. The promising variety, ECR/576, of Sudan origin, was sown again in the 1952–53 season. On that part of the field where complete NPK fertilizer was applied (ammonium sulphate 300 lb.p.f., superphosphate triple 400 lb.p.f. and sulphate of potash 300 lb.p.f.) the growth was considerably better than on the parts where only one kind of fertilizer was applied. The yield of the plot receiving NPK was 210 kg.p.f. of clean fibre. The other plots were not worth harvesting.

Deccan Hemp

In the 1951–52 season plots of Deccan hemp were very badly damaged by flea beetle, and not worth harvesting for fibre. In the 1952–53 season two varieties were sown and given the same manurial treatment as was jute. The plot given NPK fertilizer yielded as follows:

ECR/985. 270 kg.p.f. clean fibre.
ECR/980. 290 kg.p.f. clean fibre.

Flea beetle attack was heavy at an early stage of growth, but was successfully controlled by spraying with DDT.

Sunn Hemp

In the 1952–53 season this crop yielded only 41 kg.p.f. of clean fibre; it started flowering at the end of August when only six weeks old and 90–120 cm. tall.

As can be seen from these results, the coarse fibre crops tried cannot, in local conditions, give economic yields, even with the application of fertilizer. This is almost certainly due to too short a growing season between the beginning of the rains and the time when climatic conditions and/or length of day induce flowering in the varieties tried. Sunn hemp may have possibilities as a green manure.

UTILIZATION OF THE RIVERAIN FLOOD-PLAIN

Rice

These experiments were started in the 1950–51 season before the *toich* area was banked off to provide control over flooding. The Fellata variety was planted, and was flooded by the rising river to a depth of between 75 and 90 cm. just before harvest. The yield of the plot, harvested under water, was 817 kg.p.f. In the 1951–52 season the experiment was repeated with four varieties. Only part of each field was flooded, to a maximum depth of 30 cm. The fields were divided into two plots and harvested separately.

TABLE 520

YIELDS OF RICE VARIETIES ON *TOICH*, 1951–52

Variety	Yield in kg.p.f.	
	Flooded	Unflooded
Fellata	315	63
Congo	360	220
Yambio	210	120
Yebani Pearl	140	190
Average	256	148

In the 1952–53 season, when banks were built to permit control of flooding, a larger area of riverain flood-plain was sown with rice. Unfortunately the river was below average, and water had to be pumped on to some of the fields. Difficulty was also encountered in cultivating the uneven land, which carried a strong stand of indigenous grasses, and the crop was not sown until mid-August. Yields were as follows:

TABLE 521

YIELDS OF RICE VARIETIES ON *TOICH*, 1952-53

Variety	Area feddans	Yield in kg.p.f.
Fellata(*)	11·0	365
Congo	1·4	314
Yambio	4·5	344
Maridi	10·7	416
Average	—	360

(*) At least 50% lost by shedding.

COARSE FIBRES

JUTE

In the 1951–52 season four varieties of jute were sown on the *toich*. ECR/584, ECR/585 and ECR/612 again branched profusely and were not worth harvesting for fibre. ECR/576 grew to a height of 180–200 cm. and the yield was 365 kg.p.f. clean fibre. In the 1952–53 season ECR/576 yielded only 98 kg.p.f. clean fibre; this was due partly to late sowing and partly to severe competition from weeds. In both years a part of the jute plots was flooded to a depth of 15 cm. and this did not appear to affect growth unfavourably.

DECCAN HEMP

In 1952–53 Deccan hemp yielded as follows:

ECR/985. 540 kg.p.f. clean fibre
ECR/980. 416 kg.p.f. clean fibre

in spite of late sowing (2.8.52). Flooding appears to slow down the growth of this crop.

SUNN HEMP

Sown late in the 1952–53 season (17.8.52), this crop started flowering when only 120 cm. high. It was not harvested for fibre.

The yields of coarse fibre crops, especially Deccan hemp, on *toich* soils are more promising than on the other types of land. Further trials to assess the effects of flooding on these crops are needed.

DISEASES AND PESTS

DISEASES

Since the beginning of these experiments, samples of crops affected by diseases have been sent to the Plant Pathologist, Ministry of Agriculture Research Division. Results of identifications are summarized in Table 522 below.

PESTS

The pests at Malakal Experimental Farm included all forms, mammals, birds and insects, and practically all crops suffered to some degree. Table 523 gives a summary of the main pests attacking crops during the three seasons under consideration, and the extent of the damage inflicted.

TABLE 522

CROP DISEASES AT MALAKAL EXPERIMENTAL FARM, 1950-52 (IDENTIFIED BY THE PLANT PATHOLOGIST, MINISTRY OF AGRICULTURE RESEARCH DIVISION)

Crop	Disease		Season when found and identified	Degree of infection
Sorghum	Fungal leaf spot	*Cercospora sorghi* Ell. and Ev.	1950–51, 1951–52	Slight
	Fungal leaf spot	*Gloeocercospora sorghi* Bain and Edgerton	1950–51, 1951–52	Slight
	Fungal leaf spot	*Colletotrichum graminicola* (Ces.) Wilson	1950–51, 1951–52	Slight
	Fungal leaf spot	*Helminthosporium* sp. (*H. turcicum* Pass.) (?)	1950–51	Slight
	Fungal leaf spot	*Phoma indisiosa* Tassi	1950–51	Slight
	Covered smut	*Sphacelotheca sorghi* (Link.) Clint.	1951–52	Moderate
	Loose smut	*Sphacelotheca cruenta* (Kuhn) Potter	1951–52	Isolated cases
	Head smut	*Sphacelotheca reiliana* (Kuhn) Clint.	1951–52	Isolated cases
Maize	Fungal leaf stripe	*Helminthosporium* sp.	1950–51	Slight
	Maize streak disease	Virus (?)	1950–51	Slight
Bulrush millet	Rust	*Puccinia penniseti* Zimm.	1951–52	Serious
Rice	Sooty mould	*Cladosporium herbarum* Pers.	1950–51, 1951–52	Probably saprophytic
	Leaf spot	*Ophiobolus (Coshliobolus) miyabeanus* Ito and Kuribayashi (conidial stage of *Helminthosporium oryzae*) Breda de Haan	1951–52	Serious
	Leaf spot	*Nigrospora oryzae* Bek and Br.	1951–52	Slight
Sesame	Fungal leaf spot	*Cercospora sesami* Zimm.	1950–51, 1951–52	Slight
	'Blood disease'	*Pseudomonas sesamicola* Malkoff (?)	1950–51, 1951–52	Serious
Sunflower	Rust	*Puccinia helianthi* Schis.	1951–52	Serious
Safflower	Root rot	Cause unknown	1950–52	Serious
Castor	Leaf spot	*Cercospora ricinella* Sacc.	1950–51	Slight
	Zonate leaf spot	*Alternaria* sp. (*A. ricini* (Yoshi) Hansf.) (?)	1951–52	Slight
	Bacterial blight	*Xanthomonas ricinicola* (Elliot) Dawson (?)	1951–52	Slight
Groundnuts	Leaf spot	*Cercospora personata* Berk. and Curt.	1951–52	Slight
Soya bean	Bacterial blight	*Xanthomonas phaseoli* (E.F.Sm.) Dawson, var. *soiense*	1951–52	Serious
Bambara groundnuts	leaf spot	*Cercospora canescens* Ell. and Mart.	1951–52	Slight
Cowpeas	Bacterial blight	*Xanthomonas phaseoli* (E.F.Sm.) Dawson (?)	1950–51, 1951–52	Slight
	Leaf spot	*Cercospora canescens* Ell. and Mart.	1951–52	Moderate
	Leaf spot	*Phyllosticta phaseolorum* Sacc. (?)	1951–52	Moderate
	Rust	*Uromyces vignae* Barcl.	1951–52	Slight
Green gram	Leaf spot	*Cercospora canescens* Ell. and Mart.	1951–52	Moderate
	Leaf spot	*Phyllosticta* sp. (or *Ascochyta phaseolorum* Sacc.) (?)	1951–52	Moderate
Dolichos lablab	Bacterial blight	*Xanthomonas phaseoli* (E.F.Sm.) Dawson	1951–52	Slight
Velvet bean	Bacterial blight	*Xanthomonas phaseoli* (E.F.Sm.) Dawson	1951–52	Slight
Cotton	Blackarm	*Xanthomonas malvacearum* (E.F.Sm.) Dawson	1950–51	Serious
			1951–52	Serious, specially on varieties with B 2 factor only

TABLE 523

CROP PESTS AT MALAKAL EXPERIMENTAL FARM, 1950-53

Crop	Pest	Extent of Damage and Remarks
Sorghum	Grasshoppers and crickets	Seedling pests. Appreciable damage
	Millipedes	Seedling pests. Appreciable damage
	Blister beetle. *Epicauta grandiceps* Haag[1]	Seedling pests. Appreciable damage
	Blister beetle. *Psalydolia aegyptica* Wale[1]	Seedling pests. Appreciable damage
	Oleander hawk. *Daphnis nerii* L.[1]	Seedling pests. Appreciable damage
	Termites	Pest of seedlings and roots. Little damage
	Stem-borer. *Sesamia cretica* Led. ...	Damage very serious, specially in 1952-53 season
	Aphis. *Aphis sorghi* Theob.	Damage serious specially in 1952-53 season
	Shield bug. *Agonoscelis versicolor* ...	Slight damage (Ar. *Andat*)
	Birds (mainly weaver birds)	Damage at pre-harvest stage considerable
Maize	Seedling pests as for sorghum	Appreciable damage
	Stem-borer	Slight damage
	Dogs, jackals, foxes	Considerable damage, specially in 1950-51 season
Bulrush millet	Seedling pests as for sorghum	Appreciable damage
	Stem-borer	Slight damage
	Aphis	Slight damage only
	Birds	Slight damage to the awned varieties planted
Finger millet and small millets	Seedling pests as for sorghum	Often considerable damage
	Birds	Slight damage
Rice	Grasshoppers and crickets	Appreciable damage in early stages prior to flooding
	Birds	Appreciable damage in early stages prior to flooding
Sesame	Seedling pests as for sorghum	Slight damage
	Leaf roller. *Sylepta* sp.	Considerable damage
Sunflower	Seedling pests as for sorghum	Appreciable damage at cotyledon stage
	Termites	Considerable damage throughout the growing season
	Birds	Slight damage to heads
Hyptis spicigera ...	Head caterpillar (not identified)	Considerable damage in 1951-52 season
Safflower	Termites	Root damage in 1951-52 season
Castor	Termites	Seedling and subsequent damage appreciable
	Shield bug	Serious damage in 1951-52 season
Groundnuts	Termites	Considerable damage at early stages
	Birds (crows)	Very serious damage at pre-harvest stage, specially in 1952-53
Leguminous pulse crops	Seedling pests as for sorghum	Considerable damage
	White fly. *Bemisia gossypiperda* M. & L. ...	Appreciable damage
	Seed weevils	Appreciable damage
Cotton	Seedling pests as for sorghum	Appreciable damage
	Flea beetle. *Podagrica puncticollis* Wse.[1]	Appreciable damage
	White fly. *Bemisia gossypipedra*	Appreciable damage
	Thrips. *Hercothrips* sp.	Slight damage
	Aphis. *Aphis gossipyii* Glover	Slight damage
	Stem-boring beetle. *Ceroplesis irregularis* Har.[1]	Slight damage
	Cotton leaf roller (not identified)	Slight damage
	Sudan cotton worm *Xanthodes graellis* Feist.[1]	Appreciable damage
	Pink bollworm. *Platyedra gossypiella* Saunders	Serious damage in 1952-53 season
	Sudan bollworm. *Diparopsis castanea* ...	Appreciable damage
Jute	Flea beetle. *Podagrica puncticollis* Wse.[1]	Appreciable damage
	Leaf caterpillar (not identified)	Appreciable damage at early stage
Deccan hemp	Flea beetle. *Podagrica puncticollis* Wse.[1]	Very serious damage in 1950-51 and 1951-52 seasons
Sunn hemp	... ...	Remarkably free

(1) Identification confirmed by Government Entomologist, Ministry of Agriculture Research Division.

4. OTHER EXPERIMENTAL FARMS

ARIELBEK

Experiments at Arielbek were started in order that a rough assessment might be made of the yields and problems under conditions prevailing in the southern part of the Flood Region and in the neighbourhood of the Eastern Plain, which was thought to offer special grazing possibilities. They were discontinued after the first season, as it was found that the personnel available was insufficient.

The results of analysis of soil samples from Arielbek are as follows:

TABLE 524

RESULTS OF ANALYSIS OF SOIL SAMPLES FROM ARIELBEK

Depth ft.	Mechanical Analysis				
	Stones and gravel %	Coarse sand %	Fine sand %	Silt %	Clay %
0–1	0	21	35	3	42
1–2	1	24	34	7	34
2–3	1	24	31	5	39
3–4	3	17	27	6	46
4–5	8	15	31	5	41
5–6	15	14	28	5	39

Depth ft.	Chemical Analysis					
	pH	Salts %	$CaCO_3$ %	Sodium value	Nitrogen p.p.m.	Carbon %
0–1	8·32	0·027	0·43	5	277	0·254
1–2	9·13	0·048	0·48	13	217	0·203
2–3	9·32	0·069	0·95	17	284	0·240
3–4	9·36	0·090	1·50	16	200	0·167
4–5	9·36	0·081	2·40	17	210	0·138
5–6	9·26	0·090	2·30	15	175	0·097

The rain-gauge at Arielbek was not installed until August 1951. Records for that year are as follow:

September 108 mm.
October 92 mm.
November 42 mm.
December Nil

Previous rainfall in this year was definitely below average. Crop yields were poor, largely for this reason.

Cereals

Yields of the cereal varieties sown were as follows :

TABLE 525

YIELDS OF SORGHUM AT ARIELBEK, 1951–52

Variety	Yield in kg.p.f.	
	Sown on 29.5.51	Sown on 27.10.51
Athil[1] ...	57	105
Akur[1]	55	100
Challa[2]	10	50
Martin Combine	10	50
Feterita 1931 ...	135	135
Feterita Matuk	—	45
Feterita Suki ...	—	50
Average	53	76

[1] Dinka variety.
[2] Shilluk variety.

As can be seen from this table, the yields of the late sown (*angul*) crop were better than those of the early sown (*rap jang*) crop. The yields of other cereals were also very poor, as can be seen from Table 526.

TABLE 526

YIELDS OF OTHER CEREALS AT ARIELBEK, 1951-52

Crop	Variety	Yield in kg.p.f.
Maize	Local	35
Bulrush millet	ECR/344	65
Finger millet	ECR/377	60
Rice	Congo 065	35

OIL CROPS

The yields of oil crops were also low, as shown in the following table, though the castor yield was surprisingly good.

TABLE 527

YIELDS OF OIL CROPS AT ARIELBEK, 1951-52

Crop	Variety	Yield in kg.p.f.
Sesame	Local	30
Sunflower	Dwarf Manchurian	190
	Striped Grey	210
	Ex Kodok	105
Average	—	168
Safflower	Debeira ECR/601	70
Castor	ECR/278	240

LEGUMINOUS CROPS

Yields of leguminous crops were as follows:

TABLE 528

YIELDS OF LEGUMINOUS CROPS AT ARIELBEK, 1951-52

Crop	Variety	Yield in kg.p.f.
Groundnuts	Local	202
	American erect	200
Average	—	201
Soya bean	ECR/973	150
Bambara groundnut ...	—	100
Cowpea	Local	25
Tepary bean	—	80
Cluster bean	—	45
Green gram	ECR/65	60
Haricot bean	Local	20

FIBRE CROPS

The yield of cotton was unexpectedly good, the variety SP 84 yielding 310 kg.p.f. of seed cotton.

Considering the poor rainfall, the yield of Deccan hemp was also surprisingly good:

ECR/985. 150 kg.p.f. clean fibre.
ECR/986. 170 kg.p.f. clean fibre.

Yields of experiments at Arielbek were poor not only because of bad rainfall distribution but also because the inevitable lack of supervision resulted in standards of cultivation little above those of the local inhabitants.

FANGAK

During the 1951-52 season the Team carried out, in collaboration with the District Commissioner, Central Nuer District, a series of trials on observation plots at Fangak.

Rainfall at Fangak during the 1951–52 season was well below average:

Rainfall, 1951–52 .. 578 mm.
Average .. .. 1,111 mm.

Yields were as follows:

TABLE 529

YIELDS OF OBSERVATION PLOTS AT FANGAK, 1951–52

Crop	Variety	Yield in kg.p.f.
CEREALS		
Sorghum	Dair	410
	Bilwich	450
	Agono	433
	Feterita 1931	225
	Lafon	105
	Olosingo	122
Average	—	291
Bulrush millet ...	ECR/344	195
Finger millet	ECR/377	90
OIL CROPS		
Sunflower ...	Dwarf Manchurian	60
	Striped Grey	480
	Ex Kodok	280
Average	—	273
LEGUMINOUS CROPS		
Groundnuts ...	Local	230
Soya bean ...	ECR/973	120
Cowpeas	Local	200
Tepary bean ...	—	180
Cluster bean ...	—	140
Green gram ...	—	180

The standard of cultivation of these plots can be described as moderate.

KODOK

In the 1952–53 season the Team supervised a few observation plots at Kodok, the experiments being carried out by the local Agricultural Officer. Rainfall during the season was above average:

1952–53 .. .. 814 mm.
Average .. .. 663 mm.

Pests, in particular birds, caused considerable damage to some crops.

TABLE 530

YIELDS OF OBSERVATION PLOTS AT KODOK, 1952–53

Crop	Variety	Yield in kg.p.f.
CEREALS		
Sorghum	Agono	17
	Luali	176
	Feterita	56
Average	—	83
Bulrush millet ...	—	113
Finger millet	—	F
Rice (rain-grown) ...	—	65
OIL CROPS		
Sesame	—	F
Sunflower ...	Dwarf Manchurian	106
	Striped Grey	262
	Ex Kodok	308
Average	—	225
LEGUMINOUS CROPS		
Groundnuts ...	Local	170
Soya bean ...	—	20
Cowpeas	Local	239
Tepary bean ...	—	10
Green gram ...	—	76

Low yields were partly due to low standards of cultivation.

NOTES AND REFERENCES

(1) Ferguson, H., ' Note on Experiments in Tonj Aweil Area 1942–46 ', Sudan Government Report. Unpublished.

(2) Moir, T. R. G.

(3) Moir, T. R. G., ' Malakal Agricultural Station Reports, 1952–53. Report on Rice Cultivation Experiments ', Sudan Government Report. Unpublished.

(4) Analysis of the oil content of these crops was carried out by the Government Chemist on samples of the 1951–52 crop. It should be remembered that these figures were obtained by chemical analysis, and would not necessarily be obtained by mechanical extraction.

(5) For further details see: Moir, T. R. G., ' Report on Experiments in Rice Production 1951 ', and ' Malakal Agricultural Station Reports 1952–53 ' (including : ' Report on Rice Cultivation Experiments '; ' Water Requirements of Rice Crops under Pump Irrigation '; ' Fibre Crops ').

CHAPTER 6. GRASSLAND EXPERIMENTS.

1. INTRODUCTION

The most obvious, practicable, and least expensive alternative to riverain pastures no longer available under the Equatorial Nile Project is to make use of the vast areas of grassland to be found inland away from the rivers. The principal limiting factor appears at first sight to be the absence of adequate water supplies during the dry months of the year. Our investigation of domestic water supplies indicated that there would be little or no difficulty in providing suitably distributed water-points, in the form of either surface storage or deep-bore wells. It remained debatable, however, whether these grasslands were sufficiently palatable and nutritive for pasture, and if they were, whether there was adequate grazing to support, for the period required, the numbers of animals displaced from the river-front. Trials and experiments were obviously necessary to determine these very important points, as well as to find out whether inland grasslands could be improved by any of the various methods suggested in Chapter 6, Volume II. The only other alternative—apart from alternative livelihood in the form of crop husbandry or mixed husbandry—is the provision of irrigated pastures, either gravity or pump irrigation schemes, which are notoriously expensive to install and run. Irrigated pasture, however, might be the only possible remedy whatever the economic implications, and trials and experiments had to be carried out in the establishment, water-duties, herbage production, and value of irrigated pasture grasses, both indigenous and exotic.

It must be noted that the Jonglei Investigation Team was specifically instructed by the Jonglei Committee to carry out only such short-term trials as might give indications of the answers to these problems. More precise answers could only be expected from long-term trials for which there was clearly insufficient time. It must also be appreciated that the post of Pasture Research Officer on the Team was only filled at the end of 1950, five years after the start of the investigation and two years after the present Team had begun its programme of work. Moreover, the Veterinary and Pasture Section of the Team was engaged in more general survey work carrying its two members to all parts of the Jonglei Area, and it was not possible to give all experimental work the time it most certainly deserved. Local Sudanese staff had to be trained, and it was quite impossible to give constant or adequate supervision to their work on trials which extended from Kosti to Bor, a distance of about 570 miles by road. The experiments and trials recorded in this chapter are therefore in many cases of a very preliminary and superficial nature and the results must be confirmed or otherwise by a more elaborate programme of experimental work. They provide nonetheless some idea of the herbage production, nutritive value, palatability, and stock-carrying capacities of the main types of pasture found in the Jonglei Area, information which was completely lacking at the outset of our investigation.

2. NATURAL PASTURES

THE EASTERN PLAIN

The Eastern Plain lies between the high land along the east side of the Bahr el Jebel and the high land along the west banks of the Khor Veveno and Pibor River, between latitudes 6° N. and 8° N. approximately. At the outset of our investigation existing maps of the area showed no features except a few irregular water channels along the southern and northern limits, the Khors Geni and Tuni to the east, and the Khor Amwom to the west. The possibilities of this vast plain as an alternative to riverain grazing in the dry season were first given prominence by Harrison (*T.I.R.*, Appendix III) after he had made a hurried tour round the perimeter in 1948. This was in the middle of the dry season when most of the coarse grass had been burnt off and the extent of regrowth was impressive. Local information suggested that the whole plain was " a continuous thick cover of *Hyparrhenia rufa* with a sprinkling of *Andropogon gayanus* and a trace of both *Panicum* spp. and *Sporobolus pyramidalis* " and that the regrowth in the centre of the plain was as good as, if not better than, that seen from the motor road.

The need for a thorough investigation of the plain in general, and of the quality, quantity, and reliability of *Hyparrhenia* regrowth in particular, was fully appreciated, but the personnel was not available. Eventually work started in April 1950 under the Veterinary Inspector, advised by the Pasture Research Officer, S.V.S. (Harrison), and with the co-operation of the Dean, Faculty of Agriculture (Boyns). The collection of samples of grass regrowth over such a large area, in which the few roads are only open in the dry season and in which the grass grows from widely spaced tussocks about 20 cm. high (like large molehills), presented many new problems. Some of them were only partly solved, and inaccuracies in the data collected had to be accepted and allowance made.

The main objects of the investigation were to determine:

(i) The distribution of dry season regrowth after the coarse rains season growth of grass had been burnt.

(ii) The quality and quantity of dry season regrowth at all stages after burning.

(iii) The reliability of such regrowth in different areas and at different seasons; and hence

(iv) The general stock-carrying capacity of the plain in the dry season, January to May.

NATURE OF THE INVESTIGATION

To give an indication of the quantity and quality of regrowth produced, samples of regrowth had to be collected, weighed, and analysed over a number of dry seasons. A series of sampling units was erected around the perimeter of the plain, accessible from the motor road passing through Ayod, Kongor, Bor, Pibor, Akobo, Waat, and back to Ayod, a distance of 490 km. Since the raised road alters the natural surface drainage and hence is likely to affect grass regrowth, each sampling unit had to be divided into two blocks, Block I being on the side of the road with greater flooding and Block II on the side of lesser flooding (see Fig. L 3). Each block was a square measuring 8 m. by 8 m., protected by a wire-netting fence, and was subdivided into four quarters called Plots A, B, C, and D (each 4 m. × 4 m.). The intention was that each plot within a block should be subject to a different treatment, namely:

A to be cut every two weeks.
B " " " " four weeks.
C " " " " eight weeks.
D " " " " twelve weeks and at the end of the experimental season.

By taking samples at different intervals and at different stages of growth it was hoped to get an indication of the best system of pasture management. Sampling was to consist of: recording the average length of grass regrowth; cutting the regrowth, with scissors, to ground level as though it had been heavily grazed; weighing the collected sample as soon as it was cut; storing it in a special collecting basket made of very fine mesh wire-netting in order to dry it; weighing the sample when dry; retaining the sample in a cloth bag for analysis. The analysis of several hundred individual samples was not considered practicable or necessary, and it was decided to bulk all samples having similar treatment and have them analysed on a dry matter basis.

This was the intended plan, but it could not be followed exactly for various practical reasons. First, by the time the motor road had opened (late December) some of the areas where units were to be sited were already burnt and the regrowth partly grazed, while other areas were still too wet to burn. This meant that plots having similar treatments would not all be comparable because of different dates of burning. Secondly, it was soon found that two weeks was too short a period to permit of sufficient regrowth for sampling purposes. In addition, delays due to transport troubles and to other necessary work made it impossible to work to a fixed timetable; but taking the date of burning as the starting point, plots generally were cut as follows:

A after 5, 8, 12, and 16 weeks.
B after 8 and 16 weeks.
C after 12 and 16 weeks.
D after 16 weeks.

Because of the difficulty of bulking like samples, all samples from the 1950–51 series were analysed separately.

To relate the information gathered from the sampling units to actual visible stock-carrying capacity an area of sixty feddans of apparently typical plain was fenced in April 1950 near Pengko in Bor District. (We say 'apparently' because subsequent investigation revealed that this area actually lay within a wide drainage depression.) This area was divided into two halves, one being treated as a single paddock and the other sub-divided into three paddocks each of ten feddans. A herd of cattle was bought and a cement-faced brick trough erected beside the well at Pengko village for watering the herd during the dry season. The cattle grazed in and around the village during the rains, and in February 1951, three weeks after the coarse rains growth of grass had been burnt, the test herd moved into the fenced area. The small paddocks, 1, 2 and 3, were grazed in rotation—ten days in each paddock; the large single paddock, No. 4, was grazed continuously throughout the dry season. The information gained is recorded in full in the succeeding pages.

It was intended to trek on foot across the plain in one or more places to confirm or refute the information of the local inhabitants that the whole plain was one uniform stand of *Hyparrhenia rufa* and that the regrowth probably improved towards the centre of the plain. Such a trek is not simple. During and immediately after the rains, when there is adequate drinking-water in pools, the coarse grass is so high that visibility is nil. There are no paths or tracks except those of game animals. In the dry season, when the grass has been burnt, visibility is good and the going much less trying, but water-points are few and difficult to locate. For these reasons this undertaking was abandoned, and to get a broad impression of this large area two aerial reconnaissances were made in March 1951, covering the whole area of the plain. These flights provided ample evidence that previous information was misleading and had led to a much too optimistic view of the grazing possibilities of the Eastern Plain. The only persistent green regrowth of *Hyparrhenia rufa* noted was that in the broad south-north drainage lines and it seems clear that only the limited area of these depressions can be expected to provide a reasonably reliable alternative to lost riverain pasture.

Having described the nature of the survey, we turn to the details.

AIR RECONNAISSANCE

To get a general picture of the extent of the Eastern Plain and the degree of regrowth over its whole area at the end of the dry season, an air reconnaissance was carried out on 16th and 17th March 1951. This consisted of two flights, and a sketch map showing the degree of regrowth seen on these two days has been prepared (see Fig. E 13).

From the actual route reports of the flights some general observations can be made. It must be recognized, however, that interpretation of ground conditions, grass species, types of regrowth, and other such details is not easy from an altitude of 1,500 feet, at which the reconnaissance was mainly conducted.

The Eastern Plain is not a great, homogeneous area producing green regrowth throughout the dry season. Approximately 50% of the area bounded by Duk Fadiat-Pengko-Pibor-Akobo either was not burnt or had not produced visible regrowth; 30% had produced regrowth which had dried to a red-purple colour; 15% had been burnt and had produced a faint green regrowth; and 5% had been burnt and still produced strong, green regrowth at the time of the flight. Without exception the areas of strong, green regrowth were confined to depressions having a general south-north bearing (or rather south to north-west and south to north-east). Where cattle or game were seen the fact was recorded, but as both flights were completed by mid-morning (10.44 and 11.39 hrs.) many herds of cattle must still have been in their villages, it being the Nilotic practice to release the cattle for grazing rather late in the morning. However, the presence of cattle coincided with the presence of open water—except near to Duk Fadiat where it is known that there are wells. On several occasions herds of game (tiang) and cattle were seen grazing on land which showed no green regrowth. Sometimes the land appeared black as if there were no regrowth, although the animals were definitely grazing there; in other places herds were grazing where there appeared to be regrowth but dried and purple in colour. It is possible therefore that the impression of the quality of regrowth obtained by the air reconnaissance is unduly pessimistic. The main cattle concentrations were on the lower Veveno and Lotilla, the lower and middle reaches of Khors Geni and Tuni, the upper Khor Atar, and the upper Khor Fullus.

The areas where regrowth appeared strong and green but where cattle were not seen were:

(i) The western margin of the plain between Kongor and Pengko. Only two isolated pools were seen in this vicinity, so it may be assumed that lack of drinking-water accounted for the absence of cattle.

(ii) The 20–25 miles of plain eastwards from Pengko. Though cattle were not observed, it is known that cattle do graze in this area as long as there is adequate drinking-water. The sketch map suggests that this area consists of irregular depressions which in all probability become continuous northwards as the upper Khor Geni. It would be reasonable to suppose that the plain's regrowth between Pengko and the middle Geni was as useful in the middle as at either end.

(iii) The upper Khor Atar, north of Chieth Bridge. Although there were six herds of cattle seen in the near vicinity of Chieth Bridge, the area of green regrowth appeared to be capable of accommodating a much greater number. There was not much open water and this may have been a limiting factor.

Two areas where regrowth was faint green or had dried to a purple colour were:

(iv) The plain east of the line Duk Fadiat to Kongor. Herds of cattle were seen at the northern end of this area where there were pools of open water. Farther south no cattle were seen and only one line of dried-out pools was observed.

(v) The plain east and west of the upper Khor Nyanding, particularly to the east. This is a known dry season haunt of tiang.

THE COLLECTION AND ANALYSIS OF GRASS SAMPLES

Between December 1950 and February 1951 eleven sampling units were set up on the perimeter of the Eastern Plain. The units were not placed at random and the reason for their positioning is given briefly thus:

S.U. I. This is near Ayod, about the northern limit of the area grazed throughout the dry season by Gaweir herds watering from wells in the upper Khor Atar (*vide* Appendix III, *T.I.R.*).

S.U. II and S.U. III. Placed at one-third and two-thirds distance from Duk Faiwil to Kongor. Both areas are grazed in the dry season by Nyareweng and Twi Dinka cattle and water is generally the limiting factor.

S.U. IV. Alongside Pengko Test Area for correlation with the latter.

S.U. V and S.U. VI. At 15-mile intervals eastwards from Pengko. It did not appear to be worth while erecting any units farther east (on that latitude) than S.U. VI because evidence of flooding and regrowth was absent, the ground adjacent to Khor Veveno being higher than most parts of the plain.

S.U. VII. An area burnt off early in the dry season, perhaps November, where regrowth was good and grazing already in progress in January 1951.

S.U. VIII. The northern extremity of the plain extending from Lukwangali before entering open *Combretum* forest near to Akobo. Farther north is slightly higher ground with more *Setaria* spp. than *Hyparrhenia rufa*.

S.U. IX. Typical of the country between Khors Geni and Tuni at the Akobo-Waat latitude. This area is grazed by large herds of game, mainly tiang, during the dry season.

S.U. X. Near the western limit of the flood-plain on the Akobo-Waat Road; five miles to the west is higher land which is continuous with the Duk Ridge except for a few well-defined depressions or khors.

S.U. XI. At Mwot Tot. This unit contains a large mixture of grasses and is not typical of the Eastern Plain. It is included because cattle are known to graze there throughout the dry season in most years.

In the actual collection of grass samples it was intended to simulate grazing by leaving about 1½ inches of leaf at each cut. Owing to the tussock formation of *Hyparrhenia rufa* this was not an easy task for the type of labour involved, and ragged cuts were likely to give false indications as to seasonal or period growth. Also the only suitable way of cutting samples was to cut individual shoots with small scissors (1½" blade) -a most laborious process. From the outset any coarse growth remaining after burning was removed down to soil level (of the clump) and thereafter shoots of regrowth were clipped down to soil level. This may have interfered with the natural regrowth owing to damage to the growing point, but it ensured uniformity and the method was continued throughout the season.

The small quantities of grass involved in each sample required a degree of accuracy in weighing (fresh and dry weights to obtain moisture content) which was not achieved. The spring balances used (Salter's maximum 12 kg., minimum 250 gm.) would not have been adequate even in expert hands. The only reliable measure of quantity is therefore the dry weight recorded at the Faculty of Agriculture, Shambat.

A system of bulking like samples was devised to reduce the number of analyses, but owing to the uncertainty of its application all samples from the first season (1950–51) were analysed individually. A second series of samples was collected (1951–52) and weights recorded, but there was neither time nor need for further analyses.

Full records have not been included here but the information is summarized in Tables 531 to 539 below.

GRASS SAMPLING UNITS: SUMMARY

1. From 76 sample plots at eleven widely separated places around the Eastern Plain samples of regrowth were cut at varying intervals during the dry season and fresh and dry weights recorded.

2. Only samples for the season 1950–51 were subjected to chemical analysis. The best samples gave an analysis, on dry matter basis, similar to good English meadow hay.

3. The greatest quantity of crude protein per plot nearly always came from first cuts after burning of the coarse growth. That is to say that, on the average, a plot still green in March after two previous cuts would only produce a fraction (60%) of that from a plot of similar size which had not previously been cut.

4. Over the whole season, plots B produced the greatest quantity of crude protein as well as the greatest dried weight. If this trend is confirmed, it is a useful guide in deciding a system of management. (Plots B, though their coarse grass was burnt off in December-January, were left untouched until March: a second cut was taken in May.)

5. Over the whole season and taking totals for all plots, the average air-dried weight of regrowth per feddan was 123 kg. and 106 kg. in 1950–51 and 1951–52 respectively. The mean is 114 kg. per feddan.

6. On the average, one feddan produced 9·3 kg. crude protein in the season 1950–51.

7. Assuming that 10 kg. of dry regrowth will provide a maintenance-plus ration for one Animal Unit for one day, the area required for one Animal Unit for the five-month period January to May inclusive would be 12·3 feddans. If only the areas of robust regrowth in the shallow depressions are considered, 7·3 feddans per Animal Unit is enough.

TABLE 531

HYPARRHENIA RUFA REGROWTH ANALYSIS

(On Dry Matter Basis)

(Selected Samples from 16 sq. m. Plots)

Sample No.	Cut	Date of		Approx. Fresh Weight in gm.	Dry Weight in gm.	% Moisture	Percentage of Dry Matter					% SiO_2	% Ca	% P
		Burning	Sampling				Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash			
51/80	1st cut	8/1/51	17/2/51	450	224·0	3·10	9·39	2·40	23·04	51·23	13·93	8·41	0·40	0·11
51/95	ditto	1/1/51	2/3/51	250	205·9	3·88	7·11	2·42	24·79	53·79	11·89	7·54	0·43	0·22
51/110	ditto	8/1/51	3/4/51	500	202·0	3·55	6·99	2·67	23·33	55·90	11·02	7·29	0·56	0·21
51/125	ditto	8/1/51	7/5/51	250	237·0	5·00	5·53	2·45	22·95	56·39	12·68	9·82	not recorded	
51/180	subsequent cut (short)	20/12/50	3/5/51	250	160·0	5·03	8·15	2·74	24·30	53·12	11·69	7·88	ditto	
51/170	subsequent cut (medium)	4/1/51	7/3/51	500	156·1	3·53	9·75	1·97	24·13	46·89	17·26	12·00	ditto	
51/202	subsequent cut (long)	4/1/51	7/5/51	500	226·0	5·13	11·16	2·11	24·30	52·26	10·17	5·51	ditto	

TABLE 532

EASTERN PLAIN SAMPLING UNITS

AIR-DRIED WEIGHTS 1951

(In grammes)

Unit	Block	Plot A	No. of Cuts	Plot B	No. of Cuts	Plot C	No. of Cuts	Plot D	No. of Cuts	Total
I	I	752	3	533	1	562	1	438	1	2,285
I	II	157	1	206	1	73	1	90	1	526
II	I	537	4	635	2	223	2	465	1	1,860
II	II	424	4	525	2	483	1	400	1	1,832
III	I	567	3	524	2	406	2	290	1	1,787
IV	I	637	4	1,066	2	1,203	2	1,029	1	3,935
IV	II	442	4	888	2	465	2	975	1	2,770
V	I	930	4	956	2	1,160	2	919	1	3,965
V	II	871	4	1,247	2	1,181	2	1,308	1	4,607
VI	I	195	1	149	1	409	2	455	1	1,208
VI	II	224	1	240	1	202	1	237	1	903
VII	I	506	1	320	1	203	1	264	1	1,293
VII	II	314	1	198	1	253	1	303	1	1,068
VIII	I	72	1	279	2	63	2	330	1	744
IX	I	111	2	147	1	323	1	255	1	836
IX	II	134	2	103	2	281	2	139	1	657
X	I	385	4	359	2	375	2	519	1	1,638
X	II	384	3	578	2	496	2	427	1	1,885
Total for 18 feddans		7,642		8,953		8,361		8,843		33,799

(1) In the eight comparable units of two blocks the regrowth in general was greatest where the road increased the degree of flooding. The average difference is calculated at 21·8 kg. (air-dried weight) per feddan.

(2) The greatest quantity of regrowth was produced from the two units situated within 15 miles from Pengko, i.e. to the east (see Fig. E 13).

(3) Area of each plot 16 sq. m. Weight taken to nearest gramme.

TABLE 533

EASTERN PLAIN SAMPLING UNITS

ABSOLUTE DRY WEIGHTS, 1951

(In grammes)

Unit	Block	Plot A	No. of Cuts	Plot B	No. of Cuts	Plot C	No. of Cuts	Plot D	No. of Cuts	Total
I	I	720	3	518	1	543	1	414	1	2,195
I	II	152	1	198	1	71	1	85	1	506
II	I	517	4	608	2	215	2	438	1	1,778
II	II	405	4	504	2	465	1	377	1	1,751
III	I	544	3	504	2	391	2	273	1	1,712
IV	I	604	4	1,012	2	1,137	2	968	1	3,721
IV	II	352	3	846	2	444	2	939	1	2,581
V	I	884	4	912	2	1,115	2	869	1	3,780
V	II	833	4	1,198	2	1,137	2	1,258	1	4,426
VI	I	189	1	143	1	371	1	428	1	1,131
VI	II	217	1	231	1	195	1	225	1	868
VII	I	490	1	307	1	197	1	252	1	1,246
VII	II	304	1	191	1	243	1	288	1	1,026
VIII	I	68	1	269	2	61	1	312	1	710
IX	I	107	2	143	1	312	1	241	1	803
IX	II	128	2	99	2	271	2	131	1	629
X	I	368	4	344	2	361	2	492	1	1,565
X	II	369	3	555	2	473	2	403	1	1,800
Total for 18 feddans		7,251		8,582		8,002	-	8,393		32,228

Area of each plot 16 sq. m. Weight taken to nearest gramme.

TABLE 534

EASTERN PLAIN SAMPLING UNITS

DRY MATTER PER FEDDAN, 1951

(In kilogrammes)

Unit	Block	Plot A	Plot B	Plot C	Plot D	Total
I	I	189	136	143	109	577
I	II	40	52	19	22	133
II	I	136	160	56	115	467
II	II	106	132	122	99	459
III	I	143	132	103	72	450
IV	I	159	266	298	254	977
IV	II	92	222	117	246	677
V	I	232	239	293	228	992
V	II	219	314	298	330	1,161
VI	I	50	38	97	112	297
VI	II	57	61	51	59	228
VII	I	129	81	52	66	328
VII	II	80	50	64	76	270
VIII	I	18	71	16	82	187
IX	I	28	38	82	63	211
IX	II	34	26	71	34	165
X	I	97	90	95	129	411
X	II	97	146	124	106	473
Total for 18 feddans	... ...	1,906	2,254	2,101	2,202	8,463

Absolute dry matter based on 16 sq. m. plots.

TABLE 535

EASTERN PLAIN SAMPLING UNITS

CRUDE PROTEIN PER FEDDAN, 1951

(In kilogrammes)

Unit	Block	Plot A	Plot B	Plot C	Plot D	Total
I	I	17·8	11·2	10·2	6·4	45·6
I	II	4·3	3·8	1·3	1·2	10·6
II	I	14·6	12·8	4·8	8·4	40·6
II	II	12·3	12·5	10·1	3·4	38·3
III	I	12·7	11·9	8·1	2·3	35·0
IV	I	18·0	22·5	24·6	16·6	81·7
IV	II	10·3	18·6	11·0	19·5	59·4
V	I	20·3	19·1	19·8	6·2	65·4
V	II	24·2	28·0	24·0	20·0	96·2
VI	I	4·7	3·1	7·2	5·9	20·9
VI	II	5·5	5·2	3·7	3·4	17·8
VII	I	9·6	5·4	3·1	2·9	21·0
VII	II	6·4	3·2	3·8	4·0	17·4
VIII	I	1·5	5·6	1·5	4·6	13·2
IX	I	3·0	3·6	5·3	3·5	15·4
IX	II	3·1	2·2	5·4	1·9	12·6
X	I	10·2	8·5	7·8	9·2	35·7
X	II	10·7	13·4	10·4	6·9	41·4
Total for 18 feddans	... ...	189·2	190·6	162·1	126·3	668·2

Based on 16 sq. m. plots.

TABLE 536

EASTERN PLAIN SAMPLING UNITS
AIR-DRIED WEIGHTS, 1952
(In grammes)

Unit	Block	Plot A	No. of Cuts	Plot B	No. of Cuts	Plot C	No. of Cuts	Plot D	No. of Cuts	Total for Unit
I	I	—	—	—	—	—	—	—	—	—
I	II	—	—	—	—	—	—	—	—	—
II	I	506	3	562	1	—	—	—	—	1,068
II	II	224	3	260	2	109	1	—	—	593
III	I	158	2	199	2	185	2	—	—	542
IV	I	643	3	372	2	759	2	625	2	2,399
IV	II	219	2	712	2	555	2	356	1	1,842
V	I	756	4	837	3	1,215	2	1,329	2	4,137
V	II	1,497	5	1,165	3	1,169	2	1,408	2	5,239
VI	I	980	3	1,032	3	988	2	862	2	3,862
VI	II	445	3	433	3	636	1	602	2	2,116
VII	I	203	1	301	1	234	1	332	1	1,070
VII	II	542	1	472	1	363	1	523	1	1,900
VIII	I	961	2	1,092	2	1,110	1	789	1	3,952
IX	I	162	1	—	—	—	—	—	—	162
IX	II	70	1	49	1	104	1	—	—	223
X	I	76	1	—	—	—	—	65	1	141
X	II	—	—	—	—	—	—	—	—	—
Total for 18 plots		7,442		7,486		7,427		6,891		29,246

(1) Maximum regrowth from plots cut at the beginning of March and again in May (Plot B).

(2) In the seven comparable units of two blocks the regrowth was greatest when the road increased the degree of flooding. The average difference is calculated at 8·7 kg. (air-dried weight) per feddan.

(3) The greatest quantity of regrowth was produced from the three units between Pengko and the eastern Bor-Pibor boundary (IV, V, and VI).

(4) Area of each plot 16 sq. m.

TABLE 537

HYPARRHENIA RUFA REGROWTH
SUMMARY OF ANALYSES, 1951

INITIAL CUTS AFTER BURNING

	No. of Samples	Average % Crude Protein	Average % Crude Fibre	Average Air-Dried Weight per Plot in gm.	Quantity Crude Protein per Plot in gm.
February	14	9·58	23·94	256·6	24·58
March	18	8·14	24·48	269·1	21·90
April	15	6·73	24·26	396·3	26·67
May	16	5·04	25·48	410·0	20·66

SUBSEQUENT CUTS

Cut No.	No. of Samples	Period of Regrowth in Weeks	Average % Crude Protein	Average % Crude Fibre	Average Air-Dried Weight per Plot in gm.	Quantity Crude Protein per Plot in gm.
2	4	3	10·14	24·28	130·8	13·26
	3	4	9·83	26·91	156·2	15·35
	8	5	9·87	26·17	64·2	6·34
	5	8	8·24	24·98	317·7	26·17
	4	9	9·32	26·65	127·1	11·83
3	3	6	9·97	24·52	81·8	8·15
	6	7	10·11	26·01	152·0	15·36
4	6	5	10·28	24·71	102·8	10·56

Area of each plot 16 sq. m.

TABLE 538

ANDROPOGON REGROWTH, 1950–51

Percentage Present	Average Length in cm.	Period of Regrowth in weeks	Percentage Crude Protein in Dry Matter
Over 40	6	7	9·070 (short)
Over 40	10	11	10·344 (medium)
Over 40	19·4	11	9·101 (long)
10	17·6	13	8·447 (long)

TABLE 539

REGROWTH FROM MIXED PASTURE AT MWOT TOT, 1950–51

Sample No.	Period of Regrowth in weeks	Length of Regrowth in cm.	Cut No.	Percentage Crude Protein in Dry Matter	Dried Weight in gm.
65 *a*	9	19	1	11·07	42·5
65 *b*	3	8	2	10·32	179·0
65 *c*	4	4	3	8·87	507·4
65 *d*	12	14	1	7·77	620·0
65 *e*	16	10	1	6·76	534·0

(1) Samples Nos. 65 *a*, *b* and *c* are all from Plot A; Sample No. 65 *d* is from Plot B; Sample No. 65 *e* is from Plot C. *As a result of early and regular cutting the percentage crude protein of Plot A samples is higher, even in samples cut later in the season.*

(2) The grass mixture is approximately:

Hyparrhenia rufa		40%
Panicum porphyrrhizos		40%
Sporobolus sp.	(Nuer *wai*)	20%

(3) Area of each plot 16 sq. m.

THE PENGKO TEST AREA

About four kilometres east of Pengko on the south side of the Bor to Pibor road a 60-feddan field was fenced in April 1950, using local wooden poles and two strands of barbed wire. The fence was intended merely to assist the local herdsman to keep the test animals in, but later experience showed that one designed to keep wild animals out was really required. During the 1950 rains season no records of rainfall or flooding were kept, but it was recorded that on 4th November surface water was 45 to 60 cm. deep along the fence nearest the road (north) and 30 cm. deep along the side farthest from the road. By the middle of December no surface water remained although the surface was still soft mud, and most of the cattle from Pengko village were still at Anyidi (10 miles west) to which they had retreated because of the unusually heavy flooding at Pengko. This high degree of flooding was reflected in the robust regrowth in the succeeding dry season.

Even at the beginning of January 1951 the coarse grass within the field was too wet and green to burn and it was not fired until 20th January. Three weeks later the test herd entered the field and grazed there daily from 12th February until 31st May, half in paddock 4 (30 feddans) and half in rotation in paddocks 1, 2 and 3 (each 10 feddans). The cattle spent each night at the camp at Pengko, and it was noted that they avidly grazed the coarse, unburned grass around the village, presumably because the green regrowth in the test field did not provide sufficient bulk or roughage.

During February and March the regrowth was strong, fresh and succulent but as the ground dried out it became less robust, until after 3rd May there was no active regrowth. The green shoots dried to a delicate brittleness and to a brown or purple colour. It was still enough to support the 30 cattle concerned, but their foraging outside, mainly on dry *Setaria incrassata*, must be taken into account, since it provided a substantial contribution to their feed in the form of bulk. The grazing periods in each paddock are shown in Table 540.

Five wire cages, each 2 m. × 1 m., were placed in Paddocks 1, 2 and 3 on the day the herd entered each paddock and the grass they protected was cut at the end of the 10-day grazing period, when the herd was moved to the next paddock. The dry weights of the cuts, shown in

Table 541, were equivalent to 525 kg.p.f. over the season. The area actually grazed was 60 feddans and the total number of Animal Unit days grazing was 3,034 (Table 540). Thus the daily consumption per Animal Unit was 10·4 kg.

Records from succeeding years have shown that the regrowth in the 1950–51 dry season was particularly good. In fact in the following season there was not sufficient regrowth in the field for the test cattle to graze. Reference to the previous section shows that the adjacent unit, No. IV (128 sq. m.), produced a total of 6·78 kg. dry weight of regrowth in 1951 but only 4·03 kg. in 1952, and the visual difference was even more pronounced. An explanation for this marked decrease can be found in examining the rainfall figures for the preceding rains. The 1951 rainfall records for Bor show that up to 22nd September only 61% of the annual average rainfall had fallen. As would be expected, there was much less rain-flooding than in the previous year. During June no surface water was recorded at the test field. In July there was an average of 6 cm. depth of flooding at the corner posts. This rose slightly to 6·9 cm. during August but decreased quickly in September till the third week, after which it was not measurable (cf. 30 cm. in October 1950). As a result the test field was burnt off in early December instead of late January, and where regrowth was cut in January and February there was no further regrowth until encouraged by the early rains in May.

A rains season without flooding was a good season for the livestock. There were no deaths —compared with eleven in the 1950 rains season—and the general condition of the stock in October 1951 was greatly improved. Admittedly, the high mortality in the previous rains was in part due to the fact that several cows—the older and poorer beasts—calved at that time and, in their weakened state, were less able to cope with the flood conditions: calf mortality was a reflection of adult weakness. During the 1951 rains season there was neither severe flooding nor parturition.

Although there was not enough regrowth for grazing in the test field in the 1952 dry season, the herd remained at Pengko and grazed regrowth, mainly to the west of Pengko where the grass had been burnt very early and late rains had encouraged regrowth. Most of this was dead and dry by the beginning of 1952, but the cattle remained in good condition and calved satisfactorily. Of the three deaths (one abortion, one calf at birth, one calf pneumonia) none could be attributed to undernourishment.

The area covered by the grazing herd in the 1952 dry season was very wide since practically all local cattle had moved to the river (lack of water), but the fact remains that the herd thrived where there appeared to be little pasture. The drawback is in the unreliability of the regrowth and the large area required per Animal Unit to ensure health and production.

Milk records were kept from January 1951 and the yield showed a general rise until June, after which it again declined until April 1952, with a minor rise in December–January. The highest average daily yield was recorded in May 1952—our latest records; monthly yields are shown in Table 542 (p. 1032) in which the benefit of the robust green regrowth of the 1950–51 dry season is most apparent.

Another item of interest is that in the period February to April 1952 nine calves were born as compared with one in the previous six months, so that the 'drying-off' period coincided with the dry season. There was no control over breeding in this herd, and whether or not this indicates a definite breeding season we cannot say on so little data.

The source of the test herd itself must be recorded. It was collected entirely from government 'fines' cattle, except for two young stud bulls which were purchased from a nearby Murle herd. The first sixteen animals were rather a poor lot, with some old and barren cows, and they arrived at Pengko at the end of the 1949–50 dry season. During the 1950 rains they had to contend with flood conditions which at times made grazing very difficult. Before the rains had started one bull died of trypanosomiasis. At the height of the rains three old cows carried and produced calves but had not the energy to cope with mud and flood when grazing. They gave no milk, so that their calves died, and then they expired themselves from weakness and exhaustion. The second batch of 'fines' cattle arrived in December 1950 and were a much better lot; but before the disease was recognised trypanosomiasis had accounted for two more cows and their young calves died of starvation. The only other casualty was an old barren cow disposed of as meat. Thus, out of a total of 47 animals, eleven died of disease or other natural causes in the first year as compared with three, all calves, in the first six months of the second year (see Table 543).

Two general conclusions can be drawn at this stage. First, that a season of heavy rainfall and considerable flooding is followed by a dry season with strong grass regrowth which encourages milk production; and a season of low rainfall and little flooding is followed by a dry season with poor regrowth and low production. Secondly, that a season of high rainfall and heavy flooding is a great trial to livestock, particularly pregnant cattle, which have great difficulty in grazing; they are therefore not in a physical state to make the best use of the robust regrowth in the dry season following. On the other hand a season of low rainfall and light flooding greatly increases the survival rate of livestock, not only because the physical conditions at the time are better but also because cattle begin the dry season in good condition and can take advantage of the green regrowth inland or the lush swamp pastures at the river. This indicates that any development of the Eastern Plain must ensure adequate flooding of intermediate land during the rains to produce sufficient regrowth for use in the dry season, and also improved drainage of high land to prevent flooding in areas required for utilization during the rains.

TABLE 540

PENGKO TEST AREA
INTENSITY OF STOCKING, 1951

	Paddock 1	Paddock 2	Paddock 3	Paddock 4	TOTAL
Area in feddans	10	10	10	30	60
Period 1	12/2–21/2	22/2–3/3	4/3–13/3	12/2–31/3	—
Period 2	14/3–23/3	24/3–2/4	3/4–12/4	—	—
Period 3	13/4–22/4	23/4–2/5	3/5–12/5	—	—
Period 4	13/5–22/5	23/5–31/5	—	—	—
No. of days grazing	40	39	30	109	109
No. of Animal Unit* days	550	533	400	1,551	3,034

Thus: Intensity of stocking is 0·46 A.U.* per feddan, or 115·75 A.U. per sq. km.

* 1 Animal Unit (A.U.) is 1 adult cow or 8 sheep or goats.

TABLE 541

PENGKO TEST AREA
QUANTITY OF REGROWTH, 1951

DATE OF BURNING 20/1/1951

Cut No.	Date of Cutting	Fresh Weight in kg.	Dry Weight in kg.	Total Dry Weight from 30 sq. m. in kg.
PADDOCK No. 1				
1	21·2	1·25	0·312	—
2	23·3	1·25	0·376	—
3	22·4	0·75	0·319	—
4	22·5	Not recorded	0·347	—
Total			1·354	
PADDOCK No. 2				
1	3·3	1·0	0·228	—
2	2·4	0·75	0·455	—
3	2·5	0·60	0·334	—
4	31·5	Not recorded	0·402	—
Total			1·419	
PADDOCK No. 3				
1.	13·3	1·5	0·326	—
2	12·4	0·75	0·383	—
3	12·5	0·5	0·269	—
Total			0·978	3·751 kg.

Produced by 10 sq. m. protected by sampling cages in each paddock.

TABLE 542

PENGKO TEST HERD

MILK YIELDS, 1951–52

Month	No. of days recorded	No. of cows in milk	Average daily yield in pints
January 1951 ...		5	1·88
February „ ...	Every	6	3·00
March „ ...	four	6	3·26
April „ ...	days	8	3·68
May „ ...		8	2·88
June 1951 ...	28	7	3·34
July „ ...	29	7	2·83
August „ ...	27	7	2·26
September „ ...	29	6	1·76
October „ ...	29	3	1·81
November „ ...	29	3	1·69
December 1951 ...	29	3	1·80
January 1952 ...	27	4	1·94
February „ ...	18	5	1·48
March „ ...	14	8	1·40
April „ ...	18	6	2·85
May „ ...	17	9	4·36

TABLE 543

PENGKO TEST HERD

HERD RECORD

Date	Stud Bulls	Steers	Young Bulls	Cows	Heifers	Bull Calves	Cow Calves	Total
As at 31/5/50 ...	2	—	2	8	4	1	—	17
Purchased	—	—	—	9	5	1	4	19
Born	—	—	—	—	—	6	5	11
Died	1	—	—	5	—	3	2	11
Disposed of	—	—	—	1	—	—	—	1
As at 31/5/51 ...	1	—	2	11	9	5	7	35
Re-grading	2	2	1	11	11	3	5	35
Purchased	1	1	—	—	—	—	—	2
Born	—	—	—	—	—	—	1	1
Died	—	—	—	—	—	—	—	—
Disposed of	—	—	—	1	1	—	—	2
As at 30/11/51 ...	3	3	1	10	10	3	6	36
Purchased	—	—	—	—	—	—	—	—
Born	—	—	—	—	—	4	6	10
Died	—	—	—	—	—	1	2	3
Disposed of	—	—	—	—	—	—	—	—
As at 31/5/52 ...	3	3	1	10	10	6	10	43
Re-grading	3	3	4	13	12	3	5	43

CONCLUSIONS

It is fully realized that the information presented here is quite inadequate for forming final conclusions, but in the absence of any outside information we must depend upon it to form an opinion of the value of the Eastern Plain as an alternative to dry season grazing along the river. In doing so we have to remember that the 1950–51 dry season, from which the bulk of our data is drawn, was a particularly good dry season for *Hyparrhenia* regrowth when compared with succeeding seasons.

Nevertheless we have shown that cattle can live and thrive on intermediate land pasture, dominated by *Hyparrhenia rufa*, throughout the year without recourse to riverain pasture. When dry season regrowth fails in one part there is generally plenty elsewhere, and the absence of a supply of drinking-water is the main drawback. Regrowth alone is insufficient to promote well-being and an adequate supply of roughage is essential. Usually there is sufficient left unburnt, but this is quite fortuitous.

During the 1950–51 dry season the stock-carrying capacity of the best regrowth—that within the fenced field—was just under 3 feddans per Animal Unit, but all the roughage was obtained outside the field and the test animals were also allowed to graze the stubble of dura grain (owing to the absence of responsible supervision).

Because the amount of regrowth produced varies from area to area and from season to season, the indications are that a more reliable stocking rate would be one Animal Unit to 8 feddans (where regrowth is generally robust) or to 12·5 feddans (of average regrowth). To develop the plain as a dry season grazing area the two principal requirements are to ensure sufficient flooding by controlling drainage and to provide adequate domestic water supplies.

THE RIVER FLOOD-PLAIN

The vegetation of the river flood-plain of the White Nile system is composed of a great many species, of which only four grasses are present in sufficient quantity to warrant close study at this stage, namely *Vossia cuspidata*, *Echinochloa stagnina*, *Echinochloa pyramidalis* and *Oryza barthii*. Throughout most of the Jonglei Area *Vossia cuspidata* is extremely coarse, is not attractive to stock, and has therefore not received detailed attention. In Volume I (pp. 272–5) we have described the two main pasture types as 'shallow-flooded', consisting of *E. pyramidalis* and *O. barthii*, and 'deep-flooded', consisting of *E. stagnina*. Before the effects of the Project could be estimated, the periods of usefulness and stock-carrying capacities of these types had to be determined. Practically no data concerning these aspects were available at the outset of this investigation and the results of such experimental work as we have been able to carry out are recorded in the succeeding pages.

NATURE OF THE INVESTIGATION

The object of this investigation was to ascertain the quantity and quality of dry season fodder produced by each of the two main types of riverain pasture, shallow-flooded and deep-flooded, and to record any variation from area to area or from year to year. For this purpose permanent grass sampling units were set up on the river flood-plain, protected from domestic and wild animals; local practices of grassland management were followed, and samples were collected at suitable fixed intervals of time. Weights and chemical analyses of samples were recorded, and from them an indication of the stock-carrying capacity of riverain pasture was obtained. The information gained from these experiments is not great because of the number of difficulties that had to be overcome; the principal one was the complete absence of qualified technical staff until the arrival of the Pasture Research Officer at the end of 1950.

Grass sampling units were set up on the river flood-plain in Bor District in January 1951, but by that time some of the pasture had already been grazed and the samples collected did not represent a full dry season's growth. In the 1951 rains season the river level remained low throughout, and much of the flood-plain was not inundated; units sited on shallow-flooded pasture received water from rainfall only. But in October the river level (in Bor District) rose, and the units on deep-flooded pasture were flooded and remained inaccessible until April 1952. Thus the 1952 season samples were even less complete than those of 1951.

The organization of two grazing experiments received setbacks in the form of encroaching fires, inferior experimental animals, and the impossibility of regular close supervision, but in the assessment of stock-carrying capacity the results are considered to be more reliable than those from the sampling units.

THE COLLECTION AND ANALYSIS OF GRASS SAMPLES

Seven sampling units were erected on the flood-plain in Bor District (east bank) in January 1951. Each was a square 4 m. × 4 m. protected by a 40-inch strip of wire netting topped by a single strand of barbed wire, all supported by corner posts of angle iron. The treatment of shallow-flooded pasture (Units V, VI, and VII) was to burn off the coarse flood season growth of grass as soon as the flood-water had receded and the grass was dry enough, and then to cut the succeeding regrowth from the whole of the unit at monthly intervals.

Deep-flooded pasture (Units I, II, III, and IV) was not burnt, and a successful method of sampling has yet to be devised. Since cattle graze the grass while it is still flooded, samples should be taken then; but it is very difficult to simulate the extent of trampling that occurs during grazing. In the process of trampling grass stems are crushed and bent, and later forced into the mud where they take root at the nodes. From these nodes, too, the green shoots appear and it is this 'treatment' which ensures a good thick sward when the surface water disappears. This was not appreciated in the first season (1951), when the pasture was allowed to dry out before first samples were collected. The removal of all growth at that time made the production of regrowth almost impossible, and the partial removal of coarse growth was equally unsatisfactory.

In the second season (1952) samples were collected from deep-flooded units, while there was still 50 cm. of water, by cutting that part of the grass above water-level and trampling the remainder. But, as previously recorded, the river level rose instead of falling, and either the units were too deeply flooded to allow access or there was no regrowth above the water-level. Additional units were set up on the flood-plain north of Malakal at the beginning of the 1951–52 dry season, but lack of staff and damage to fences prevented the collection of a complete season's growth from any of the new units.

Although the figures are incomplete, the weights of samples of both shallow-flooded and deep-flooded pasture from the river flood-plain in Bor District are given, and the average weights of edible herbage per feddan are calculated for comparison (Tables 547 and 548). It will be seen that deep-flooded pasture produces dry season edible herbage seven times greater by weight than that of shallow-flooded pasture. The difference may not be as great as these figures suggest, as will be seen when we come to describe the actual grazing experiments. Nevertheless there is a marked difference; deep-flooded pasture is much more valuable than shallow-flooded pasture, especially in the first half of the grazing season.

Some of the samples of shallow-flooded pasture were analysed (Jonglei Nos. 122–131, 147–153, 156, 158) and the crude protein content was found to vary from 4·92% (cut at Melut in March) to 18·28% (cut in April at Jonglei) with an average of 13·84% for the eighteen samples. Eleven samples of deep-flooded grasses analysed (Jonglei Nos. 135–146) had a range of crude protein from 6·28% to 16·76% with an average of 10·82%; samples of mature grass were included in the latter series.

When these percentages are applied to the figures for herbage yields (Tables 547 and 548) we calculate that shallow-flooded pasture produced 28·5 kg. and deep-flooded pasture 155 kg. crude protein per feddan (cf. *Hyparrhenia rufa* regrowth with an average of 9·5 kg. crude protein per feddan). But it is repeated that the samples do not represent a complete season's growth, and that eight plots, each only 16 sq. m. in area, cannot be considered truly representative of the whole river flood-plain between Juba and Kosti.

TABLE 544

SHALLOW-FLOODED GRASS

ANALYSIS

Jonglei Ref.	Shambat Ref.	Date of Cutting	Area cut in sq. m.	Height of grass in cm.	Weight of sample in kg. Fresh	Weight of sample in kg. Dry	Fraction for analysis	Dry weight of fraction in gm.	% Moisture in fraction	On Dry Matter Basis: Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash	Silica	Remarks
119	52/70	30.3.51	16	10	0·50	—	whole	476·0	3·58	13·39	2·31	28·26	40·58	15·45	10·79	*E. pyramidalis* and *Oryza* sp.: 79 days' regrowth after burning.
120	/71	4.5.51	16	6	1·50	—	part	64·3	3·58	16·43	2·47	25·39	42·44	13·28	8·40	*E. pyramidalis*: 35 days' regrowth after burning.
121	/72	4.5.51	16	14	1·75	—	whole	435·5	3·75	15·64	2·42	25·35	41·63	14·96	8·65	ditto
122	/165	7.5.52	12	—	0·25	0·25	whole	271·1	5·58	15·29	2·36	26·14	42·67	13·54	11·39	
123	/166	4.6.52	12	—	5·25	1·00	part	330·5	5·58	17·56	2·36	28·47	35·43	16·18	8·61	
124	/167	29.6.52	12	—	7·50	1·50	part	413·0	4·85	13·34	2·29	31·09	39·75	13·54	7·51	
125	/168	24.4.52	12	—	3·00	1·25	whole	941·6	6·18	10·96	2·91	30·11	40·25	15·77	9·17	
126	/169	16.5.52	12	—	0·50	0·25	whole	316·2	6·23	13·34	2·67	32·15	36·24	15·60	9·31	*Echinochloa pyramidalis* and *Oryza* sp. regrowth cut within experimental grazing field on Awarajok Island.
127	/170	14.6.52	12	—	2·75	0·75	part	359·4	7·13	16·82	3·59	28·78	36·73	14·08	7·91	
128	/171	14.4.52	12	—	6·25	2·00	whole	2,390·0	5·95	10·88	2·18	31·26	37·87	17·81	10·35	
129	/172	2.5.52	12	—	0·75	0·25	whole	259·6	6·68	12·38	2·18	33·41	35·80	16·23	9·27	
130	/173	27.5.52	12	—	3.50	0·75	part	283·2	6·03	15·46	2·45	32·60	32·38	17·11	9·29	
131	/174	26.6.52	12	—	4·50	1·00	part	299·0	7·28	11·60	2·37	29·61	38·73	17·69	10·30	
147	/189	4.5.52	16	18	0·75	0·50	whole	280·1	6·85	14·79	2·74	28·40	41·14	12·94	7·17	1 month after burning.
148	/190	4.4.52	16	15	0·25	0·25	whole	140·0	5·68	18·28	3·05	24·15	41·23	13·28	8·69	*E. pyramidalis* regrowth cut from sampling units at Jonglei — 4 months after burning.
149	/191	4.5.52	16	21	2·25	0·75	whole	527·7	5·83	13·61	2·50	28·51	43·23	12·16	4·88	1 month after cutting.
150	/192	4.4.52	16	10	0·25	0·25	whole	65·7	5·55	8·62	1·96	26·26	46·54	16·62	11·06	4 months after burning.
151	/193	4.5.52	16	18	2·75	0·75	whole	507·0	7·28	14·62	1·62	29·82	41·75	12·19	4·64	1 month after cutting.
152	/194	22.2.52	16	—	6·00	4·75	part	3,420·0	6·03	4·26	0·88	35·52	46·38	12·98	9·68	*E. pyramidalis* cut at Kodok — Mature grass.
153	/195	10.4.52	16	—	0·50	0·25	whole	255·8	6·93	10·20	2·74	25·79	37·10	24·18	20·58	2 months 'regrowth after cutting.
156	/198	30.3.52	16	—	2·00	2·00	whole	3,000·0	5·78	4·92	0·90	31·71	48·68	13·78	8·28	*E. pyramidalis* and *Oryza* sp. cut at Melut — Regrowth 14 weeks after cutting
158	/200	12.12.52	2	30	—	—	whole	627·8	4·80	5·56	1·58	35·98	44·92	11·97	8·67	Mature growth

TABLE 545
DEEP-FLOODED GRASS
ANALYSIS

Jonglei Ref.	Shambat Ref.	Date of Cutting	Area cut in sq. m.	Average length in cm.	Weight of sample in kg. Fresh	Weight of sample in kg. Dry	Fraction for analysis	Dry weight of fraction in gm.	% Moisture in fraction	On Dry Matter Basis: Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash	Silica	Remarks
113	52/64	5.3.51	4	8	1·25	0·61	whole	547·1	3·28	13·35	1·22	28·69	39·81	16·94	8·61	*E. stagnina*: 23 days' regrowth after removing coarse growth
114	/65	31.3.51	8	45	17·5	—	part	418·1	4·35	16·56	1·99	27·13	40·31	14·01	5·28	,, 59 days' regrowth after cutting
115	/66	5.3.51	16	15	4·00	2·50	part	145·0	3·75	16·77	2·42	27·67	40·21	12·94	7·95	,, 23 days' regrowth after cutting
116	/67	31.3.51	16	14	4·00	1·70	whole	1,700·0	3·15	4·30	1·70	36·24	47·23	10·53	7·36	,, 26 days' regrowth after cutting
117	/68	9.2.51	8	—	31·20	—	part	2,500·0	3·30	5·79	0·93	35·60	47·09	10·58	6·83	,, mature flood-season growth
118	/69	4.5.51	16	—	0·50	0·16	whole	99·2	3·60	8·08	1·38	31·46	45·46	13·62	9·06	,, 34 days' regrowth after burning
132	/175	28.2.52	—	—	29·25	—	part	517·2	6·28	4·34	1·23	33·72	43·34	17·37	13·58	Mixed sample of mature *E. stagnina*, *E. pyramidalis* and *Oryza*
133	/176	17.4.52	—	—	2·00	1·25	part	571·7	6·63	13·63	2·41	28·15	40·52	15·29	9·10	*E. stagnina*: approx. 60 days' re-growth, part sample
134	/177	4.6.52	—	—	3·00	0·50	whole	478·0	6·28	8·22	1·33	33·82	43·61	13·02	8·32	*E. stagnina*: 48 days' regrowth after cutting
135	/178	5.3.52	16	150	13·25	2·30	part	1,050·0	6·63	6·28	1·55	31·89	48·39	11·89	8·49	,, mature flood season growth
137	/180	5.5.52	16	170	10·00	1·25	part	551·6	7·45	13·81	2·49	31·31	40·53	11·86	6·46	,, 30 days' regrowth after cutting
138	/181	5.1.52	16	100	3·00	0·50	whole	550·0	7·28	8·12	1·11	31·33	48·92	10·52	5·99	,, regrowth after grazing
139	/182	5.2.52	16	30	11·25	1·50	whole	1,350·2	6·45	9·87	1·18	34·15	43·07	11·74	5·22	,, 31 days' regrowth after cutting
140	/183	6.4.52	16	60	6·00	2·50	part	863·8	6·65	11·72	1·66	27·96	45·56	13·10	6·83	,, 60 days' regrowth after cutting
141	/184	5.5.52	16	50	3·75	1·00	part	457·5	6·80	16·76	2·02	30·40	36·39	14·43	7·11	,, 29 days' regrowth after cutting
142	/185	9.12.51	4	60	5·9	0·75	part	740·0	6·48	7·07	1·37	32·83	41·89	16·84	13·74	,, 4 sq. m. cut to ground level; remainder cut leaving 9" of stem
143	/186	4.2.52	16	50	11·00	2·50	whole	2,585·0	6·88	11·42	2·04	30·96	40·93	14·66	9·13	,, unit had been under water; regrowth robust
144	/187	4.3.52	16	6	1·25	1·00	whole	639·9	6·95	9·88	1·83	28·73	47·88	11·69	7·36	,, poor regrowth from area cut for 142
145	/188	4.4.52	16	17	1·00	0·50	whole	349·1	7·65	10·71	2·04	29·56	45·19	12·51	8·45	,, 31 days' regrowth, not strong
146	/189	4.5.52	16	21	4·75	1·00	part	478·3	7·83	13·39	2·09	29·98	41·85	12·69	7·32	,, 30 days' regrowth, strong
155	/197	10.4.52	16	—	2·75	0·75	whole	761·6	6·43	7·06	1·44	30·01	43·53	17·95	13·57	,, 49 days' regrowth after cutting
157	/199	30.3.52	16	—	3·75	3·75	part	1,648·3	4·73	4·18	1·24	31·80	48·47	14·31	10·60	,, mature growth partly consumed by grazing animals.

TABLE 546

ECHINOCHLOA PYRAMIDALIS

ANALYSIS, DIGESTIBILITY COEFFICIENTS, AND DIGESTIBLE NUTRIENTS OF MATURE GRASS

(One Sample: Jonglei Ref. No. 44: Shambat Ref. D.T. No. 37)

	Moisture	Organic Matter	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extractives	Ash	Silica SiO_2	S.E.	T.D.N.
Composition of Dry Matter	4·38	87·07	3·30	1·13	30·96	51·69	12·92	10·34	—	—
Digestibility Coefficients	—	60·30	21·02	43·52	63·32	61·37	—	—	—	—
Above, in parts of fodder actually consumed by sheep ...	—	66·30	24·23	48·75	68·57	67·73	—	—	—	—
Digestible Nutrients ...	—	52·50	0·69	0·49	19·60	31·72	—	—	41·93	52·62
Above, in parts of fodder actually consumed by sheep ...	—	57·73	0·80	0·55	21·23	35·01	—	—	48·09	57·48

TABLE 547

SHALLOW-FLOODED PASTURE
HERBAGE YIELDS
(All weights in kg.)

Unit No.	Year	1st Cuts after Burning	Subsequent Cuts	Total Fresh Weight	Average Percentage Moisture	Total Dry Weight
VI	1951	0·50	1·50	2·00	70	0·6
VI	1952	2·60	0·75	3·35	70	1·00
VII	1951	0·50	1·75	2·25	70	0·68
VII	1952	0·25	2·25	2·50	70	0·75
VIII	1952	0·25	2·75	3·00	70	0·90
Total from 80 sq. m.	—	4·10	9·00	13·10	70	3·93
Total from 1 feddan (4,200 sq. m.) ...	—	—	—	688	—	206

TABLE 548

DEEP-FLOODED PASTURE
HERBAGE YIELDS
(All weights in kg.)

Unit No.	Year	1st Cuts after Burning	Subsequent Cuts	Total Fresh Weight	Average Percentage Moisture	Total Dry Weight
I	1951	14·00	33·25	47·25	80	9·45
I	1952	3·50	10·00	13·50	80	2·70
I(*a*)	1952	6·00	5·25	11·25	80	2·25
II	1951	5·30	8·00	13·30	80	2·66
II	1952	13·25	10·25	23·50	80	4·70
III	1952	9·75	2·00	11·75	80	2·35
IV	1951	62·40	0·50	62·90	80	12·58
IV	1952	9·50	10·00	19·50	80	3·90
V	1951	28·50	0·25	28·75	80	5·75
V	1952	23·60	18·25	41·85	80	8·37
Total for 160 sq. m.				273·55	80	54·71
Total from 1 feddan (4,200 sq. m.) ...				7,181		1,436

GRAZING EXPERIMENTS

The direct method of ascertaining the stock-carrying capacity of a particular type of pasture is to select a known area typical of that pasture and have it grazed to capacity, recording the number of Animal Unit days grazing provided throughout the season. To be reliable the experiment should continue for a number of years so that an average figure may be obtained. The two experiments which are described below were of too short duration to yield figures of accuracy, but they give a useful indication of the carrying capacities of the pastures investigated.

SHALLOW-FLOODED PASTURE

Early in 1950, as soon as the flood-waters from the 1949 high river had receded and the coarse growth of grass had been burnt, an area of 30 feddans of typical shallow-flooded pasture was fenced on Awarajok Island (near Malakal) and divided into four paddocks; Paddocks 1, 3, and 4 were each 5 feddans and Paddock 2 measured 15 feddans. Normally most of Awarajok Island is under water from July until the following January or February, and in 1950, owing to pressure of other duties, the burning of the grass, erection of the fences, and transference to the island of the test herd of cattle were not completed until the beginning of May. By that time the regrowth of grass was so vigorous that a total of 90 head of cattle could not graze down more than 25 of the 30 feddans. The attempt to mow the regrowth by machine (an Allen scythe) was not successful owing to the uneven surface created by the carpet of charred stems.

In 1951 the river level fell sufficiently by mid-February to allow work to commence. A 5-metre strip of grass was cut by hand on either side of all fences, to protect the posts, and the whole area was fired on 12th February. Since the grass was not perfectly dry, combustion was not complete and a thin layer of scorched and twisted stalks remained. The new growth appeared and the herd was transferred to the island camp on 20th March; but on 22nd March a fire from the other end of the island spread to and fired the layer of scorched residue within the fenced area. In this disaster some of the fence and all of the pasture in Paddocks 1 and 2 were destroyed. As a result of this only Paddocks 3 and 4 were available for grazing until 20th May, and even then the regrowth was weak and the ground cover poor. Thus in 1951 a herd of 30 cattle could not be maintained throughout the dry season on an area 5 feddans larger than that which had supported 90 head, though for a shorter period, the previous year. These details are recorded to illustrate the significant relationship between time of burning and vigour of subsequent regrowth and the need for control of burning if the fullest use is to be made of riverain pasture.

In 1952 the test area was burnt off on 5th March (the delay was due to the necessity of protecting the posts by fire-lines) and the test herd entered the field on 5th April. Between then and 29th June 3,094 Animal Unit days grazing was produced by this 30-feddan field over a period of 85 days, i.e. 60 Animal Units per day or 2 Animal Units per feddan. But the records show that there was a general loss of body weight of 2·6 kg. per head, although there was plenty of good pasture towards the end of the grazing period. The field was obviously overstocked; there should have been an increase in weight over this season (cf. 1953).

In 1953 the experiment was continued by the Sudan Veterinary Service. A herd of 15 young bullocks entered the experimental field on 25th March and grazed there until 29th June (1,880 Animal Unit days) during which time there was a live-weight gain of 17·7 kg. per head. It should be added that the regrowth was assisted by good early rains.

The conclusion is that the carrying capacity of shallow-flooded pasture at Malakal is approximately 0·5 Animal Units per feddan (119 A.U. per sq. km.) over the season when shallow-flooded regrowth is available, i.e. March to June inclusive.

One fact of note is the rate of growth of *Echinochloa pyramidalis* after rainfall and before flooding by river spill. Permanent grass sampling plots were protected within each paddock of the grazing field on Awarajok Island; the grass in the plots in Paddock 1 was cut down to ground level on the day the cattle were removed from Paddock 1 to the next paddock in the rotation. This was repeated in each paddock. Before cutting, the average height of the plants was recorded and the figures from one plot are given below:

DATE OF SAMPLING		Interval in days	Average Height in cm.	Average Daily Growth in cm.
1st	2nd			
28/4	5/6	38	85·0	2·24
5/6	25/6	20	116·8	5·84

Rainfall at Malakal up to 4/6/53 was 199 mm. and between 4/6/53 and 24/6/53 a further 80 mm. rainfall was recorded, a total of 279 mm. up until 24th June.

Fresh and dry weights of all grass cut from these plots were also recorded; the figures are summarized at the bottom of Table 549 below. The high yield of regrowth in 1953 was due to the relatively heavy early rains.

TABLE 549

SHALLOW-FLOODED PASTURE

SUMMARY OF STOCKING INTENSITIES, LIVE WEIGHT GAINS, AND AVAILABLE PASTURE

	1950	1951	1952	1953
Intensity of Stocking in Animal Unit days				
Paddock 1 (5 feddans)	625	170	510	233
Paddock 2 (15 feddans)	NR	652	2,548	900
Paddock 3 (5 feddans)	780	470	900	225
Paddock 4 (5 feddans)	NG	405	1,136	522
Total for 30 feddans	1,405+	1,697	5,094	1,880
Live weight gain or loss per head in kg....	NR	NR	−2·8	+17·7
Fresh weight of grass in kg. per feddan ...	NR	2,683	3,763	7,875
Dry weight of grass in kg. per feddan ...	NR	787	904	2,012

NR = ' not recorded '
NG = ' not grazed '

TABLE 550

SHALLOW-FLOODED PASTURE

LIVESTOCK WEIGHTS, 1953

Bullock No.	Live Weight in Kg.	
	Beginning of Experiment	End of Experiment
21	275	302
24	364	362
25	324	341
26	355	370
29	343	345
33	339	350
34	316	333
43	325	347
45	281	302
54	321	340
46	290	326
48	307	337
49	286	306
55	249	264
57	304	320
Total	4,679	4,945
Total gain during experiment		266
Average gain during experiment		17·7

DEEP-FLOODED PASTURE

An area of 30 feddans of typical deep-flooded pasture was fenced on the Nile flood-plain (east bank) immediately downstream of Malakal. *Echinochloa stagnina* was dominant and there was a fair percentage of *Oryza* sp. on the ridges. The fence was erected in May 1951 so that the coarse, flood season growth of grass would not be disturbed by local livestock in the following dry (low river) season. The fenced area was divided into three 10-feddan paddocks and these were grazed in rotation. It will be appreciated that the great bulk of flood season growth permitted either a high stocking rate for a short period followed by a long period at a low stocking rate on regrowth only, or a moderate stocking rate over a prolonged period. We wished to keep the same number in the experimental field throughout the low river season.

In 1952 the herd consisted of 50 adult bullocks with an average live weight of 370 kg. They entered the protected area on 4th February and grazed the mature growth of Paddock 1 until 28th February, by which time little remained but a carpet of trampled stems. Paddock 2 was then grazed until 21st March, and then Paddock 3 until 15th April. At the end of this first cycle there was an average live weight increase of 0·3 kg. per beast; i.e. at that stocking rate the pasture was providing little more than a maintenance ration. By this time the regrowth in Paddock 1 was quite strong and that in Paddock 2 was noticeable.

During the remainder of the dry season the size of the herd was not altered (except that two casualties were removed and not replaced). The second cycle, which began on 16th April, was completed by 25th May, approximately half the duration of the first cycle, and there was an average loss of live weight of 3·3 kg. per head.

The third grazing cycle was completed in 19 days, because of the shortage of regrowth, and there was a further loss of live weight of 0·5 kg. per head. In the remaining five days before the end of the experiment on 18th June 1952 there was yet another loss of 2 kg. per head. Thus, at a stocking rate of 1·6 Animal Units per feddan, there was a gross loss of live weight of the herd amounting to 266 kg., or 5·5 kg. per head. Under 1952 conditions the stocking rate was much too high, but the rainfall was considerably below average and this affected the amount of regrowth, especially in the latter half of the test period.

In 1953 the test herd was reduced to 30 head, out of which there were two casualties (not replaced) during the season; the average live weight was 223 kg. These animals were a completely new batch and were either adult or growing bullocks. The first grazing cycle began on 2nd February and ended on 23rd March, a period of seven weeks (cf. 10 weeks in 1952) and there was an average live weight gain of 29·5 kg. per head. The second grazing cycle was longer than intended, 24th March to 13th May (7 weeks) and there was a live weight loss of 1·9 kg. per head. But in the third cycle (14th May to 25th June—6 weeks) a gain of 8·4 kg. per head was recorded.

Thus, at a stocking rate of 1 Animal Unit per feddan (actually 0·93 A.U.) there was a live weight gain of 36·0 kg. per head per dry season, or 0·25 kg. per head per day. In contrast to 1952, the early rains of 1953 were relatively heavy and the regrowth at the end of the experimental period benefited.

TABLE 551

DEEP-FLOODED PASTURE
SUMMARY OF STOCKING INTENSITIES AND LIVE WEIGHT GAINS

	Animal Unit Days	
	1952	1953
Paddock 1 (10 feddans)	2,016	
Paddock 2 (,, ,,)	2,352	4,032
Paddock 3 (,, ,,)	2,064	
Total for 30 feddans	6,432	4,032
Live-weight gain or loss per head in kg.	−5·5	+45

TABLE 552

DEEP-FLOODED PASTURE

LIVESTOCK WEIGHTS, 1953

(All weights in kg.)

Bullock No.	On Purchase 26/1/53	Beginning of Experiment 2/2/53	23/3/53	13/5/53	End of Experiment 25/6/53
1	310	307	338	331	340
2	271	266	297	291	296
3	273	285	308	316	319
4	286	279	295	234	241
5	307	309	340	337	338
6	303	268	300	309	323
7	225	223	257	266	272
8	282	287	335	333	333
9	205	196	226	226	300*
10	254	259	285	283	287
11	255	252	287	283	292
12	187	184	210	225	229
13	267	274	304	293	294
14	174	167	192	193	210
15	151	155	184	175	182
16	210	204	234	243	352*
17	194	183	285	291	297*
18	184	186	212	211	228
19	187	185	214	260	274
20	175	180	215	265	267
21	226	219	265	261	263
22	216	214	240	222	248
23	192	184	185	159	171
24	152	151	200	188	229
25	197	179	212	216	231
26	271	264	292	278	261
27	223	218	237	232	235
28	272	265	297	288	297
Total	5,840	5,760	6,498	6,449	6,660
Total gain after entry	—	—	738	689	900
Average gain after entry ...	—	—	29·5	27·6	36·0

* These figures are suspect because weights were taken during that period without adequate supervision. Therefore the weights of the three beasts concerned have been omitted from the total and average.

THE STOCK-CARRYING CAPACITIES OF RIVERAIN PASTURES

SHALLOW-FLOODED PASTURE

From the experience of the grazing experiment on Awarajok Island we have stated (see p. 1038) that shallow-flooded pasture has a stock-carrying capacity of 0·5 Animal Units per feddan from March to June at Malakal (119 A.U. per sq. km.). From the 1953 data we extract the following figures :

	Up to 31st March	1st April to 29th June
Animal Unit Days per 30 feddans	105	1,775
Animal Unit Days per sq. km. ...	833	14,082
Animal Units per sq. km. ...	27·8 (1 month)	156·5 (3 months)

This ignores any contribution from the coarse, flood season growth before burning; while its value as fodder is low it is not entirely worthless.

The only digestibility trial on shallow-flooded grasses concerned a sample of *Echinochloa pyramidalis* cut in October, dried, and stacked as hay (Shambat No. D.T. 37). This had a crude protein content of 3·30% on a dry matter basis, but the digestible crude protein was 0·69%. Further, the sample was cut while green and alive; had it been left to mature, wilt, and 'die' in the ground, the percentage of crude fibre would have increased and that of crude protein decreased. For example, mature *Setaria incrassata* was found to contain 1·62% crude protein and 40·55% crude fibre (dry matter basis) but digestible crude protein was zero (Shambat No. D.T. 39).

We assume that one feddan of shallow-flooded pasture will produce flood season growth of 1,000 kg. dry matter having 0·4% digestible crude protein, and we have calculated the daily requirement (maintenance plus low production) of one Animal Unit to be 0·25 kg. protein equivalent per day; the stock-carrying capacity can be calculated at 16 Animal Unit days per feddan. But at least half of the shallow-flooded pasture is burnt as soon as it is exposed, so that the carrying capacity is reduced to 8 Animal Unit days per feddan or 63·5 Animal Unit months per sq. km. When this is added to the 27·8 A.U. months' regrowth (up to 31st March, above) the total carrying capacity up to 31st March is seen to be 91·3 Animal Unit months per sq. km.

Since there can be no claim to accuracy, we have taken the stock-carrying capacity of one square kilometre of shallow-flooded pasture at Malakal to be 100 Animal Unit months until 31st March and 160 Animal Units per month thereafter.

DEEP-FLOODED PASTURE

It will be remembered that the field work of the Team ended in June 1952; on the information collected up to that date, we calculate the stock-carrying capacity of deep-flooded pasture, to be 400 Animal Units per sq. km. (1·7 A.U. per feddan) for the first two months when the bulky flood season growth is available, and thereafter 240 Animal Units per sq. km. (1 A.U. per feddan) on regrowth alone. This can be expressed as approximately 190 Animal Unit days per feddan. Results obtained by the Veterinary Service in 1953 confirm our assessment, but suggest that it may be slightly high. However, only a continuation of experiments over a period of several years can be expected to produce more accurate figures.

If we turn to the figures of herbage yields for confirmation we are at a great disadvantage in not knowing the digestible coefficients of deep-flooded grasses. One feddan of deep-flooded pasture can produce at least 155 kg. of crude protein (see p. 1034). One sample of *Echinochloa stagnina* hay, having a crude protein content of 6·04% was shown by Boyns[1] to have a digestible crude protein content of 2·23%. Since the ratio crude protein : digestible crude protein would be closer in the case of regrowth, we can take this figure with safety and apply it to our known yield, 155 kg., which figure is also incomplete. The yield of digestible crude protein per feddan would then be 57·35 kg. We have calculated (see p. 571) that the daily requirement of one Animal Unit for maintenance and low production is 0·25 kg. digestible crude protein. Thus one feddan should support 229 Animal Unit days or 1·5 Animal Units throughout the 150 days' season on riverain pasture (357 A.U. per sq. km.). This is reasonable confirmation, but the fact that these figures are based on very meagre data, and are therefore accepted with caution, is too evident to require emphasis.

3. MISCELLANEOUS GRASSLANDS

In many parts of the Jonglei Area grasslands inland are not grazed in the dry season for two main reasons. Either the swamp pastures at the main rivers, which are fresh and green in the dry season, are sufficient for local needs and the dry inland grasses are not required, or the inland pastures are inaccessible owing to lack of water supplies. However, it was necessary to establish the actual grazing value of these inland grasses in the dry season in order to determine whether inland pastures could be opened up as alternatives to riverain pastures lost under the Project.

In the Flood Region there is no lack of coarse grass remaining at the end of the rainy season but this is either unpalatable or is of low nutritive value. Such is the local belief, and to prove it true or false a series of simple experiments was arranged. Three small areas, each of four feddans, were fenced in, their perimeters protected by fire-lines, and the contained grasses grazed by a few test animals whose live weight gains and losses were recorded. Two of the fields, at Nagdiar and Kodok, were so far from Malakal that the experimental animals were only weighed twice, before moving to the test field at the beginning of the dry season, and on returning to Malakal at the end of the dry season—or when all the grass within the test field had been consumed. The third field, at Gonio, was close to Malakal and the experimental animals were weighed at weekly intervals. Records over two seasons are therefore more complete for the Gonio field and so this experiment is described in full, the others more briefly. The chemical analysis of some of these mature grasses is tabulated at the end of this section.

GONIO GRAZING TRIAL

The four-feddan field, situated about 300 yards from the right bank of the Nile just upstream of Malakal, was fenced in December 1951 and protected by fire-lines. *Setaria incrassata* and *Hyparrhenia* spp. were the principal grasses; *Sorghum purpureo-sericeum* and *Andropogon gayanus* were less evident and there was a large number of unidentified annual grasses. By the time the experiment began (February 1952) all these grasses, particularly the four named, had become coarse and brittle and much of the seed had been shaken from the heads. The four cattle selected for the trial were Nos. 21 and 22, immature 4-year old Nilotic bullocks, No. 28, an adult Nilotic bullock, and No. 29, an immature Arab bull. At night they were kept tied at the stockyard at the Malakal Experimental Farm—because of the danger of attack from wild animals—and they walked the short distance to and from the Gonio field each morning and evening. Drinking-water was provided at the field.

The trial began on 1st February 1952. Whilst the seed-heads of the grasses were still available all four beasts actually gained weight, but as the heads disappeared and as leaf became scarce live weight decreased regularly until the end of May. By mid-April all the *Sorghum*, *Hyparrhenia*, and the various annuals had been eaten, and only the stiff stems and rough leaves of *Setaria* and *Andropogon* remained. In May the early showers of rain encouraged germination and growth of the new season's grass and from June onwards steady gains in weight were recorded. As is seen in the following record of live weights, the losses during the months January–May were 29 kg., 47 kg., 71 kg., and 42 kg. respectively. No. 28 suffered the greatest loss, perhaps because it received an injury to an eye which interfered with its sight and later with its ability to graze. There is no doubt that the loss of weight recorded was a good indication of the low nutritive value of the grass, though it has to be admitted that, just before the new season's grass appeared, grazing was lacking in quantity as well as quality.

To show that the poor quality of the grassland was confined to the dry season when the plants were mature or dead, the trial was continued with the same animals throughout the rainy season of 1952. Heavy rain showers frequently cause such surface flooding that this heavy clay land cannot be grazed for days at a time, but in 1952 the weather was such that continuous grazing was possible. With the growth of fresh grass all the test animals gained weight steadily. Bullock No. 28 became increasingly blind and this, combined with its age, prevented it making as good a recovery as the other three, which gained weight at an average rate of 0·5 kg. per head per day during the four months June to September. They not only gained the weight lost in the dry season but added a further 27 kg. per head on the average. However, in so doing they consumed most of the grass and by mid-October grazing was already scarce. At the end of October three of the four beasts were removed in the hope that the grass remaining would be sufficient for the remaining animal throughout the dry season. But by this time all growth had ceased and the remaining bullock gradually lost weight until removed in December 1952.

The conclusions to be drawn from this brief experiment are that this natural high land, or high intermediate land, pasture has a stock-carrying capacity of one Animal Unit per feddan during the rainy season but that, if grazed to this extent, no pasture remains for the dry season. Conversely, if not grazed during the rainy season this grassland may be stocked in the dry season at the rate of one A.U. per feddan and the livestock will survive, but will certainly not thrive. It is noteworthy that, given no alternative, Nilotic cattle can graze this coarse, mature grass, but it is very unlikely that it would allow them to maintain their condition even if an unlimited quantity were available. Live weight gains and losses are recorded in Table 553.

KODOK GRAZING TRIAL

The four-feddan field used for this experiment was about 400 yards in from the left bank of the Nile two miles upstream of Kodok (Shilluk District) and was chosen as being representative of much of the land within a few miles of the river between Kodok and Renk.

Sorghum purpureo-sericeum (Ar. *anis*) was dominant and there was a fair admixture of *Brachiaria obtusiflora* and *Setaria incrassata* in addition to various annual grasses. Because of difficulties over fencing and transport, this trial did not start until 7th April 1952, and because the dry season was nearly at an end six beasts were used. The site of the trial was 45 miles from Malakal, and, there being no weighing machine available at Kodok, cattle were weighed at Malakal on 5th April, embarked on a steamer and taken to Kodok, and entered the field on 7th April.

Grazing was reported to be in short supply by 24th April at which time the livestock were still in good condition, but the animals remained within the field until 11th May by which time all had lost condition. Until they could be brought back to Malakal (5th June) they were grazed on land similar to that within the field, but the new growth brought on by the early rains helped them partly to regain their lost condition. When weighed on 5th June they were found to have lost an average of 11 kg. per head.

This field was not grazed during the rainy season because of the impossibility of supervision, but on 19th November one bullock, No. 23, was admitted to the field and remained there until 19th May 1953. At first it maintained condition well, but towards the end of the dry season the grass became scarce until finally the only grazing remaining consisted of the fresh shoots of new growth. The animal lost 59 kg. (from 314 kg. to 255 kg.) during the trial (the weight on 20th May was actually 234 kg. but this was immediately after a hungry, and perhaps a thirsty, journey from Kodok; 255 kg. was the weight recorded two days later).

Thus four feddans of this high land, or high intermediate land, could not support one A.U. throughout the dry season. We must add that the 1952 rains had been relatively light and that the growth of grass was much less luxuriant than in previous years. A further piece of information is that a second control bullock, which was weighed on the same days as No. 23 and which accompanied the latter to and from Kodok, lost 21 kg. weight although it was grazing natural pasture along with the Government herd; for this loss we can offer no explanation except to repeat that in this particular year grass was not as abundant as is usual.

NAGDIAR GRAZING TRIAL

About two miles west of the Sobat, alongside the Malakal-Nagdiar road, this four-feddan field was on land subject to heavier flooding than the two previous fields. The principal grasses were *Setaria incrassata* and *Andropogon gayanus*, with small quantities of *Hyparrhenia, Sorghum, Panicum, Sporobolus*, and *Echinochloa* species. As with the Kodok experiment, there was some delay in starting, and six bullocks were therefore used in the first season. These were weighed at Malakal on 6th March 1952 and taken by steamer to Nagdiar, at which village they were to be tethered nightly. Grazing of the test field began on 7th March 1952. Because of the distance from the river, water could not be supplied at the field and the animals were only able to drink at early morning, before moving to the field, and in the evening on their return to camp. They all appeared to be affected by this long, thirsty day in the sun and a grass roof was built to provide shade; but the *Setaria incrassata*, of which the roof was made, was evidently more attractive than the local grass and was soon consumed. By the end of April all six beasts were looking thin although there was plenty of grass. One animal died on 15th May as a result of a digestive disorder of which constipation was the main symptom. Bone meal was fed to two of the bullocks but without any effect.

On 19th June the animals were brought back to Malakal and weighed; there was an average loss of 4·4 kg. per head, although two animals—not those receiving bone meal—actually showed a gain. It must be remembered that the new season's growth of grass had already appeared, as at Gonio and Kodok, and was by this time quite appreciable at Nagdiar.

This trial, like the Kodok one, was repeated in the following dry season commencing in November 1952, when the grass, though mature, was not yet dry and dead. Only two bullocks were used this time, both grazing within the field from 26th November 1952 until 23rd May 1953, by which time the new season's growth of grass was about 20 cm. high. Nevertheless both animals lost weight, No. 31 from 313 kg. to 245 kg., and No. 42 from 283 kg. to 226 kg.—an average loss of 62 kg. per head. There was no shortage of grass at any time during this second dry season, although latterly it was coarse, and both animals appeared to keep their condition well, particularly No. 31 which lost the more weight.

CONCLUSIONS

From the information gained from these three short grazing experiments it appears that mature high land, or high intermediate land, grasses of the types described cannot satisfactorily support cattle throughout the dry season, and that to supply sufficient bulk alone at least four feddans would be required for each Animal Unit.

TABLE 553

GONIO GRAZING TRIAL
LIVESTOCK WEIGHTS, 1952

Date	Bullock No. 21	Bullock No. 22	Bullock No. 28	Bullock No. 29
1 February ...	225	258	318	268
7 ,, ...	229	260	325	269
14 ,, ...	221	254	319	265
21 ,, ...	224	250	316	257
28 ,, ...	225	254	320	265
7 March ...	222	258	313	256
14 ,, ...	222	254	313	252
21 ,, ...	227	256	311	259
28 ,, ...	219	253	309	257
7 April ...	219	248	290	245
14 ,, ...	209	232	285	237
21 ,, ...	209	232	283	235
29 ,, ...	206	229	271	235
6 May ...	210	226	269	235
13 ,, ...	205	227	259	226
20 ,, ...	198	224	250	228
27 ,, ...	196	222	250	228
3 June... ...	198	221	250	230
10 ,, ...	200	229	247	232
18 ,, ...	211	231	248	246
27 ,, ...	218	234	260	256
6 July	219	240	255	255
23 ,, ...	235	256	263	280
5 August ...	234	244	257	257
12 ,, ...	249	250	262	292
19 ,, ...	251	259	271	299
26 ,, ...	252	255	273	304
2 September ...	248	260	278	305
9 ,, ...	246	263	283	310
16 ,, ...	246	267	270	303
23 ,, ...	243	263	282	303
30 ,, ...	254	273	274	304
7 October ...	248	261	264	298
14 ,, ...	245	268	264	301

TABLE 554

ANALYSIS OF SOME MATURE SUDAN GRASSES
(ON A DRY MATTER BASIS)

	Moisture	Crude Protein	Fat	Soluble Carbo-hydrate	Fibre	Ash	Remarks
Hyparrhenia spp.	4·0	3·1	1·5	46·4	37·3	11·4	Cut Nov. near Malakal.
Sorghum purpureo-sericeum	4·0	2·6	1·3	47·8	37·0	11·0	Cut Nov. near Kodok Grazing Trial.
Pennisetum ramosum ...	3·0	3·7	1·8	47·0	37·0	10·0	Cut Nov. near Malakal.
Setaria spp.	5·0	7·0	2·0	45·2	29·7	16·0	Mainly *S. incrassata* hay cut at flowering stage.
Schoenefeldia gracilis (Ar. *umm fereita*)	—	2·0	1·1	51·6	36·4	8·9	Cut Nov. in Kosti District, common near Saba-Asuda well-centre.

THE SEMI-ARID REGION

At the outset of the investigation it was known that some grasslands in the Semi-Arid Region provided good grazing all the year round, but the stock-carrying capacities of these pastures were unknown. The only unused grasslands of this Region were in the south, bordering on the Transitional Belt between the Semi-Arid and Flood Regions, and grazing potentialities were not known. Since time was short and trained staff not available, simple experiments had to be designed to give an indication of the nutritive value of these grasses and their stock-carrying capacities. Such experiments were conducted in two parts of Kosti District, one near Jebel Megeinis, and one around the Saba-Asuda well-centre, about 30 km. south-west of Kosti.

JEBEL MEGEINIS EXPERIMENT

The grassland in the vicinity of Jebel Megeinis is predominantly *hariq* grassland, but there is a small proportion of the annual short grass type which is more characteristic of the northern part of the Semi-Arid Region. With the object of assessing the feeding and grazing values of these pastures, clippings of the more prominent grasses were taken throughout the period July–November 1950 and in July–October 1951. The samples were then submitted for chemical analysis. In addition samples from different hays made in both years were also submitted for analysis, and it was hoped that larger samples could be fed to sheep so that some indication of the palatability of the herbage could be obtained. As far as was possible grass samples of the selected grasses were taken from pure stands. (These were *Aristida mutabilis* (Ar. *dambalab*) which is common in the Semi-Arid Region on the short grass plain, *Sorghum purpureo-sericeum* (Ar. *anis*), *Hyparrhenia* sp., probably *H. pseudocymbaria* (Ar. *anzora*), and *Cymbopogon nervatus* (Ar. *nal*) which are the common grasses of the *hariq* grasslands.) Although this was the intention it will be appreciated that it was not always possible to find completely pure stands and the analyses should be considered as those of mixtures dominated by the grass species indicated.

FIRST SEASON (1950)

In the first year many imperfections in the sampling technique became apparent, and the experiment must be considered incomplete in many respects. The main reason for this was that the sampling area was far away from Malakal, with the result that no supervision was possible during the rainy season when the samples were being collected.

GRASS SAMPLES FOR ANALYSIS

As far as was possible different areas, carrying pure stands of the above four grasses, were selected monthly between the months of July and November inclusive and enough herbage for analysis (roughly one kilogramme) was cut from each selected site. Prior to cutting, the height of the grass was recorded. This was done by taking the average of the heights of twenty plants. Immediately after cutting the herbage was weighed, allowed to dry, then re-weighed. Unfortunately, since the areas from which the samples were taken were irregular in shape, the size of the plots (given in Table 555 at the end of this section) are only approximate. No replicates of the samples were taken.

HAY SAMPLES

Hay was made only from *Aristida mutabilis* (Ar. *dambalab*). Two cuts were taken. The first was on 24th August prior to the flowering of the grass, the cut herbage taking about four days to dry; the second cut was on 10th October, i.e. well after flowering when the herbage was fairly coarse. Unfortunately no record of the size of the area from which the grass was cut was made and no weights were recorded. Samples were submitted for analysis and a digestibility trial was conducted at the Faculty of Agriculture, Shambat. The results of the analysis and trial are given in Tables 557 and 558.

SECOND SEASON (1951)

In the first season samples sufficient for chemical analysis were collected but could not be related to areas; in the second season this deficiency was made good and all samples were duplicated. For each of the four grass species two sampling units, each 16 sq. m., were selected and fenced. Each unit was quartered and each quarter was cut once during the season, the first in July, the second in August, the third in September, and the fourth in October. The heights of the grasses prior to cutting were recorded and the weights of the cut herbage, both fresh and dry, were noted. Hay was also made from additional areas, as in the first season, but greater care was taken to ensure that the area from which the grass was cut was measured and that yields were recorded.

GRASS SAMPLES FOR ANALYSIS

The heights and dry weights of the samples and the areas from which they were cut are recorded in Table 556, together with the result of the chemical analysis. It will be noted that the cuts for each species have been duplicated. It will be further noted that the chemical analysis is in two parts, the second part being on a soil-free basis. This was found necessary because when the samples arrived at the Faculty of Agriculture, Shambat, they were found to be heavily contaminated with soil. The analysis was conducted in the usual manner and then the percentage of soil in each sample analysed was calculated. The figures expressing each constituent as a percentage of the dry matter on a soil-free basis were then calculated and are given in the second part of the table. These are the figures which should be used in any comparative study, since they give as accurately as can be assessed the true chemical composition for each of the grasses at the different growth stages.

Hay Samples

For each of the four main grass species two additional units were fenced, the first of 100 sq. m. and the second of 25 sq. m. The larger units were cut for hay in late August and the smaller in late November. It was intended that all eight hay samples should be submitted to chemical analysis and be fed to sheep to determine digestibility but, partly owing to the light rains, the quantity was insufficient for feeding trials. The results of the chemical analyses are given in Table 559.

Interpretation of Results and Analyses

The clip samples of all four species indicate a general trend in change of chemical composition during the season in both years. In the 1950 results the rapidity with which the nutritives value declined between July and August and thereafter is striking, the most significant change taking place with *Sorghum purpureo-sericeum* which had a surprisingly high protein content in the July cut. The decline in nutritive value was not so rapid in the 1951 samples; in fact there was a gradual falling off. In comparing the analyses for the two years it should be noted that the growth in 1951 was at least one month behind that of 1950; rainfall was probably the factor most responsible.

The results of both years' analyses indicated that the feeding value of all four grasses was high in the early rains period (July 1950, August 1951). This was particularly so in the case of *Sorghum purpureo-sericeum* which had the highest crude protein content of all the first samples in both years. The results of the analyses of the second samples differed considerably; those of the 1950 samples indicated low feeding values, whereas those of 1951 were only slightly inferior to the first cuts and indicated a higher feeding value than the grasses cut at the comparable period in 1950. By the time the third cut was taken samples for all four grasses and for both years showed extremely low protein and soluble ash and high crude fibre content. Even allowing for high digestibility of the crude fibre it is not unreasonable to assume that such fodders fed alone would not supply maintenance requirements. The results of the ten hay samples analysed indicate that hay made from grasses after flowering (say in October or November) is of poor feeding value and would not supply maintenance requirements. On the other hand hay made from grasses cut prior to flowering or in August should provide reasonably good fodder, with the exception of that made from *Aristida mutabilis*.

TABLE 555

JEBEL MEGEINIS

ANALYSIS OF GRASS SAMPLES, 1950

(on dry matter basis)

Grass	Date of cutting	Size of Area Cut sq. m.	Average Height of Grass in cm.	Weight of Sample in gm.		% Dry Matter in Fresh Sample	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash	Silica SiO_2	Calcium Ca	Phosphorus P
				Fresh	Dry									
Aristida mutabilis (Ar. *Dambalab.*)	21. 7.50	1·5	18	1,021·5	138·88	13·59	9·52	2·85	30·42	40·75	16·46	10·30	0·53	0·13
	21. 8.50	2·0	49	1,135·0	296·66	26·14	5·45	1·98	34·83	43·70	14·04	9·11	0·36	0·07
	21. 9.50	2·0	71	1,816·0	445·25	24·52	3·21	1·52	36·53	47·68	11·06	8·46	0·31	0·11
	21.10.50	—	50	908·0	683·68	75·30	1·56	1·00	38·13	45·21	14·10	12·63	0·28	0·04
	21.11.50	2·0	50	908·0	876·82	96·57	1·46	0·99	37·75	48·77	11·03	9·63	0·23	0·14
	21.11.50						1·36	0·81	38·16	48·46	11·21	9·65	0·22	0·16
Sorghum purpureo-sericeum (Ar. *Anis.*)	17. 7.50	6·0	30	1,135	133·43	11·76	20·36	2·90	22·32	35·56	18·86	3·86	0·99	0·28
	17. 8.50	1·0	100	1,135	287·55	25·33	5·90	1·48	34·29	45·96	12·36	3·21	0·52	0·17
	17. 9.50	0·5	150	1,816	755·59	41·61	2·47	0·94	38·90	49·38	8·31	4·65	0·39	0·16
	17.10.50	—	200	2,270	798·41	35·17	1·27	0·75	42·17	48·53	7·28	4·75	0·30	0·08
	17.10.50	—	—	—	—	—	1·54	0·78	41·40	47·34	8·94	4·97	0·45	0·08
	22.11.50	2·0	200	908	901·38	99·27	1·45	0·60	41·05	47·33	9·57	5·17	0·39	0·06
	22.11.50						1·37	1·28	41·15	47·59	8·61	5·01	0·39	0·06
Hyparrhenia pseudocymbaria (Ar. *Anzora*)	21. 7.50	2·0	20	1,135	134·04	11·81	8·90	3·35	28·54	44·27	14·94	9·64	0·44	0·26
	21. 8.50	1·5	61	1,362	289·44	21·25	4·86	2·41	32·42	49·04	11·27	6·64	0·39	0·13
	21. 9.50	0·5	150	1,816	527·18	29·03	3·21	2·04	37·45	49·33	7·97	5·03	0·32	0·13
	21.10.50	—	150	908	598·30	65·89	2·38	1·91	37·77	50·19	7·75	5·72	0·34	0·15
	21.11.50	2·0	150	908	895·61	98·64	1·82	1·17	40·84	48·76	7·41	5·72	0·27	0·12
	21.11.50						1·45	0·88	39·96	47·61	10·10	5·50	0·38	0·18
Cymbopogon nervatus (Ar. *Nal*)	21. 7.50	0·5	15	1,135	71·25	6.28	9·96	2·71	24·20	49·76	13·37	5·10	0·90	0·37
	21. 8.50	0·5	46	1,362	185·18	13·60	6·45	3·35	29·66	49·90	10·64	5·81	0·58	0·27
	21. 9.50	1·0	100	1,816	537·93	29·62	3·18	2·00	34·92	50·16	9·74	6·18	0·33	0·19
	21.10.50	—	150	908	792·73	87·30	4·00	2·53	32·94	51·82	8·71	5·59	0·37	0·16
	21.11.50	0·5	100	908	900·74	99·20	1·27	1·69	36·58	52·22	8·24	5·80	0·31	0·11
	21.11.50						1·37	1·34	39·42	50·35	7·52	5·01	0·32	0·10

TABLE 556

JEBEL MEGEINIS
ANALYSIS OF GRASS SAMPLES, 1951
(on dry matter basis)

Grass	Date of Cutting	Size of Area Cut sq. m.	Average Height of Grass in cm.	Dry Weight of Sample in gm.	% Moisture in Sample	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Total Ash	Silica SiO_2	% Soil in Sample	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash
Aristida *mutabilis* (Ar. *Dambalab*)	25. 7.51	4	7	91·8	3·50	3·85	0·57	10·36	17·67	67·54	56·82	62·90	10·38	1·54	27·92	47·63	12·53
	25. 7.51	4	7	161·0	3·78	4·50	0·65	13.77	21·08	60·00	50·49	55·50	10·11	1·46	30·94	47·37	10·11
	25. 8.51	4	10	272·8	5·00	5·99	1·63	28·56	37·68	26·14	21·11	21·16	7·60	2·07	36·23	47·79	6·31
	25. 8.51	4	15	213·0	5·55	6·67	2·36	28·48	42·53	19·96	16·18	15·40	7·88	2·79	33·66	50·27	5·40
	25. 9.51	4	30	590·7	5·33	4·57	1·85	28·26	40·68	24·64	19·96	19·82	5·70	2·31	35·25	50·74	6·00
	25. 9.51	4	30	495·9	5·25	6·24	2·25	27·65	44·30	19·56	16·13	15·34	7·37	2·66	32·66	52·33	4·98
	25.10.51	4	50	795·4	2·85	2·03	1·47	31·17	46·44	18·89	16·91	16·26	2·42	1·76	37·22	55·46	3·14
	25.10.51	4	50	703·5	3·38	2·49	1·74	32·81	46·92	16·04	14·21	13·10	2·87	2·00	37·76	53·99	3·38
Sorghum purpureo-sericeum (Ar. *Anis*)	25. 7.51	4	4	3.0	Insufficient Material for Analysis												
	25. 7.51	4	3	1·5													
	25. 8.51	4	10	45·7	3·65	13·21	2·23	22·29	43·25	19·02	12·04	10·56	14·77	2·49	24·92	48·36	9·46
	25. 8.51	4	10	114·4	5·98	13·50	2·16	23·06	44·26	17·02	10·30	8·08	14·69	2·35	25·09	48·15	9·72
	25. 9.51	4	15	214·9	5·75	9·66	2·44	25·46	44·72	17·72	9·00	6·01	10·28	2·60	27·09	47·58	12·45
	25. 9.51	4	50	103·0	6·00	8·10	2·13	26·38	48·84	14·55	8·60	6·54	8·67	2·28	28·23	52·26	8·56
	25·10·51	4	50	234·9	4·58	4·44	1·78	28·90	51·17	13·71	7·94	5·77	4·71	1·89	30·67	54·30	8·43
	25.10.51	4	30	322.0	3·75	4·14	1·82	31·17	49·90	12·97	7·53	5·29	4·37	1·92	32·91	52·69	8·11
Hyparrhenia pseudocymbaria (Ar. *Anzoro*)	25. 7.51	4	6	2·0	Insufficient Material for Analysis												
	25. 7.51	4	3	1·5													
	28. 8.51	4	15	175·3	4·98	12·76	2·82	22·42	37·24	24·76	10·16	8·37	13·93	3·08	24·47	40·64	17·88
	28. 8.51	4	13	91·2	5·90	13·72	2·32	24·21	40·06	19·69	8·50	6·43	14·66	2·48	25·87	42·81	14·18
	25. 9.51	4	50	261·1	5·05	7·93	1·72	26·86	50·64	12·85	7·19	4·90	8·34	1·81	28·24	53·25	8·36
	25. 9.51	4	35	150·0	4·90	9·41	2·19	24·27	46·52	17·61	10·88	9·21	10·36	2·41	26·73	51·24	9·26
	25.10.51	4	75	203·8	4·35	4·55	1·41	33·23	51·06	9·75	5·91	3·40	4·71	1·46	34·40	52·86	6·57
	25.10.51	4	80	316·7	4·03	4·74	1·41	33·11	50·65	10·09	6·28	3·83	4·93	1·47	34·43	52·67	6·50
Cymbopogon nervatus (Ar. *Nal*)	25. 7.51	4	5	1·0	Insufficient Material for Analysis												
	25. 7.51	4	4	0·5													
	25. 8.51	4	5	29·0	10·73	13·08	4·18	21·51	39·83	21·40	13·38	12·13	14·89	4·76	24·48	45·33	10·54
	25. 8.51	4	5	16·1	5·28	11·13	4·65	18·63	41·65	24·01	14·52	13·46	12·86	5·37	21·45	48·13	12·19
	25. 9.51	4	40	261·2	6·33	8·92	4·48	23·68	49·62	13·29	7·10	4·79	9·37	4·98	24·87	52·12	8·66
	25. 9.51	4	15	167·5	5·63	8·39	2·12	22·78	48·77	17·94	11·55	10·05	9·33	2·36	25·33	54·22	8·76
	25·10·51	4	55	166·2	5·68	4·73	2·44	31·63	50·94	10·26	6·15	3·68	4·91	2·53	32·84	52·89	6·83
	25.10.51	4	50	219·5	5·98	4·14	2·02	32·97	50·15	10·72	5·78	3·25	4·28	2·09	34·08	51·83	7·72

TABLE 557

JEBEL MEGEINIS

ANALYSIS OF *ARISTIDA MUTABILIS HAY*, 1950

	Composition of Dry Matter								Digestible Coefficients					Digestible Nutrients					S.E.	T.D.N.
	Moisture	Organic Matter	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash	Silica SiO_2	Organic Matter	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Organic Matter	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.		
Cut before flowering	4·40	83·86	4·85 T.P.= 4·21	1·86	36·40	40·75	16·14	13·13	53·85	17·30 T.P.= 14·25	40·74	68·35	45·80	45·16	0·84 T.P.= 0·60	0·76	24·88	18·66	29·70	46·10
Cut after flowering	3·33	85·07	1·27 T.P.= 1·09	1·32	37·76	44·72	14·93	13·32	51·04	Nil	39·10	63·70	40·95	43·43	Nil	0·52	24·05	18·31	25·70	43·53

TABLE 558

PERCENTAGE OF *ARISTIDA MUTABILIS* HAY CONSUMED BY SHEEP

(Cut at Jebel Megeinis, 1950)

Material	Sheep A	Sheep B	Mean
Hay cut before flowering	92·41	100·00	96·21
Hay cut after flowering	77·61	97·79	87·70

TABLE 559

JEBEL MEGEINIS

ANALYSIS OF HAY SAMPLES, 1951

(on dry matter basis)

Sample	Date of Cutting	Area in sq. m.	Dry Weight in gm.	Moisture in Sample %	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash	Silica SiO_2
Aristida mutabilis	25. 8.51	100	12,800	4·75	5·74	1·78	32·26	39·42	20·79	17·14
	25.11.51	25	6,170	4·03	2·59	1·39	31·08	44·20	20·74	18·89
Sorghum purpureo-sericeum	25. 8.51	100	1,135	3·40	12·64	2·85	22·36	45·92	16·23	9·94
	25.11.51	25	1,525	4·73	2·90	1·15	33·41	51·54	11·00	7·06
Hyparrhenia pseudocymbaria	25. 8.51	100	450	5·30	14·69	2·01	23·02	41·40	18·88	9·93
	25.11.51	25	4,100	4·50	3·34	1·39	33·19	48·47	13·61	8·53
Cymbopogon nervatus	25. 8.51	100	285	5·90	12·23	4·07	19·27	44·63	19·80	11·19
	25.11.51	—	1,425	4·65	2·02	1·34	34·19	54·87	7·58	4·51

SABA-ASUDA EXPERIMENT

The villages of Saba and Asuda are approximately 30 km. south-west of Kosti and about the same distance from the Nile and from the nearest large well-centre at Gedid. At Saba there is one well-field and at Asuda, about 3 km. away, there are two. The country around this centre is fairly typical *qoz* catena with sandy, almost treeless *qoz*, producing short annual grasses, alternating with flat plains covered partly by fairly thick *Acacia seyal* and *Acacia mellifera* and partly by open grassland (see Vol. I, Chap. 2, pp. 148–50). Thousands of cattle, sheep, and goats were known to water at this centre in the dry season and it was sufficiently far from any large watering-centre to be considered an entity. It was thought that the stocking intensity of the area could be measured by counting the number of animals watering at this centre throughout the dry season and relating this number to the area of grassland grazed by animals from this centre. Greater accuracy could have been obtained by fencing a known area and grazing it with a controlled number of livestock; but this method would have required staff, materials, livestock, and time, none of which were available in sufficient quantity.

During the dry season before the 1950 rains a recorder was stationed at each of the three groups of wells with instructions to record daily the number of cattle, sheep, and goats watering at the centre. In addition there was one ranger whose duty it was to join a herd as it left the centre after watering and accompany it until it returned to water the following day or two days later. At the grazing place farthest from the well-centre the ranger blazed a tree to mark the spot. This routine, though simple, did not work smoothly at first, but from February onwards it went well. In this way a series of points soon circled the watering-centre indicating the perimeter of the area grazed, and the perimeter was gradually pushed out until, in April, the area grazed was estimated to be 400 sq. km. Distances from the centre to the perimeter were measured on the mileometer of a motor vehicle and, owing to the impossibility of moving in a straight line, this method was liable to error. No distances were measured to the north-west because thick bush made it impossible for a vehicle to get through.

From Table 561 below it will be seen that the average number of Animal Units watering daily at this well-centre was 4,146, indicating a stocking rate of 10 A.U. per sq. km., or 1 A.U. per 24 feddans. It must be remembered that groups of cattle sometimes came into this area both from the river and from the well-centre at Gedid, so that the stocking intensity may have been slightly higher than indicated by our records. Another point of note is that the stocking rate of 1 A.U. to 24 feddans applies to 24 feddans of land, which includes bush, cultivations, villages, and small encampments; but as a working figure it is sufficiently accurate for our purpose.

TABLE 560

SABA-ASUDA WELL-CENTRE

NUMBER OF ANIMALS RECORDED WATERING, DRY SEASON 1950

Weekly Periods	Saba		Asuda (small)		Asuda (large)	
	Cattle	Sheep and Goats	Cattle	Sheep and Goats	Cattle	Sheep and Goats
February						
8th–14th ...	16,285	9,848	17,890	6,739	1,419	1,456
22nd–28th ...	13,054	11,008	11,345	1,485	1,493	1,629
Total	29,339	20,856	29,235	8,164	2,912	3,085
March						
8th–14th ...	18,352	16,478	4,826	5,446	1,689	1,094
22nd–28th ...	16,880	12,740	5,161	6,091	4,842	3,672
Total	35,232	39,218	9,987	11,537	6,531	4,766
April						
8th–14th ...	13,456	1,456	1,946	1,325	8,488	8,817
22nd–28th ...	13,780	1,356	1,349	1,831	7,924	9,035
Total	27,236	2,812	3,295	3,156	16,412	17,852

TABLE 561

SABA-ASUDA WELL-CENTRE

AVERAGE NUMBER OF ANIMALS WATERING DAILY

Month	Cattle	Sheep and Goats	Animal Units
February	4,392	2,293	4,679
March	3,696	3,966	4,192
April	3,353	1,701	3,566
Average through the dry season	3,813	2,653	4,146

4. IRRIGATED PASTURES

The following experiments were designed primarily to give some indication of the amount of water required to keep a pasture green and productive throughout the dry season and to provide information on the management of irrigated pastures (stock-carrying capacity, hay-making, etc.). Other experimental work in connection with hay-making has been described in Chapter 4, Vol. I. Finally some results are given of the preliminary work carried out in connection with introduced and indigenous grasses and legumes which were studied to determine their suitability for use in irrigated pastures. All the experiments and investigations were conducted at the Malakal Experimental Station (East Bank), and the reader is therefore referred to pp. 990–1 of this volume for an account of the soil and climatic conditions under which the experiments were carried out.

WATER-DUTY : RATE AND FREQUENCY

Two closely related experiments were set out to determine the optimum rate and frequency of applying water to pasture, in the dry season, in order to maintain grass growth.

EXPERIMENT A

This experiment was replicated four times, and conducted over a term of two years (1950–1951 and 1951–1952) on a natural *Setaria incrassata* type pasture. This is the dominant type of pasture around Malakal and has the following grass composition:

Setaria incrassata ... ... Dominant grass.
Ischaemum brachyatherum ... ...
Hyparrhenia spp. (*H. rufa* and *H. dissoluta*)
Panicum porphyrhizos ... ...
Pennisetum ramosum ... ... All occurring in varying proportions.
Cymbopogon sp. ... ...
Andropogon gayanus ... ...
Cyperus sp. ... ...

Small plots $\frac{1}{10}$-feddan in area (33 m. × 12·75 m.) were marked out and enclosed within small banks so that water could be impounded. Each plot was separated from its neighbour by an open space 1·5 m. wide along its longitudinal axis, and by the minor irrigation channels along its shorter axis. Each plot was given one of the following irrigation treatments during the dry season:

200 m³. water per feddan applied every 7 days.
200 m³. " " " " " 14 "
200 m³. " " " " " 21 "
200 m³. " " " " " 28 "
400 m³. " " " " " 7 "
400 m³. " " " " " 14 "
400 m³. " " " " " 21 "
400 m³. " " " " " 28 "
600 m³. " " " " " 14 "
600 m³. " " " " " 21 "
600 m³. " " " " " 28 "
Control (no water applied).

The above treatments were replicated four times, so that in all there were 48 plots.

The irrigation water was drawn from the Nile by means of a 6-inch pump and conducted to the experimental area by an unlined main channel. A v-notch and a gauge were erected in the channel, enabling the rate of water flow to be measured. The water was conducted to the plots by a series of minor channels from which it was allowed to flow on to the plots by openings made in the surrounding banks. The amount of water passing on to a plot was controlled, and the time required for the requisite amount of water to pass on to the plot was calculated from the rate of flow in the main channel.

Differences as a result of varying treatments were estimated on the basis of the amount of herbage produced by the plots throughout the irrigation period. All cutting of the grass was done by hand with sickles, and fresh and air-dried weights were recorded. Analysis of the data was, however, limited to air-dried weights. As the result of experience in the first year, changes in experimental technique were found desirable in the second season; for this reason the results must be considered separately.

FIRST SEASON (1950–51)

The results showed a significant difference between groups of treatments, the general trend being an increase in yield of grass with higher applications of water.

TABLE 562

EFFECT OF DIFFERENT WATERING TREATMENTS ON GRASS YIELDS, 1950–51

Treatment (Actual)	Number of Applications	Total Amount of Water Applied m^3.p.f.	Yield of Grass (Air-Dried Weights from Plot 33 m. × 12·75 m.) in kg.
438 m^3.p.f. every 14 days ...	12	5,250	145·1
598 ,, ,, 14 ,, ...	12	7,180	143·3
452 ,, ,, 21 ,, ...	9	4,070	141·1
225 ,, ,, 7 ,, ...	24	5,400	140·1
631 ,, ,, 21 ,, ...	9	5,680	133·0
418 ,, ,, 7 ,, ...	22	9,200	125·1
641 ,, ,, 28 ,, ...	7	4,490	115·6
255 ,, ,, 14 ,, ...	12	3,060	103·8
395 ,, ,, 28 ,, ...	6	2,370	99·1
195 ,, ,, 28 ,, ...	6	1,170	91·4
274 ,, ,, 21 ,, ...	9	2,470	80·5
Control	—	Nil	50·0
Significant Difference (p = 0·05)	—	—	27·7

SECOND SEASON (1951–52)

In the first season yields were based on the amount of grass cut at intervals from within the total area of the plot (33 m. × 12·75 m.). It was noticed, however, that there was a strong border effect, the grass around the fringes of the plots being taller and more vigorous in growth than that towards the centre. This was attributed to lack of competition around the outer edges and to the influence of a greater water supply caused by moisture seeping from the irrigation channels and adjoining plots. To overcome the effect of seepage the actual area from which measured cuts were taken in the 1951–52 season was reduced to 30 m. × 10 m., thus ignoring a border of approximately 1·5 m. in width around the plots. In the 1950–51 season each plot was cut when the grass reached the early flowering stage, and between January and June each plot was cut approximately 7 times. Very often, however, cuts were taken either too early (well before flowering) or too late (well after flowering) and on occasions some plots were overlooked; this was due to the lack of experience of the operators. In the second season each plot was cut to a definite schedule. It was hoped that from the analysis of the herbage cut some information would be gained on the composition of the herbage at different growth stages and also some indication of herbage production trends. Both these are important from the point of view of the management of pasture.

Each plot (30 m. × 10 m.) was therefore sub-divided by marker pegs into 10 sub-plots, 6 m. × 5 m. in area, each of which was cut as follows :

Sub-plot (*a*) cut every week.
" (*b*) " " 2 weeks.
" (*c*) " " 3 "
" (*d*) " " 4 "
" (*e*) " " 5 "
" (*f*) " " 6 "
" (*g*) " " 7 "
" (*h*) " " 8 "
" (*i*) " " 9 "
" (*j*) " " 10 "

Samples cut at the same intervals of time were bulked together after fresh and air-dried weights had been measured, and at the end of the season a sample of each (i.e. grass one week old, two weeks old, etc.) was submitted to the School of Agriculture, Shambat, for chemical analysis. Furthermore greater care was taken to ensure that the watering treatment conformed as closely as possible to that set out in the design of the experiment.

As in the previous season, the results showed a significant difference between certain groups of treatments, the same general trend observed in the first season again being evident.

TABLE 563

EFFECT OF DIFFERENT WATERING TREATMENTS ON GRASS YIELDS, 1951-52

Treatment	Number of Applications	Total Amount of Water Applied m^3.p.f.	Yield of Grass (Air-Dried Weights from Plot 30 m. × 10 m.) in kg.
400 m^3.p.f. every 7 days ...	24	9,600	40·0
600 " " 14 " ...	12	7,200	39·3
200 " " 7 " ...	24	4,800	34·8
200 " " 14 " ...	12	2,400	30·5
600 " " 21 " ...	8	4,800	30·5
400 " " 14 " ...	12	4,800	27·3
600 " " 28 " ...	6	3,600	27·1
400 " " 21 " ...	8	3,200	27·1
400 " " 28 " ...	6	2,400	25·2
200 " " 28 " ...	6	1,200	21·8
200 " " 21 " ...	8	1,600	20·5
Control	—	Nil	8·7
Significant Difference (p=0·05)	—	—	7·2

The analysis of the grass cut from the plots is given in Table 564 below :

TABLE 564

SETARIA INCRASSATA

ANALYSIS OF GRASS SAMPLES, 1951-52

(Composition of Dry Matter)

Sample	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash	Silica SiO_2
Grass cut at 1 weekly intervals	8·23	1·59	31·32	40·48	18·39	14·18
" " " 2 " "	8·63	2·83	30·77	35·23	22·53	17·81
" " " 3 " "	8·42	1·91	31·21	38·55	19·91	15·36
" " " 4 " "	7·21	1·89	30·17	38·00	22·72	17·81
" " " 5 " "	7·31	1·77	32·41	38·66	19·86	14·99
" " " 6 " "	6·70	2·20	28·92	39·01	23·17	17·63
" " " 7 " "	7·09	1·94	28·90	38·03	24·03	17·96
" " " 8 " "	6·82	1·58	32·61	37·39	21·60	16·90
" " " 9 " "	6·26	1·54	28·39	40·31	23·51	17·49
" " " 10 " "	5·78	1·53	33·15	38·62	20·92	15·83

EXPERIMENT B

This experiment, which was not replicated, was carried over a term of two years (1950–51 and 1951–52). A pasture composed only of *Echinochloa pyramidalis* was established and plots 33 m. × 12·75 m. were marked out as in Experiment A. The *Echinochloa pyramidalis* was collected from the riverain flood-plain at Malakal. It was thought that this grass, which is a swamp grass, would have a higher water requirement than the *Setaria incrassata* type grassland and the experiment was really put down to confirm this supposition.

Different plots of *Echinochloa pyramidalis* were subjected to one of the following treatments during the dry season :

300 m³. water per feddan applied every 7 days.
,, ,, ,, ,, ,, ,, 14 ,,
,, ,, ,, ,, ,, ,, 21 ,,
,, ,, ,, ,, ,, ,, 28 ,,
600 m³. ,, ,, ,, ,, ,, 7 ,,
,, ,, ,, ,, ,, ,, 14 ,,
,, ,, ,, ,, ,, ,, 21 ,,
,, ,, ,, ,, ,, ,, 28 ,,

In all other respects the management was identical with that given to Experiment A. The results are again considered separately.

First Season (1950–51)

In general terms, higher water treatments gave higher yields, although there was no definite steady trend in this respect.

TABLE 565

EFFECT OF DIFFERENT WATERING TREATMENTS ON GRASS YIELDS, 1950–51

ECHINOCHLOA PYRAMIDALIS

Treatment (based on average throughout dry season)	Number of Applications	Total Amount of Water Applied m³.p.f.	Yield of Grass (Air-Dried Weights from plots 33 m. × 12·75 m.) in kg.
307 m³.p.f. every 21 days ...	8	2,460	227·0
605 ,, ,, 7 ,, ...	23	13,920	141·5
614 ,, ,, 21 ,, ...	10	6,140	135·0
612 ,, ,, 14 ,, ...	12	7,340	127·5
310 ,, ,, 14 ,, ...	12	3,720	123·0
288 ,, ,, 7 ,, ...	24	6,920	104·0
312 ,, ,, 28 ,, ...	6	1,870	100·5
600 ,, ,, 28 ,, ...	6	3,600	72·8

Second Season (1951–52)

All changes in management adopted in the second season in Experiment A were also applied to Experiment B. Although again there was no definite trend, the higher applications of water generally produced the higher yields, thus following to a certain degree the results of the first season.

TABLE 566

EFFECT OF DIFFERENT WATERING TREATMENTS ON GRASS YIELDS, 1951–52

ECHINOCHLOA PYRAMIDALIS

Treatment	Number of Applications	Total Amount of Water Applied m³.p.f.	Yield of Grass (Air-Dried Weights from plots 30 m. × 10 m.) in kg.
600 m³.p.f. every 7 days ...	24	14,400	41·2
600 ,, ,, 14 ,, ...	12	72,000	34·2
600 ,, ,, 21 ,, ...	8	4,800	32·9
300 ,, ,, 7 ,, ...	24	7,200	29·4
300 ,, ,, 21 ,, ...	8	2,400	29·0
300 ,, ,, 28 ,, ...	6	1,800	25·4
600 ,, ,, 28 ,, ...	6	3,600	24·0
300 ,, ,, 14 ,, ...	12	3,600	19·8

The analysis of the grass cut from the plots in the course of the experiment (second season) is given in Table 567 below:

TABLE 567

ECHINOCHLOA PYRAMIDALIS
ANALYSIS OF GRASS SAMPLES, 1951–52
(Composition of Dry Matter)

Sample	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash	Silica SiO_2
Grass cut at 1 weekly intervals	8·67	1·45	34·01	35·60	20·26	14·12
" " " 2 " "	9·72	2·07	27·90	42·48	17·83	12·28
" " " 3 " "	9·48	2·53	28·22	42·52	17·24	12·29
" " " 4 " "	9·84	1·83	30·25	40·44	17·64	13·09
" " " 5 " "	9·64	1·90	30·38	39·14	18·94	14·78
" " " 6 " "	8·69	2·10	28·30	43·34	17·57	11·98
" " " 7 " "	8·92	2·37	29·09	39·42	20·20	15·55
" " " 8 " "	7·55	2·37	32·61	38·68	18·78	14·41
" " " 9 " "	7·11	1·13	32·27	39·18	20·30	15·72
" " " 10 " "	7·07	1·71	32·20	42·84	16·18	11·64

From the above experiments some incidental information was obtained which is worthy of record. Both experiments began in December and ended during the following May, i.e. they covered the dry season during which the pastures were irrigated. During the period May to December of each year (i.e. the rainy season) no irrigation water was applied, the normal annual rainfall being sufficient to produce growth during that period. Before the experiments could begin again in December it was necessary to remove the rainy season's growth from the plots.

During 1950 the herbage was removed at the end of September, but, owing to the absence of qualified staff, no record of the yield of grass harvested from the plots was taken. However, the grass harvested from Experiment A (*Setaria incrassata* dominated) was made into hay, samples of which were later submitted for chemical analysis and feeding trials. The grass was cut at the flowering stage. The results of the analysis and trials are given in the following tables:

TABLE 568

ANALYSIS OF HAY
RAINS GROWTH CUT FROM EXPERIMENT A IN SEPTEMBER 1950

	Organic Matter	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash	Silica SiO_2
Composition of Dry Matter ...	81·88	6·61	1·24	31·38	42·65	18·12	13·22
Digestibility Coefficients	52·87	59·53	48·42	58·35	49·28	—	—
Digestible Nutrients	43·29	3·27	0·62	18·31	21·02	—	—

S.E. ... ... 30·41
T.D.N. ... ... 43·95
Moisture in sample ... ... 3·95

TABLE 569

ANALYSIS OF HAY USED IN FEEDING TRIAL
RAINS GROWTH CUT FROM EXPERIMENT A IN 1950

	Organic Matter	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.
Digestibility Coefficients	57·87	52·02	51·04	64·81	53·86
Digestible Nutrients	43·38	3·44	0·63	20·34	22·97

S.E. ... ... 35·45
T.D.N. ... ... 48·17

Percentage fodder actually consumed by two sheep in trial:

Sheep A	Sheep B	Mean
94·68	84·84	89·76

In 1951 the grass was cut from both experiments in the first week of September and made into silage. Molasses was not available for use in the making of the silage. The grass harvested from the Experiment A was ensiled in a rectangular brick silo and then covered over with soil; that harvested from Experiment B was chopped by hand and placed in a pit silo. In both cases the grass was about 3 to 3½ months old when cut. The recorded yields of the grass harvested from Experiment A were lost, but that of *Echinochloa pyramidalis* cut from $\frac{6}{16}$ feddan (Experiment B) gave 2,780 kg. fresh weight. Samples of the silage made from the grass from both experiments were analysed and the results are given in Table 570 below.

TABLE 570

ANALYSIS OF SILAGE

(Composition of Dry Matter)

	Sample	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash	Silica SiO_2
Made from grass cut from Experiment A. *Setaria incrassata*	1	4·38	1·17	36·91	41·71	15·85	12·63
	2	3·49	1·23	40·11	42·71	12·45	9·85
Made from grass cut from Experiment B. *Echinochloa pyramidalis*	1	7·47	2·63	32·06	41·65	16·19	13·52
	2	5·32	1·80	36·64	42·05	14·18	11·43
	3	5·03	1·60	39·72	41·68	11·94	8·00
	4	4·18	1·09	40·76	42·49	11·47	6·80

Determination of acetic and butyric acids in Samples 3 and 4 :

	Sample 3	Sample 4
	%	%
Total Acetic	1·07	3·95
Free Acetic	0·47	1·36
Combined Acetic ...	0·60	—
Total Butyric	0·83	0·51
Free	0·25	0·86
Combined Butyric ...	0·58	—

In December 1951 the grass was again removed from all plots connected with Experiments A and B and made into hay. The yields (both fresh when cut and three days later when part dry) are given in the Tables 571 and 572 below. The size of the plots was approximately $\frac{1}{16}$ feddan in area.

TABLE 571

GRASS YIELDS FROM EXPERIMENT A

CUT IN DECEMBER 1951

(in kilogrammes)

Plot No.	Replicates A Fresh Weight	A Air-Dried Weight	B Fresh Weight	B Air-Dried Weight	C Fresh Weight	C Air-Dried Weight	D Fresh Weight	D Air-Dried Weight
1	530·0	240·0	391·0	250·0	377·0	250·5	682·0	540·0
2	250·0	75·0	452·5	95·0	460·0	390·0	950·0	730·5
3	390·5	275·5	630·0	450·0	345·0	280·0	540·0	290·0
4	150·0	90·0	240·0	180·5	415·5	190·8	444·5	342·5
5	380·0	290·5	333·8	217·0	597·0	287·0	650·0	290·0
6	440·0	130·0	348·0	133·0	330·5	224·0	634·0	275·0
7	600·0	300·0	460·0	250·0	966·5	622·0	898·0	604·0
8	670·5	250·0	575·0	352·0	620·0	310·6	754·5	232·0
9	200·0	190·0	940·0	490·0	704·5	493·0	345·0	254·0
10	377·0	245·0	232·0	201·5	755·5	267·5	584·5	406·5
11	391·0	130·5	345·0	188·0	205·5	89·8	562·0	154·0
12	540·0	290·5	130·0	70·0	600·0	302·0	512·0	293·0

NOTE: Size of plots 33 m. × 12·75 m.

Taking the average yields of the first 10 plots, 5,161 kg. fresh weight per feddan were harvested.

TABLE 572

GRASS YIELDS FROM EXPERIMENT B
CUT IN DECEMBER 1951
(in kilogrammes)

Plot No.	Fresh Weight	Air-Dried Weight
1	472·5	282·5
2	605·0	412·0
3	289·5	174·5
4	945·0	530·0
5	526·5	252·0
6	625·0	314·0
7	743·4	342·5
8	842·0	421·0

NOTE: Size of plots 33 m. × 12·75 m.

MANAGEMENT

In order to acquire some basic data on the management and probable stock-carrying capacity of irrigated pasture an experiment was carried out at the Malakal Experimental Station. In this experiment 9 paddocks of *Setaria incrassata* type pasture, each one feddan in area, were fenced and irrigated at the rate of approximately 400 m³. per application. Each paddock was irrigated in rotation with an interval of 2 days between waterings, except in the initial waterings of the first season when the routine had not been established. In this way each paddock was watered every 18 days. The irrigation period lasted approximately from December to May/June; during the rest of the year rainfall alone was sufficient to enable plant growth to continue. Throughout the irrigation period cattle grazed the paddocks rotationally (following the watering schedule with a 16-day interval), spending two days grazing each paddock and taking 18 days to complete a rotation. On the 19th day they were weighed, and then grazed outside the paddocks[2]. In this way a paddock, once watered, had a 16-day rest period which enabled the soil to dry out sufficiently for stock to graze comfortably and allowed an uninterrupted period during which the grass could grow. During the rainy period the cattle grazed outside the experimental paddocks, the grass within the paddocks growing unchecked until later in the year (November/December) when it was cut and made into hay.

The experiment was carried over a period of two years and, since modifications in management were found desirable in the second year, the management and the results for each period are considered separately.

First Season (1950–51)

Irrigation

The experiment began on 31st December 1950 with the irrigating of Paddock I. Prior to irrigation the rank growth of grass from the previous rains was removed from all 9 paddocks by cutting. Unfortunately no record of the yield of this grass was taken and it was not conserved. In Table 573 a summary of the water treatment received by each paddock is recorded:

TABLE 573

IRRIGATION: FIRST SEASON, 1950–51

Paddock No.	First Watered on	Last Watered on	Total No. of Waterings	Total Amount of Water Applied m³.	Approx. Amount of Water Applied per Application m³.
1	13.12.50	23.4.51	8	3,108	388·5
2	16.12.50	25.4.51	8	3,180	397·5
3	19.12.50	27.4.51	8	3,220	402·5
4	22.12.50	29.4.51	8	3,220	402·5
5	23.12.50	1.5.51	8	3,260	407·5
6	26.12.50	3.5.51	8	3,148	393·5
7	27.12.50	5.5.51	8	3,216	402·0
8	30.12.50	7.5.51	8	3,145	393·0
9	31.12.50	9.5.51	8	3,145	393·0

Intensity of Stocking

The cattle entered Paddock 1 on 1st December 1950, and from that date onwards until 27th May 1951 they grazed all the paddocks in rotation (eight rotations), spending 2 days grazing in each paddock. The cattle received no supplementary feeding and their numbers were adjusted at the beginning of each rotation according to the amount of grazing available. The numbers grazing each paddock during each rotation are given in Table 575 and summarized in Table 574 below. The cattle consisted of cows (dry and in milk) and calves.

TABLE 574

INTENSITY OF STOCKING, 1950–51

Paddock Number	Number of Days Grazed	Number of Animal Unit Days Grazing
1	16	202
2	16	204
3	16	202
4	16	205
5	16	206
6	16	206
7	16	206
8	16	206
9	16	206
Total feddans ...	144	1,843

From the above table the average rate at which the paddocks were stocked throughout the dry season is calculated to have been 1·42 Animal Units per feddan. A study of Table 575, however, will show that this rate fluctuated throughout the season, the rate being high initially, then falling until it remained fairly constant during the fifth and sixth rotations, and then rising again towards the end of the period.

Condition of Cattle

The cattle used in this experiment (1950–51) were cows and in-calf heifers obtained from government fines herds, and were consequently neither in good condition nor of high quality. They were of mixed ages and their previous history was unknown. They were first weighed on 5th February 1951 after they had completed two rotations on the irrigated pastures. Afterwards weights were taken at the end of each rotation. Milk yields were recorded from the beginning of January but, owing to lack of supervision, trained staff, and proper measuring vessels and scales, and the fact that mature cows do not let down their milk without suckling their calves, the records are incomplete and not fully accurate. The livestock weights are given in Table 576 and the monthly milk yields in Table 577.

TABLE 575

INTENSITY OF STOCKING PER PADDOCK PER ROTATION, 1950-51

Paddock Number		1		2		3		4		5		6		7		8		9	
		Cows	Calves	Cows	Calves	Cows	Calves	Cows	Calves	Cows	Calves	Cows	Calves	Cows	Calves	Cows	Calves	Cows	Calves
First Rotation	1st Day	15	5	15	5	15	5	15	5	15	5	15	5	15	5	15	5	15	5
	2nd Day	15	5	15	5	15	5	15	5	15	5	15	5	15	5	15	5	15	5
Second Rotation	1st Day	14	5	15	5	15	5	15	5	15	5	15	5	15	5	15	5	15	5
	2nd Day	15	5	15	5	15	5	15	5	15	5	15	5	15	5	15	5	15	5
Third Rotation	1st Day	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4
	2nd Day	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4
Fourth Rotation	1st Day	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4
	2nd Day	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4
Fifth Rotation	1st Day	8	4	10	4	8	4	8	4	8	4	8	4	8	4	8	4	8	4
	2nd Day	8	4	8	4	8	4	7	4	8	4	8	4	8	4	8	4	8	4
Sixth Rotation	1st Day	8	4	8	4	8	4	8	4	8	4	8	4	8	4	8	4	8	4
	2nd Day	8	5	8	4	8	4	8	4	8	4	8	4	8	4	8	4	8	4
Seventh Rotation	1st Day	8	4	8	4	8	4	10	4	10	4	10	4	10	4	10	4	10	4
	2nd Day	8	4	8	4	8	4	10	4	10	4	10	4	10	4	10	4	10	4
Eighth Rotation	1st Day	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4
	2nd Day	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4
TOTAL		167	69	170	68	168	68	171	68	172	68	172	68	172	68	172	68	172	68

TABLE 576

LIVESTOCK WEIGHTS, 1950-51

(In kilogrammes)

No.	Name	End of 2nd Rotation (5.2.51)	End of 3rd Rotation (23.2.51)	End of 4th Rotation (14.3.51)	End of 5th Rotation (20.4.51)	End of 6th Rotation (9.5.51)	End of 7th Rotation (28.5.51)	End of 8th Rotation (16.6.51)	Gain or Loss
1	Cotliet dit (cow) ...	190	(Died)	—	—	—	—	—	—
2	Lualbuot ,, ...	180	182	173	194	191	194	203	+23
3	Reng ,, ...	163	145	155	170	179	171	179	+16
4	Car tot ,, ...	153	155	150	168	162	172	162	+ 9
5	Kur ,, ...	141	138	130	145	140	141	147	+ 6
6	Yan tot ,, ...	164	176	171	177	174	173	176	+12
7	Lual ,, ...	146	142	136	149	141	145	137	− 9
8	Jokliet ,, ...	223	223	160	178	171	179	186	−37
9	Boryan ,, ...	215	217	206	224	218	220	228	+13
10	Yanlual ,, ...	204	197	193	190	188	194	209	+ 5
11	Kaklual ,, ...	215	231	212	222	210	Used in Fodder Trials, May–June, and not used in grazing experiment after end of 2nd Rotation.		
12	Jokloke ,, ...	165	200	155	194	188			
13	Car dit ,, ...	259	261	254	248	242			
14	Yan Ngok ,, ...	183	173	177	201	197			
15	Cotliet ,, ...	150	155	150	161	159	164	180	+30
16	Ruath Yan (male calf)	86	88	83	105	111	118	127	+41
17	Dau Liet (female calf)	55	60	60	73	79	77	97	+42
18	Dau Kuac (female calf)	55	62	57	73	77	82	97	+42
19	Ruath Lual (male calf)	54	(Died)	—	—	—	—	—	—
20	Dau Yan (female calf)	51	56	63	66	73	75	90	+39

TABLE 577

MONTHLY MILK YIELDS, 1950-51

(In pints)

No.	Name	JANUARY		FEBRUARY		MARCH		APRIL		MAY		JUNE	
		Yield	No. of Days in Milk	Yield	No. of Days in Milk	Yield	No. of Days in Milk	Yield	No. of Days in Milk	Yield	No. of Days in Milk	Yield	No. of Days in Milk
1	Cotliet dit	Nil	Nil	29·4	26	45·5	31	—	—	—	—	—	—
2	Lualbuot	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
3	Reng	22·0	30	21·4	28	33·6	31	35·9	30	42·5	31	40·1	30
4	Car tot	19·3	30	1·3	3	Nil	Nil	Nil	Nil	Nil	Nil	13·9	7
5	Kur	Nil	Nil	43·5	27	60·7	31	77·9	30	84·3	31	104·2	31
6	Yan tot	Nil	Nil	26·4	28	35·0	31	39·5	30	42·8	31	48·5	30
7	Lual	2·5	3	27·7	28	38·1	31	50·8	30	57·4	31	42·9	30
8	Jokliet	2·8	3	25·8	28	32·7	31	37·4	30	39·7	31	40·3	30
9	Boryan	36·0	30	40·9	28	56·0	31	59·3	30	63·4	31	65·3	30
10	Yanlual	33·3	30	28·3	28	21·9	20	28·0	30	17·6	22	Nil	Nil
11	Kaklual	Nil	Nil	Nil	Nil	37·9	19	72·5	30	69·9	31	25·9	30
12	Jokloke	24·8	30	0·5	1 (Dry)	58·0	30	104·5	30	115·5	31	63·6	30
13	Car dit	Nil	Nil	Nil	Nil	Nil	Nil	40·9	30	50·2	31	21·8	24
14	Yan Ngok	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	14·7	11	57·7	30
15	Cotliet	28·8	30	1·5	2 (Dry)	Nil	Nil	28·0	30	20·1	31	Nil (Dry)	Nil

HERBAGE PRODUCTION

To estimate approximately the amount of herbage produced by the irrigated paddocks throughout the grazing period two wire cages, each 4 sq. m. in area, were placed at random in each paddock immediately before the cattle entered to graze. When the cattle were withdrawn after two days' grazing the grass within the cages was cut and weighed. This represented the amount of grass produced in the 18-day period between one two-day grazing period and the next. Each paddock received a similar treatment. From these representative samples the amount of herbage produced during each rotation and by each paddock per season has been estimated and recorded in Tables 578 and 579.

TABLE 578

HERBAGE PRODUCED PER ROTATION, 1950–51

	Fresh Weight in kg.
First Rotation	6,169
Second Rotation	4,277
Third Rotation	2,711
Fourth Rotation	2,673
Fifth Rotation	3,934
Sixth Rotation	3,467
Seventh Rotation	4,486
Eighth Rotation	5,219
Total for Season	32,936

TABLE 579

HERBAGE PRODUCED PER PADDOCK PER SEASON, 1950–51

Paddock	Fresh Weight in kg.
1	4,316
2	3,837
3	3,197
4	3,334
5	3,048
6	3,147
7	3,923
8	5,035
9	3,099
Total per Season	32,936

No analysis of the grass was made in this season, but samples were submitted in the 1951–52 season (see Table 586). On the above basis the average daily ration per Animal Unit throughout the season (assuming the paddocks were fully grazed) was 17·9 kg. fresh weight. However, examination of Table 578 shows that this daily ration was not constant throughout the season, being high initially, falling during the third and fourth rotations, and then gradually rising again (compare with live-weights: Table 576). If we assume that the dry matter content of the fresh herbage is 20%, then the average dry matter intake per beast per day works out at approximately 3·6 kg. This is far below that required even for maintenance[9]. These figures therefore confirm that the stocking intensity of 1·42 A.U. per feddan was far too high (again see Table 576). Taking herbage production alone, if we assume that the average live weight of the cattle is 200 kg. and the average beast can consume up to 2½% of its live weight in dry matter, the average dry matter intake would be 5 kg., or 25 kg. fresh weight. Therefore with a total production of 32,936 kg. fresh weight from the paddocks throughout the 144-day grazing period, the theoretical stocking should have been 1 A.U. per feddan, varying slightly throughout the season according to the productivity of the pasture.

SECOND SEASON (1951–52)

IRRIGATION

Paddock 1 was first watered on 1st December 1951 and each of the other paddocks was watered at two-day intervals thereafter (i.e. Paddock 2 on December 3rd, Paddock 3 on December 5th, and so on). The treatment given to each paddock throughout the season is recorded in Table 580.

TABLE 580

IRRIGATION: SECOND SEASON, 1951–52

Paddock No.	First Watered on	Last Watered on	Total No. of Waterings	Total Amount of Water Applied m³.	Approx. Amount of Water Applied per Application m³.
1	1.12.51	23.4.52	9	3,600	400
2	3.12.51	25.4.52	9	3,600	400
3	5.12.51	27.4.52	9	3,600	400
4	7.12.51	29.4.52	9	3,600	400
5	9.12.51	1.5.52	9	3,600	400
6	11.12.51	3.5.52	9	3,600	400
7	13.12.51	5.5.52	9	3,600	400
8	15.12.51	7.5.52	9	3,600	400
9	17.12.51	9.5.52	9	3,600	400

Prior to irrigation, the old rains growth in each paddock was cut and made into hay, yields of which are given in Table 581. The grass was approximately five months old when cut and was cut from each paddock three days before the paddock was first watered.

TABLE 581

GRASS YIELDS FROM PADDOCKS, 1951

Paddock No.	Yield in kg.p.f.	
	Fresh Weight	Air-Dried Weight
1	2,016	1,628
2	2,920	1,040
3	2,340	19,20
4	1,705	850
5	3,422	1,930
6	2,516	1,732
7	4,323	3,120
8	2,115	1,006
9	2,833	1,842
Total	24,190	15,065

Through an oversight, samples of the hay were not submitted for analysis, but hay made from herbage cut from open grassland adjacent to the paddocks, and having a similar composition to that within the paddocks, had the following composition.

TABLE 582

ANALYSIS OF HAY

Moisture in Sample	Dry Matter Basis					
	Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash	Silica SiO_2
1·58	4·23	1·32	38·23	43·01	13·21	9·25

Intensity of Stocking

Young bullocks replaced the cows and calves used in the first season and were introduced into Paddock 1 on 18th December 1951. From then onwards until 27th May 1952 they grazed all paddocks in rotation, spending 2 days grazing in each paddock and taking 18 days to complete a rotation. The bullocks received no supplementary feeding and the number grazing the paddocks was kept at the constant figure of 10 throughout the season. The pastures were therefore stocked at the rate of 1·1 Animal Units per feddan throughout the 162-day grazing period.

Condition of Cattle

The young bullocks used, although not of high quality, were in fairly good condition on purchase. Their ages were estimated and are given in Table 583, together with the live weights recorded at the end of each rotation. From this table it is evident that soon after they entered the grazing paddocks in December they started to lose weight and that they continued to do so until about the fourth rotation, when they started to gain. They continued gaining steadily until the experiment ended, by which time the average live weight gain per beast over the period of 162 days was 21·6 kg., or 0·13 kg. per day.

TABLE 583

LIVESTOCK WEIGHTS, 1951–52
(In kilogrammes)

Herd No.	Estimated Age on 17.12.51	Live Weights: On Purchase 3.12.51	Prior to Commencement 17.12.51	End of 1st Rotation 4.1.52	End of 2nd Rotation 22.1.52	End of 3rd Rotation 9.2.52	End of 4th Rotation 27.2.52	End of 5th Rotation 16.3.52	End of 6th Rotation 2.4.52	End of 7th Rotation 21.4.52	End of 8th Rotation 9.5.52	End of 9th Rotation 27.5.52	Gain Col. 13– Col. 4
40	2 years	185	196	185	179	174	180	180	190	191	200	214	+18
41	3 „	206	213	200	196	198	200	205	219	216	219	235	+22
42	2 „	187	198	192	190	187	196	202	200	193	204	218	+20
43	2 „	218	234	224	226	227	230	230	237	235	243	255	+21
44	2 „ 8 months ...	194	198	202	198	195	206	207	215	216	226	232	+34
45	2 „ 3 „ ...	195	206	202	202	191	200	204	203	206	211	224	+18
46	2 „ 8 „ ...	232	234	223	225	224	229	231	231	230	239	252	+18
47	2 „ 8 „ ...	220	223	219	222	224	228	236	242	243	254	264	+41
48	2 „ 10 „ ...	221	233	220	219	219	227	225	232	229	241	255	+22
49	4 „	233	244	238	238	228	225	229	226	224	233	246	+ 2

HERBAGE PRODUCTION

An estimate of the amount of herbage produced by the pastures throughout the grazing season was made by adopting the method tried in the first season (see p. 1062), and is given in Tables 584 and 585.

TABLE 584

HERBAGE PRODUCED PER ROTATION, 1951–52

	Fresh Weight in kg.
First Rotation	1,344
Second Rotation	1,216
Third Rotation	1,535
Fourth Rotation	1,806
Fifth Rotation	1,609
Sixth Rotation	2,084
Seventh Rotation	3,972
Eighth Rotation	4,712
Ninth Rotation	4,961
Total for Season	23,239

TABLE 585

HERBAGE PRODUCED PER PADDOCK PER SEASON, 1951–52

Paddock	Fresh Weight in kg.
1	2,386
2	2,133
3	2,693
4	2,783
5	2,342
6	2,935
7	3,186
8	2,495
9	2,286
Total for Season	23,239

A sample of the grass cut from within the cages was submitted for analysis and had the following composition:

TABLE 586

ANALYSIS OF GRASS FROM PADDOCKS, 1951–52

(Dry Matter Basis)

Crude Protein	Ether Extract.	Crude Fibre	N-Free Extract.	Ash	Silica SiO_2
10·25	1·98	27·08	37·98	22·71	15·97

On the basis of the total amount of herbage produced and the rate at which the paddocks were stocked, the average daily ration throughout the season was 14·3 kg. fresh weight. An examination of Table 584 will show, however, that the productivity of the pasture increased with each successive rotation (compare with live weights in Table 583). Such a ration would have a dry matter content of approximately 3·0 kg., which is below that required for animal maintenance. It must be appreciated that the stock supplemented this ration by grazing the dry *Setaria incrassata* surrounding the paddocks on their way to and from the pasture. The stocking rate of 1·1 A.U. per feddan was nonetheless obviously too high. Taking the herbage produced (23,239 kg. in 162 days) and assuming an average intake of 25 kg. fresh weight per beast, the theoretical stocking rate should have been 0·7 A.U. per feddan, but again this would vary throughout the season.

CONCLUSION

Actual stocking rates of 1·4 A.U. and 1·1 A.U. per feddan in the 1950–51 and 1951–52 seasons were too high. From the amount of herbage produced it has been estimated that rates should have been nearer 1·0 A.U. in the 1951–52 season and 0·7 A.U. in the 1951–52 season. As mentioned, the stock obtained some supplementary feed by grazing the dry *Setaria incrassata* dominated pasture surrounding the paddocks on their way to and from the paddocks each day. Moreover, in assessing the stocking capacity of such pasture, account should be taken of the grass which could be conserved at the end of the rains. Although not a highly valuable product, it would provide much of the necessary bulk. If this were taken into account, a stocking rate of 1·0 A.U. per feddan (or even higher) should be possible.

GRASS AND LEGUME TRIALS

These trials, which were of a preliminary and elementary nature, were designed to determine the suitability of both indigenous and introduced grasses and legumes for either the production of irrigated pastures or the production of fodder crops under irrigation. During the short period available all that could be done was to try out as many grasses and legumes as space, time, and staff allowed, in order to determine if they were suited to climatic conditions or to the new conditions produced by growing under irrigation; and later to establish them in plots to determine their production. The production stage was reached in the case of some of the indigenous plants but not in the case of the introduced species. Below brief accounts are given of those species, both indigenous and introduced, which were tried and studied[1].

INDIGENOUS GRASSES AND LEGUMES

Phragmites communis

A plot of this grass was established in 1950 and it continued to grow well until the close of the experiment. It is dominant over a large area of the flood-plain between Juba and Gemmeiza. It was later quite clear that this grass has no value as a grazing plant or as a fodder crop.

Hyparrhenia rufa

A plot was planted out with this grass in July 1950 from material collected outside Malakal and it soon became well established. A cut taken in January 1951 (after approximately 6 months) gave 740 kg.p.f. fresh weight of herbage. Subsequent cuts on 28th February, 22nd March, 11th April, and 4th July gave 425, 752·5, 547·5, and 3,620 kg.p.f. fresh weight. Although the grass continued to grow during the irrigation period (December to the end of May), its appearance was not good until the start of the rainy season, when growth quickened and the grass took on a fresher appearance. In 1952 the plot ($\frac{1}{10}$ feddan) was sub-divided into 8 sub-plots, and the grass in each was cut right back to ground level on the same date (30.8.52). Each sub-plot was then cut once; the first one 2 weeks after the initial cutting, the second 4 weeks later, and so on, until the eighth sub-plot was cut 16 weeks after the initial cut. Both fresh and air-dried weights were recorded and the samples were later submitted to the School of Agriculture, Shambat, for analysis. The results of the analysis are not yet available, but the yields are recorded in Table 587.

TABLE 587

HYPARRHENIA RUFA

YIELDS AT DIFFERENT GROWTH STAGES

Age of Herbage	Yields from Sub-Plots ($\frac{1}{80}$ feddan)	
	Fresh Weight in kg.	Air-Dried Weight in kg.
2 weeks	1·25	0·50
4 „	10·00	1·50
6 „	14·00	5·00
8 „	28·25	8·50
10 „	45·25	17·75
12 „	20·90	10·75
14 „	22·00	9·50
16 „	10·50	4·50

Hyparrhenia rufa is a perennial grass well distributed throughout the Flood Region and it might be suitable for pasture formation under irrigation, although its tufted habit would make sward formation difficult.

Setaria incrassata

This perennial grass, like *Hyparrhenia rufa*, occurs widely throughout the Flood Region and is the dominant grass around Malakal. It has already been considered in connection with the irrigation trials. In 1952 a plot was sampled in the same way as for *H. rufa*. The results of the chemical analysis are not yet available but the yields are given below :

TABLE 588

SETARIA INCRASSATA

YIELDS AT DIFFERENT GROWTH STAGES

Age of Herbage	Yields from Sub-Plots ($\frac{1}{40}$ feddan)	
	Fresh Weight in kg.	Air-Dried Weight in kg.
2 weeks	3·25	1·50
4 ,, ...	1·75	1·25
6 ,, ...	4·25	1·50
8 ,, ...	9·00	1·75
10 ,, ...	9·85	3·75
12 ,, ...	8·00	3·75
14 ,, ...	11·50	5·55
16 ,, ...	12·00	4·75

Ischaemum brachyatherum

A plot was planted out with this perennial grass in 1950 from material collected from around the Malakal Experimental Station, and it soon became established. A first cut was taken in January 1951, giving 1,120 kg.p.f. fresh weight. Subsequent cuts taken on 28th February, 26th March, and 5th July gave 322·5, 772·5, and 1,770 kg.p.f. fresh weight respectively. It did not appear to be growing happily under irrigation in the dry season but grew vigorously once the rains began. In 1952 it was subject to the same sampling as *H. rufa* (see p. 1067), and the results are given below. The chemical analysis figures are not yet available.

TABLE 589

ISCHAEMUM BRACHYATHERUM

YIELDS AT DIFFERENT GROWTH STAGES

Age of Herbage	Yields from Sub-Plots ($\frac{1}{40}$ feddan)	
	Fresh Weight in kg.	Air-Dried Weight in kg.
2 weeks	3·50	1·75
4 ,, ...	3·75	1·75
6 ,, ...	8·50	3·50
8 ,, ...	10·50	4·00
10 ,, ...	11·50	10·00
12 ,, ...	12·75	6·50
14 ,, ...	19·95	12·20
16 ,, ...	—	—

This grass might prove useful as a pasture plant under irrigation, although again, like *Hyparrhenia rufa* and *Setaria incrassata*, it has a tufted habit.

Setaria sp. (probably *S. lynseii*)

A plot of this grass was planted from material collected from land sloping to the lagoon near the Experimental Station. It easily became established, growing tall, and producing much bulk. It appears to be tolerant of both over and under watering. It is probably more suitable as a fodder grass grown in rows than a pasture grass, although it is rather coarse and stock might find such fodder unpalatable. In July 1952 it was sampled in the same way as *Hyparrhenia rufa*. The results of the chemical analysis are not yet available.

TABLE 590

SETARIA SP. (*S. LYNSEII*)

YIELDS AT DIFFERENT GROWTH STAGES

Age of Herbage	Yields from Sub-Plots ($\frac{1}{40}$ feddan)	
	Fresh Weight in kg.	Air-Dried Weight in kg.
2 weeks	6·75	3·00
4 ,, ...	9·00	2·25
6 ,, ...	14·25	1·50
8 ,, ...	29·75	9·00
10 ,, ...	38·00	19·75
12 ,, ...	42·25	15·25
14 ,, ...	41·25	18·25
16 ,, ...	42·50	20·25

Panicum repens

This grass was planted out during the rainy season of 1951 and soon became established. The material in the form of rhizomes was obtained from near Malakal. It is a short, spreading, rhizomatous perennial grass, tough and probably very unpalatable except in the very early stages. It proved to be a most troublesome weed in irrigation channels and in adjoining plots. It might be suitable as a pasture grass if grazed well down and combined with other species which would prevent it becoming dominant. Samples at different growth stages were taken as above. The results of analysis are not yet available.

TABLE 591

PANICUM REPENS

YIELDS AT DIFFERENT GROWTH STAGES

Age of Herbage	Yields from Sub-Plots ($\frac{1}{50}$ feddan)	
	Fresh Weight in kg.	Air-Dried Weight in kg.
2 weeks	4·55	2·00
4 „	23·25	3·50
6 „	27·50	8·50
8 „	54·50	23·75
10 „	61·25	20·75
12 „	62·25	24·25
14 „	56·75	28·25
16 „	59·00	23·75

Echinochloa pyramidalis

Two types of *E. pyramidalis* were established in plots by collecting plants from the flood-plain near the Experimental Station. *E. pyramidalis* (*duiyang*—E. Nuer) is the most common type found on the flood-plain; it is not so tall as *E. pyramidalis* (*reil*—E. Nuer) which is a much larger type, producing much vegetative growth and flowering heads, and is also more hairy than *E. pyramidalis* (*duiyang*). Both have done exceptionally well and would be suitable for growing in rows under irrigation as pasture or as fodder grasses. The following yields at various growth stages were recorded between August and October 1952 for *E. pyramidalis* (*duiyang*):

TABLE 592

ECHINOCHLOA PYRAMIDALIS

YIELDS AT DIFFERENT GROWTH STAGES

Age of Herbage	Yields from Sub-Plots ($\frac{1}{50}$ feddan)	
	Fresh Weight in kg.	Air-Dried Weight in kg.
2 weeks	5·25	1·00
4 „	8·50	2·25
6 „	21·50	5·75
8 „	31·75	9·75
10 „	28·00	13·75
12 „	42·75	9·95
14 „	35·10	14·25
16 „	30·00	17·25

Echinochloa stagnina

Rhizomes of this grass were collected from the flood-plain near the Experimental Station and sown out in 1952; eventually a plot was established. No cuts were taken. It did not do as well as *E. pyramidalis* and would probably prove difficult to maintain in pasture because of its high water requirements, although it is worthy of further trial.

Vossia cuspidata

Two types were established from rhizomes collected from near the river bank. One type is much larger than the other, and is also more hairy and broader leaved. Both types grew well, but they are both so coarse and relatively unpalatable that they are considered unsuitable for use as irrigated pasture grasses or as fodder grasses.

Echinochloa colona

Established during the rains of 1950, the plants withered and died during the dry season. This is an annual grass, and is unsuitable for use as a pasture or fodder grass under irrigation.

Sporobolus pyramidalis

This grass grew well from material planted during the 1951 rainy season. It is a very tufted perennial grass with tough, unpalatable herbage which makes it unsuitable both for pasture and as a fodder crop.

Vetiveria nigritana

The remarks made concerning *Sporobolus pyramidalis* apply equally to *V. nigritana*. It is extremely unpalatable to stock.

Cynodon dactylon

A thick stand of this grass was established by July 1952 when sample cuts, recorded in Table 593, were taken at different growth stages. Figures of analysis are not yet available.

TABLE 593

CYNODON DACTYLON

YIELDS AT DIFFERENT GROWTH STAGES

Age of Herbage	Yields from Sub-Plots ($\frac{1}{40}$ feddan)	
	Fresh Weight in kg.	Air-Dried Weight in kg.
2 weeks	5·50	2·50
4 "	13·00	3·50
6 "	28·50	11·25
8 "	38·80	17·50
10 "	42·50	13·00
12 "	64·00	22·55
14 "	30·00	16·77
16 "	29·00	16·00

Cynodon dactylon might prove useful as a sward grass in mixture with others if well grazed, otherwise it tends to become rank and tough.

The annuals *Sorghum purpureo-sericeum*, *Rottboellia exaltata*, and *Brachiaria obtusiflora* were planted out from seedlings collected near the Experimental Station in the rains of 1951. They all made quick growth and produced much herbage although, with the possible exception of *Brachiaria obtusiflora*, they were stemmy and woody at maturity. During the dry season plants arising from self-sown seed did not do well under irrigation, although no trial was made by sowing out plots directly with seed and irrigating during the dry season. Other annuals, *Setaria pallidifusca*, *Pennisetum ramosum*, *Eriochloa nubica*, *Panicum porphyrrhizos*, *Digitaria* sp., *Brachiaria* sp. and *Elusine* sp., were also tried; with the possible exception of *Setaria pallidifusca*, which produces more bulk than the others, they proved to be of little use as fodder grasses and, being annuals, not suitable for the establishment of permanent irrigated pasture.

Hyparrhenia sp. (*H. pseudocymbaria*)

This grass was also tested, but it produces too little leaf to be a good fodder grass. This also applies to *Cymbopogon* sp. (*C. nervatus*).

Panicum sp.

Two perennial grasses (in Eastern Nuer called *tol* and *tol muoth*) which are probably *Panicum* spp., although flowering heads have not been produced for identification, were established in $\frac{1}{10}$-feddan plots. Both might prove useful as pasture grasses under irrigation, though they are rather tough. *Tol* is said to grow on the *toich*, while *tol muoth* grows on higher ground. No cuts have been taken.

An attempt was made to establish a few indigenous legumes found growing close to the Experimental Station (*Crotalaria* spp. and *Desmodium* spp.). They proved difficult to grow and no plots were established.

Although some of the above grasses were successfully established in plots and gave reasonable yields it must be remembered that the plots were established by transplanting material from where the grasses were found growing naturally, and not by establishment from seed. Once the grasses were established seeds were collected on which germination tests were made. The perennial grasses were shown to have a low germination percentage.

INTRODUCED GRASSES AND LEGUMES

In the course of the experimental period (1950–52) seeds of grasses and legumes not indigenous to the Jonglei Area were obtained from various sources and tried under irrigation at Malakal Experimental Station to test their suitability either for inclusion in irrigated pastures or as irrigated fodder crops.

In the early stages, when sufficient seed was available, $\frac{1}{10}$-feddan plots were sown, half the plots being ridged and the other half left flat. Later, however, lack of space and staff, together with the small amounts of seed that we were able to obtain, made it necessary to base observations on single plant rows. All the preparation of the land and sowing or planting was done by hand. No fertilizers were used, and irrigation water was applied only when necessary, no fixed amounts being given.

GRASSES *

Commercial seed of the following was obtained from England and sown out into $\frac{1}{10}$-feddan plots. Although resown a number of times, all were failures, either because of non-germination of the seed or, when the seed did germinate, the dying out of young seedlings.

Lolium perenne (Perennial rye grass)
Lolium italicum (Italian rye grass)
Phleum pratense
Festuca pratense
Dactylaglomerata
Phalaris tuberosa
Johnson grass

Since these are mainly temperate grasses this result was expected.

Chloris gayana

Commercial supplies of this grass were first tried on a $\frac{1}{10}$-feddan plot; although there were signs of germination, no plants developed. A later supply of seed (*C. gayana* ex Uramabo and *C. gayana* ex Mpwapwa) from the Veterinary Department, Mpwapwa, Tanganyika, was sown out in rows but failed to germinate.

This grass is therefore provisionally considered to be of little use for growing under irrigation at the Malakal latitude. *Chloris gayana* is indigenous to the Southern Sudan, being found in the wetter parts of Equatoria; material from this area, however, was not tried.

Eragrostis sp.

Seeds of *E. mildbraedii* were obtained from the Kawanda Research Station, Uganda, but failed to germinate. Seeds of *E. curvula* (Ermillo type 1950) were obtained from the Department of Agriculture, Pretoria, South Africa. The seeds germinated after a few days and plants became well established. It is a rather coarse grass and would probably have little or no value in irrigated pastures. Seeds were harvested.

Teff Grasses

Three varieties, Teff grass var. Erowit, Teff grass var. Inbruin, and Teff grass var. Inwit, were obtained from the Department of Agriculture, Pretoria, South Africa, and sown out in single rows on ridges in February 1952. They germinated well and flowered six weeks later. They made good growth until donkeys broke into the plot and grazed them right back. They would probably have very little use in irrigated pastures. A further type of Teff grass, ECR/1232, obtained from Wad Medani, was sown out in June 1952 and again in August 1952. This failed to germinate.

Bothriochloa spp.

Seeds of *B. insculpta* obtained from the Veterinary Department, Mpwapwa, Tanganyika, and of *Bothriochloa* spp. near *pertusa* (*B. glabia*) from the Department of Agriculture Experimental Station, Serere, Uganda, failed completely. *B. insculpta* is indigenous to the Sudan, being found in Eastern District, Equatoria.

Brachiaria brizantha

Seeds were received from Mpwapwa, Tanganyika, but were a complete failure.

Panicum spp.

Seeds of *Panicum maximum* ECR. 716 obtained from Wad Medani Research Farm were sown on 25.8.1951. They failed to germinate so also did those of *P. maximum* ECR. 1232. *P. maximum* Oliphants River, seeds of which were obtained from the Department of Agriculture, Southern Rhodesia, also failed. *P. maximum* (var. Trochoglume), seeds of which were received from Australia and sown out in August 1952, germinated and a single row was established. *P. antidotale* (ex Australia), seeds of which were obtained from the Department of Agriculture, S. Rhodesia (via Wad Medani) also proved a complete failure.

Pennisetum spp.

P. purpureum (Gold Coast strain): Seeds of this grass were obtained from Wad Medani and were a complete failure, since they failed to germinate. An attempt to establish this grass from roots supplied from Mpwapwa, Tanganyika, also failed.

P. typhoides Babala: Seeds were supplied by the Department of Agriculture, Pretoria, South Africa, and were sown on ridges in October 1951, germinating a few days later. This grass flowered and produced seeds. Owing to lack of bulk, it would probably have little value as a fodder crop under irrigation at Malakal latitude.

Paspalum spp.

This is by far the most promising group, of which a large number of introductions have been made, the main group being received from Australia.

P. dilatatum: Commercial seed of this species was sown out in a $\frac{1}{10}$-feddan plot in January 1951. Germination was poor and the grass was regarded as a failure until the inspection of the weed-infested plot after the rainy season of 1951 revealed three healthy and vigorously growing plants. The plot was cleaned, the plants nursed and later broken up to provide stock from which a whole plot was eventually established. The plants flowered and seeded and continued to grow well, apparently being tolerant of both over and under watering. *P. dilatatum* together with some others considered below is the most promising grass (from this introduced selection) so far established.

P. scrobiculatum ECR/1271: Seeds were obtained from Wad Medani Research Station and failed completely.

P. notatum: Seeds were obtained from the Department of Agriculture, Serere, and from Wad Medani Research Farm (*P. notatum* Pensecola, ECR/1270), but failed completely.

In 1953 small samples (6 gm. of each) of a wide range of *Paspalum* species (38 samples in all) were received from Australia[1]. These were sown out in tins containing fine Sobat silt. Young seedlings of the majority of the samples were eventually produced and these were later transferred to the field in the rainy season of 1953, where they have since become established. In some cases there were only one or two plants, but when these became firmly established some were broken up to provide stock for propagation. Since the seeds arrived late in the season and at the end of the Team's period of experimental work, it is not possible to give an account of each type, but there is a very wide selection from which to choose. Some are tall and bulky, suitable for forage grasses, others are extremely prostrate and suitable for inclusion in pastures. When inspected in December 1953, out of the total number of 38 introductions, 30 were found to be established.

Setaria splendida

Root stock was obtained from the Veterinary Department, Mpwapwa, Tanganyika, but the plants failed to establish themselves.

LEGUMES

Commercial seeds of *Trifolium pratense*, *T. repens*, and *T. hybridum* were obtained from England and sown out into $\frac{1}{10}$-feddan plots in January 1951. Germination was very poor and only where the plots were ridged did any plants develop. Most plants withered and died, but a few of each survived, and by July they were in a fairly healthy condition. Some plants continued to exist until 1952 when the Jonglei Investigation Team experimental period ended. Temperate clovers are in any case obviously unsuited to the climatic conditions of the Sudan and would have little value in irrigated pastures.

Trifolium subterraneum

Seeds were obtained from Wad Medani Research Farm (*T. subterranean* ECR/1258). As with other *Trifolium* species, germination was poor and only a few plants survived, mainly where grown on ridges. Some of these later developed into healthy plants. This species would probably not be suitable for pasture formation under irrigation in the Sudan, although further trials may be worth while since it forms the basis of such pastures in Australia.

Trifolium johnstoni

Seeds were obtained from Nairobi, Kenya, and sown out on ridges in August 1951. Germination was poor and a year later the few plants established did not produce flowering heads.

Medicago sativa (Lucerne, Alfalfa)

This is already grown in the Sudan (*berseem*), mainly in the north. Seeds were obtained from the Department of Agriculture, Pretoria, South Africa, and from Wad Medani. Another, Alfalfa hairy Peruvian, was obtained from Wad Medani Research Farm. All three germinated well. In all cases where the seeds were planted in the ridges growth was better than where plants were growing on the flat. They proved very susceptible to attack by white fly and blister beetle (*Epicanta aethiops* Lat.). Although the plants reached the flowering and seeding stages, they did not appear happy except during the winter months. It is doubtful if this species could be used as a large-scale dry season forage crop grown under irrigation.

Medicago luplulina

Commercial seeds were obtained from England and were sown both on ridges and on the flat in January 1951. Germination was good but the plants never flowered.

Alysicarpus spp. (Alice Clovers)

Two species, *A. longifolius* (seeds of which were obtained from Wad Medani Research Farm—ECR/1126—and the Henderson Research Station, Southern Rhodesia) and *A. vaginalis* (from Wad Medani), were tried. Both species germinated but neither grew well, although *A. vaginalis* is indigenous to the Southern Sudan.

Melilotis spp. (Sweet Clovers)

Seeds of *M. indica*, *M. alba*, and *M. huban* (huban clover) were obtained from the Henderson Research Station, Southern Rhodesia. Seeds of *M. indica* were also obtained from Wad Medani (ECR/1233) and from England. They all proved difficult to establish, germination being poor. Two others from Wad Medani Research Station, sweet clover (yellow flowered ECR/1043) and Cape sweet clover (ECR/1234) proved equally difficult to establish. These last two are spreading types suitable for pastures, but from the results so far it is doubtful whether any would be suitable either in pasture or as fodder producers under irrigation in the Jonglei Area.

Lespedeza spp.

L. stipulacea Korean was obtained from the Henderson Research Station, Southern Rhodesia, and another, Lespedeza, common, No. 733, from Wad Medani. Failures were recorded in both cases, either at the germination stage or soon afterwards.

Stylosanthes spp.

Samples of *S. bojeri* (from the Henderson Research Station, Southern Rhodesia, and from Australia), *S. guianensis* (from the Henderson Research Station), and *S. gracilis* (from Ol Jorok Orok, Kenya, and from Australia) were tested, but all failed either owing to non-germination or to dying off of seedlings soon afterwards.

Desmodium spp.

Species of *Desmodium* are indigenous to the Sudan, but on the whole they are unsuccessful and not very leafy. The following were received from foreign sources and tried:
D. discolor (from the Henderson Research Station) did reasonably well, being an erect plant about 3 ft. high and not very leafy, but of no use for pastures and of little use as a fodder crop.

D. scorpiurus (Samson clover) is similar to the above but has not taken well.

Desmodium sp. 11797 ,, ,, 11796 ,, ,, 11792 ,, ,, 11794 ,, ,, 11500 ,, ,, 11741 ,, ,, 11740 ,, ,, 8990	Received from Australia. All failed except *D. uncinatum* 11740, *D. uncinatum* 11741, *D. uncinatum* C.P.I. 8990, and *D. canum* C.P.I. 11796, of which a few plants were established in the field after seedlings had been transplanted from a seed-box.

Glycine javanica

Seeds were obtained from the Henderson Research Station, Southern Rhodesia, and from Nairobi, Kenya, and were sown directly into ridges in the field. Although germination was poor, both lots have done extremely well, spreading thickly over the ground and producing a large bulk of leafy vegetative growth. This species would probably be suitable as a fodder crop or for growing in fodder mixtures. The main drawback is that no seed was produced during the period under observation.

Indigofera spp.

I. hirsuta: Seeds, obtained from the Henderson Research Station, were sown directly on to ridges in the field. Germination was reasonably good and plants flowered and produced seed.

I. retroflora: Seeds were obtained from the Henderson Research Station. They germinated and produced seed.

I. tettensis: Seeds from Kenya were sown out on ridges in August 1951, germinated and grew reasonably well; this is a prostrate, creeping type.

All these species may have some use in pastures, although they do not appear to be very palatable.

Centrosema spp.

Seed of *C. pubescens*, obtained from the Henderson Research Station, did not germinate when sown on ridges in the field.

Seeds of *C. plumeri* were obtained from Wad Medani Research Farm and germinated soon after sowing in October 1951. Good vegetative growth, but not much bulk, was made and the plants eventually flowered and produced seed. The indications were that this legume might prove useful as a fodder crop.

Crotolaria intermedia

Seeds of this as well as of *C. spectabilis* were obtained from Wad Medani Research Farm; one lot of *C. intermedia* was also received from Nairobi. Both were established on ridges in rows but the plants were not healthy, particularly the *C. intermedia*. The *C. spectabilis* grew to a height of 3 feet. Both species produced seed. These species are not very leafy and did not appear to be particularly palatable. They are therefore probably unsuitable for growing under irrigation either in pasture or as a fodder grass.

Phaseolus lathyroides

Two lots of seed were obtained, one from the Henderson Research Station and the other from Wad Medani Research Farm (*P. lathyroides* ex Java ECR/1136). Both did well. This is one of the most promising legumes so far tried at Malakal. An annual, it is upright and not very leafy, but it should give considerable yields of green fodder if cut before the stems become woody. It is a prolific seeder, the seed dropping too readily, which might be a nuisance. It is probably not suitable for irrigated pasture unless closely grazed, since it would soon become dominant, but it might be useful for cutting as green fodder.

Phaseolus semi-erectus (Kordofan Pea)

Seeds were received from Wad Medani Research Farm and sown out on the flat. The legume did extremely well, giving a very dense cover. When mature the base of the stems tended to become woody but the leaves and pods appeared very palatable. *Phaseolus semi-erectus* would probably be a very useful legume for growing together with other plants in fodder mixtures or in rows alternating with rows of perennial grasses in irrigated pastures.

Phaseolus trilobus

Seeds were received from Wad Medani Research Farm and were sown out in January 1951. Germination was good and plants were soon established; flowers were produced by March and seeds by April, after which the plants were cut back. During the rainy season they produced a large bulk of leafy vegetation but in the following dry season production slackened off considerably. *Phaseolus trilobus* is a useful fodder producer but for its poor winter production.

Vigna spp.

Vigna nilotica, *V. vexillata* (both from the Henderson Research Station, Southern Rhodesia), *V. hirta*, and *V. sinensis* (both from the Department of Agriculture, Pretoria, South Africa) were sown out in ridged rows. All germinated well, flowered and produced seed. They are not suitable for pasture, and in general they did not produce sufficient bulk to warrant their consideration as possible fodder plants.

Dolichos spp.

Two lots were tried, *Dolichos lablab* (FCR/1228) from Wad Medani, and *Dolichos* sp. ex Kilima from Nairobi. Both did very well, producing a large bulk of vegetation growth. *Dolichos* sp. ex Kalima did not seed. *Dolichos lablab* (*lubia*) is already an established fodder crop in the Gezira. It is not suitable for growing in pasture.

Lupinus lutens

This proved a complete failure.

Desmanthus depressus

Seeds were received from Australia and sown in pots in Sobat silt, the seedlings being later transplanted to the field, where soon afterwards they died.

Cajanus bicolor

Two lots, *C. bicolor* C.P.I. 11380 and *C. bicolor* C.P.I. 12141 were received from Australia. Both were easily established. They grew up to 2 metres high with much foliage, and seeds were produced. The older, lower parts of the stems became woody with maturity.

Pueraria phaseoloides

The following samples were received: *P. phaseoloides* Puerto Rico from the Henderson Research Station, Southern Rhodesia, *P. phaseoloides* from Ol Jorok Orok, Kenya, and from Wad Medani *P. phaseoloides* FCR/1273, FCR/1274, and FCR/1275. All were established easily and produced thick, leafy and healthy vegetative growth. They are probably suitable for inclusion in forage mixtures.

FODDER SHRUBS

Seshania sp. from the Henderson Research Station was easily established in single ridged rows.

5. PALATABILITY TRIALS

Various fodder crops and the residues from such food crops as rice and groundnuts were available at the Malakal Experimental Station after the 1951 rainy season, and it was desirable to find out something about their usefulness for stock feeding. Trained personnel was not available to conduct detailed experiments, but simple feeding trials were carried out with twelve different fodders between January and June 1952. Two batches of bullocks were bought for the purpose, one of 2–3 year-olds, part Nilotic and part Arab, and the other of 5–6 year-olds, all Nilotic; all were immature. Several of the younger animals were entire on purchase and were castrated before the trials commenced. Details of the various fodder crops are given in Chapter 5 of this volume (pp. 1003, 1008).

METHOD

Several pens, each large enough to hold two bullocks, were constructed at Malakal of local timber, and it was intended that test animals should remain in their pens continuously throughout the trial. However, because of biting insects, it was found necessary, in spite of the application of insecticides, to tie them up at night around smoke fires in accordance with local practice. From dawn until dusk they remained in their pens where water was always available. The fodders under trial were weighed and fed to stock twice daily, early morning and mid-day. Two bullocks were used in each trial. They were weighed the day the trial began and every seventh day thereafter.

If a beast was used in two separate trials, a suitable interval was allowed during which it grazed on natural pasture. There were five control bullocks, two from the younger group and three from the older; they followed normal local grazing practice, but the riverain pasture near the stockyard was limited and two of the controls actually lost weight over the 24-week trial period.

RESULTS

Since all the test animals were immature there should have been a general gain in weight, particularly among the younger batch. But, as shown in the following table, only one agricultural by-product (52/8), one lot of hay (52/7), and one sample of air-dried grass (52/12) permitted small live weight gains (cf. 0·3 kg. per head per day on deep-flooded swamp pasture,

p. 1040). All fodders were reasonably palatable, except for one lot of silage made from *Setaria incrassata* which was sour, Legumes Various (52/5) which lost most of their leaf in harvesting, and *Feterita* (52/10) whose stalks were like canes. Rice straw was fed continuously without any supplement for 24 weeks and was obviously palatable though of low nutritive value. The quantities of most other fodders were too small to allow prolonged trial and the results are therefore of only limited value. Trial 52/12 was of particular interest ; this *Setaria incrassata* was cut at various stages of growth from small plots, weighed, dried quickly in the sun, and re-weighed to determine herbage yields in terms of fresh and air-dried weights (see p. 1055). The samples were thus mostly green, of good texture and sweet smell, and were obviously relished by the animals to which they were fed.

The general conclusions are that all the fodders listed would probably give better results if harvested earlier, but groundnut tops and legume hay would be best grazed in the field to avoid handling losses ; that rice straw is palatable but can only provide useful bulk ; and that dura stalks and *Setaria* hay, when well harvested, can probably provide a complete ration in themselves.

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SUMMARY OF RESULTS OF PALATABILITY TRIALS

Trial No.	Fodder	Animal No.	Initial Live Weight in kg.	Duration of Trial in weeks	Average Daily Ration in kg.	Live Weight Gain or Loss in kg.	Remarks
Control ...	Natural High Land and Riverain Pasture	1	150	24	*ad lib.*	− 2	Condition maintained fairly well throughout
,, ...		20	129	24	,,	+ 3	
,, ...		31	252	24	,,	− 6	
,, ...		33	261	24	,,	+ 1	
,, ...		34	216	24	,,	+11	
52/1 ...	Rice Straw ...	10	122	24	10	−12	Condition maintained fairly well throughout
52/1 ...	,, ...	30	286	24	10	−38	
52/2 ...	Groundnut Hay ...	2	126	3	15	+ 1	Fodder not relished at first—improved later.
,, ...	,, ...	32	285	3	15	− 5	
52/3 ...	Sweet Sorghum Hay	15	130	3	10	− 2	Palatable ; condition maintained ; dung became red
,, ...	,, ,, ,,	35	267	3	10	−10	
52/4 ...	Sudan Grass Hay ...	6	133	2	10	− 6	Hay liked ; but insufficient for trial
,, ...	,, ,, ...	36	292	2	10	−10	
52/5 ...	Legumes Various ...	14	151	2	10	− 3	Coarse stems not relished. Insufficient
,, ...	,, ,, ...	37	280	2	10	−14	
52/6 ...	Forage Mixture ...	5	115	5	20	+ 2	Total ration not eaten. Condition maintained
...	,, ,, ...	38	319	5	20	− 2	
52/7 ...	*Setaria* Hay ...	2	119	13	10	+ 6	Hay from *S. incrassata* grown under irrigation
,, ...	,, ,, ...	32	259	13	10	+ 9	
52/8 ...	Dura Stalks ...	6	117	7	10	+10	Sample palatable ; fair amount of residue
,, ...	,, ,, ...	36	271	7	10	+ 5	
52/9 ...	Ensilage	39	274	10	20	− 2	Poor quality silage, except for *Echinochloa* silage at end
,, ...	,, ...	58	234	10	20	− 7	
52/10 ...	*Feterita* Stalks ...	6	127	3	10	− 8	Stalks dry and coarse
,, ...	,, ,, ...	36	276	3	10	−20	
52/11 ...	Hay Mixture ...	2	125	6	10	− 1	Grass mixtures cut after 1951 rains from Malakal Pump Scheme
,, ...	,, ,, ...	32	268	6	10	− 6	
52/12 ...	Sun-dried Grass ...	6	120	6	10	+ 9	*Setaria incrassata* ; both beasts lost weight in last week owing to poorer quality grass
,, ...	,, ,, ...	36	254	6	10	+13	

NOTES AND REFERENCES

(1) Boyns, B. M., private communication.

(2) The weighbridge was about 6 km. from the experimental paddocks, so that the cattle had to walk a total distance of 12 km. This left insufficient time for cattle to spend a full grazing day in the paddocks. In the second season this routine of weighing on the 19th day was not strictly followed owing to inadequate supervision of the herdsmen.

(3) It should be mentioned that although the stock were in the paddocks for 8-9 hours daily, they managed to pick up some roughage on their way to and from the paddocks.

(4) Other legumes are given in Chapter 5, p. 998, of this volume.

(5) Commonwealth Scientific and Industrial Research Organization, Division of Plant Industry, Canberra, Australia.