INSTITUTE of
HYDROLOGY

MALAKAL WATER SUPPLY

A STUDY OF THE
WATER RESOURCES OF
THE MALAKAL AREA

Malakal Water Supply

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This report has been prepared for

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INTRODUCTION

Malakal is the capital of the Upper Nile Province of Southern Sudan and is situated immediately downstream of the confluence of the River Sobat and the White Nile. The surrounding area is extremely flat forming part of the central dry plains of Sudan and the river is confined to one channel for the first time since Mongalla.

Two reports have recently been written which include Malakal as one of their major subjects. The Strojexport study[1] presents a detailed geophysical survey which assesses the hydrogeological potential of an area including Malakal and the Mefit report[2] studies all aspects of the possible future development of Malakal including a brief hydrological and hydrogeological Summary.

Climate

Malakal has the typical humid, tropical climate characteristic of southern Sudan. The diurnal temperature range can be more than 10°C whilst the annual variation is fairly stable ranging from 26.1°C to 31.1°C in July and April respectively. A summary of available temperature and rainfall data is shown in table 1. The average annual rainfall measured at Malakal is 787 mm most of which occurs between May and September, however the rainfall increases rapidly to the south and to the east where the mean annual rainfall is 1800 mm in the Ethiopian highlands.

. *Geophysical investigations of Groundwater Structures, Central and Northern parts of the Upper Nile Province, Geophysics and Strojexport, 1977.*

Regional development study. Mefit S.P.A. 1978.

TABLE 1.

SUMMARY OF CLIMATOLOGICAL VARIABLES FOR MALAKAL (1941 - 1970)

	MONTHLY RAINFALL (mm)	MEAN MAXIMUM TEMPERATURE (°C)	MEAN MINIMUM TEMPERATURE (°C)
JAN	tr	35.4	18.4
FEB	tr	36.8	19.8
MAR	7	38.6	22.4
APR	21	38.3	23.8
MAY	102	35.7	23.4
JUN	109	32.7	22.2
JUL	149	30.7	21.6
AUG	167	30.5	21.6
SEP	144	31.7	21.8
OCT	82	33.3	21.8
NOV	6	35.0	19.7
DEC	tr	34.9	18.1

River Flow

The flow in the White Nile at Malakal is made up of a contribution from the Sobat, of about 13 milliard m^3/year, and from the White Nile leading from the swamps, of about 14 milliard m^3/year. The flow in the Sobat is highly seasonal with monthly flows varying between 212 and 2000 million m^3. In contrast the Sudd acts as a large storage area attenuating all seasonal inputs to such an extent that the outflows show virtually no seasonal distribution. Figure 1 has been constructed using the normal flows from 1912 to 1952[1] and illustrates the contributions and seasonal distribution of the two tributaries compared with measurements at Malakal. The outflow from the Sudd ensures a sustained river flow of the order of 1100 million m^3/month throughout the dry season.

Geology

The geology of the area around Malakal is shown in Figure 2 together with the geological succession.

The interpretation of the geophysical survey carried out by Strojexport shows the Basement Complex to underlie the whole of the study area and form a large basin up to 900 metres deep called the Malakal depression. These Basement Complex rocks are of Pre Cambrian age and form a series of crystalline igneous and metamorphic rocks which are generally hard and impermeable. Although not confirmed by drilling in the Malakal depression the geophysical survey suggests that Mesozoic Nubian sediments several hundred metres thick overlie the Basement Complex. In fact borehole 3663 south of Kodok but outside the Malakal depression is thought to penetrate Nubian sandstones and conglomerates at a depth of 283 metres below ground level.

The Umm Ruwaba sediments fill the Malakal depression and their thickness varies from about 200 metres to greater than 400 metres. These sediments are likely to be less consolidated than the Nubian and mainly comprise a predominately clayey sequence of sands and gravels.

The Nile Basin, Volume II, Hurst et al.

Normal flows near Malakal

1912-1952

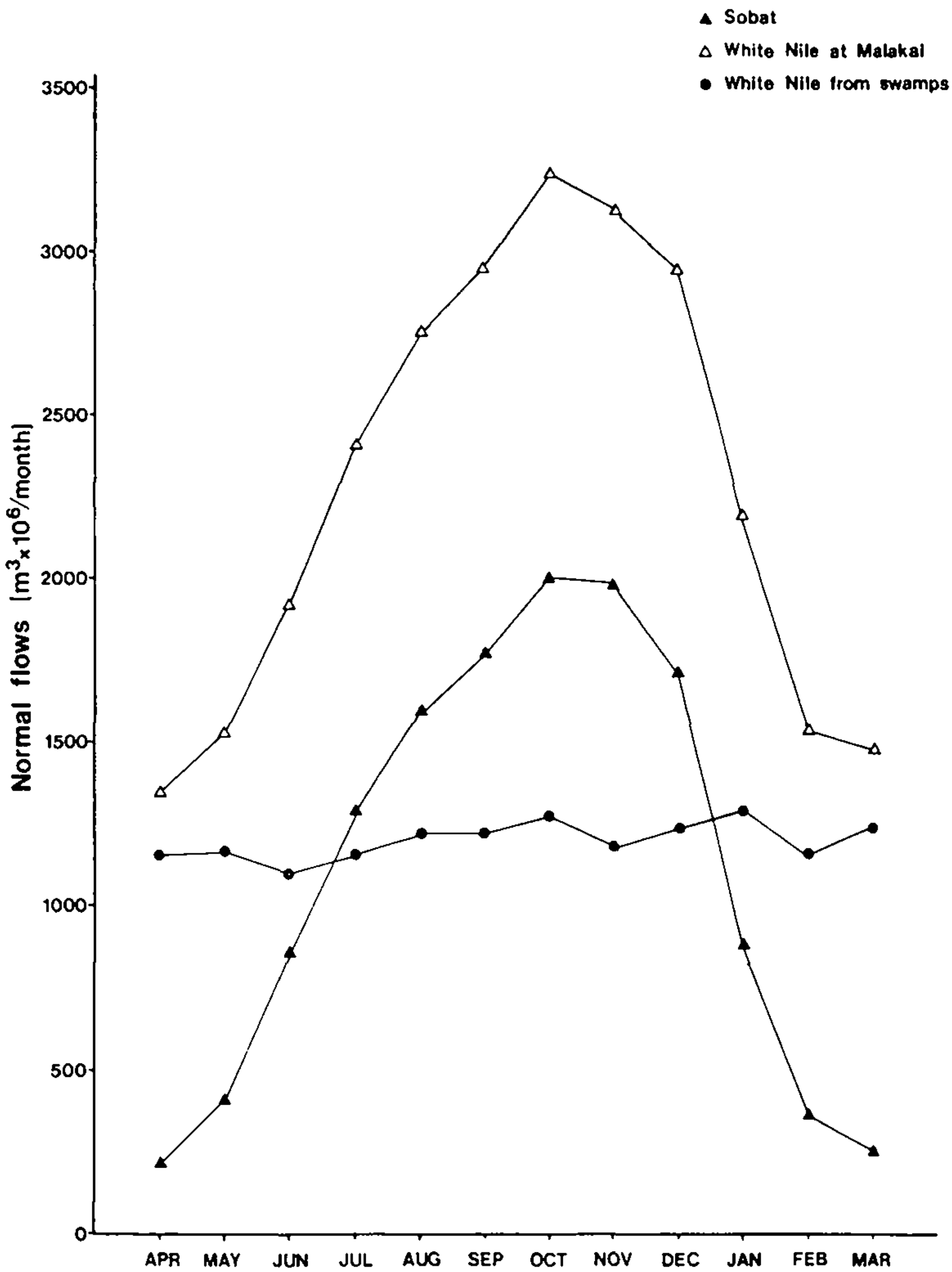

Figure 1

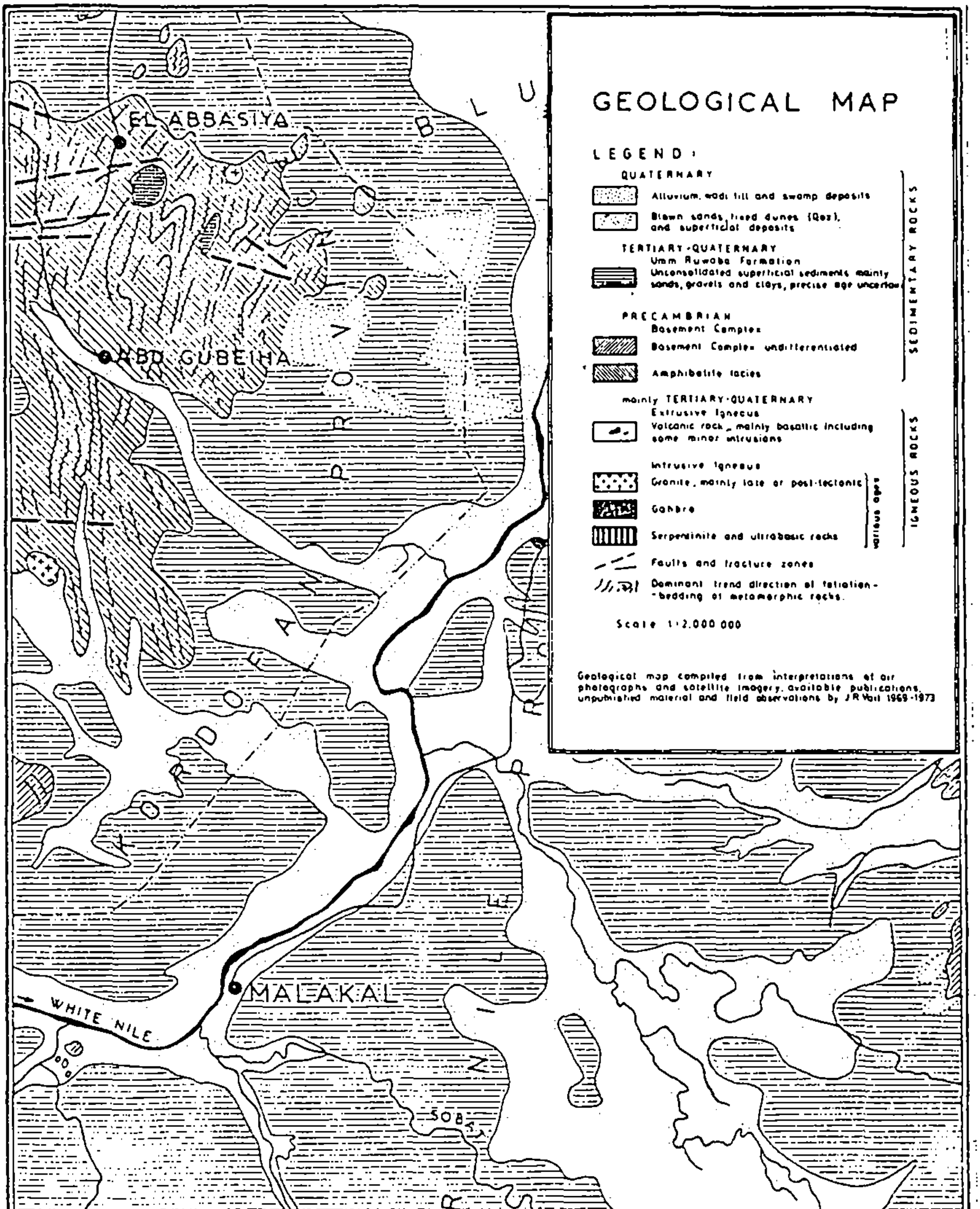
GEOLOGICAL MAP
LEGEND:
QUATERNARY
Alluvium, wadi fill and swamp deposits
Blown sands, fixed dunes (Qez), and superficial deposits
TERTIARY-QUATERNARY
Umm Ruwaba Formation
Unconsolidated superficial sediments mainly sands, gravels and clays, precise age uncertain
PRECAMBRIAN
Basement Complex
Basement Complex undifferentiated
Amphibolite facies
SEDIMENTARY ROCKS
mainly TERTIARY-QUATERNARY
Extrusive Igneous
Volcanic rock _ mainly basaltic including some minor intrusions
Intrusive Igneous
Granite, mainly late or post-tectonic
Gabbro
Serpentinite and ultrabasic rocks
various ages
IGNEOUS ROCKS
Faults and fracture zones
Dominant trend direction of foliation-bedding of metamorphic rocks.
Scale 1:2.000 000
Geological map compiled from interpretations of air photographs and satellite imagery, available publications, unpublished material and field observations by J.R.Vail 1969-1973
EL ABBASIYA
ABU GUBEIHA
MALAKAL
WHITE NILE
SOBAT
BLUE
UPPER NILE

Figure 2

The superficial deposits in the Malakal area are predominantly alluvial clays and silts with minor thin sands. The area covered with alluvium is about 20 km wide and these sediments overlie the Umm Ruwaba formation.

The geological interpretation of the Strojexport geophysical survey is shown in Figure 3 and line of sections in Figure 4. It can be seen from section AA[1] that the Umm Ruwaba sediments are fairly uniform and range in thickness from about 200 to 300 metres. However a large increase in thickness of the Umm Ruwaba to the west of Malakal is shown in section BB[1]. The report does not show the total depth to the top of the Basement Complex although this could be calculated using the original gravity data.

Groundwater Occurrence

Several boreholes have been constructed in the Malakal area and their location is shown in Figure 5. No boreholes penetrate the Basement Complex and by comparison with other areas in the Sudan this formation can be considered to be non water bearing and effectively form the base of the aquifer.

The Nubian sediments are potentially a very good aquifer in the adjoining Kordofan Province but the extension of this aquifer to the Malakal area has not been proved. The geophysics suggest that the water in this aquifer has a higher degree of mineralisation than in other Nubian formations but further exploratory drilling is necessary to confirm the presence of this aquifer and its relationship to the aquifer in the overlying Umm Ruwaba sediments. The Umm Ruwaba formation is water bearing throughout the Malakal area. However the lenticular nature of the sediments and high clay content gives rise to both horizontal and vertical discontinuity of these aquifer systems and the water quality is very poor. Shallow aquifers are likely to occur but almost certainly will have very limited storage and recharge potential.

Water level

The depth to groundwater in the Malakal area is shown in Figure 5 and also in the geological cross sections in Figure 3. It varies from 25 metres just south of Malakal to 86 metres below

Geological sections

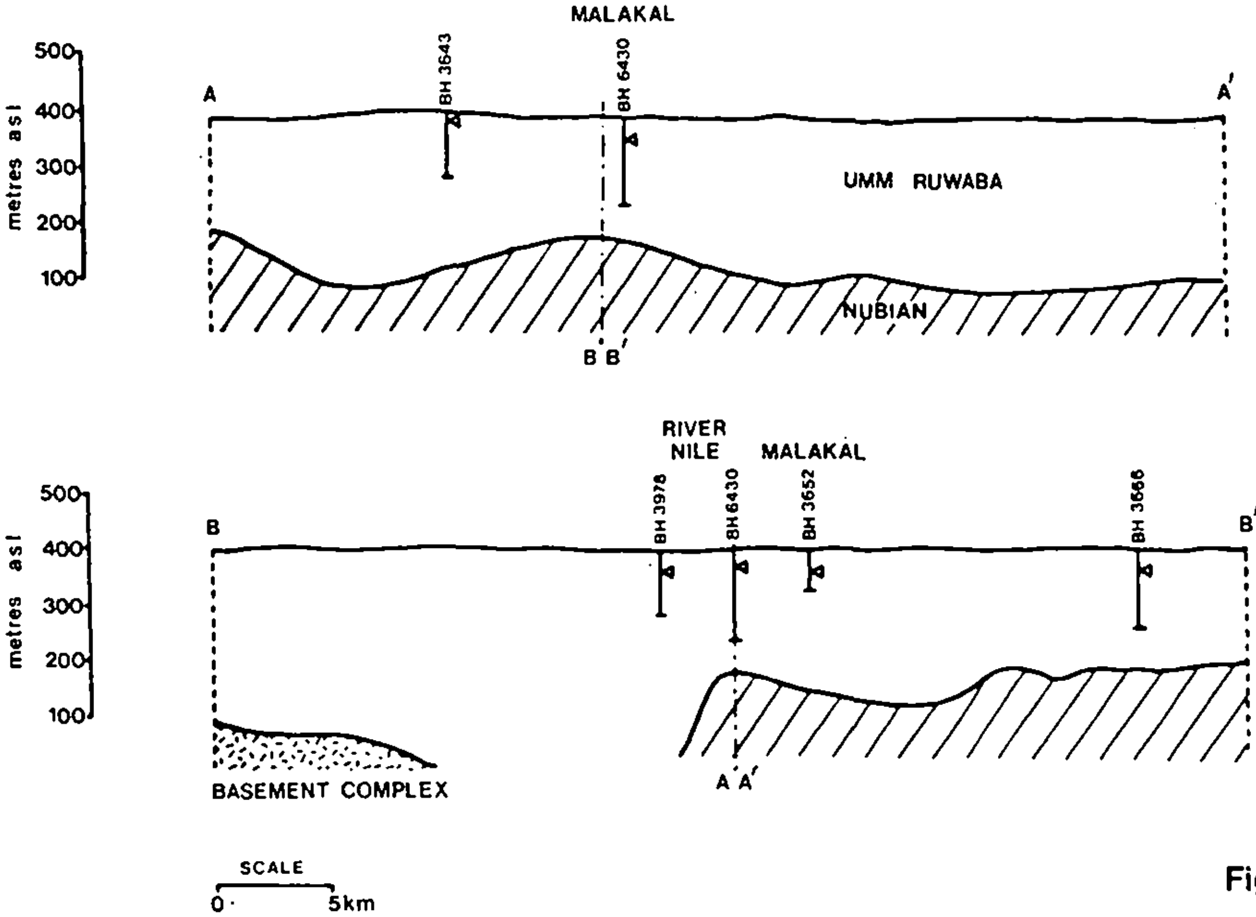

Figure 3

Location of geological sections

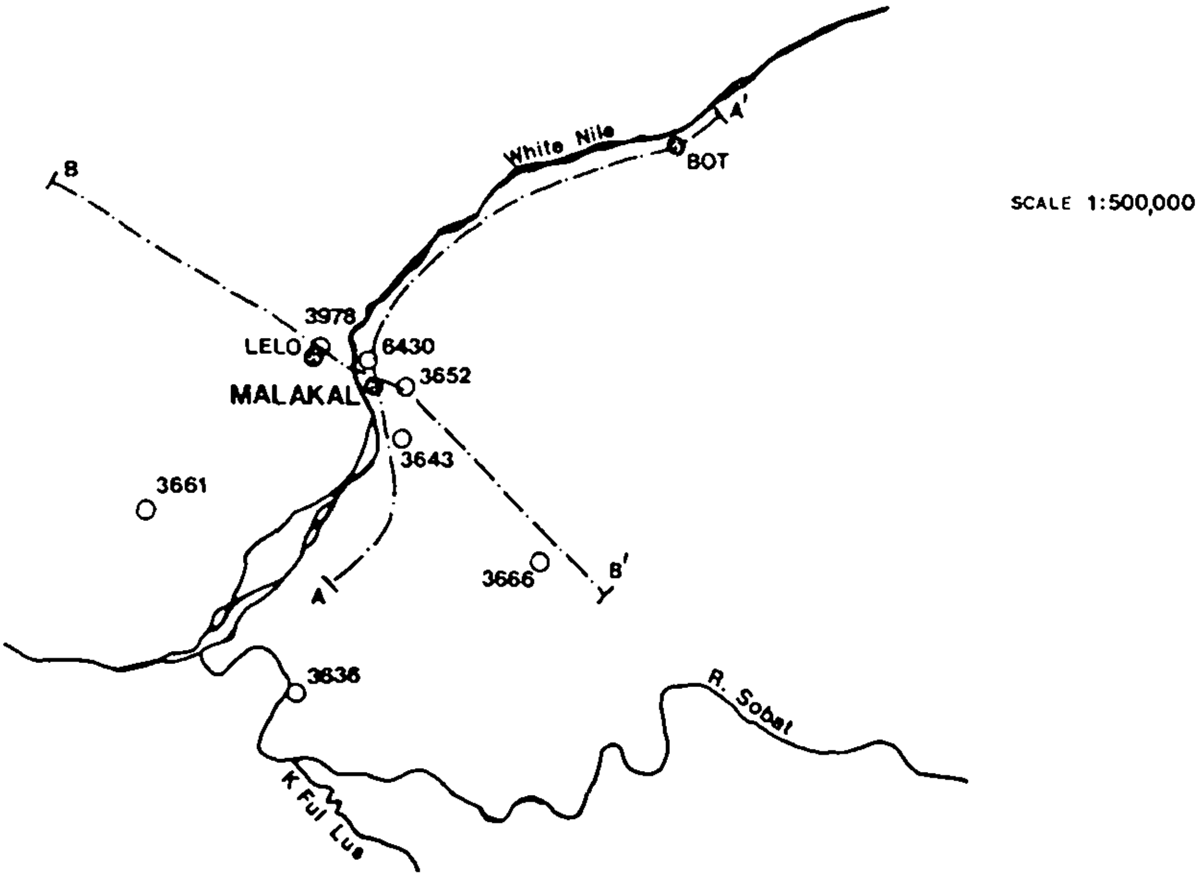

Figure 4

Location of boreholes

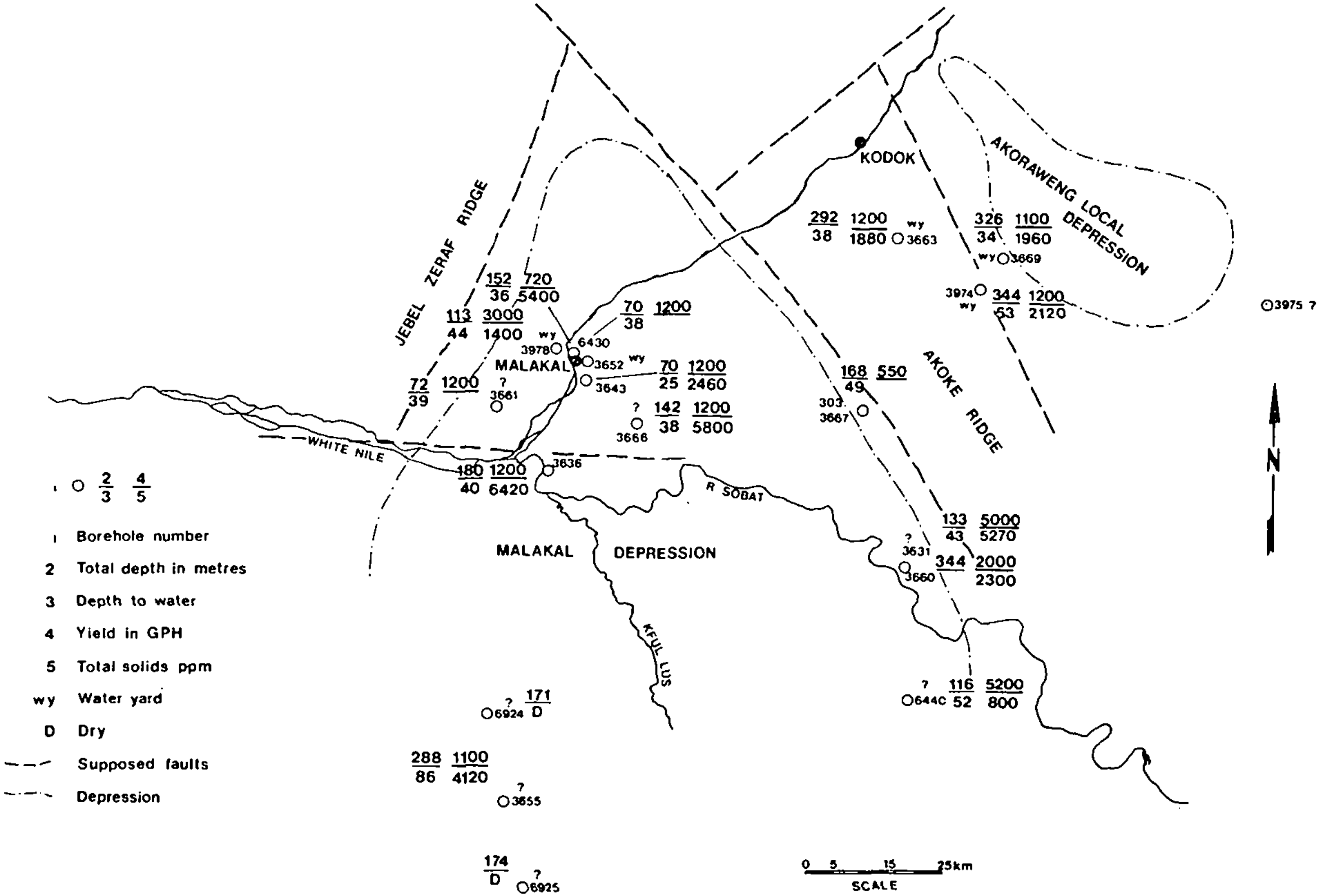

Figure 5

ground level at borehole 3655 some 85 km to the south.

Strojexport assess the sediments in the Malakal depression to have a total thickness between 400 and 900 metres, the effective saturated thickness however will be much less than this because of the high clay content.

We have not attempted to contour the groundwater elevations because there are too few boreholes covering a large area. However there does not appear to be a groundwater high in the immediate vicinity of Malakal which drains radially. Strojexport on the other hand consider the general groundwater movement to be to the North so we must assume that the groundwater high at Malakal is just a local effect and probably arises from river leakage.

No routine water level measurements have been carried out in the study area except on borehole 6430 where Strojexport reported the water level to fall 0.12 metres in the 3 month dry period from February to April 1977.

Evidence of recharge from rainfall does exist on boreholes 3669 3663 and 3978 where tritium concentrations ranging from 229 to 278 tritium units have been measured from groundwater samples taken and analysed by Strojexport. These apparently large tritium concentrations indicate that recharge has taken place from rain water during the last 30 years.

Aquifer characteristics

No reliable pumping tests have been carried out in the area. Strojexport, using Logans[1] approximation, have calculated the transmissivity of the Umm Ruwaba formation to be 3.3, 14.9 and 17.2 m^2/day for boreholes 6430, 3666 and 3636 respectively. It is unlikely that the bailertests were carried out for a sufficiently long period for the flow through the aquifer to be in steady state, however these results do show the transmissivity to be extremely low; indicative of fine grained material with a high clay content. Salama[2] suggests that the transmissivity in the Sudd Basin of the

Analysis and evaluations of pumping test data ILRI Bulletin 11 Kruseman and De Ridder 1976

2. *Groundwater resources of Sudan. Rural Water Corporation. R.B. Salama 1976.*

Umm Ruwaba sediments should be in the range 100 to 500 m^2/day.

Groundwater conditions in the Umm Ruwaba are about certain to be confined to semi confined and have a storage coefficient in the range 10^{-2} to 10^{-5}.

Should the Nubian sediments be proved to exist at depth their aquifer characteristics are likely to be more favourable than those of the Umm Ruwaba. The groundwater will be confined but ther transmissivity could be in the range 100 to 1000 m^2/day according to Salama.

Groundwater quality

Very poor quality water is present in the Umm Ruwaba aquifer the total dissolved solids range from 6420 to 1400 ppm around Malakal with an average value of 4300 ppm. We have only been able to obtain one groundwater chemical analysis for borehole 3666 which is shown in table 2, by WHO standards this water is unsuitable for human consumption. Strojexport point out that in general the total dissolved solids increase with borehole depth which can be accounted for by the very low permeability of the aquifer. The geophysical survey suggests that the underlying Nubian aquifer will contain good quality groundwater but without exploratory drilling we are unable to comment further.

TABLE 2.

CHEMICAL ANALYSIS FOR RWC BOREHOLE 3666 WATER SAMPLE
(Source Government Analyst, Khartoum)

pH	7.5
Total solids	5800 ppm
Total $CaCo_3$ hardness	2600
Total alkalinity as $CaCO_3$	3400
Excess alkalinity as $Na_2\ CO_3$	Nil
Ca	616
Mg	258
Na	-
K	-
Cl	1680
SO_4	1870
NO_3	10
NO_2	20
F	0.32
Ammoniacal nitrogen as N	0.44
Albuminoid nitrogen as N	0.48
As	-
Pb	-

WATER RESOURCES

Available River Flow Data

Discharge measurements are collected every five days at Malakal and are incorporated to produce the mean ten day discharges presented in the Nile Basin supplements. Thus ten day mean and monthly discharges are available from 1905 to the present at Malakal.

Estimate of Safe Yield

There are some unexplained periods of high flow in the Malakal record, the most notable of which is from 1962 to the present which coincides with an increase in level in Lake Victoria. During this period the flows seem to be drawn from a different distribution with a higher mean annual flow than in previous years. The annual minimum ten day flows were ranked and plotted in Figure 6 for the periods 1905 to 1961 and 1962 to 1980 using the Weibull distribution[1] with the probability of exceedance of

$$Pi \quad \frac{i - 0.44}{N + 0.12}$$

i = rank
N = total number of years

The two curves show a distinct difference in the data sets with the 1962 to 1980 data exhibiting minimum flows of approximately 15 million m^3/day higher than the corresponding return period flows for the earlier period. Obviously the inclusion of the recent data in the total set would tend to increase the estimate of the safe yield, but as we cannot determine the likelihood of occurrence of any future high flow periods or their likely duration these data have been excluded from the analysis. Thus the 100 year return period ten day flow is approximately 28.2 million m^3/day.

The estimated requirement for Malakal water supply is only 0.2 million m^3/day or 0.7% of the 100 year ten day flow, therefore it is extremely unlikely that this requirement will not be available from the White Nile at Malakal. Furthermore the abstraction of 0.2 million m^3/day will have a negligible effect on the White Nile downstream

Low Flow Studies. Institute of Hydrology, 1980.

10 day annual minimum flows for MALAKAL (1905-1980)

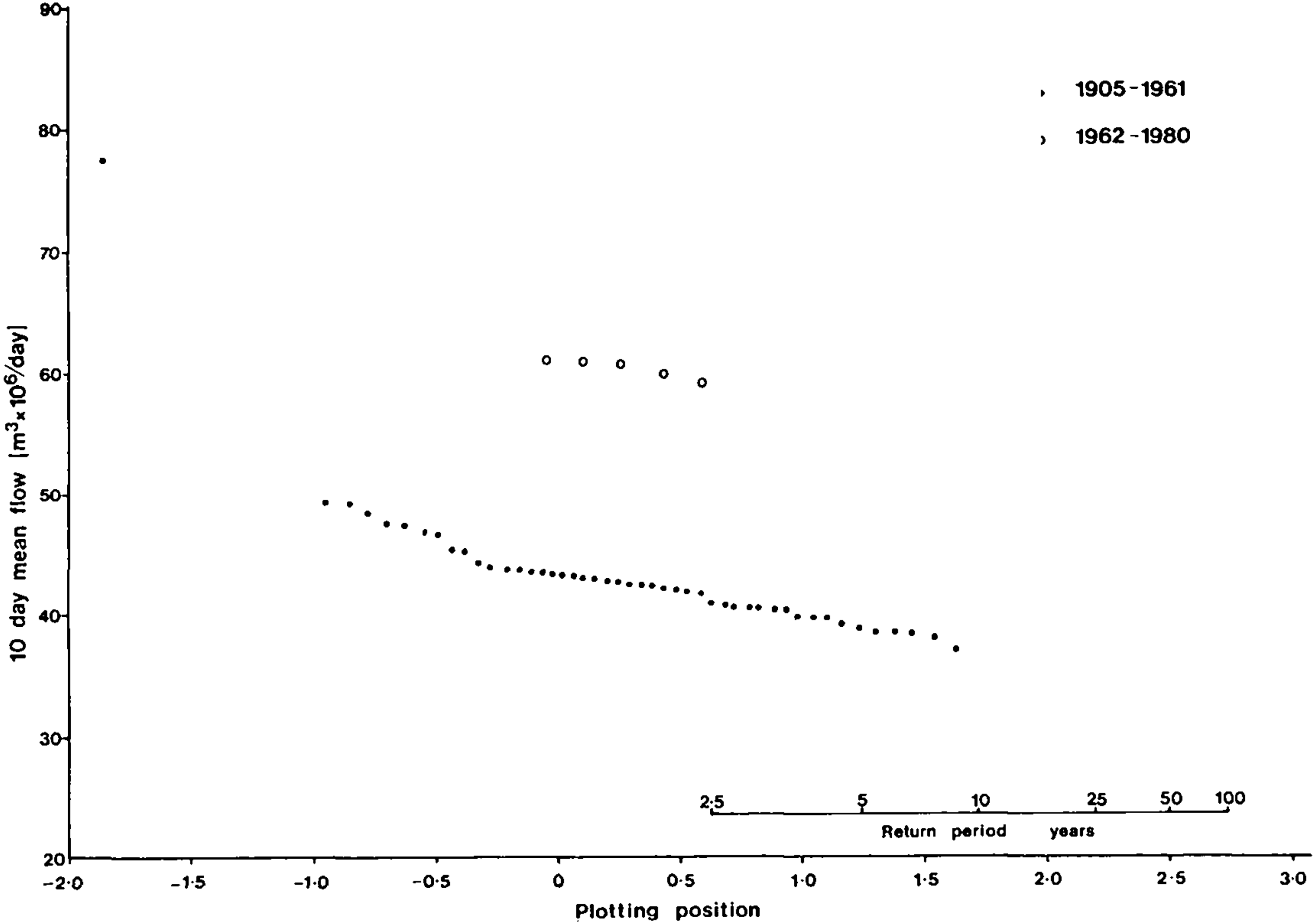

Figure 6

of Malakal.

The Effect of Conservation Measures

There are a number of conservation measures at different stages of planning or construction, whose aim is to increase the flows at Malakal available for irrigation. These projects are the Jonglei Project (Phase I) which is at present under construction, Phase II which depends on upstream storage, and the Bahr el Ghazal conservation scheme; the Machar Marshes scheme would have most effect on the White Nile below Malakal. The effects of the Jonglei Project (Phase I) are of most direct relevance. The project comprises a canal with a discharge capacity of 20 million m^3/day, and the benefits would be obtained by diverting a steady flow down the canal and thus reducing natural flows down the Bahr el Jebel and the present evaporation losses in the Sudd. The seasonal and year to year variations in the Bahr el Jebel flows into the Sudd would remain but at a lower base level, so that the natural outflows would also fluctuate but at a lower level than at present; the addition of the steady flow of the canal will result in a net benefit which will vary seasonally and will also be greater in years of high flow. The monthly benefit has been assessed[1] during two average years (1912 and 1960) and these may be smoothed to give the average benefits below which should be added to natural flows, in million m^3/day:

J	F	M	A	M	J	J	A	S	O	N	D
12.7	12.8	10.7	8.0	6.7	8.3	9.0	10.8	13.1	16.6	16.0	14.3

For water supply purposes it may be sufficient to note that the flow will not fall below the steady flow of the Jonglei Canal (20 million m^3/day less transmission losses and any irrigation from the canal).

The quality of the canal water will be closer to the present conditions at Mongalla than at the tail of the swamps, because at present the water spills several times into the swamps during its passage and the sediment is deposited. It will therefore contain more sediment during the summer high flow season than at present; however, the Sobat with its sediment load will continue to dominate the flood flows.

1. *Executive Organ for the Development Project in Jonglei Area, Jonglei Project (Phase One), Khartoum, January 1975.*

There will thus be an increase in flows at Malakal but the sediment load will be somewhat increased.

Groundwater

By comparison with other areas in the Sudan, the only aquifer in the Malakal area which is likely to contain exploitable quantities of potable water will be in the Nubian sediments. However exploratory drilling will be necessary to confirm the presence of this aquifer unit for at present only the Strojexport geophysical survey has indicated the existence of this formation. Borehole construction would be complicated to ensure that the overlying Umm Ruwaba aquifer containing poor quality water did not contaminate the Nubian aquifer.

Should exploratory drilling confirm the Nubian aquifer then further tests would be needed to check whether there is any hydraulic connection between the two aquifers and also to determine the aquifer characteristics and saturated thickness of the Nubian sediments.

Unfortunately the geological cross section BB^1 shows a large increase in thickness of the Umm Ruwaba to the west of Malakal. Because of this, drilling should be concentrated as far to the east of Malakal as possible so that the total depth of the exploratory boreholes can be kept as small as possible, say 350 to 400 metres, and also avoid any edge effects that may be present.

Recommendations

The surface water resource at Malakal is more than adequate to sustain the projected water demand.

The only possible alternative to this resource is groundwater, taken from the Nubian aquifer. However the presence of this aquifer has not been confirmed and an extensive exploratory drilling programme would be necessary before we could define its potential. This exploration would be expensive and the borehole construction complicated and may result in this possible resource being unsuitable for water supply.

We recommend that the future water supply for Malakal be met by a run of river scheme.

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