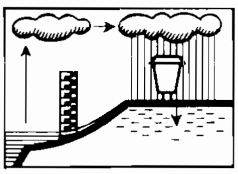
UNITED NATIONS DEVELOPMENT PROGRAMME

Office for Projects Execution

The Democratic Republic of the SUDAN

Project SUD/79/004/PISU

HYDROLOGY – STUDY OF THE KONGOR AREA



OFFICE DE LA RECHERCHE SCIENTIFIQUE ET TECHNIQUE OUTRE-MER

ORSTOM

PARIS

THE DEMOCRATIC REPUBLIC

of the SUDAN

UNITED NATIONS DEVELOPMENT PROGRAMME

Office for Projects Execution

HYDROLOGY - STUDY

OF

THE KONGOR AREA

-:-:-:-:-:-:-:-:-:-:-

by

Jacques CALLEDE

Hydrologist

OFFICE DE LA RECHERCHE SCIENTIFIQUE et TECHNIQUE OUTRE MER

PARIS

1981

ABSTRACT

In 1980, the ORSTOM Hydrological Department set up and operated a measurement method in the easily flooded zones of the Nile Between Juba and Malakal (Sudan). This method aimed at determining the occurrence of the flooding in these regions.

New techniques such as satellite telemetry and isotopic analyses were used successfully.

Therefore, the zone situated east of the dike which protects the Dinka population against the Nile overflows is flooded only by rain water. An hydrological phenomenon such as the creeping flow was not analysed for lack of adequate rainfall. Moreover, it was not possible to know the level of the flooding which would correspond to an exceptional flood of the Nile.

A programme including additional measurements was worked out.

RESUME

En 1980, le Service Hydrologique de l'ORSTOM a installé et exploité un dispositif de mesure dans la zone inondable du Nil entre Juba et Malakal (Soudan). Ce dispositif était destiné à déterminer les mécanismes de l'inondation de ces régions.

Des techniques nouvelles (télétransmission des mesures par satellites, analyses isotopiques) ont été employées avec succès.

Il en résult que la zone située à l'Est de la digue (protégeant la population Dinka des débordements du Nil) n'est inondée que par l'eau de pluie. Un phénomène hydrologique le "ruissellement rampant", n'a pas été analysé faute d'une pluviométrie suffisante. Il n'a pas été possible de connaître le niveau de l'inondation correspondant à une crue exceptionnelle du Nil.

Un programme de mesures complémentaires a été établi.

CONTENTS

Page

INTRODUCTION

800 kilometres downstream from the frontier between the Sudan and Uganda and 1 100 kilometres from Lake Albert, the White Nile or Bahr-el-Jebel (arab word meaning "mountain river") enters the widest swamp in the world : the Sudd (arab word meaning "block") whose origin comes from the vegetation islands which cover the minor bed. This swamp is composed of a permanent part on both sides of the minor bed whose area would amount to about 8 000 km^2. During the rainy season, the bad drainage conditions (due to the low gradient) along with the overflow of the Nile amount to the flooding of about 80 000 km^2.

In these swamps, losses by evapotranspiration represent nearly half the upstream discharge. Therefore, in 1904, the water requirements for the irrigation of the Nile Valley led Sir W. GASTIN to emphasize that it was necessary to reduce these losses. Several solutions were contemplated : and it was A.D. BUTCHER's solution [21] which was considered in 1938. It consists in digging a channel of 300 km in length, the Jonglei Channel, which will divert the course of a good many of the White Nile waters. Currently, the project is in progress since 40 km are already dug.

Since this considerable project was accompanied by an agricultural development on both sides of the channel, it was advisable to have a previous knowledge of the hydrological conditions prevailing in the plain situated on the right bank by distinguishing :

- the zone situated between the minor bed and the protective dike which will be flooded as a result of the overflow of the Nile,
- the zone situated east of the dike which is a large flat and very poorly drained area.

For this purpose, in a letter n° SUD/79/004 dated of February, 1980, the United Nations Development Programme and more precisely the section of the Operation Programmes Execution asked the ORSTOM Hydrological Department :

- "to determine the shape of the hydrograph,
- to know the role played by the Nile flood and the role played by local runoff".

For this purpose, three techniques were used :

- "in situ" measurements of the water level and precipitation depth along with immediate satellite telemetry,

- use of the opportunities given by remote sensing (LANDSAT satellite) along with an aerial reconnaissance in high water,
- isotopic analyses of water in order to know whether it is rainwater or water from the Nile.

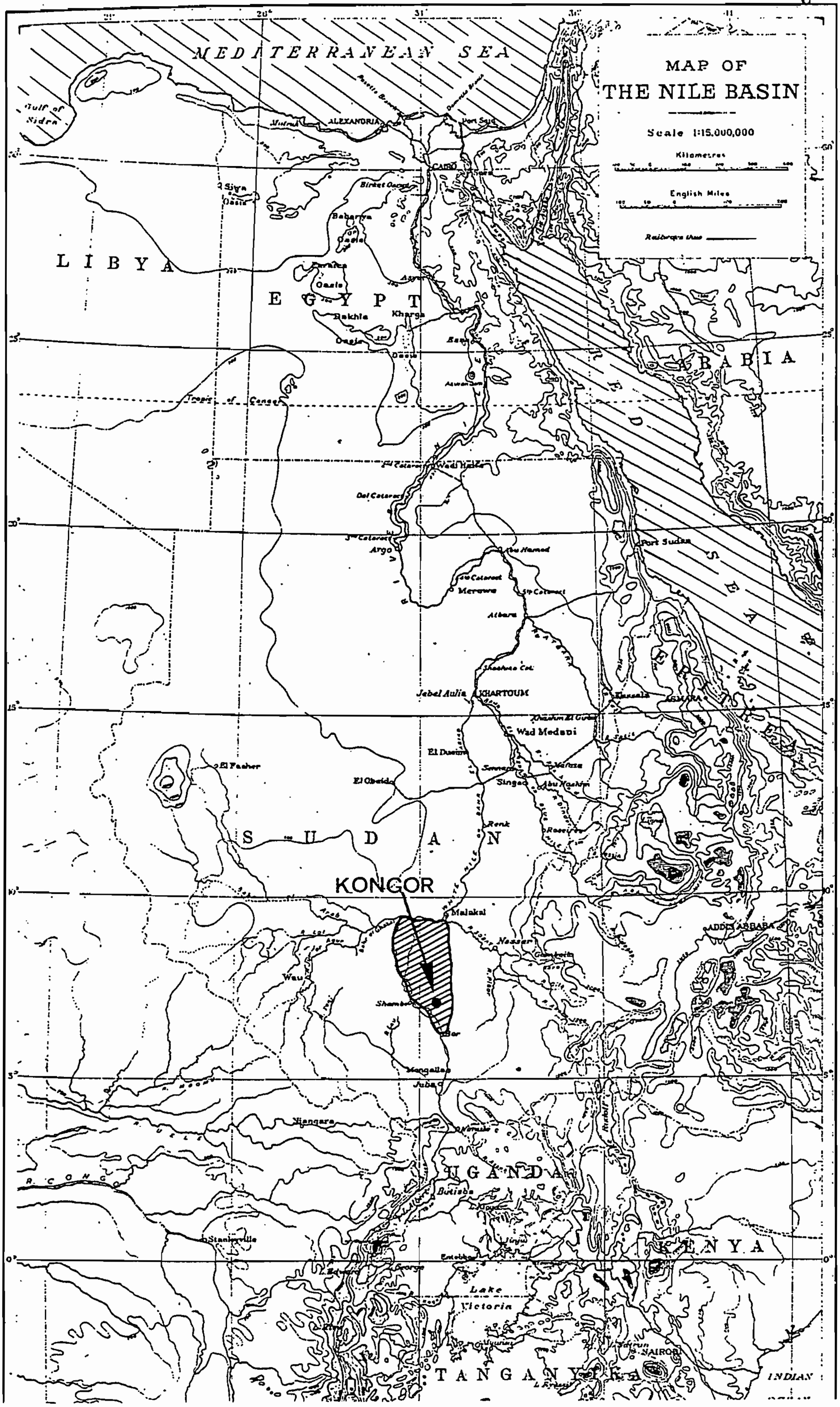
This document is the final report of this study dealing mainly with the region situated near Kongor which is a village about 100 km north of the southern boundary of the SUDD.

Doctor Jacques CALLEDE who is an hydrological engineer at ORSTOM was entrusted with making this study which included the setting up of the network, its operation and the analysis of the results.

The translation and page-setting was carried out by Miss DESART who is working as a translator at ORSTOM.

The author wants to thank Mr and Mrs CAMBELL (UNDP/OPE/PISU), Mr GRUTZ-MACHER and Mr ROWBOTTON (ILACO),Mr ARDAGH (FAO), the Khartoum UNDP Staff and the Sudanese Government for their able assistance.

Fig-1



MAP OF
THE NILE BASIN
Scale 1:15,000,000
Kilometres
English Miles
MEDITERRANEAN SEA
Gulf of Sidra
ALEXANDRIA
Port Said
CAIRO
Siwa Oasis
Baharya Oasis
Farafra Oasis
LIBYA
EGYPT
Dakhla Oasis
Kharga Oasis
Assuan
Tropic of Cancer
ARABIA
RED SEA
Wadi Halfa
Port Sudan
Abu Hamed
Merowe
Atbara
KHARTOUM
Jebel Aulia
Kassala
ASMARA
Wad Medani
El Dueim
El Fasher
El Obeid
Sennar
Singa
Renk
Roseires
SUDAN
KONGOR
Malakal
Nasser
Wau
Shambe
Bor
Mongalla
Juba
Nimule
ADDIS ABABA
UGANDA
R. CONGO
Stanleyville
Entebbe
Jinja
KENYA
L. Edward
Lake Victoria
NAIROBI
TANGANYIKA
INDIAN

1. - GEOGRAPHICAL DESCRIPTION

1.1. - SITUATION

The Sudd is situated in the southern part of the Republic of the Sudan between 06° and 10° latitude North and 030° and 032° longitude East.

It is a wide and triangular plain whose altitude amounts to about 406 m at Kongor [5].

The two most important towns such as Malakal in the North and Bor in the South are connected by a road which is passable only in the dry season. Kongor which is the zone under study is situated on this road about 100 km north of Bor.

Two all weather air strips are situated at Bor and Malakal. A dry season air strip connects up with the UNDP camp at Kongor.

The White Nile is navigable in any season from Bor to Malakal.

1.2. - RELIEF

Apart from the minor bed of the Nile, it is difficult to speak of relief since the zone under study is strictly flat. Man is most often responsible for the irregularities such as, for instance, the dikes which are 2 m wide on an average and 0.5 m high and are useful for protecting houses or fields. There are also the "hafirs" which are ponds dug by man and intended to water the cattle. Apart from this, everything is strictly flat : for instance, the thalwegs which can be seen in the RBV pictures of the LANDSAT satellite show only depressions ranging from 30 to 50 cm in depth which are invisible to the naked eye when walking through the region.

The longitudinal slope amounts to only 0.1 m per kilometre (0.1 ‰). The cross slope can be considered as equal to zero or at least insignificant.

1.3. - SOILS

All the soils in the zone under study are hydromorphic and practically impervious. "In situ" measurements which were made by the Pengko Pilot Project through a methodology similar to MUNTZ's one show percolating velocities such as $K = 10^{-6}$m/s. The results of the surveys concerning the water level in the three telemetry stations show percolating velocities which are still lower, as we will see further on. As a matter of fact, it is apparent from the whole measurements that the percolating velocity should not be higher than [illegible]$.10^{-7}$ m/s, say about 0,5 cm per day : the results given by the telemetry stations are theoretically better for they spread over a longer period than the results obtained by Muntz's measurements and it was observed that, generally, MUNTZ's measurements give velocities which are slightly too high.

Only such an impervious soil makes it possible to dig numerous hafirs which will impound the water necessary for watering the cattle. As far as I am concerned, I saw these small ponds being dug when the motor pump was started in the UNDP camp at Kongor : the water level in these small hafirs which were called weer in this case had not dropped considerably in the course of the night.

1.4. - <u>THE FLOODING IN THE REGION OF KONGOR</u>

Drainage conditions are very poor in this large and impervious plain which is going to be turned into a large swamp by rainfalls and the Nile overflow. In the dry season, only the zones bordering the minor bed of the Nile are flooded. The horned cattle are pasturing in the toich, the local word for the zones which will be flooded in the rainy season. The occurrence of the first rainfalls leads to a stagnancy of water in the very place where rain is falling. In July-August, the Nile flood is going to inundate the plain, therefore, men and cattle will move towards the East in order to find a dry soil. So, a dike which is at least 150 km long was built from Bor towards the North in order to serve as a protection against the Nile flood. This dike keeps roughly along the western limit of the Bor-Kongor-Malakal road.

The Nile overflow zone (that is to say the zone bounded to the East by the dike) which is seen from the plane or in the pictures transmitted through LANDSAT satellite distinguishes very clearly from the rest of the plain.

2 - CLIMATOLOGY IN THE REGION OF KONGOR

The region of Kongor gets a tropical climate characterized by a rainy season (April - October) and a dry season (November - March).

There was a meteorological station at Bor near the port but, nowadays, it is closed.

Nowadays, a second station is operating at the Pengko Pilot Project, that is to say 50 kilometres east of the previous one. This station makes measurements about air temperature and humidity, wind, rainfall, evaporation on tank and duration of insolation.

The reference meteorological station is situated at Juba, 160 kilometres far in the South.

2.1. - *AIR TEMPERATURE*

The mean air temperature amounts to 27.7° C at Bor [5], the maximum daily mean amounts to 33.7° C and the minimum daily mean amounts to 21.1° C.

These values are rather similar to those observed [3] at N'Délé (Central African Republic) which is situated roughly 150 kilometres far in the North. This station gets temperatures amounting respectively to 28.8° C, 33.3° C and 20.4° C.

2.2. - *HUMIDITY*

At Bor, the mean relative humidity amounts to :

71 % at 06 UT
48 % at 12 UT
70 % at 18 UT

Comparatively, the values recorded at N'Délé are very similar amounting to 77, 48 and 64 %, which would show an annual mean vapour pressure of 20 millibars ranging from 11 millibars (dry season) to 25 millibars (rainy season)

2.3. - *EVAPORATION*

It must be pointed out that, as far as evaporation is concerned, the reference used is measured in large water surfaces (for instance, lakes) and that, under these conditions, this evaporation is very similar to the potential

BOR
(Pengko Pilot Project)

Weather Station

North of the SUDD

The White Nile (on the top).
In the center of the picture, the confluent with turbid water of Sobat River and the beginning of Jonglei channel.

The White Nile above BOR

evapotranspiration (PET) which is measured for an area covered with a short-cut grass.

We will point out that evaporation can be determined either through "*in situ*" measurements (on tanks, for instance), or through formulas based on real physical phenomena (PENMAN) or on local correlations between various meteorological parameters.

- The use of THORNTHWAITE's formula leads to an annual evaporation (PET) ranging from 1700 to 1750mm [23] .

- On the other hand, the use of PENMAN's formula [4] leads to an annual evaporation amounting to 2150mm, which is rather high when comparing it with the value of 2300mm prevailing in Lake Chad.

- The "A Class of Weather Office" tank which is set up at the station of Pengko Pilot Project leads to an annual evaporation amounting to 2050mm. When applying to it a PET/ "A class" transposition coefficient of 0.7 [13] , we get a PET amounting to 1440mm. This value may be a little imprecise and above all too low for the tank is covered with a close-meshed netting which is intended to prevent birds from drinking the water in the tank.

- The correlation established by C. RIOU [25] between the maximum daily monthly mean and the PET (PET mm/day = 0.30 x Tmax °C - 5,9) leads to rather conclusive results amounting to 1530 mm per year.

Finally, we can agree with an annual potential evapotranspiration amounting to about 1530 mm.

This value which seems to be appropriate when compared with :

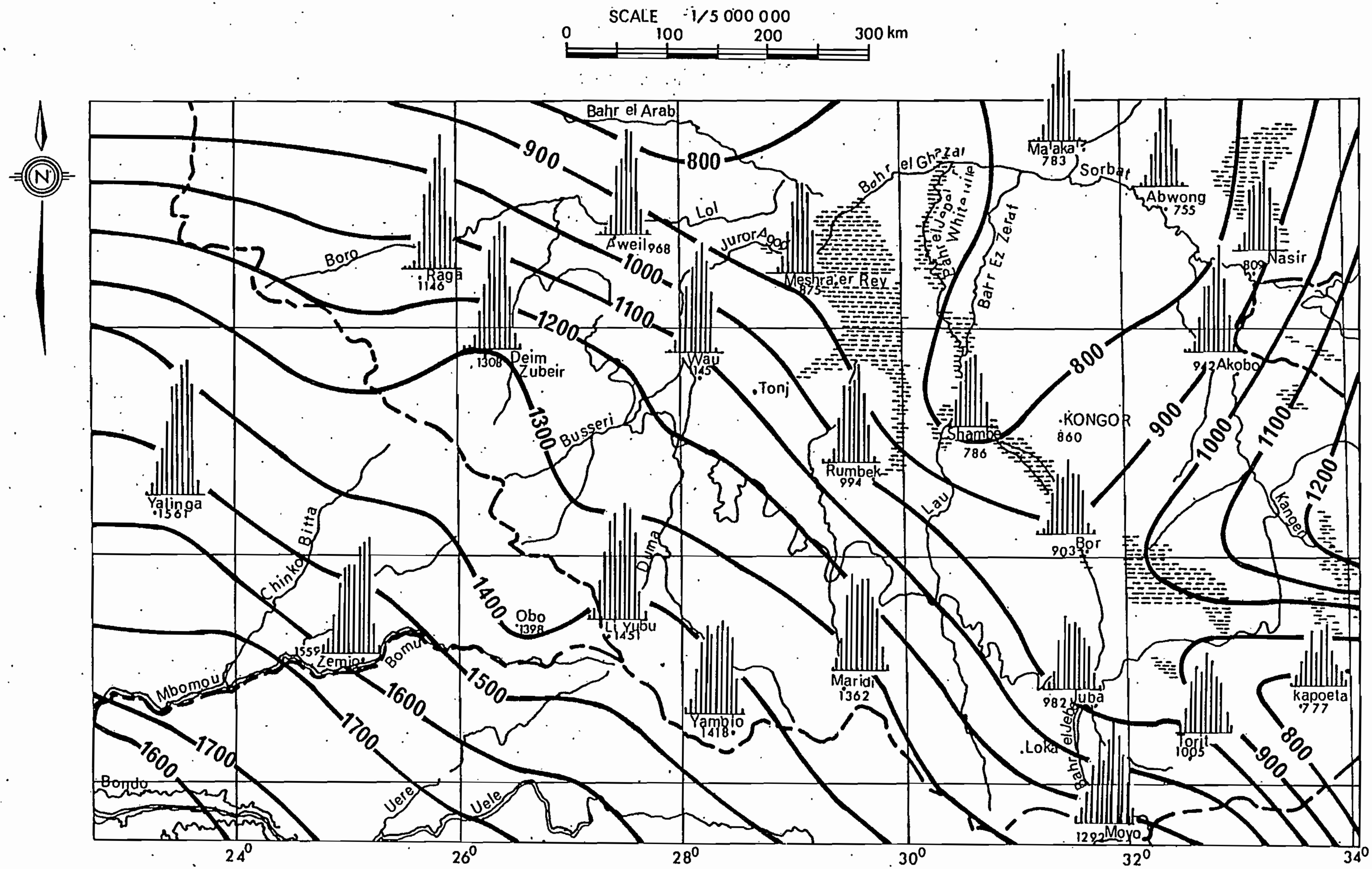
Bangui (04° N) = 1200mm/year
Moundou (08° 30N) = 1600mm/year
Lake Chad (14° N) = 2300 mm/year

is precise enough as far as our study is concerned.

Let us mention here the coefficient 0.54 for PET/ "A class" which was determined by OMAR and EL BAKRY [24] when they studied evaporation in the lake of Aswan High dam. Let us also note that our evaluation about the daily mean (4.2mm) is slightly higher than the one mentioned by HURST [22] , that is to say 3.4mm.

POTENTIAL EVAPOTRANSPIRATION ON BOR AREA (mm/day)

Type of determination	J	F	M	A	M	J	J	A	S	O	N	D	Year
PENMAN	217	190	202	186	183	159	140	140	150	177	189	217	2150
RIOU's correlation	165	135	160	140	120	95	90	95	110	140	135	145	1530
"A Class" tank observed data	225	225	280	250	220	115	95	95	105	140	145	155	2050
corrected (k = 0,7) data	160	160	195	175	155	80	65	65	75	100	100	110	1440
Adopted value monthly	160	160	180	160	150	90	80	80	90	120	120	140	1530
daily	5,2	5,7	5,8	6,0	4,8	3,0	2,6	2,6	3,0	3,9	4,0	4,5	4,2



MEAN ANNUAL RAINFALL (mm)

Fig 2

2.4. - *PLUVIOMETRY*

The annual pluviometry amounts to 860mm at Kongor, while it amounts to 903mm at Bor. Given the latitude (about 07° lalitude North), these values seem to be rather low when compared with the neighbouring stations situated in the same latitude [2] such as :

Rumbek = 994mm
Wau = 1145mm
Yalinga= 1561mm
Obo = 1398mm

The plotting of the isohyets shows rather well the low annual rainfalls prevailing in the Sudd (Fig. 2)

Several explanations can be put forward :

- this zone receives fewer rainfalls than the zones situated in the East, as a result of the Ethiopian relief (the Nile plain is situated 400 metres up, while the Ethiopian mountains culminate at 3000m. It represents a real barrier to the masses of humid air from the Red Sea (which is shown by the isohyets) and this hypothesis is quite valid.

- similarly, this zone receives fewer rainfalls from the West as a result of the relief which separates the Congo basin from the Nile basin. Here, in the West, the M'Bomou plain towards Obo is only 600 metres up, while the drainage divide is 800 m up on the frontier and rises only at 1300 m. Kongor is only 400m up. This hypothesis is less satisfactory as far as the monsoon rainfall from the West is concerned.

- Another explanation could result from the fact that the Sudd would not enjoy the storm-lines which are observed in the Central African Republic, the Republic of Chad and the westernmost countries [17, 29] . This hypothesis is based on the fact that, in the region of Sudd, there are no North/South storm lines as is the case far in the West- which move from the East to the West (this results from an investigation which was made with the Meteorological Department, the aircraft pilots, and the International Development Organizations). Another confirmation is given by the examination of daily rainfalls which are recorded over 10 years (that is to say, which can be reached or exceeded one year out of 10).

At Bor, it amounts to 103mm [4] .

It amounts to	116mm at Bangui (RCA)	(annual rainfall	: 1590mm)
	110mm at Bambari (RCA)	(" "	: 1482mm)
	109mm at Alindao (RCA)	(" "	: 1546mm)
	93mm at Amtimam (Chad)	(" "	: 895mm)
	103mm at Sahr (Chad)	(" "	: 1143mm)

These are stations situated in the Republic of Chad or in the Central African Republic and whose decennial downpours had already been calculated [11, 12].

This could show that the decennial downpour at Bor is not representative of a rainfall amounting to 900mm but would be better for a region which is drained by 1200mm each year (fig. 3). However, it was observed that the very high daily rainfalls occur mainly at the beginning of the rainy season, which leads to consider that the deficiency in annual rainfalls compared with the westernmost regions is occurring mainly in July - August - September, that is to say when the storm lines are the most active. This can be clearly seen in the distribution of monthly rainfalls (figure n° 4) at the stations of Bor and Yalinga

This would imply that the disappearance of the swamps in Bahr-el-Jebel could have serious consequences on the whole annual rainfalls in the countries of Central and Western Africa which are situated west of the Sudan. The annual volume of the Nile which would pass through the future Jonglei channel would amount to only 4.7×10^9m3 (information given by the CCI, the company which is digging the channel). Water losses in the swamps through the Bahr-el-Jebel and the Bahr-el-Gazal are evaluated [26] at 28×10^9m3/year in a normal year.

Let us suppose that the whole water of the channel results from the portion which ought to have been evaporated if the channel did not exist, that is to say, supposing that in high waters there is no influence of the channel on the inflows from the Bahr-el-Jebel. In this case, the losses are reduced to 4×10^9m3, which represents about 15 % of saved water in a normal year. This percentage represents undoubtedly the maximum influence of the channel (except, may be in a bad year) on the reduction of the global losses by evaporation.
On the one hand, we estimated that water channel is taken from the plain flooding, and on the other hand, we disregarded the inflow of rain water falling on the 80 000 km2 of the Sudd.

The influence of the Jonglei channel on the formation of storm lines is perhaps insignificant, but it remains to be confirmed.

Fig- 3

VARIATIONS OF DECENNIAL DAILY RAINFALLS

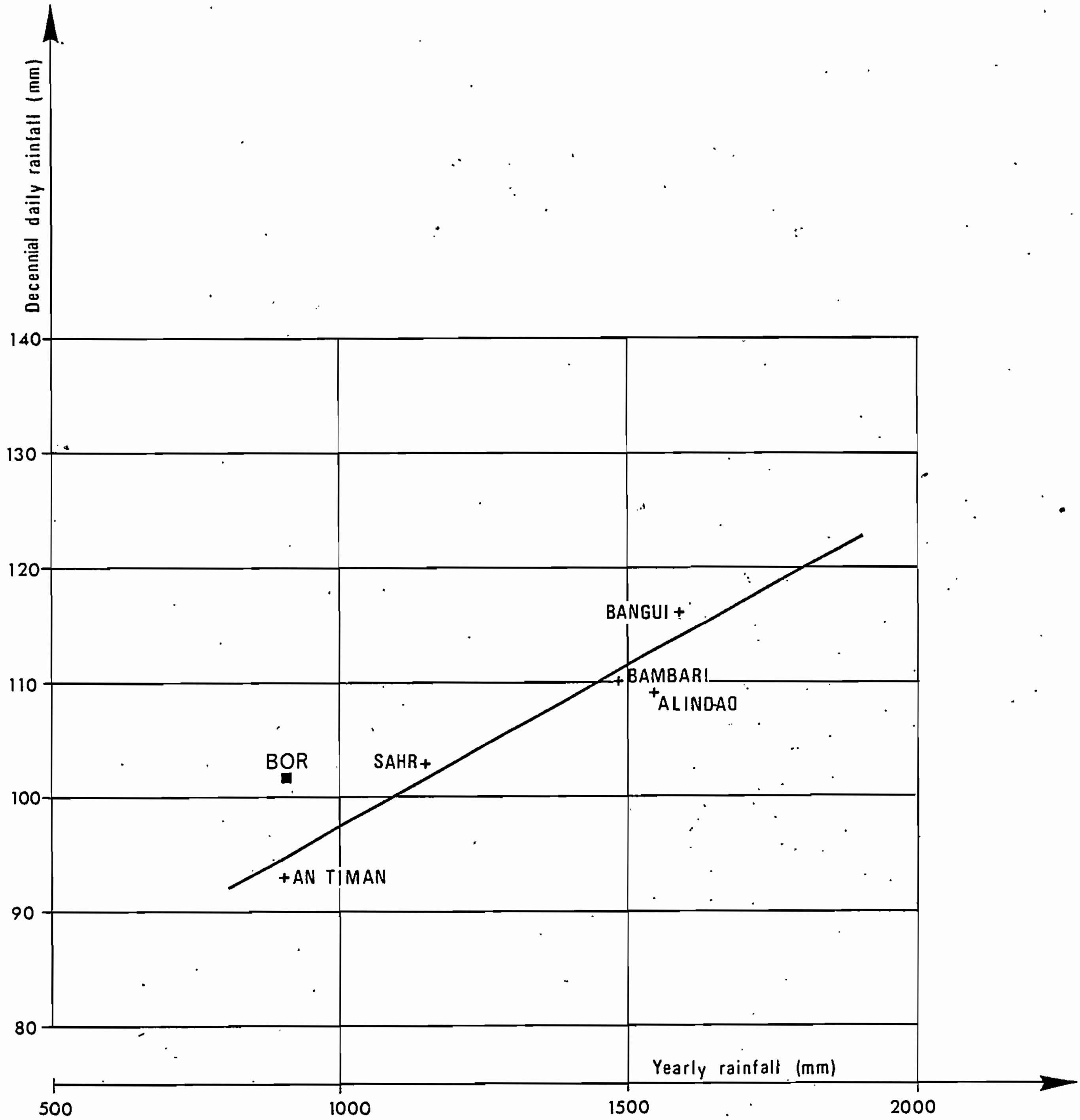
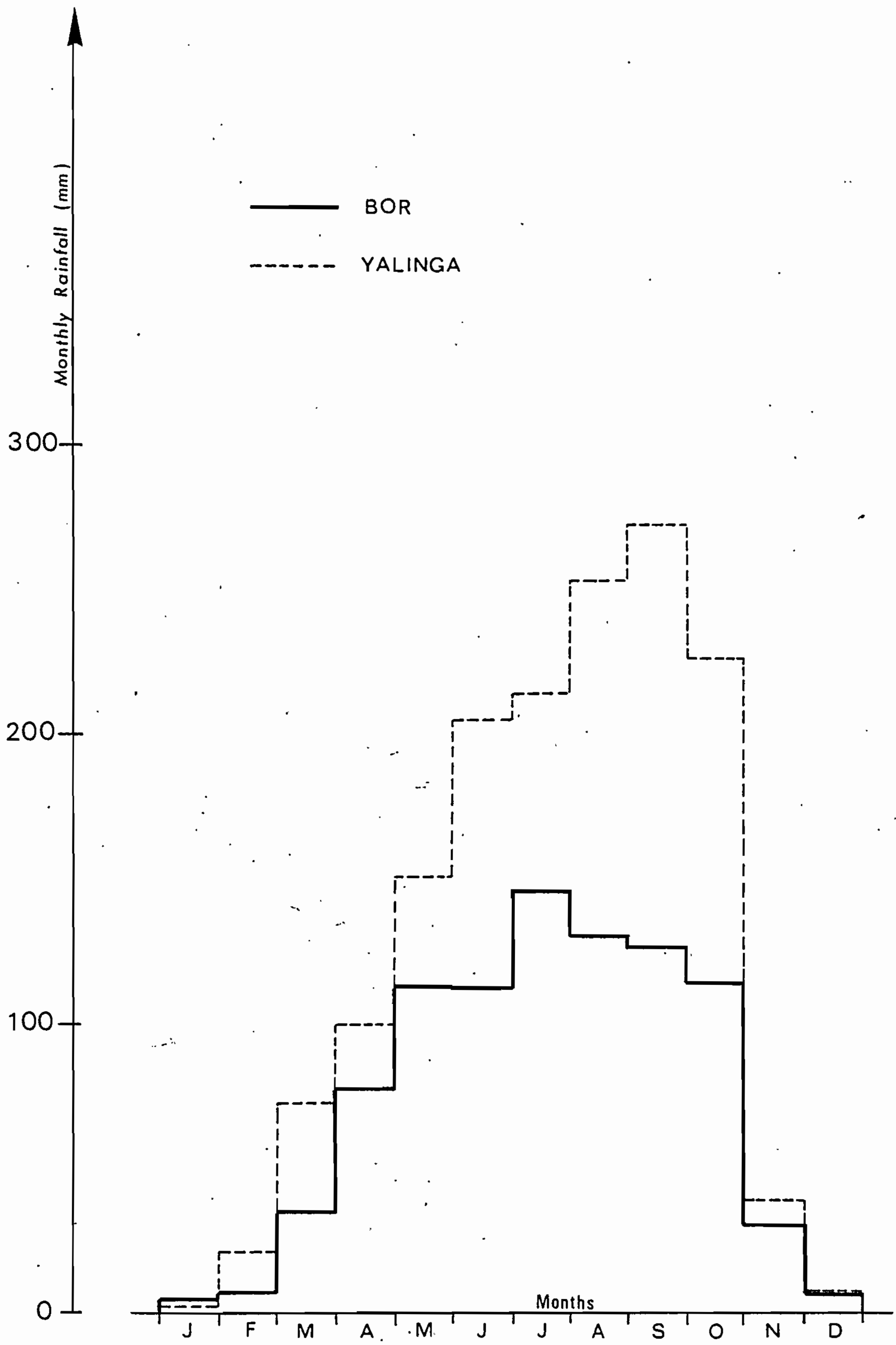


Fig - 4

MONTHLY RAINFALLS IN BOR AND YALINGA

(THESES STATION ARE ON THE SAME PARALLEL)



3. - THE HYDROMETRICAL NETWORK

The hydrometrical network is composed mainly of the Bor and Jonglei stations which can be increased with the station of Mongalla.

The base levelling grants the altitude of 360.00 m to the stream gauging station situated at Khartoum.

3.1. - THE BOR STATION

A station was set up in the port of Bor in 1905. "The gauge consisted of two masonry steps with marble scales from 9.50 m to 10.50 m and from 10.50 to 12.00 m. The zero level of the gauge is 408.52 with reference to the zero of the Khartoum gauge which is assumed to be at 360.00 m" [5] .

A second station for the water supply would have been set up 25 m from the pumping station on the same level, for the previous station would have been destroyed in 1975, since it was used as the mooring points of boats sailing in the Nile [4].

We did not find these two stations when we went there in April and October 1980.

On the other hand , a third station was set up on a by-pass channel close to the station of water elevation used to irrigate the parcels of the Pengko Pilot Project at Bor. Its zero level is set at 418.65 m but this station which is too close (about 2 m) to the pump strainers, is under the influence of the operating pumps.

3.2. - THE JONGLEI STATION

Its zero level is set at 402.19 m. This station would be operational since April 1924.

3.3. - CORRELATION BETWEEN THE WATER LEVELS OBSERVED AT BOR AND JONGLEI

Figure n° 5 shows the correlation between the annual maximum values observed at Jonglei and Bor. It is odd to observe that the amplitude of water levels is more important at Jonglei than at Bor, which seems to be contradictory when assuming that the overflows in the plains must lead to a regulation of the Nile levels. However, it must be pointed out that :

- Jonglei is situated downstream from Bor and regulation could not have time to be felt.

Correlation between BOR and JONGLEI

(maximum yearly water level)

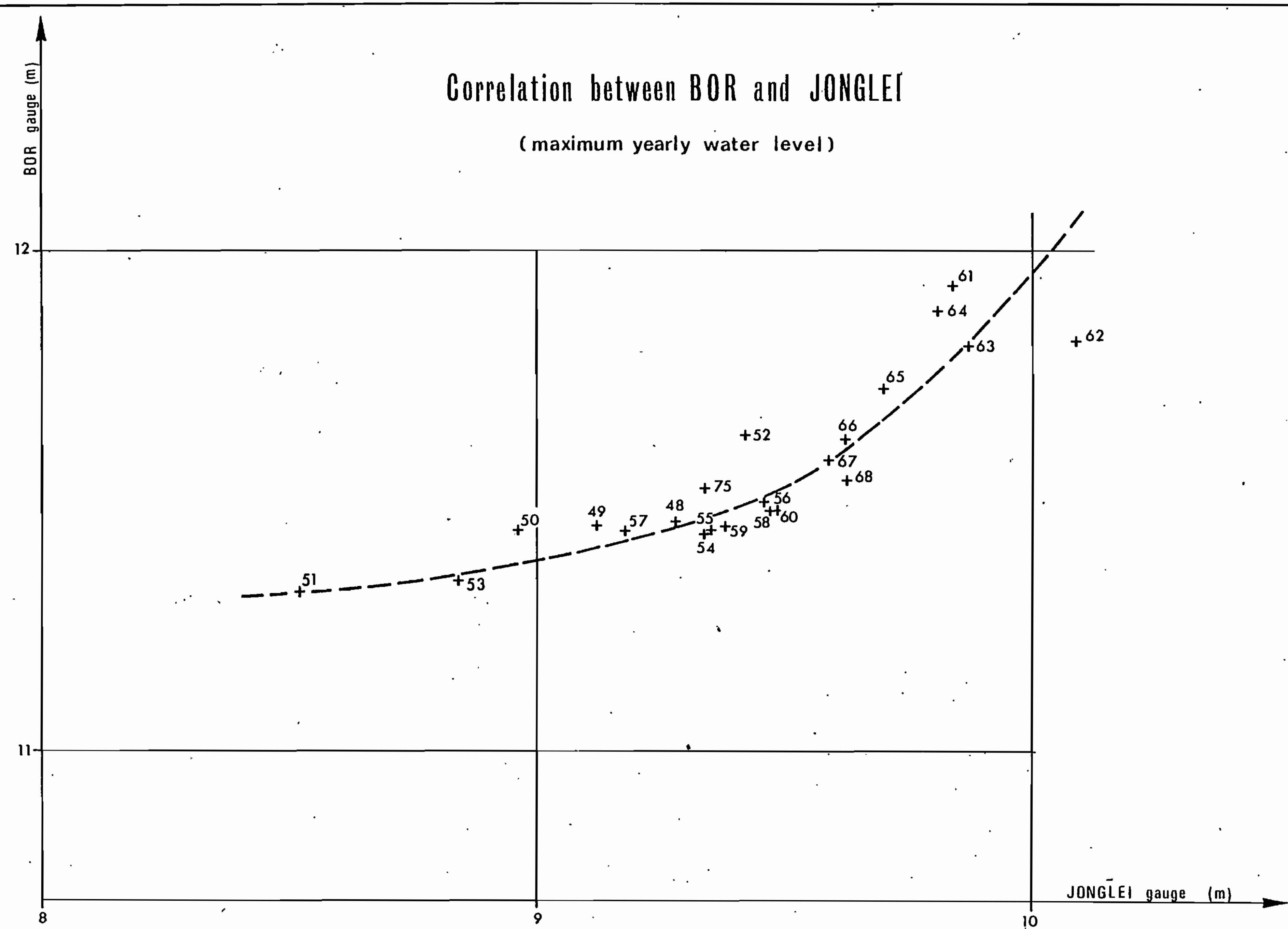


Fig- 5

- The Nile slope is decreasing sharply from Bor and therefore, a decrease in the slope is going to lead to a decrease in the speed and therefore, to an increase in the water in the water level given the same discharge.

3.4. - STATISTICAL STUDY OF WATER LEVELS AT JONGLEI

Although a statistical study should deal only with discharges, the ignoring of the latter at Jonglei leads to the fact that we can work only on the sample "water level".

The statiscal year distribution is shown in figure n° 6.

Since the maximum annual water level must reach an asymptotic limit (given the overflows into the overbank channel), the distribution of annual maxima does not follow a classical statistic law.

According to our graphic fitting, the water level would reach or exceed 9.78 m one year out of ten and would range from 10.10 to 10.13 m one year out of 100.

This last evaluation is clearly lower than this made by ILACO [5] which amounts to 10.30 m .

The estimation concerning the ten-year or one-hundred years water levels remains, however, inaccurate, for it seems that the bottom of the Nile minor bed is rising at Jonglei over the years. It would seem [4] that the bottom level rose by 50 cm from 1910 to 1950, say a mean increase amounting to 1.3 cm/a year upstream from Bor. Successive measurements [5] which were made at Jonglei when the Nile is flowing entirely in its minor bed show the following shifts of calibration :

From	1934	to	1959-60	78 cm	3 cm/a year
From	1959-60	to	1960-61	26 cm	26 cm/a year
From	1960-61	to	1963-64	66 cm	22 cm/a year
From	1963-64	to	1970-74	54 cm	6 cm/a year

These values are considerable and inconsistent with the fact that the transportation of sediments from the White Nile is considered as very low (from 26 to 170 g /m^3) and similar in size to those which were measured [14] in Central African Republic (say 200 g. /m^3).

Since the depth of the minor bed in relation to the banks is about 3.8 m [27], this bed would be filled up in 65 years, which is of course quite an absurd hypothesis.

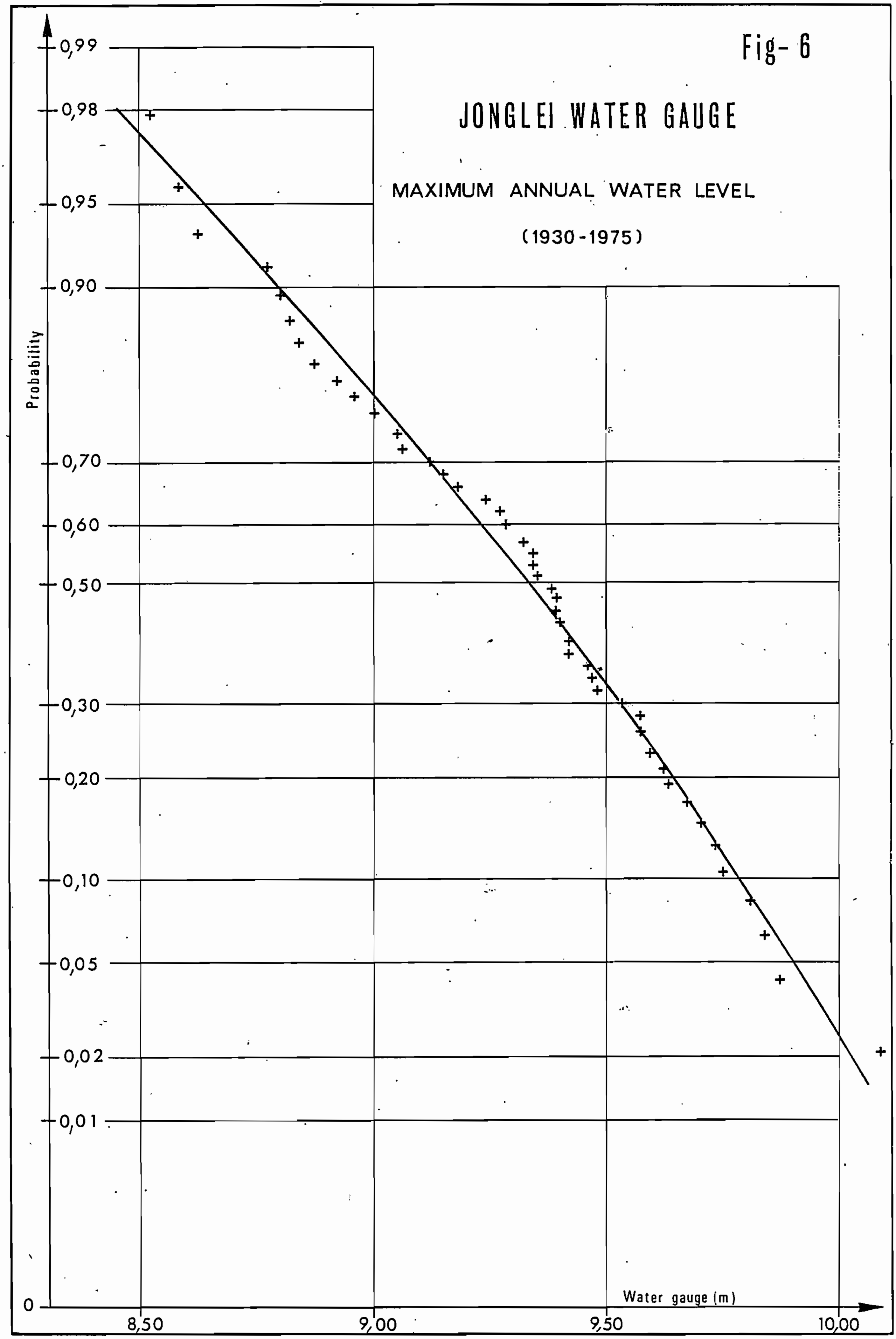


Fig- 6
JONGLEI WATER GAUGE
MAXIMUM ANNUAL WATER LEVEL
(1930-1975)
Probability
0,99
0,98
0,95
0,90
0,70
0,60
0,50
0,30
0,20
0,10
0,05
0,02
0,01
0
8,50
9,00
9,50
10,00
Water gauge (m)

We must consider that the variations in the minor bed result not from suspended deposits but from modifications in the bed under the influence of the current (bed load).

This seems to be all the more probable as, at Jonglei, the Nile minor bed appears in the form of a braided pattern channel which can be clearly seen in the LANDSAT images. Therefore, from year to year, an arm of the minor bed is scouring, while another one is silting up mainly when the floods are considerable.

Nevertheless, the scouring-silting balance may not be established at the hydrological station.

3.5. - *EVOLUTION OF THE FLOODS SINCE 1930*

Figure n° 7 shows the highest annual water levels, year after year since 1930. It seems that, since 1961, the maximum level of the Nile is clearly higher than previously. Moreover, this was emphasized in a ILACO report [5] which gave several explanations for this phenomenon.

Since we knew that there was a rather good correlation between the yearly Nile flow and this of the adjacent basins [10] and more especially the Chari basin, we indicated in figure n° 7 the highest yearly water levels of the Congo (Zaïre) at Kinshasa and of the Ubangi at Bangui. It is visible to the naked eye that the evolution of the water levels is almost similar from one year to the other.

Nevertheless, the coefficients of linear correlation (r) show only a rather loose relation between the Congo and the Ubangi and no relation at all between the Nile and the Congo or the Nile and the Ubangi.

Nile	and	Ubangi	:	r	=	0.19	(41 years)
Nile	and	Congo	:	r	=	0.18	(44 years)
Congo	and	Ubangi	:	r	=	0.59	(39 years)

This is valid for the period from 1930 to 1979.

The period from 1961 to 1975 corresponds to very high water levels. In 1961, floods with a return period of at least 50 years were observed on the Congo [19], the Ubangi, the Chari, etc... This also corresponds to a high flood on the Nile : it seems in figure n° 7 that the high water levels of the Nile remain higher than those of the Congo and the Ubangi.

Nile	and	Ubangi	:	r	=	0.38	(15 years)
Nile	and	Congo	:	r	=	0.66	(13 years)
Congo	and	Ubangi	:	r	=	0.96	(13 years)

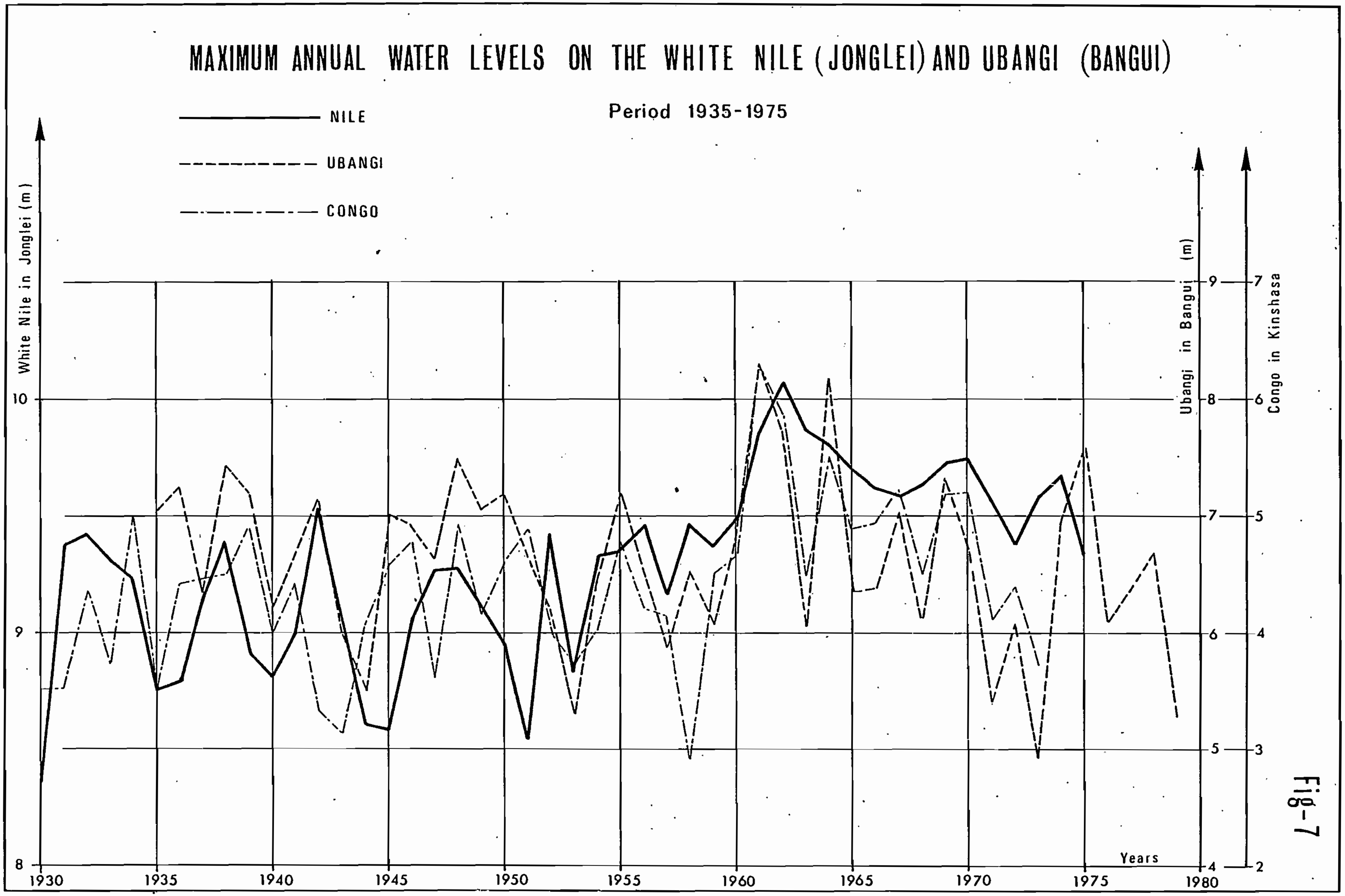

MAXIMUM ANNUAL WATER LEVELS ON THE WHITE NILE (JONGLEI) AND UBANGI (BANGUI)
Period 1935-1975
NILE
UBANGI
CONGO
White Nile in Jonglei (m)
Ubangi in Bangui (m)
Congo in Kinshasa
Years
8
9
10
4
5
6
7
8
9
2
3
4
5
6
7
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980

Fig-7

Maximum yearly water level in

White Nile(Jonglei), Ubangi (Bangui) and Congo (Kinshasa)

Period 1930 - 1979

Water levels

Year	Jonglei (m)	Bangui (m)	Kinshasa (m)
1930	8.37	—	3.52
1931	9.39	—	3.53
1932	9.42	—	4.38
1933	9.32	—	3.73
1934	9.24	—	4.99
1935	8.77	7.05	3.53
1936	8.80	7.25	4.43
1937	9.15	6.35	4.47
1948	9.40	7.46	4.51
1939	8.92	7.20	4.87
1940	8.82	6.22	4.00
1941	9.00	6.70	4.43
1942	9.53	7.08	3.35
1943	9.06	5.98	3.13
1944	8.62	5.50	4.09
1945	8.58	6.97	4.50
1946	9.05	6.92	4.80
1947	9.27	6.64	3.62
1948	9.28	7.50	4.94
1949	9.12	7.06	4.17
1950	8.96	7.20	4.62
1951	8.52	6.64	4.90
1952	9.42	6.20	4.00
1953	8?84	5.30	3.74
1954	9.34	6.47	4.02
1955	9.35	7.20	4.80
1956	9.46	6.50	4.22
1957	9.18	5.88	4.17
1958	9.47	6.55	2.91
1959	9.38	6.10	4.52
1960	9.48	6.80	4.67
1961	9.84	8.32	6.26
1962	10.09	7.69	5.84
1963	9.87	6.05	4.50
1964	9.81	8.19	5.53
1965	9.70	6.35	4.90
1966	9.62	6.39	4.94
1967	9.59	7.04	5.23
1968	9.63	6.11	4.53
1969	9.73	7.32	5.18
1970	9.75	6.76	5.20
1971	9.57	5.40	4.10
1972	9.39	6.06	4.42
1973	9.57	4.93	3.74
1974	9.67	6.83	—
1975	9.34	7.64	—
1976	—	5.89	—
1977	—	5.97	—
1978	—	6.30	—
1979	—	5.30	—

The correlation between the Congo and the Ubangi is very high, which is rather normal since the Ubangi is a tributary of the Congo.

So, it seems that the high coefficient of flow of the period 1961-1976 is found on the Nile as well as on the Congo (or the Ubangi). An hydrological study which was made by Mr. P. TOUCHEBEUF de LUSSIGNY [18] about the Inga dam situated on the Congo comes to the conclusion that "the chronological series of floods is subject to a steady phenomenon which is superimposed on the purely random fluctuations" for the period 1961-1970. As a matter of fact, the ten-year mean water levels are as follows at Kinshasa :

1931 - 1940	=	4.24 m
1941 - 1950	=	4.16 m
1951 - 1960	=	4.19 m
1961 - 1970	=	5.21 m
1971 - 1973	=	4.09 m

We find again the same phenomenon on the Nyabarongo at Kigali, that is to say on a tributary of the High Nile upstream from Lake Victoria [7] :

1956 - 1960	=	1.93 m
1961 - 1965	=	2.51 m
1966 - 1970	=	2.15 m
1971 - 1974	=	1.92 m

Such a phenomenon can be accounted for only by a superabundant yearly rainfall during the period 1961-1970. For this purpose, we calculated the means concerning the periods 1951-1960, 1961-1970 and 1971-1976 at several stations for which we got the records :

unit = mm

Stations	*1951-60*	*1961-70*	*1971-76*	$\bar{x}$
Brazzaville *(Popular Republic of Congo)*	1 365	1 430	1 319	1 379
Bangui *(Central African Republic)*	1 511	1 471	1 549	1 590
Bangassou *(C.A.R.)*	1 694	1 648	1 600	1 712
Rubona *(Rwanda)*	-	1 288	-	1 170

We can see that only the stations situated south of the Equator (Brazzaville, Rubona) show a yearly rainfall 1961-1970 higher than the mean ($\bar{x}$). In his 1976 technical report [5], ILACO ascribed the high levels of the Nile, from 1961, to :

- the existence of the Owen Falls dam which regulates the discharges from Lake Victoria,
- the intrusion of the Nile stream channels by water hyacinths,
- the modifications in the minor bed,
- a meteorological sequence which is clearly more rainy than in the previous years.

It would seem that only the meteorological conditions prevailing in Central Africa south of the Equator during the period 1961-1970 are responsible for this series of particularly high water levels. Let us recall that the Owen Falls dam was built [26] in 1946, that is to say fifteen years before the period under consideration. It seems to be rather unlikely that an accumulation of water hyacinths or a raising of an arm of the minor bed are not compensated by the scouring of the minor bed in another arm.

4. - THE SATELLITE TELEMETRY NETWORK

The network of hydrometeorological stations which are equipped with satellite telemetry is shown in figure n° 8. We used the ARGOS System. Two polar orbiting satellites revolve round the Earth. Ground stations transmit every 200 seconds, whether a satellite is visible or not. When the satellite is visible, say about eight times a day, the message is intercepted and retransmitted in a rather complicated way to the TOULOUSE ARGOS Centre (France) where it is decoded.

A magnetic tape file (DISPOSE file) is created at Toulouse and a copy is sent to us each month in Paris. On the other hand, after being transcribed, messages are sent to the Global Telecommunication System (GTS) of the World Meteorological Organization form Toulouse to Paris, where, several times a day, they appear on the outputs of the teleprinters from the Meteorological Department to which we could have access.

It would have been possible to send these messages to Khartoum through the GTS but it was not considered as being useful.

4.1. - TECHNICAL DESCRIPTION OF THE TELEMETRY STATIONS

Each station measures the level of the flood and the falling of rain between each passage of the satellite. There is no storage, for the variations in the flood are very slow.

The sensor measuring the flood level is a float which follows the water variations. To this float is attached a cable which is wound round an axis and the other end of the cable is equipped with a counterweight which provides the whole unit with a static equilibrium... The variation in the water level is going to result in a rotation of the axis. An encoder which is connected mechanically to the axis gives the digital value of the water level in binary code (GRAY code).

The rainfall sensor is a tipping bucket which produces an impulse for each 0.2mm of rain. These impulses are counted by an electronic counter. The encoder-transmitter interface is included into the electronic box of the transmitter.

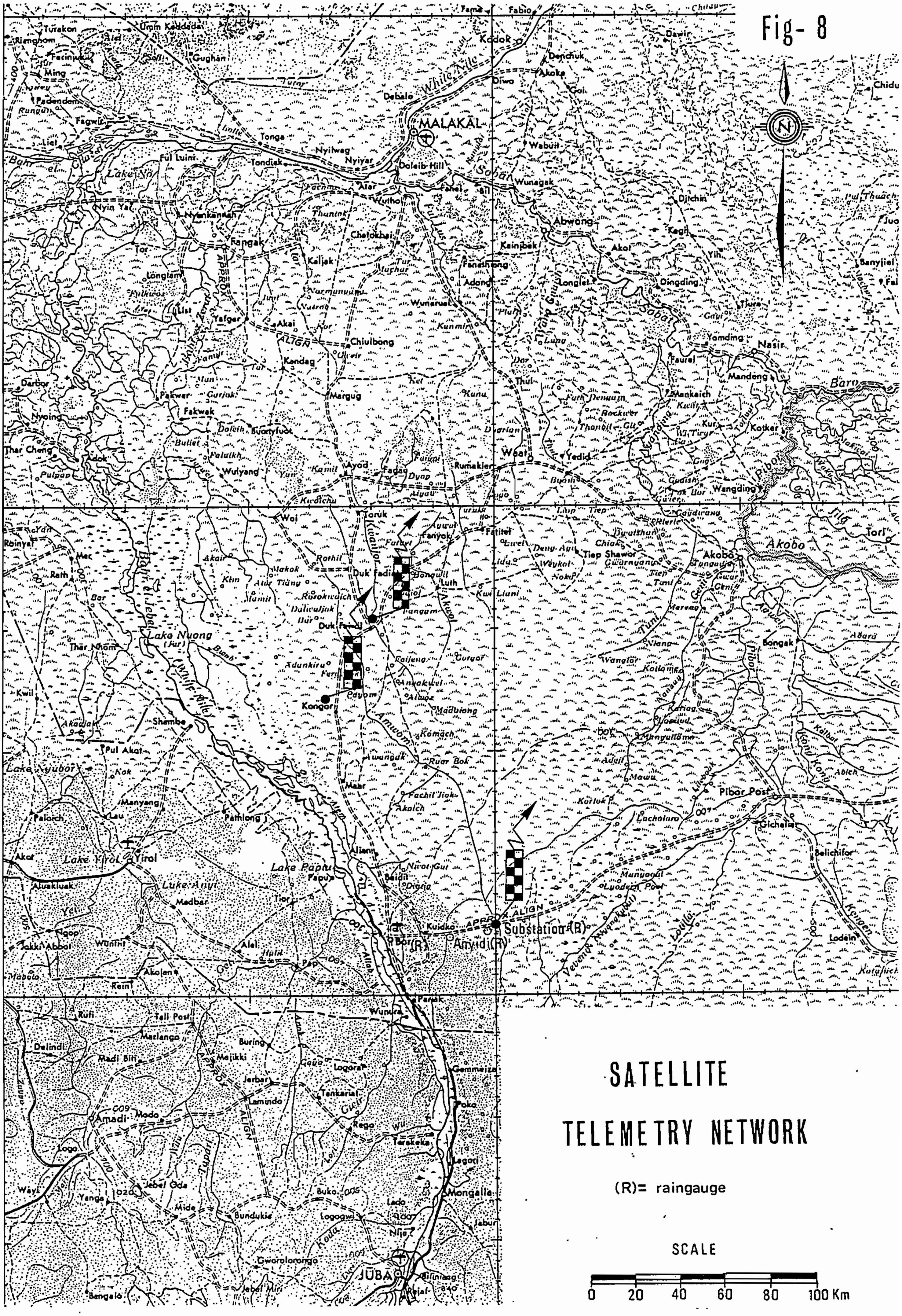


Fig- 8

SATELLITE

TELEMETRY NETWORK

(R)= raingauge

SCALE

The antenna output goes through a KX13 coaxial cable. The antenna is mounted on the upper part of the box which contains the whole unit. It is protected by an hemispheric casing made of plastic.

The power supply is secured by dry batteries for the power consumption is very low (50mW). The flood sensor-encoder unit, transmission electronics, antenna and dry batteries are contained in a metallic box situated above the maximum possible flood level and mounted at the top of a well which is intended to protect the float. Box and well were made by a Sudanese blacksmith.

The manufacturers and tradesmen are :

- NEYRTEC at Grenoble (FRANCE) for the flood sensor-coder,
- PRECIS-MECANIQUE at Bezons (FRANCE) for the rainfall sensor,
- ELECTRONIC MARCEL DASSAULT at Saint-Cloud (FRANCE) for electronics,
- CIT Alcatel at Lannion (FRANCE) for the antenna,
- CIPEL at Levallois (FRANCE) for the electronic power,
- EQUIPEMENTS ELECTRIQUES DE L'EST at Montreuil (FRANCE)
- COMPTOIR ELECTRIQUE DU PERREUX (FRANCE) for other supplies.

4.2. - *THE NETWORK STATIONS*

4.2.1.- *The station of Pengko Pilot Project Substation*

It is situated 50 kilometres East of Bor ; say 200 metres after the camp of Pengko Pilot Substation. It was set up on April 18th, 1980 and was operational without any problem up to the end of the measurement campaign (December 15th, 1980).

It is established in a "ditch" situated nearly in the site of a "thalweg" which is invisible to the naked eye when walking through the region but which drains the latter.

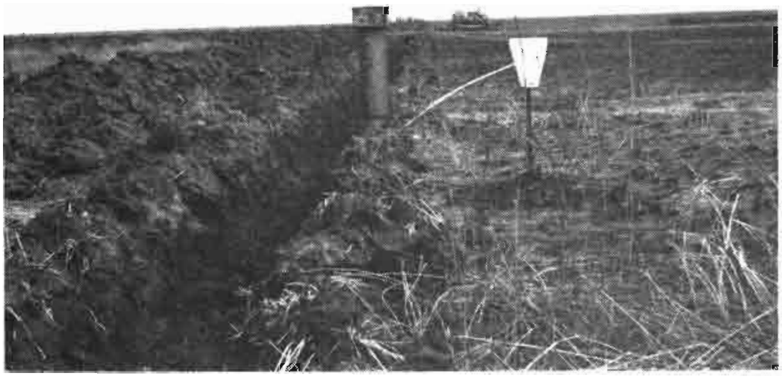
The bottom of the ditch gets an elevation of 1.25m (which is a relative altitude specific of the station), while the top of the ditch, that is to say the level of the earth itself is set at 1.90m.

Rainfalls were not abundant enough so that there was not an overflow of the ditch.

We visited the station on October 26th, 1980.

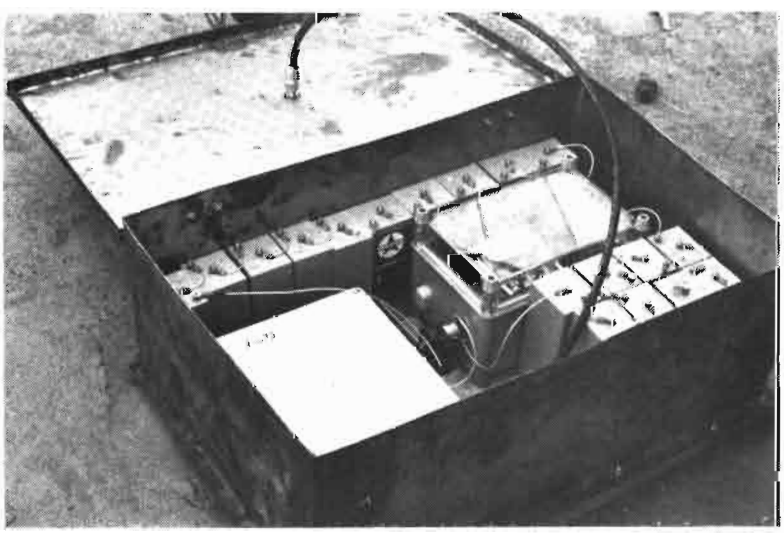
SATELLITE TELEMETRY STATION

BOR Substation



Dry season

Rainy season



Inside of telemetry box
from left to right :
ARGOS transmitter, water level encoder, batteries.
on the top : antenna

4.2.2.- *The Kongor station*

This significant station was set up on April 15th, 1980. It is situated 5 kilometres north-west of the village of Kongor and in an "hafir" about 200 metres inside the zone flooded by the Nile. A rather precarious caretaking was established since the caretaker will have to withdraw towards Kongor when the flood reaches its house situated a few metres from the station.

The station was operational without any problem up to July when it stopped transmitting. At that time, we thought that this failure was caused by man or a wild animal, etc... but the information gathered in October 1980 show that it was a failure of the station itself. Since Mr ARDAGH (FAO) got no boat, he was unable to go to the station but he assured me that the station was still existing.

4.2.3.- *The Duk-Faiwill station*

It is situated 500 metres north of the village of Duk Faiwill which is situated 48 kilometres north of Kongor.

The station was set up in an "hafir" on April 16th, 1980 and the thalweg shown on the maps was invisible to the naked eye.

It did not stop transmitting up to the end of the campaign (December 15th, 1980).

4.3. - *RESULTS OF TELETRANSMISSION*

4.3.1.- *Number of messages received*

From the moment when measurements were undertaken to the moment when they were stopped, say December 15th, 1980, the number of messages received amounted to :

	Duration (days)	Total of the messages	Messages/day	False messages	Rate of correct transmission %
ARGOS Substation	242	2135	8.82	24	98.9
ARGOS Kongor	89	763	8.57	7	99.1
ARGOS Duk Faiwill	245	2053	8.38	28	98.6
Mean value			8.60		98.8

Let us recall here that the ARGOS System had planned to collect 7.5 messages per day, while we collected 8.6, say 15 % more.

It results from the fact that the ARGOS System calculated its daily collection rate, while considering that the satellite does not operate at less than 5° above the skyline. Experience showed us that data collection can be carried out below 5°, but it is then possible to make some errors as a result of bad propagation. It is possible to suppress automatically these erroneous messages by taking into account only the messages which have been repeated at least once. As a matter of fact, since transmission occurs every 200 seconds, the satellite can receive the same message bit for bit five times on end. In fact, the satellite computer will suppress the repetitive messages, but it will note how many times this repetition occurred. This indication is shown in the DISPOSE file and it is obvious that we could have suppressed systematically any message which would not have been repeated at least once. Indeed, this solution led to suppress all the false messages, but also a good many correct messages (about 3 correct messages against one false message), so we gave it up in favour of a manual control which gave us complete satisfaction.

The rate of correct data collection amounting to 98.8 % can be considered as excellent.

Telemetry data were operated from the DISPOSE file on the computer of the ORSTOM Hydrological Service starting from the magnetic tape which is received in Paris each month.

4.3.2.- *Measurements of water levels* (*fig. 9 - 10 - 12*)

The analysis of these data concerns :
- the water level rise under the influence of rainfalls,
- the water level fall under the influence of infiltration and evaporation.

4.3.2.1. *Water level rise*

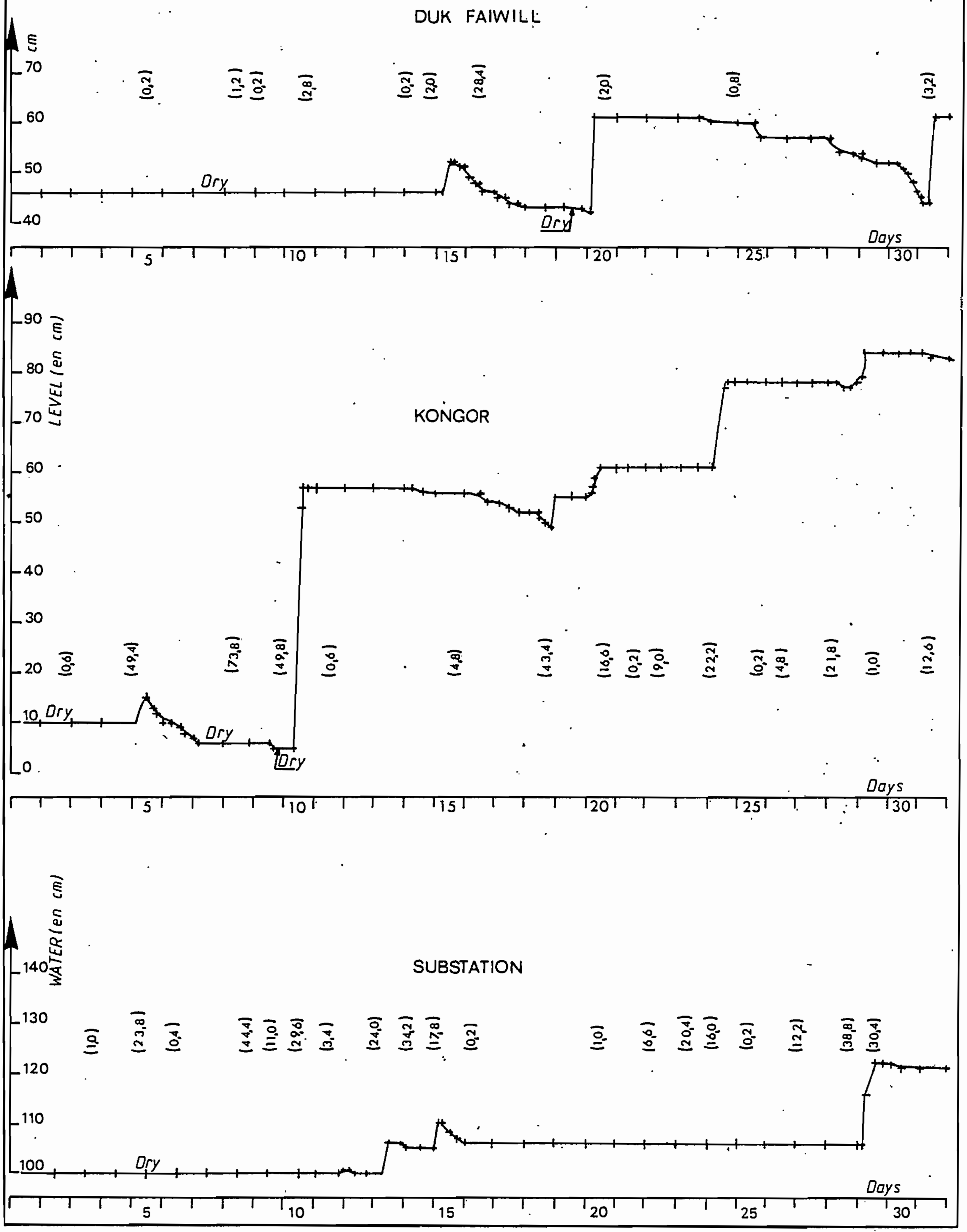
The pictures and the following table indicate how the water level is rising in relation to rainfalls.

Fig 9

Water level in the Satellite Telemetry Stations

May 1980

(0,2)=Rainfall



Water level in the Satellite Telemetry Stations

June 1980
(0,4)=Rainfall

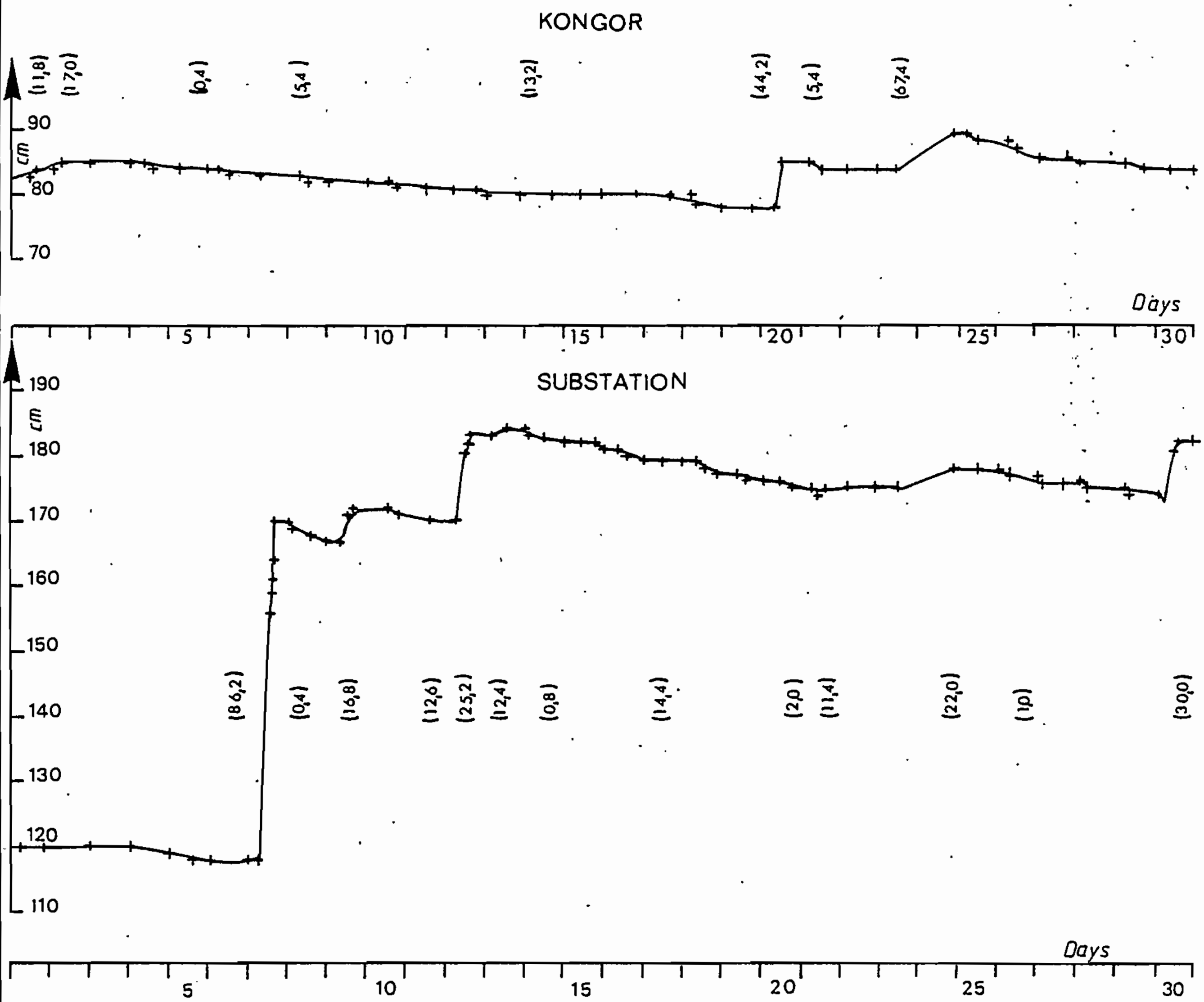


Fig 11

Water level in the Satellite Telemetry Stations

July 1980
(1,6) = Rainfall

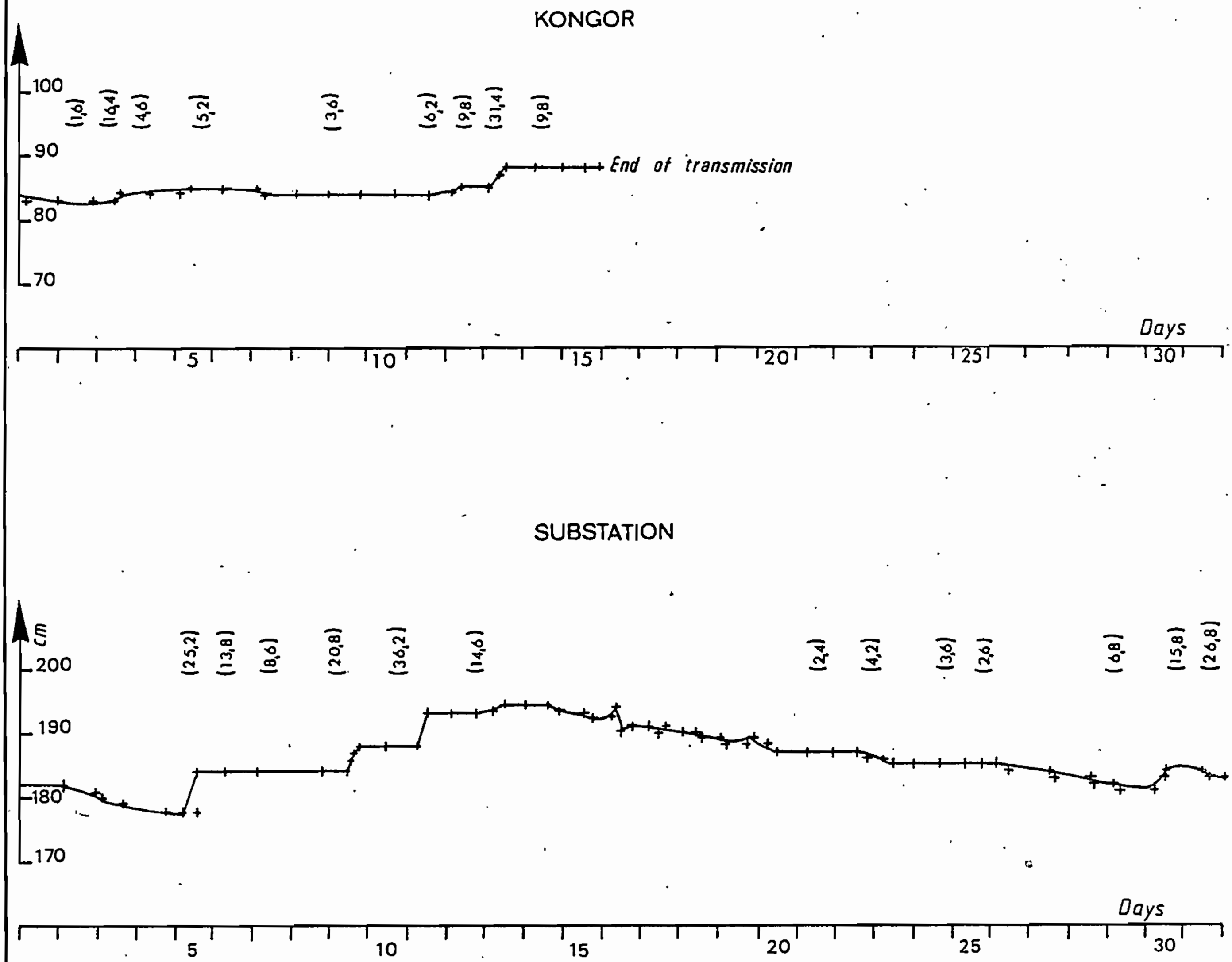
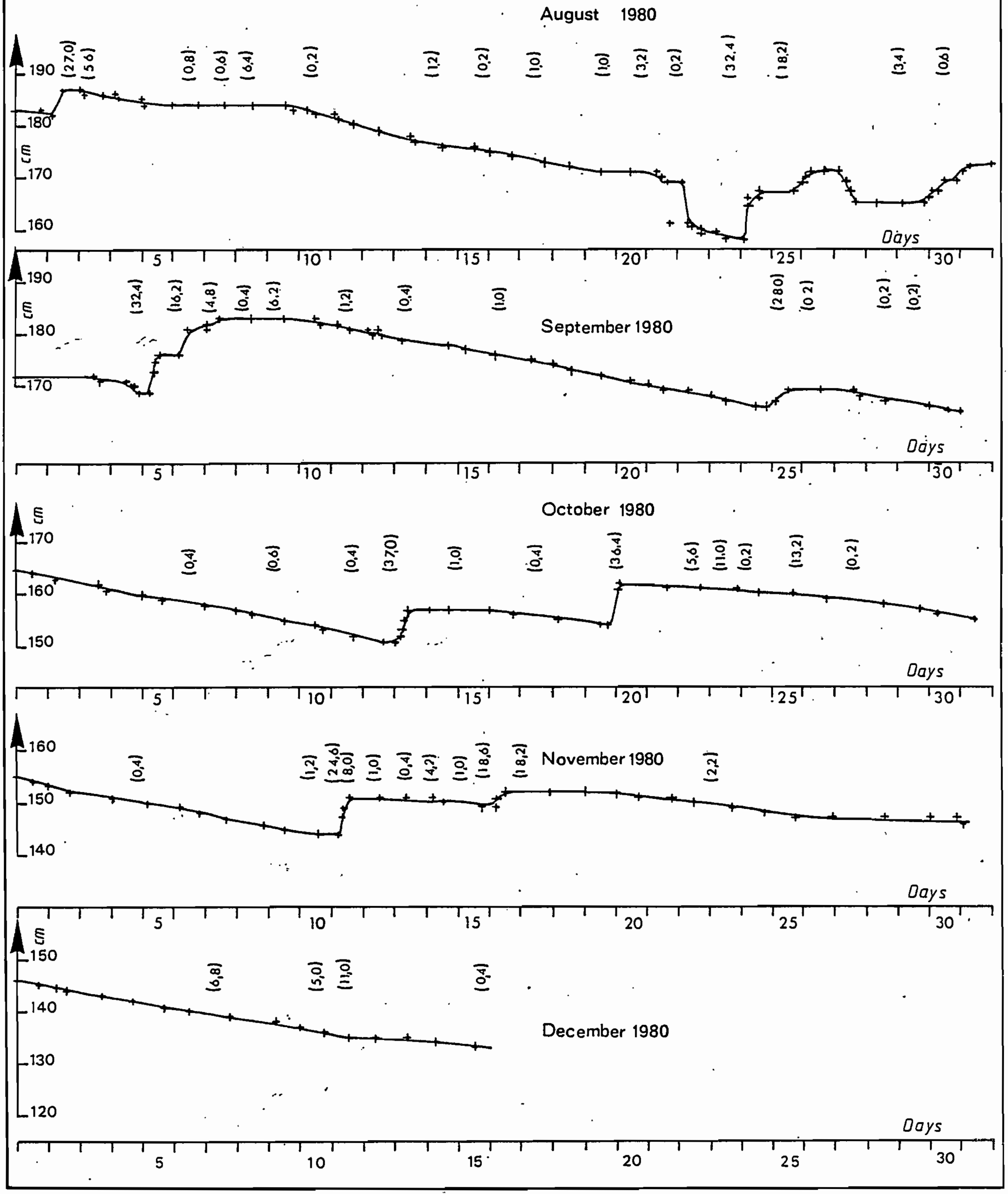


Fig 12

Water level in the Satellite Telemetry Stations

Substation

(0,8) = Rainfall



Satellite Telemetry Station

Water level rise and rainfall

Date	Water level rise (cm)	Rainfall (cm)	W/R
	ARGOS SUBSTATION		
13/5	6	2.4	2.5
15/5	5	1.3	3.9
29/5	10	3.8	2.6
29/5	6	3.1	1.9
7/6	52	8.6	6.0
9/6	5	1.7	2.9
12/6	13	2.5	5.2
30/6	9	3.0	3.0
5/7	6	2.5	2.4
9/7	4	2.1	1.9
11/7	5	3.6	1.4
13/7	1	1.4	0.7
2/8	5	2.7	1.9
24/8	9	3.2	2.8
26/8	4	1.9	2.1
5/9	7	3.2	2.2
6/9	5	1.6	3.1
25/9	3	2.8	1.1
13/10	6	3.7	1.6
20/10	8	3.3	2.4
11/11	7	3.3	2.1
16/11	3	1.9	1.6
	ARGOS KONGOR		
5/5	(10)	4.9	2.0
10/5	52	5.0	10.4
19/5	6	4.3	1.4
20/5	6	1.7	3.5
24/5	17	2.2	7.7
28/5	7	2.2	3.2
20/6	6	4.4	1.4
24/6	5	6.7	0.7
	ARGOS DUK FAIWILL		
15/5	(16)	0.2	80
20/5	19	0.2	95
31/5	17	0.3	57

- ARGOS Substation

The beginning of the rainy season caused the water level to rise sharply in relation to rainfalls (the $\frac{\text{water level}}{\text{rainfall}}$ ratio = $\frac{W}{R}$ is often higher than 5), which corresponds to the filling up of the ditch where the telemetry station was set up.

From July, the ratio $\frac{W}{R}$ is stabilized around 2.4 with a standard deviation amounting to 0.6.

In no case, the ditch has overflowed : the highest level observed was 1.94m, while the ground level was 2.03m at the telemetry station.

Moreover, it does not seem that there was much flow in the ditch (when I went there on October 26th, 1980, the water level was 1.60m and the ditch water speed was equal to zero).

Without being wrong, we can consider the ditch as a very extended "hafir" which would be filled with the rain falling into it and that streaming on the sides of the ditch : this would correspond to the area of 1 to 2m in width which is situated on the eastern side of the ditch and is limited by a little dike;

- ARGOS Kongor

The runoff in the surroundings of the "hafir" where the station is set up causes the water level to rise more than rain, mainly at the beginning of the rainy season ($\frac{W}{R}$ = 10).

- Duk Faiwill

At this station, the $\frac{W}{R}$ ratio is about 80, which shows that the runoff is considerable when the "hafir" is filled up. It is a pity that the data which were transmitted from June 18th are no longer significant.

4.3.2.2. *Water level fall*

The discharge of the ditch is very low and even equal to zero. Therefore, the decrease in the water level can be considered as the total represented by evaporation and infiltration.

- ARGOS Substation

The water level decreases from 2.0 to 13.4mm per day, whether the event is measured at the beginning, in the middle or at the end of the rainy season. The mean value amounts to 8.5mm and the modal value to 11.5mm. The standard deviation is 3.3.

A sharp decrease by 8cm occurred on August 22nd and results probably from a human intervention on the ditch (we must not forget that the Substation is situated in an area where agricultural experiments are made).

- ARGOS Kongor

In May, the decrease in the water level was about 2.5mm a day. In June, it was 5mm.

- ARGOS Duke Faiwill

In May, the only measurement showed a decrease by 2.6mm, that is to say a value similar to potential evapotranspiration.

4.3.3.- *Measurements of rainfall*

Teletransmission which is combined with the classical rainfall records emphasized the spatial distribution in relation to rainfalls (see tables in the following pages).

For this purpose, we considered :

- the group of stations including Bor, Anyidi (station situated on the road Bor-Substation, halfway between these two points), Substation.
- the whole stations including Duk-Faiwill.

We undertook a monthly study concerning the number of showers related to the whole raingauges of each group :

Satellite Telemetry Station

Water level fall

Month	Date	Duration (days)	Fall (cm)	Rainfall (mm)	Fall+Rainfall (mm)	Fall by day (mm)
ARGOS SUBSTATION						
5	16 - 28	13	0	57	57	4.3
6	14 - 21	8	9	17	107	13.4
6	25 - 30	6.5	4	1	41	6.3
7	5 - 9	4	0	22	22	5.5
7	17 - 23	7	6	7	67	9.6
7	26 - 30	4	4	7	47	11.8
8	2 - 8	6.5	2.5	13	38	5.9
8	9 - 21	12.5	15	7	157	12.6
9	9 - 23	15	17	9	179	11.9
9	26 - 12	17	19	2	192	11.3
10	13 - 19	6.5	3	1	31	4.8
10	20 - 11	22	18	31	211	9.6
11	11 - 15	4.5	2	16	36	8.0
11	15 - 25	9	5	20	70	7.8
11	26 - 30	5	1	0	10	2.0
12	1 - 11	10	10	5	105	10.5
12	11 - 15	5	3	11	41	8.2
ARGOS KONGOR						
5	10 - 16	6	1	5	15	2.6
5	20 - 23	3.8	0	9	9	2.4
5	25 - 28	3.7	0	5	5	1.4
6	3 - 15	13.3	5	19	69	5.2
6	10 - 15	5	1	13	23	4.6
6	20 - 23	3	1	5	15	5.0
7	6 - 12	6	1	20	30	5.0
ARGOS DUK FAIWILL						
5	20 - 25	5	1	3	13	2.6

Month	Bor/ Substation Group			The whole zone		
	Total number of rainy days	Amount of rain observed in the whole zone	%	Total number of rainy days	Amount of rain observed in the whole zone	%
January	0	/		/	/	
February	1	0		/	/	
March	12	0		/	/	
April	26	12	46	/	/	
May	38	15	40	70	15	21
June	24	6	25	62	6	10
July	53	8	15	/	/	/
August	47	4	9	/	/	/
September	32	0	0	/	/	/
October	24	4	17	/	/	/
Total	257	49	19			

One rain out of 5 is related to the three raingauges which are situated along a straight road and cover 50km. This situation supposed that these daily rainfalls which are observed at each station corresponded to the same rainy event, which maybe is not true in reality. This emphasizes the smallness of the zone which is watered by a shower and the absence of organized rainy systems such as the storm lines.

Teletransmission emphasized another aspect, that is to say, the disproportion existing between the number of rainy days which is observed on the classical raingauges and this obtained through teletransmission.

Number of rainy days

Month	Raingauge Substation or Anyidi				ARGOS Substation			
	Total	>10mm	<10mm	<1mm	Total	>10mm	<10mm	<1mm
May	(11)	(5)	(6)	(3)	14	10	4	1
June	12	6	8	3	18	9	9	8
July	10	3	7	3	24	7	17	10
August	10	3	7	3	24	3	21	13
September	5	2	3	0	22	3	19	16
October	(7)	(6)	(1)	Bor	(17)	(3)	(14)	(13)
Total	55	25	32	12	119	35	84	61

We can see at once that the number of rainy days observed is more important at the telemetry station as compared with the classical station. The distance between both stations ranging from 500 to 1000m, it can be admitted that only the very heterogeneous feature of rains causes such deviations to occur from May to the end of July. Nevertheless, there are big differences between the monthly totals during this period :

Monthly totals

	Telemetry station	Substation	
May	(291.2)	(131.6)	
June	236.4	158.1	
July	183.6	104.8	
August	106.6	82.2	
September	94.8	(70.6)	Anyidi
October	(101.6)	(219.6)	Bor

It is advisable to recall that the determination of rainfalls in the telemetry system which is set up here, is made through a counter which increases by one unit each time 0.2mm of rain is falling. The value of this counter is telemetered at each passage of the satellite without being resetting to zero. The counter includes 12 digits, the passage to zero will be performed only when the counter is in position 4096 + 1, say after measuring 819mm of rainfall. Apart from this particular situation, the chronological series of the positions of this counter will indicate similar values (rainfall equal to zero) or ascending values (rain was falling between two data collections). A value lower than the value previously telemetered indicates that there is an error in the transmission and it will be suprressed. Therefore, we have a measurement method which is quite reliable and free from any random error.

The increase in the number of rainy days is particulary considerable from July to October as far as rains lower than 10mm are concerned. It is advisable to observe that a good many rains which are measured automatically by the telemetry system are lower than 1mm : in most cases, they are only dews. These dews and even these small rains seem to be ignored by the observer of the Substation.

4.4. - CONCLUSIONS

This first operational use of the ARGOS System as far as the hydrometric and rainfall data collection is concerned complied with what could be expected from this method.

The equipment was easily brought into operation and the use of telemetered data raised no difficulty. The amount of daily data collections proved to be higher than the amount which was planned by the ARGOS System.

As far as rainfall is concerned, we observed that no rain or dew higher than 0.2mm could avoid being telemetered.

However, we can regret that the Kongor station which is the most interesting in the network stopped to operate in July without being possibly started again as a result of the flood.

KONGOR AREA
YEAR 1980
DAILY RAINFALLS

	JANUARY			FEBRUARY			MARCH		
	BOR	ANYIDI	SUB-STATION	BOR	ANYIDI	SUB-STATION	BOR	ANYIDI	SUB-STATION
1	.	.	.	.	.	.	.	.	.
2	.	.	.	.	.	.	.	.	.
3	.	.	.	.	.	.	.	.	.
4	.	.	.	.	.	.	.	.	.
5	.	.	.	.	.	.	.	.	.
6	.	.	.	.	.	.	.	.	.
7	.	.	.	.	.	.	.	.	.
8	.	.	.	.	.	.	0.5	.	.
9	.	.	.	.	.	.	.	.	.
10	.	.	.	.	.	.	.	.	.
11	.	.	.	.	.	.	.	.	.
12	.	.	.	.	.	.	.	.	.
13	.	.	.	.	.	.	.	.	.
14	.	.	.	.	.	1.8	.	.	.
15	.	.	.	.	.	.	.	.	.
16	.	.	.	.	.	.	.	.	.
17	.	.	.	.	.	.	.	.	.
18	.	.	.	.	.	.	.	.	.
19	.	.	.	.	.	.	.	.	.
20	.	.	.	.	.	.	.	.	0.2
21	.	.	.	.	.	.	.	.	.
22	.	.	.	.	.	.	.	.	0.2
23	.	.	.	.	.	.	.	.	.
24	.	.	.	.	.	.	.	.	.
25	.	.	.	.	.	.	7.5	.	.
26	.	.	.	.	.	.	1.0	.	2.2
27	.	.	.	.	.	.	.	1.6	2.9
28	.	.	.	.	.	.	0.5	.	2.9
29	.	.	.	.	.	.	.	.	8.1
30	.	.	.	=	=	=	.	0.9	.
31	.	.	.	=	=	=	.	.	.
SUM	.0	.0	.0	.0	.0	1.8	9.5	2.5	16.5

KONGOR AREA

YEAR 1980

DAILY RAINFALLS

APRIL

	BOR	ANYIDI	SUBSTATION	ARGOS SUB.	KONGOR	DUK FAIWILL
1	.	.	.	-	-	-
2	.	.	.	-	-	-
3	1.0	.	0.5	-	-	-
4	2.5	1.1	1.8	-	-	-
5	.	5.0	1.2	-	-	-
6	.	.	.	-	-	-
7	.	.	.	-	-	-
8	.	.	.	-	-	-
9	.	.	17.1	-	-	-
10	.	.	.	-	-	-
11	.	.	.	-	-	-
12	.	.	.	-	-	-
13	.	.	.	-	-	-
14	.	1.5	.	-	-	-
15	4.0	3.3	1.3	-	-	-
16	30.0	5.6	12.1	-	.	.
17	.	7.9	-	-	.	.
18	.	.	-	-	.	.
19	.	.	-	0.2	.	.
20	.	.	-	.	.	9.8
21	.	.	-	.	0.8	1.4
22	.	.	-	.	.	.
23	7.0	.	-	45.8	15.8	1.8
24	2.7	6.8	-	0.4	0.2	.
25	.	.	-	.	9.6	.
26	.	1.3	-	.	.	.
27	.	.	-	0.4	17.2	.
28	4.7	.	-	2.8	31.2	0.6
29	.	2.9	-	.	6.0	.
30	.	.	-	.	0.4	0.8
31	=	=	=	=	=	=
SUM	51.9	35.4	-	-	-	-

KONGOR AREA

YEAR 1980

DAILY RAINFALLS

MAY

	BOR	ANYIDI	SUBSTATION	ARGOS SUB.	KONGOR	DUK FAIWILL
1	.	2.9	-	16.1	9.2	7.4
2	.	5.2	-	7.6	0.6	.
3	.	.	-	1.0	.	.
4	.	.	-	.	.	.
5	53.5	60.7	-	13.8	49.4	0.2
6	.	.	-	0.4	.	.
7	.	.	-	.	.	.
8	0.5	1.0	25.7	44.4	73.6	1.2
9	.	.	0.3	11.0	.	0.2
10	6.0	36.5	17.7	29.6	49.8	2.8
11	.	.	8.8	3.4	0.6	.
12	.	.	23.2	.	.	.
13	.	.	14.8	24.0	.	0.2
14	.	3.8	.	47.8	.	0.2
15	2.5	.	.	4.4	4.8	1.8
16	.	.	0.8	.	.	0.2
17	.	.	0.2	.	0.4	.
18	.	.	.	.	43.6	.
19	.	.	.	.	16.4	2.2
20	4.6	1.5	.	1.0	0.2	.
21	1.3	.	.	.	.	.
22	6.1	4.8	6.7	28.2	9.0	0.2
23	.	.	8.6	.	0.4	.
24	14.0	11.2	.	16.2	21.8	0.8
25	.	.	.	.	0.2	.
26	.	.	.	12.2	4.8	.
27	.	.	.	.	.	.
28	.	.	.	38.4	21.8	.
29	89.5	61.0	24.8	30.4	1.0	.
30	.	.	.	.	.	.
31	.	.	.	0.2	12.6	3.2
SUM	178.0	188.6	-	330.1	320.2	20.6

KONGOR AREA

YEAR 1980

DAILY RAINFALLS

JUNE

	BOR	ANYIDI	SUBSTATION	ARGOS SUB.	KONGOR	DUK FAIWILL
1	.	.	.	.	28.8	0.6
2	.	.	3.8	0.2	0.2	.
3	.	.	.	.	0.2	.
4	.	.	.	0.2	.	0.2
5	.	.	.	.	0.2	0.4
6	.	.	.	.	0.2	.
7	.	13.5	.	87.0	.	.
8	.	.	.	.	5.4	.
9	.	.	79.7	17.0	.	.
10	8.5	20.2	.	0.2	0.2	.
11	.	.	18.3	12.4	.	.
12	.	.	0.1	25.2	0.2	.
13	14.3	3.8	.	12.8	.	.
14	.	.	22.7	0.4	13.2	.
15	.	.	11.8	.	.	.
16	.	.	.	.	.	.
17	.	.	.	14.4	.	51.2
18	.	.	.	.	.	.
19	.	.	.	.	9.0	.
20	11.4	32.0	2.6	2.0	35.4	6.4
21	1.0	18.4	0.6	11.2	5.4	.
22	.	.	1.3	.	.	.
23	.	.	9.3	.	.	.
24	.	39.0	.	22.0	67.6	.
25	.	.	.	0.2	.	.
26	.	.	7.5	0.8	0.2	.
27	5.7	34.5	.	0.2	0.2	.
28	.	.	.	0.2	.	.
29	.	.	0.4	.	.	.
30	.	.	.	30.0	.	.
31	=	=	=	=	=	=
SUM	40.9	161.4	158.1	236.4	166.4	58.8

KONGOR AREA

YEAR 1980

DAILY RAINFALLS

JULY

	BOR	ANYIDI	SUBSTATION	ARGOS SUB.	KONGOR
1	4.8	5.0	.	0.6	5.4
2	.	0.4	.	.	1.4
3	.	.	.	0.2	16.4
4	35.0	.	.	.	4.6
5	21.5	13.0	34.8	25.2	5.2
6	.	0.9	44.5	13.8	.
7	.	.	.	0.2	0.2
8	3.7	.	0.2	8.4	3.4
9	7.5	10.3	10.7	20.6	11.4
10	.	.	.	.	0.2
11	17.0	19.2	.	36.2	6.2
12	2.5	8.0	.	0.4	13.2
13	.	11.1	.	14.2	28.6
14	.	.	.	0.2	9.6
15	.	.	.	.	0.2
16	.	.	.	0.2	-
17	.	.	.	0.2	-
18	.	.	.	0.2	-
19	.	.	0.6	0.2	-
20	.	.	.	2.4	-
21	.	22.4	2.3	.	-
22	.	.	0.8	4.2	-
23	.	.	.	.	-
24	10.0	.	3.5	3.6	-
25	.	.	.	2.6	-
26	.	.	2.1	0.2	-
27	.	.	5.3	0.2	-
28	.	.	.	.	-
29	.	.	.	6.8	-
30	3.5	.	.	16.0	-
31	.	18.5	.	26.8	-
SUM	105.5	108.8	104.8	183.6	-

KONGOR AREA

YEAR 1980

DAILY RAINFALLS

AUGUST

	BOR	ANYIDI	SUBSTATION	ARGOS SUB.
1	.	.	.	.
2	.	25.3	.	32.6
3	11.1	12.2	27.1	0.4
4	.	.	0.7	0.2
5	5.3	.	.	0.2
6	.	.	.	1.0
7	4.6	.	.	1.0
8	.	.	4.9	6.8
9	.	.	.	0.2
10	.	.	.	0.2
11	6.6	.	.	0.4
12	0.4	.	.	.
13	.	.	.	.
14	0.2	.	0.9	1.8
15	.	.	.	.
16	.	.	.	.
17	.	61.0	2.3	1.2
18	.	.	0.6	1.0
19	.	.	.	0.4
20	.	.	2.9	3.2
21	.	.	.	0.4
22	.	.	.	.
23	.	.	9.2	.
24	2.1	.	20.7	32.6
25	.	.	12.9	18.4
26	.	12.0	.	0.2
27	.	.	.	0.2
28	.	.	.	3.4
29	19.5	.	.	0.4
30	.	.	.	0.2
31	7.6	.	.	0.2
SUM	57.4	110.5	82.2	106.6

KONGOR AREA

YEAR 1980

DAILY RAINFALLS

SEPTEMBER

	BOR	ANYIDI	SUBSTATION	ARGUS SUB.
1	.	.	-	0.2
2	.	.	-	.
3	.	.	-	.
4	.	.	-	32.4
5	.	8.6	-	16.4
6	.	.	-	4.6
7	.	20.2	-	0.8
8	.	.	-	0.2
9	.	.	-	6.6
10	1.5	.	-	.
11	.	.	-	0.4
12	.	.	-	0.2
13	.	6.1	-	0.6
14	3.5	.	-	0.4
15	.	.	-	.
16	.	.	-	1.0
17	.	.	-	.
18	.	.	-	0.4
19	.	.	-	.
20	.	.	-	0.2
21	1.4	.	-	.
22	.	.	-	0.2
23	.	.	-	0.2
24	.	.	-	.
25	.	.	-	26.4
26	9.5	33.0	-	0.2
27	.	.	-	0.4
28	9.0	2.7	-	0.4
29	.	.	-	0.2
30	.	.	-	0.2
31	=	=	=	=
SUM	24.9	70.6	-	94.8

KONGOR AREA

YEAR 1980

DAILY RAINFALLS

OCTOBER

	BOR	ANYIOT	SUBSTATION	ARGUS SUB.
1	.	.	-	0.2
2	.	.	-	.
3	.	.	-	.
4	.	.	-	.
5	30.5	.	-	.
6	.	.	-	0.4
7	.	.	-	.
8	.	.	-	0.2
9	.	.	-	0.4
10	.	.	-	0.4
11	10.7	.	-	0.2
12	.	.	-	.
13	39.5	.	-	37.2
14	.	.	-	0.6
15	.	.	-	0.2
16	.	.	-	0.2
17	25.5	.	-	0.4
18	.	.	-	0.2
19	.	.	-	33.2
20	74.4	.	-	3.4
21	.	.	-	.
22	13.0	.	-	5.8
23	.	.	-	11.0
24	6.0	.	-	6.8
25	.	.	-	0.2
26	.	.	-	0.6
27	-	.	-	.
28	-	.	-	.
29	-	.	-	.
30	-	.	-	.
31	-	.	-	.
SUM	-	.0	-	101.6

5. - THE RESULTS OF ISOTOPIC HYDROLOGY

In order to study the isotopic composition of the waters in the Kongor plain, we asked for the assistance of Professor J.C. FONTES, Director of the Laboratory of isotopic Hydrology and Geochemistry at the University of Orsay (Paris-Sud).

We determined togother the schedule sampling and his laboratory made the analyses which were indispensable to this study.

5.1. - BRIEF RECOLLECTION OF THE THEORIES ABOUT ISOTOPIC HYDROLOGY

The isotopic composition of a water is expressed in terms of "delta" unit (δ), magnitude and sign. A delta unit corresponds to a fraction out of one thousand of the difference between the ^{18}O content of the sample and this of a standard value taken as a reference :

$$\delta = \frac{Q\ \text{sample} - Q\ \text{standard}}{Q\ \text{standard}} \times 1\,000$$

Q being the ratio $\frac{^{18}O}{^{16}O}$ or $\frac{D}{H}$ D = deuterium

The standard reference ratio (Q standard) is called Standard Mean Oceanic Water (SMOW) and it describes the mean theoretical isotopic composition of waters in oceans.

For a given temperature, the vapour pressure of "isotopic water" $H_2\,^{18}O$ is lower than this of "light water" $H_2\,^{16}O$, which results in leading evaporation to form clouds impoverished in ^{18}O as compared with SMOW. It is the contrary for condensation which concerns more particularly the "heavy" molecule $H_2\,^{18}O$ and DHO.

So, we will observe that rainfalls get a content of heavy isotopes (^{18}O) lower than the SMOW(the values of δ are then negative) and evaporation of continental waters (whose origin results from rainfalls and runoff) leads therefore to an enrichment of lake and river waters in heavy isotopes (^{18}O).

5.2. - LOCATION OF SAMPLES

Map n° 13 shows the location of the samples which concerned :

- rainfall (at Bor and Kongor)
- Nile waters at Bor

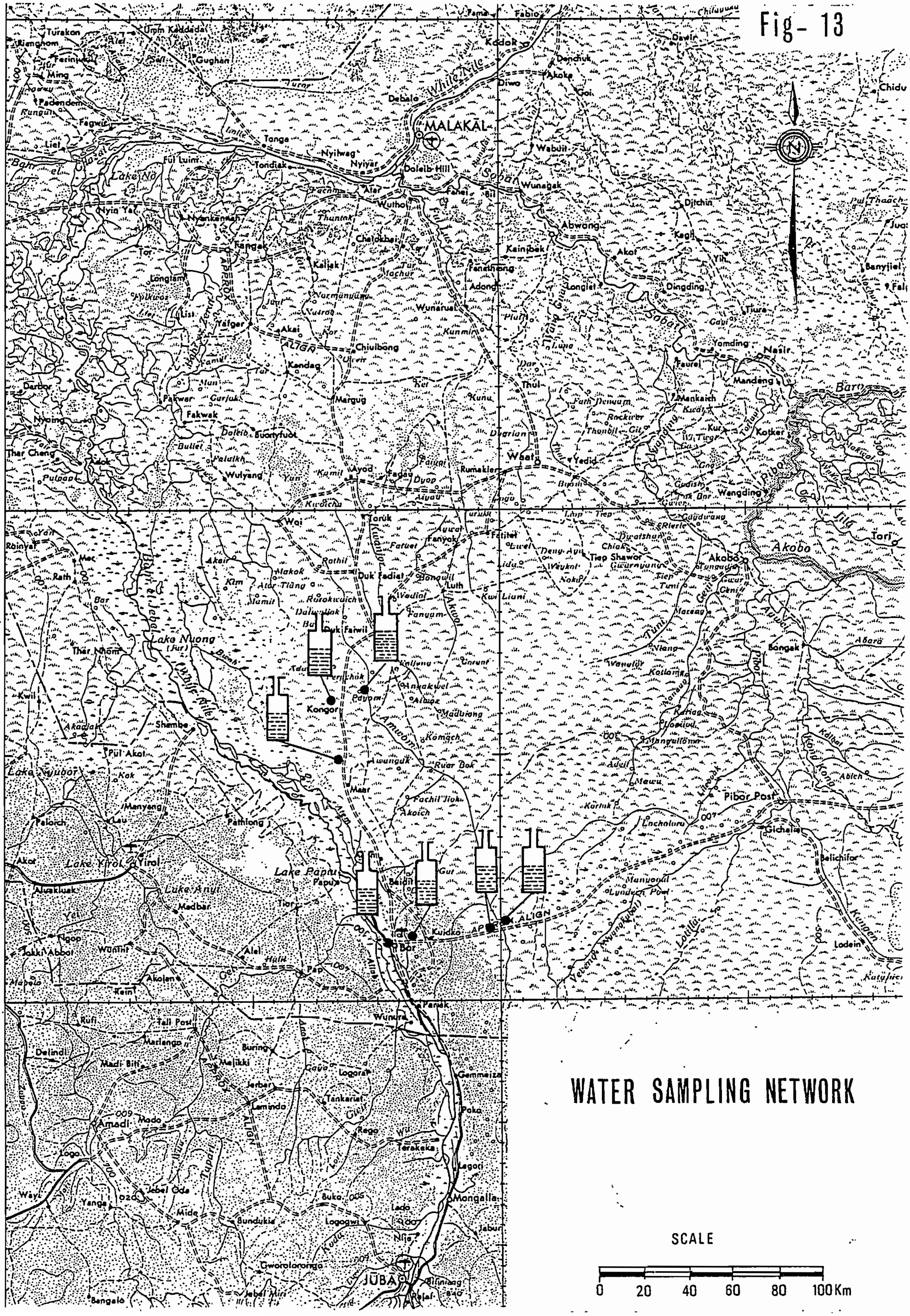


Fig- 13

WATER SAMPLING NETWORK

- waters of the flood plains at Kongor, between Kongor and Bor, and at Bor (Pengko Pilot Project Substation).

Samples were taken from May to October 1980.

5.3. - RESULTS OF ANALYSES AND INTERPRETATION

The results of the analyses in terms of delta unit (δ) as was defined above, are shown in the table on the following page.

They were gathered in the diagram n° 14 which shows the evolution of the isotopic composition in relation to time. These results confirm the theories mentioned in paragraphe 5.1.

In March 1980, the Nile water came from Lake Victoria. On April 19 th, 1980, its isotopic composition was $\delta = + 7.92$. Water supplies from the runoff, that is to say meteoric water, lead to the decrease of δ which amounts to + 3.0 in July and August and to + 2.5 in September. It rises again only at the end of September when rainfalls are much less abundant ($\delta = + 3.8$ on October 7 th).

Rainfalls show a negative δ at Kongor as well as at Bor, except in June when there is an anomaly which is hard to explain (at Kongor as well as at Bor). This anomaly is well described by 6 samples which were taken at that time. But, in July, the value of δ returns to more classical value ($\delta = - 1.5$ on July 15 th).

Therefore, we get two curves : one of which has a positive and shows the isotopic variation of the Nile water in terms of ^{18}O. The other one which shows the isotopic variation of rain water is distinguished from the first one by negative values of δ (except in June).

These samples which were taken in the flooded plains (or in ponds which still contained water in the dry season) gave very coherent results as compared with our two curves of isotopic variation in the Nile and rainfall.

In the Kongor region, the first sample which was taken on April 19 th, gives $\delta = + 9.44$, that is to say a value much higher than this of the Nile (+ 7.92) at that date. This emphasizes the fact that, under the influence of evaporation, the residual water is enriched with isotopes ^{18}O. In June and July, the variation in the isotopic composition follows this of rainfall, but in September, we return to the curve of the Nile. So, the flood caused by rainfall is replaced by the flood caused by the Nile.

At Pengko Project Substation, the isotopic composition follows this of rainfall up to the end of July. In September-October, the values of δ are really positive, which is, once more, consistent with the theory stating that

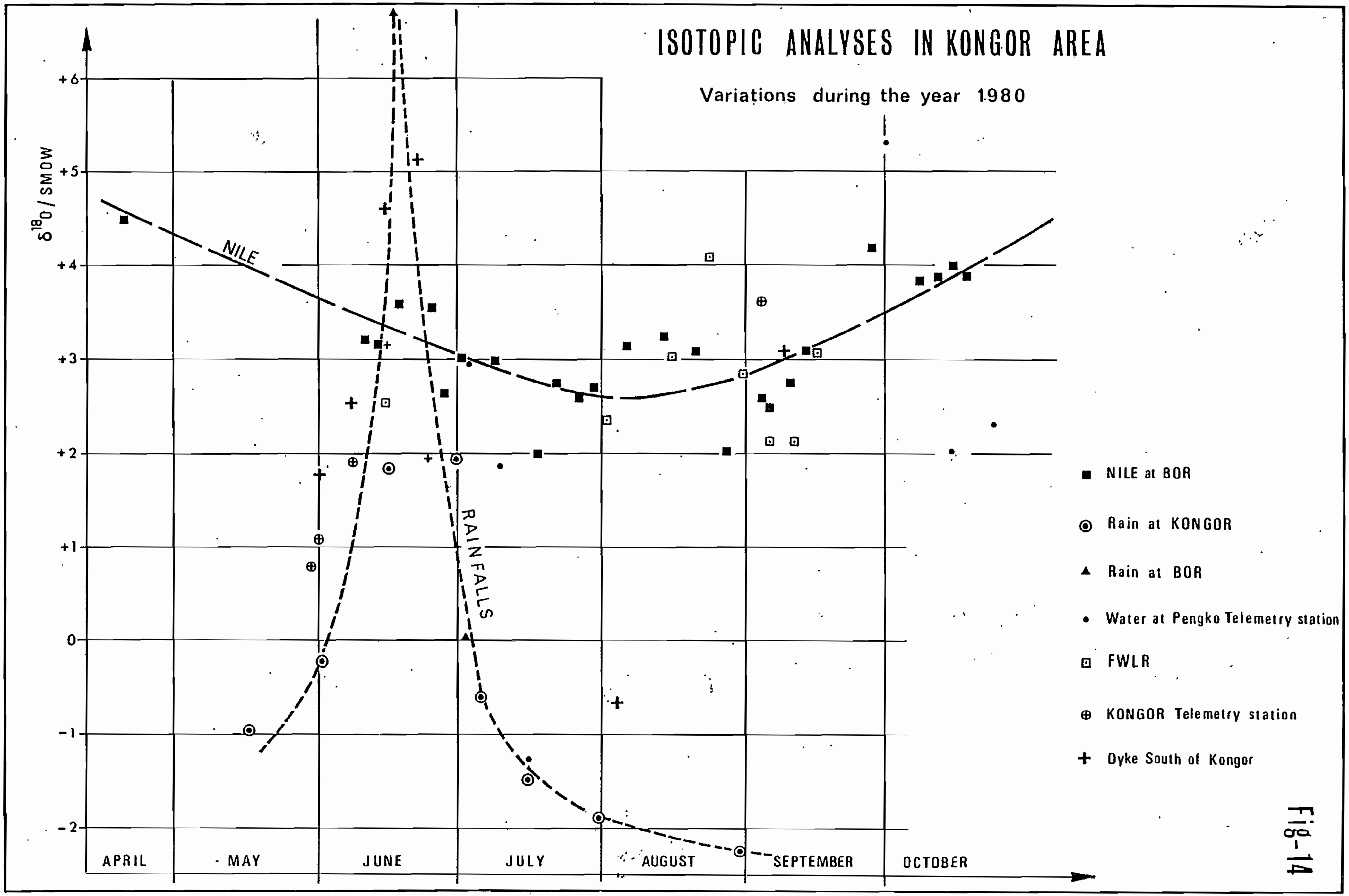

ISOTOPIC ANALYSES IN KONGOR AREA
Variations during the year 1980
$\delta^{18}O$ / SMOW
+6
+5
+4
+3
+2
+1
0
-1
-2
NILE
RAINFALLS
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NILE at BOR
Rain at KONGOR
Rain at BOR
Water at Pengko Telemetry station
FWLR
KONGOR Telemetry station
Dyke South of Kongor

Fig-14

KONGOR AREA

Amount of heavy isotopes in the water

Year 1980

Unit : $\delta^{18}O$/SMOW

KONGOR telemetry station

Date	
30.5	+1.11
28.5	+0.80
7.6	+1.91
13.6	+3.15
23.6	+1.95
3.9	+3.66

BOR Substation

Date	
2.7	+2.98
9.7	+1.89
15.7	-1.26
23.9	+7.72
30.9	+5.34
14.10	+2.06
23.10	+2.31

BOR Rainfall

Date	
10.6/23.6	+6.72
23.6/7.7	-0.03
23.6/7.7	+0.08

Road KONGOR/BOR

Date	
19.4	+9.44
31.5	+1.77
7.6	+2.51
14.6	+4.62
21.6	+5.11
3.8	-0.69
8.9	+3.10

FWLR

Date	
14.6	+2.53
6.8	+2.33
15.8	+3.04
23.8	+4.12
30.8	+2.84
6.9	+2.14
10.9	+2.12

KONGOR Rainfall

Date	
15.5	-0.95
1.6	-0.21
15.6	+1.84
30.6	+1.94
5.7	-0.60
15.7	-1.49
25.7	-1.88
25.8	-2.29

KONGOR AREA

Amount of heavy isotopes in the water

Year 1980

Nile water at BOR harbour

Date		Date	
19.4	+7.92	13.8	+3.26
10.6	+3.21	20.8	+3.11
13.6	+3.13	27.8	+2.03
17.6	+3.59	3.9	+2.58
24.6	+3.55	5.9	+2.48
27.6	+2.63	9.9	+2.76
1.7	+3.01	13.9	+3.11
8.7	+2.99	27.9	+4.19
17.7	+1.99	7.10	+3.84
21.7	+2.75	11.10	+3.89
26.7	+2.58	14.10	+4.01
29.7	+2.69	17.10	+3.89
5.8	+3.15		

the samples are taken in a ditch containing a stagnant water subject to evaporation, while rainfalls are decreasing. It is normal that the ^{18}O content increases.

5.4. - *CONCLUSION*

The isotopic analysis which is a very recent method for the differentiation of the origin of waters is still quite adapted to the study of the flooding in the Kongor plain.

6. - REMOTE SENSING OPERATION

(Chapter achieved in collaboration with Mrs R. Chaume, ORSTOM Remote Sensing Office)

The use of the remote sensing method was made possible through the FAO remote sensing office which agreed to convey us five LANDSAT MSS scenes (Multi-Spectral Scanner) concerning the Kongor area and a serie of RBV LANDSAT images (Return Beam Vidicon) concerning the Sudd from Bor to Malakal. Moreover, the UNDP/OPE gave us the magnetic tapes corresponding to 3 MSS images which are related to the same zone and are taken at three different dates (March, May and October 1979).

The FAO images enabled us to appreciate the excellent quality of the scenes and therefore to select the corresponding magnetic tapes.

The RBV images were as useful as a traditional air photographic mosaic.

6.1. - OPERATION OF THE MSS IMAGES

Given an image taken in the dry season, another one taken at the beginning of the rainy season and the last one taken at the height of the flood, we are going to try to determine the evolution of the flood in the Kongor plain.

6.1.1.- Digital Processing

The scene classified as LANDSAT 186 055 taken at three different dates in the 1979 year (March 27th, May 2nd and October 11th) was used by the Digital Department of the ORSTOM Remote Sensing Office under the control of J. NOEL, a research scientist in order to show that a computer processing can be considered as far as an hydrological study of the waters of the White Nile in the Sudan was concerned.

The digital analysis was made through a Mini-6 computer (CII-Honeywell Bull) which was linked to a display unit Pericolor (Numelec-Sein). The latter makes it possible to study simultaneously a zone of 256 by 256 pixels, which represents an area of about 15 km. The principle of this study was "the degradation" of reflectance values, that is to say the cutting out of the range of reflectance values into a limited number of categories to which a colour is given. The digital analysis led to make a degradation of the reflectance values on channel 7 (wavelength from 0.8 to 1.1 μ) and to define five grades (or categories) in relation to the intensity of reflectance.The degradation is obtained through iteration by displaying on the Pericolor unit the points corresponding to each reflectance value from the highest one to the lowest one in the range. The cartographic units which are characterized by probable and rather compact shapes correspond to adjacent reflectance values which determine a category or grade. This grade is given a colour through the display unit. By simplifying under the best conditions the distribution of reflectance values related to a channel, the display unit gives a representation in which we can see geographic or physical units.

The results of this operation appeared in the form of a map which was produced directly by the plotting table Benson ; the plotting software making it possible to get maps to the chosen scale.

6.1.2.- *Ground truth*

The aim of the "ground truth" operations consists in relating the degree applied to a pixel (elementary area of the image whose dimensions are 56 m by 79 m as far as our LANDSAT images are concerned) to its true meaning at ground level. These ground operations were carried out during J. CALLEDE's two expeditions and were increased with a series of oblique aerial photographs. These photographs using a support from the Laboratoire régional de l'Est Parisien (Centre de Melun) des Ponts et Chaussées were taken both in KODACHROME and EKTACHROME Infrared false colours. Unfortunately, logistic requirements did not make it possible to take photographs with an air vehicle (although it was initially planned) which should be adapted to this expedition. We thank warmly the pilot of Twin Otter from the UNICEF for being kind enough to modify somewhat his route Juba-Khartoum in order to enable us to take photographs of the zone under consideration. Unfortunately, we were at too high an altitude in order to take photographs especially in infrared which were detailed enough.

6.1.3.- *Interpretation of the images*

We got the magnetic tapes for three images which correspond to the scene classified as LANDSAT 186.055. Data acquisition was performed as follows :

- March 27th, 1979 (dry season)
- May 2nd, 1979 (beginning of the rainy season)
- October 11th, 1979 (end of the rainy season, but high water level of the Nile)

A copy of these magnetic tapes was sent as a reciprocity to the FAO Remote Sensing Office in Rome. A first representation was undertaken to the scale of 1/200 000, by using a pixel out of 2.

A more detailed analysis was made to the scale of 1/50 000.

Figure n° 15 indicates the limits of the scene 186-055 and the areas analysed to the scales 1/200 000 and 1/50 000.

The following colour (figure 16 and 17) plates were made through the photographic reduction of the drawings to the scale of 1/200.000 and 1/50 000 and correspond to documents which are respectively to the scale of 1/200 000 and 1/800 000.

6.1.3.1. *Image of March 27th, 1979*

At that date, it is the dry season. Soils are covered with a vegetation whose type and importance are dependent upon their degree of humidity. We can see very clearly the meanders of the mean-water bed of the Nile (on channel 7) and rather well the separation between the region flooded by the Nile and the rest of the zone in the images representing the whole zone 186-055 to the scale of 1/1000000. (Document not provided with the report).

Digital processing also shows that there is a difference between the plant cover which is situated west of the dike and the one which is situated east of it. We will also observe that there is a zone with high reflectance which is limited to the west of the dike and the site of Kongor. This must correspond to zones which are not very flooded and are inhabited in the dry season. We can also distinguish very clearcly the lakes and the mean-water beds of the Nile, on the 1/200 000 scale document (not provided with the report).

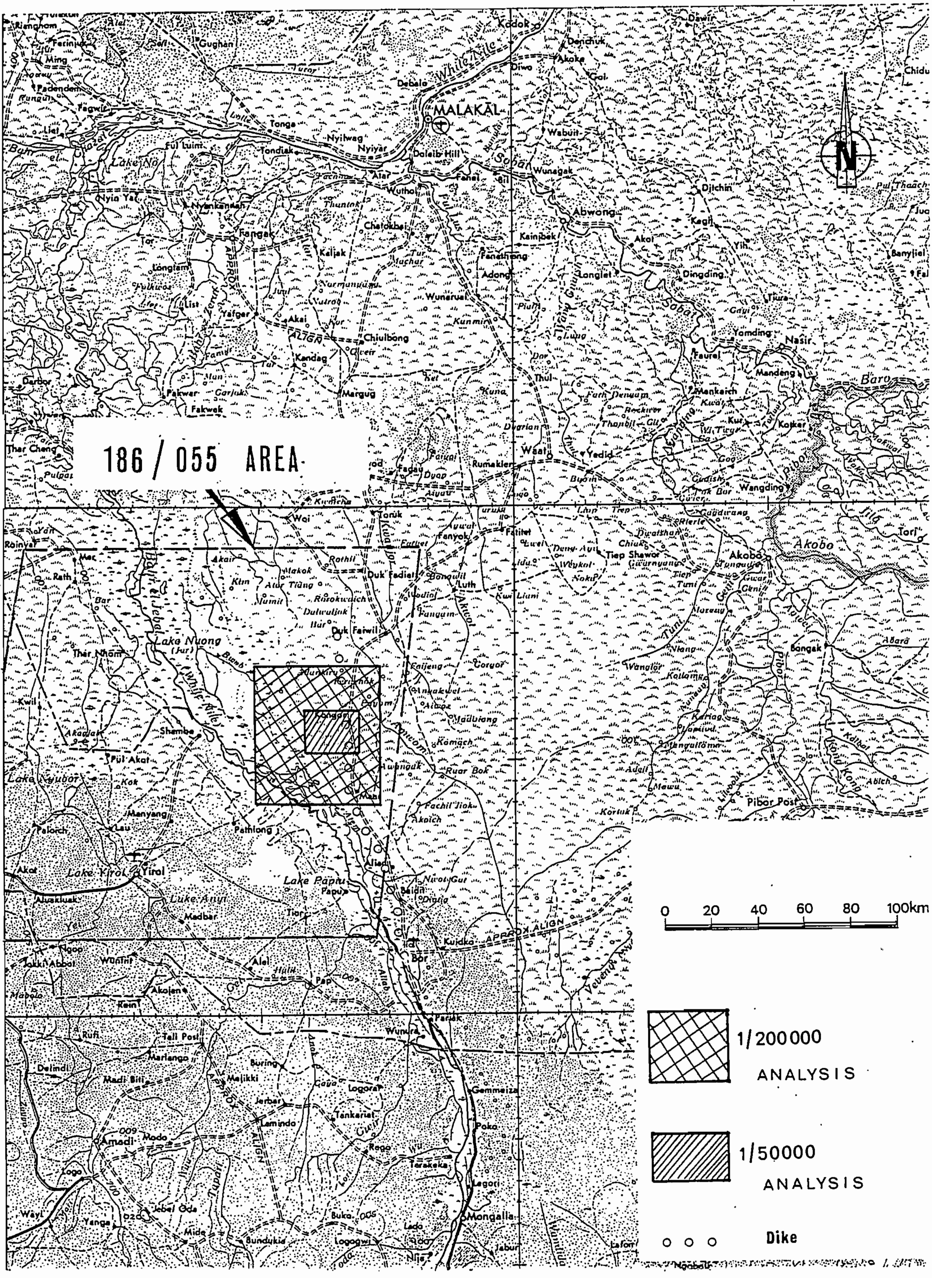
From the detailed analysis to the scale of 1/50 000 (fig. 16, scale 1/200 000), we can distinguish :

- in black(degree of 0-32 in brilliancy), the shades of clouds and lakes.
- in blue (degree of 33-40), the vegetation situated in its majority east of the dike.
- in green (41-46), the vegetation situated in the West.
- in orange (50-54), the vegetation zone which is clearly distinguished and situated west of the dike. We will observe that a few islets which correspond to groupings of a few straw huts in the dry season can be seen in the drawing.

Fig- 15

REMOTE SENSING OPERATIONS

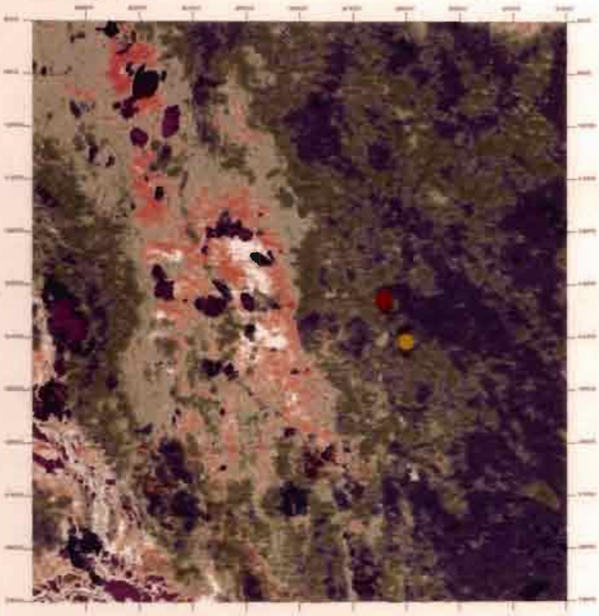
(Next pages: fig 16 and 17)



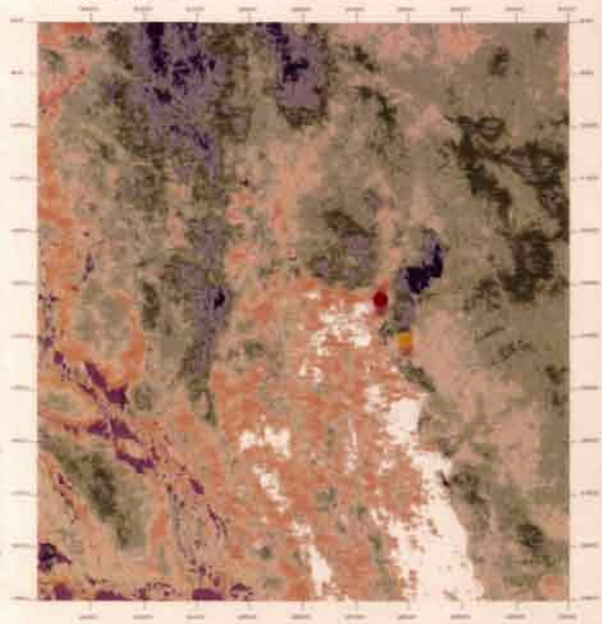
KONGOR AREA

remote sensing operation

02 May 1979



11 October 1979



Scale 1 / 800 000

0 8 16 24 32 40 km

27 Mars 1979

Scale 1 / 200 000

0 2 4 6 8 10 km

ORSTOM

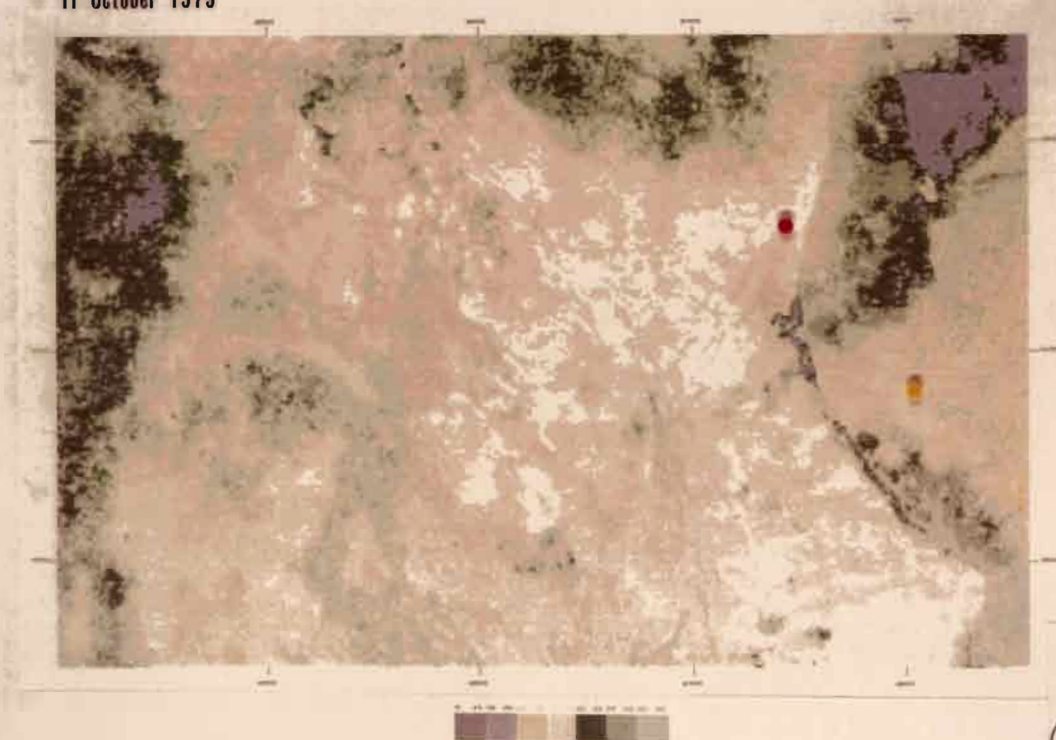
TELEDETECTION

KONGOR AREA

remote sensing operation

02 May 1979

11 October 1979



Scale 1 / 200 000

TELEDETECTION

6.1.3.2. *Image of May 2nd, 1979*

The rainy season has begun. In the scene 186-055, the images show that there is a real increase in the area of the lakes, as well as the occurrence of numerous new lakes almost anywhere, but mainly in the region subject to the Nile flood.

The representations to the scale of 1/200 000 and 1/50 000 confirm these observations. (On fig. 16 - scale 1/800 000 - and fig. 17 - scale 1/200 000). We can find :

- the flooded zones (degree 0-12) in black (1/50 000) or in violet (1/200 000).
- the zones covered with a vegetation specific of the zones likely to be flooded either east of the dike or west of it (degree 13-42) which is shown in blue or in green
- the zone which is orange-coloured in the previous scene and corresponds to sites still inhabited.

In this scene, the flood can originate only in a concentration of the runoff derived from the rain towards points of lesser altitude.

6.1.3.3. *Image of October 11th, 1979*

The rainy season is coming to an end but the Nile water level is very high. The image of the zone 186-055 shows not only any increase in the area of the lakes but also a decrease even a disappearance of the latter outside the high-water bed. However, the operations of "ground truth" showed that the water surface disappeared under the high vegetation. We could see water under the vegetation only when the sun disc reflected on it. On the other hand, we can see in the images the trace of the privileged courses (slight depressions) of the water in the zone.

The analyses to the scale of 1/200 000 and 1/50.000 show the progression of the vegetation which is normally situated east of the dike, while the aerial photographs distinguish clearly the vegetation west of the dike (in mauve) from this situated east of it (in green). We can distinguish the inhabited zones situated east of the dike in the photographs as in the analysis. As a matter of fact, each house is protected against runoff by a small dike of about 50m in diameter. (fig.16 - scale 1/800 000 - and fig. 17 - scale 1/200 000).

We will distinguish :

- in black or blue, the flooded zones where water is directly visible (degree 0-22).

- the flooded zones under a plant cover which are shown in green (23-39).

- the less flooded or even inhabited zones which are shown in orange (40-59).

6.2. - *OPERATION OF THE RBV IMAGES*

The RBV images showed us mainly the big diversification in the soil nature and occupation without putting us in a position to make a correct analysis of them (which, moreover, was not planned in our programme).

The good space resolution of the radiometer could emphasize details such as roads, villages, dikes, etc...

Thus, we could reveal the privileged courses of runoff waters, if, however, there is a course ...

The thalweg called "Amvom" in the map to the scale of 1/2.000 000 corresponds, downstream from Duk Faiwill, to a tangible fact, while nothing enables to materialize it at ground level.

It is obvious that a stereo-triangulation based on 5 or 6 astronomical points would allow to make a computer digital processing corresponding to the RBV images and would lead to a topographic map to the scale of 1/100.000 which would be precise enough for any works concerning the hydro-agricultural development of the Sudd.

7 - HYDROLOGY OF THE KONGOR AREA

In the preceding chapters, we gave the results of the hydrometric measurements which were made in 1980. These measurements enable to make a synthesis about the hydrology of the Kongor area.

We are going to study :

- the flooding in the White Nile overbank channel,
- the creeping flow.

7.1. - THE FLOODING IN THE WHITE NILE OVERBANK CHANNEL AND THE PLAINS BORDERING THE RIGHT BANK

Given the existence of the dike which runs along the road Bor-Kongor, we will distinguish two zones ; the first one being situated west of the dike and the second one east of it.

7.1.1.- Flooding west of the dike (between the dike and the Nile minor bed)

7.1.1.1. Occurrence of the flooding

The occurrence of the flooding in this zone can be described as follows :

- In March, that is to say almost at the end of the dry season, the whole area between the Nile (minor bed) and the dike is dry. Only permanent lakes which can be clearly seen in the Landsat images still exist as well as a few ponds. During our first expedition (March - April 1980), we also observed very small ponds along the Kongor-Bor dike. In fact, these ponds represented what left the previous flooding of the Nile. The isotopic analysis of the water in these ponds revealed a high ^{18}O content, thus showing that evaporation was the main cause for the drying of this area.

- In May, at the beginning of the rainy season, the flooding begins here and there at the mercy of rainstorms. The small depressions, and a few "hafirs" are filled with rainwater, which can be clearly seen in the Landsat image.

The meteoric origin of the flooding is confirmed :

- by the low level of the Nile which has not reached its overflow point,

- by the records at the telemetry stations. The increase in the water level is synchronous with rainfalls and, without a new rain, the level decreases under the influence of evaporation and infiltration.

- until the overflow point of the Nile, the flooding results only from rain. This is confirmed by the isotopic analyses which show a ^{18}O content similar to this of rain up to July, and a slow variation which catches up with the ^{18}O content of the Nile in September - October.

- when the water level is high (from September to November), the plain is under water. This body of water is concealed by the plant cover. It is only a large green area when seen from the plane (October 1980) : only the reflection of the sun on the body of water through plants enables to realize the existence of the flooding.

7.1.1.2. *Water level in the area*

It would be very hopeful to know what will be the level of the flooding at the foot of the dike according to the Nile water level, so as to foresee a dike high enough to protect from the exceptional flood (one hundred or one thousand year).

Unfortunately, it was not possible to determine this water level for we could not get some records of the Nile after 1975.

A first idea was given in a ILACO report [5] . The gauge datum is 402.19m at Jonglei, while the bank level is 410.80m.

In 1975, the maximum water level was 9.34m, say an elevation of 411.53m. Therefore, the flooding was 0.73cm. For a one hundred years flood, the flooding would be 1.52m.

This evaluation can be highly criticized mainly if it must be extrapolated throughout the length of the dike. It does not take account of :

- the lengthwise slope of the ground which can be different from the lengthwise slope of the Nile water surface.

- the cross slope (slip-stream curve) which is not necessarily equal to zero. Indeed, the low variations in the level, from day to day, must not give a very high hydraulic gradient but this remains to be checked.

- and mainly the variation in the ground level as compared with the mean general slope of the plain.

An additional study which is rather simple to undertake (water gauge along the dike) proves to be quite necessary.

7.1.2.- *Flooding east of the dike*

The major difference lies in that the flooding results only from rain with no intervention from the Nile.

This is confirmed by the measurements made at the Pengko Project Substation Telemetry station : there is a perfect synchronism between rainfall and increase in the water level. Without rain, the water level decreases slowly under the combined influence of evaporation and infiltration. There was never an increase in the water level without previous rain.

May be it could be supposed that there is between Bor and Mongalla (that is to say 100km south of Bor) an overflow into the Bor-Juba road when the Nile reaches its high level and that the Nile supplies with water the zones situated far east of it. It is not confirmed that this phenomenon occurs each year.

The flooding of the Nile is confirmed by the fact that, since the beginning of the flooding, fishes can be caught in the ponds. Upon inquiry, we observed that :

- the phenomenon is far from being general : there is no fish in the ponds of the Substation.

- the fishes belonging to the *Protopterus genus*, the family of *Lepidosirenidae* and the sub-order of *dipneusti* are rather abundant in the area. These fishes [9] are characterized by a remarkable adaptation to the temporary absence of water. They can breathe the atmospheric air through a pseudolung and live outside water during the whole dry season. It is usual to see [1] the inhabitants digging the soil of dried ponds in order to catch them.

- other species (*heterodis niloticus, claridae anguillaris, claridae lazera*) would be rather well adapted for the migration into flood plains. *Heterodis* were seen [1] jumping from the dry roads into water. *Claridae* get [1] an additional respiratory system.

Therefore, it would seem that the presence of fishes in the ponds situated east of the dike is not an absolute proof of the flooding by the Nile.

7.1.3.- Drying of the flooded plains

We have just shown that plains dried up under the combined influence of evaporation and infiltration.

Evaporation was evaluated in paragraph 2.3.

If we consider again the values about the decrease in the water level between two rains, we get the following balances (unit = mm/day).

Month	Decrease of the level	Evaporation	Infiltration
Duk Faiwill			
May	2.6	4.8	-
Kongor			
May	2.5	4.8	-
June	5.0	3.0	2.0
Substation			
June	9.9	3.0	6.9
July	9.0	2.6	6.4
August	9.3	2.6	6.7
September	11.6	3.0	8.6
October	7.2	3.9	4.3
November	5.9	4.0	1.9
December	9.4	4.5	4.9

These results about Duk Faiwill and Kongor are not significant, except that they show a very low infiltration. As far as the Substation is concerned, we can suppose that there would be an infiltration amounting to about 7mm/day ($10^{-7} m.s^{-1}$) in June - July which would be reduced to 4mm/day in December. These values apply to an impervious soil. The slight decrease in infiltration could be accounted for by a structural modification such a clay swelling.

Given a decrease by 9mm/day (evaporation + infiltration), it corresponds to a decrease by 108cm within 4 months (from November to February) which includes to a large extent the drying of the rain flooding.

It must not be forgotten too that, when the level of the Nile decrease (after the flood), there is a drainage of the swamp towards the Nile, which can be applied to the region situated between the Nile and the dike.

7.2. - *THE CREEPING FLOW*

7.2.1.- *Description of the phenomenon*

A good illustration of the creeping flow would consist in spilling a bottle of water on a desk : the flow corresponds to the creeping flow on a reduced scale. As a matter of fact, the rain water flow occurs locally without many preferential orientations on this flat surface which gets neither slope nor relief and is moreover watertight.

The phenomenon can be summed up as follows (figure 18) :

- in the dry season, the whole area is dry (top figure),
- first rainfalls : the holes in the ground are flooded with rain water and there pools and small ponds are formed (central figure),
- when the shower is considerable, these pools and ponds overflow and tend to reach places of lesser altitude, through privileged ways (that is to say through thalwegs which are invisible to the naked eye). This flow is the creeping flow (bottom figure).

In fact, the low lengthwise slope results in orientating the flow southwards-northwards.

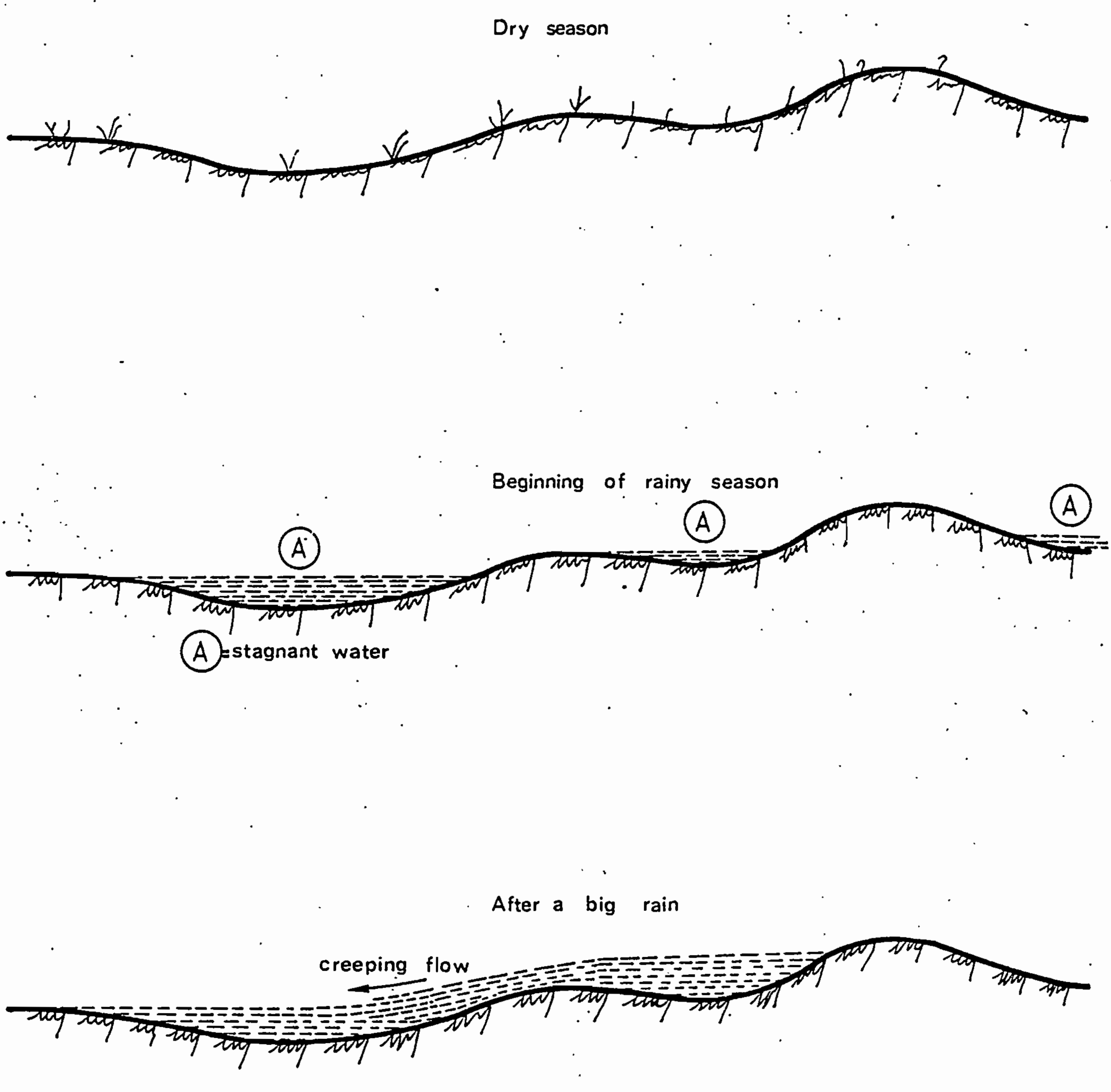
In 1949, J.S.R. DUNCAN observed [1] that there was a flow on either side of the Kongor-Malakal road ("two main waves"), the road being flooded with about 0.60m.

In June 1980, R.J. ROWBOTTON observed that the water velocity between Anyidi and Substation amounted to $0.12ms^{-1}$. On August 5th, the velocity ranged from 0.09 to $0.14ms^{-1}$.Other measurements about the velocity amounted to $0.05ms^{-1}$.

Therefore, the flow is very slow.

Fig 18

The mecanism of creeping flow



7.2.2.- *Mathematical analysis of the phenomenon*

Rain which is falling on the ground is represented by the following equation :

$$R_S = R - I_t + r$$

where

R_S = rain on the ground

R = rain falling from clouds (measured by rain gauge)

I_t = interception by plants

r = draining of leaves.

Small ponds, holes and other depressions are filled up with water or go on filling up under the action of R_S. Losses by evapotranspiration (E_V) and infiltration (I_f) will day after day reduce S which is the storage volume applied to a zone.

This volume S gets an upper value (Smax) beyond which there will be runoff in other mini-thalwegs and formation of a surface flow called creeping flood.

We will get a flow if :

$$R - I_t + r + S > Smax$$

Unfortunalety, it is not easy to solve this equation for many terms are badly determined or unknown.

It is difficult to know the rain on the ground for the rain falling from clouds, the interception by plants and the draining of leaves are very heterogeneous factors. Infiltration and evapotranspiration are better known but the storage volume varies from one place to the other. Finally, the preferential channels of the creeping flow are also dependent upon topography.

7.2.3. - *The runoff plot of the Pengko Pilot Substation*

R.J. ROWBOTTON set up a runoff plot of 0.013km2 in area in order to observe runoff.

The first observations are as follows :

Rainfall (mm)	Rainfall volume (m3)	Drainage (m3)	Runoff coefficient (%)	Duration (days)
102.5	1333	400	30	15
84.8	1102	400	36	9
60.2	783	500	64	9
45.6	593	100	17	7
38.3	498	50	10	12

We got no information about the rainfall distribution and their intensity, which accounts for the differences between the runoff coefficients.

These measurements make it possible to have already an idea about the creeping flow. Given a shower of 100mm falling in the center of a circle of 10km in radius along with a regular decrease from the center (100mm) to the extremity of the radius (0mm), the rainfall volume amounts to 2×10^7m3. The volume of the creeping flow with a runoff coefficient of 50 % will amount to 10^7m3. Supposing that this volume goes through a channel of 500m in length by 0.4m in depth with a constant mean velocity of $0.1ms^{-1}$, the duration of the flow will be about 6 days.

7.2.4. - *End of the creeping flow*

Of course, the flow is quite different in reality. This body of water is spreading slowly through the plain and the depth of the moving sheet of water decreases as time goes by. And each day takes away unrelentingly about 1cm from this sheet of water (by evaporation and infiltration)... except if it is raining again. Then this sheet of water will disappear or will increase the level of a more or less considerable pond or will go on flowing northwards.

7.2.5. - *Conclusion about the creeping flow*

It would be interesting to get a better knowledge of this peculiar phenomenon and for this purpose, it would be advisable to set up a system all along the Bor-Anyidi-Substation road including water level recorders and rain gauges.

The runoff plot would profit by being improved so as to know the amount and intensity of rainfall and the flow discharge.

8 - CONCLUSIONS

These works which were carried out in 1980 in the Kongor area made it possible to try new techniques in order to solve a rather unusual hydrological question. Therefore, we can draw some interesting conclusions which will be used in the future.

8.1. - THE EQUIPMENT AND THE TECHNIQUES USED

8.1.1.- The satellite telemetry system

This very recent technique showed that it was possible to make without any expensive equipment a remote transmission of water level data using an adequate amount of daily collections in order to get a good knowledge of the phenomenon measured.

On the contrary, it seemed that this system could be defective. A telemetry station must not be set going in inaccessible places with the conviction that it will operate adequately for months on end. In fact, telemetry makes it possible to check the good operation of the station, however, it is necessary to be able to make repairs when there is a failure. Such was not the case for the Kongor area and we still do not know the reason for the failures.

Therefore, a method for intervening in the defective stations will have to be planned in the future and first of all the possible access to the stations must be considered, which is not obvious.

8.1.2. - The isotopic analyses

This technique gave very interesting results, although the schedule sampling was not totally carried out as a result of the difficult access. It confirmed the filling phenomenon of the region situated west of the dike.

8.1.3. - Remote sensing operation

The remote sensing operation which made use of the images taken by the Landsat satellite also gave excellent results in order to account for the flooding.

8.2. - THE RESULTS OF THE ANALYSIS

The whole works made it possible to account for the development of the flooding in the Kongor area.

West of the dike, the ground is first of all flooded by rain water, then the flooding results from the Nile.

East of the dike, only rainfalls lead to the flooding. The absence of relief is the cause of a particular type of runoff which is called creeping flow.

Unfortunately, the 1980 rainy season did not give birth to heavy storms and no creeping flow could be observed at the Pengko Pilot Substation which is, however, a privileged site in order to study it.

We could evaluate potential evapotranspiration at 1530mm/year (4.2mm/day). Infiltration is not very important in these hydromorphic soils amounting to about $10^{-7} m.s^{-1}$.

Finally, we could realize that the storm lines which represent a considerable portion of the rains falling on Central and Western Africa resulted from the Sudd which is a large swampy plain including the Kongor area. Therefore, we wonder whether the Jonglei channel will have no influence on the storm lines.

It was not possible to determine precisely the water level in the zone situated west of the dike when there is an exceptional flood.

8.3. - WORKS TO CARRY OUT IN ORDER TO IMPROVE THIS STUDY

For this purpose, it would be hopeful to increase this study with observations whose aim will consist in acquiring a better knowledge of the creeping flow and in determining the level of the flooding resulting from the Nile.

8.3.1. - Study of the flooding level

Water gauges will have to be set up along the road Bor-Kongor when it runs along the dike and its water level will have to be observed at least once a week. The number of these stations is dependent only upon the local conditions (to find observers) or the possible movements in the rainy season. The setting up of 3 or 4 stations seems to be very adequate (excluding this of Bor). A station (Kongor) could be equipped with a OTT R16 water level recorder if the UNDP/OPE/PISU (at Kongor) can check it and change the diagrams. Another station could be set up for the satellite telemetry. It would be very interesting to be able to connect these stations with a levelling network so as to know the altitude of the water level at ± 1cm.

3 water gauges were already sent up UNDP/Khartoum as soon as November 1980. It would be necessary, as far as possible, to reconstruct the highest water levels of the flooding in 1980, 1979, 1978, etc... at each station, so as to make a correlation with the highest water levels of the Nile.

An hydrometric station proves to be necessary at Bor. It will have to be equipped with a OTT R16 water level recorder and the altitude of the station will have to be determined with a precision of ± 1cm in relation to the gauge zero at Khartoum.

Of course, it will be necessary to get or evaluate the Nile levels at Bor, Jonglei or Mongala from 1976 to 1981.

8.3.2. - *Study of the creeping flow*

It is very difficult to make such a study because the creeping flow is occurring completely at random.

We suggest to go on operating the Pengko Pilot Project Substation and even to set up the third telemetry station between Anyidi and the Substation.

When there is a creeping flow, it would be necessary to be able to evaluate the low surface velocities.

Runoff plots which are already set up at the Substation by the Pengko Pilot Project are an interesting system. It would be necessary to improve it by equipping each plot with a rain gauge recorder and by setting up, as far as possible, a measurement method (PARSHALL flume) on the channel bringing water to the "hafir". The network of rain gauges will have to be increased with 5 to 10 rain gauges

8.3.3. - *Particular studies*

We will quote here :

- the installation of the meteorological station at Bor (Pengko Pilot Project) including a Colorado tank and a "A class" tank on which a large-meshed protective device against birds will be set up. A KIPP and ZONEN pyranometer linked to a single integrator would make it possible to know the global solar radiation. Moreover, a THORNTHWAITHE evapotranspirometer could be set up.

- new samples concerning the Nile water, the water in the flooded zones and rain according to a certain schedule. These samples will make it possible to improve the isotopic analyses undertaken in 1980.

- it would be possible to increase the remote sensing operation with the analysis of two new scenes.

8.3.4. - *Evaluation of the works to carry out*

At first sight, this additional study would cost about 20 000$ and would be included in the programmes of the Pengko Pilot Project which could achieve a considerable part of the logistics.

B I B L I O G R A P H Y

1 - Anon. - 1954 - "The Equatorial nile project and his effects in the Anglo-Egyptian Sudan. Being the report of the jonglei investigation team". Sudan Government, Waterlow.

2 - Anon. - 1961 - "Climatological Atlas of Africa". CCTA, Lagos Nairobi, 55 pl.

3 - Anon. - 1968 - "Extrait des annales des Services Météorologiques de la France d'Outre-Mer. Territoires de l'Afrique Equatoriale Française et du Cameroun. Année 1959". Direction de la Météorologie Nationale, PARIS, 184 p.

4 - Anon. - 1975 - "Penko plain development project pre-feasibility study", Ilaco, Arnhem, the Netherlands.

5 - Anon. - 1976 - "Jonglei pilot scheme study", Ilaco, Arnhem, the Netherlands, 142 p.

6 - Anon. - 1979 - "Kongor integrated rural development project. DRAFT PROJECT PLAN". Ilaco, Arnhem, the Netherlands.

7 - Anon. - 1973 - to 1979 "Receuil des données hydrologiques observées en République Rwandaise". Ministère de l'Agriculture et de l'Elevage, KIGALI.

8 - AUBERT (J.) DORIDOT (M.) RICK (P.) - 1979 - "La photographie aérienne oblique. Une technique légère appliquée a la Géologie de Génie Civil et aux Etudes d'Environnement", in Bulletin de Liaison des Laboratoires des Ponts et Chaussée, n° 103, sept-oct. 1979, PARIS, pp 9 - 35, 7 fig, 60 ph, 27 réf.

9 - BLACHE (J.) and all. - 1964 - "Les poissons du Bassin du TCHAD et du bassin adjacent du MAYO-KEBRI. Etude systématique et biologique". Mémoires ORSTOM, n° 4, 477 p., 147 fig, 95 réf.

10 - BOUCHARDEAU (A.) - 1957 - "Monographie du Lac TCHAD" ORSTOM, PARIS, 112 p., 24 pl., 1 m.
LEFEVRE (R.)

11 - BRUNET-MORET (Y.) - 1966 - "Complément a l'étude générale des averses exceptionnelles en Afrique Occidentale. République du TCHAD", ORSTOM/CIEH, PARIS, 27 p.

12 - CALLEDE (J.) - 1970 - "Etude hydrologique des ouvrages d'Art des routes nationales N° 2 et 9 en République Centrafricaine". ORSTOM, PARIS, 21 p., 10 fig.
ROUQUEROL (Y.)

13 - CALLEDE (J.) - 1972 - "Données climatologiques receuillies a la station bioclimatologique de Bangui pendant la période 1963 - 1971" in Cahiers ORSTOM série Hydrologie, vol. IX, n° 4, pp 3 - 26, 20 tab, 11 fig, 14 réf.
ARQUISOU (G.)

14 - CALLEDE (J.) - 1974 - "Bassin versant représentatif de Sarki, République Centrafricaine. Bilan de 5 ans d'observation". ORSTOM, Service Hydrologique, PARIS, 120 p., 63 fig., 53 tab.

15 - CALLEDE (J.) - 1979 - "Transmission par satellite des données hydrométriques. Expériences de l'ORSTOM au Sénégal et esquisse d'une technologie" in Cahiers ORSTOM, Série hydrologie, vol. XVI, n° 1, pp 25 - 53, 26 fig., 13 réf.

16 - CALLEDE (J.) - 1981 - "Hydrology study of the Kongor Area, preliminary report" ORSTOM, PARIS, 9 p., 2 fig.

17 - DHONNEUR (G.) - 1970 - "Essai de synthèse sur les théories des lignes de grains en Afrique Occidentale et Centrale", ASECNA, Direction de l'Exploitation Météorologique, DAKAR, 56 p.

18 - DUMOULIN (S.) - 1979 - "SOUDAN", Petite Planète, PARIS, 190 p.

19 - FEYTMANS (G.) - 1962 - "Note sur la crue du fleuve CONGO en 1961". Bulletin de l'Académie Royale des Sciences Outre-Mer, pp 293 - 297.

20 - FONTES (J.C.) MAGLIONE (G.) ROCHE (M.A.) - 1969 - "Elements d'hydrologie isotopique dans le bassin du Lac TCHAD, in "Peaceful uses of atomic energy in Africa" Kishasa - 28 Juillet 1er Aout 1969, pp 209 - 219, 4 tab., 4 fig., 10 réf.

21 - HURST (H.E.) BLACK (R.P.) SIMAIKA (Y.M.) - 1951 - "The Nile basin, vol.8 : The future conservation of the nile". Ministry of Publics works Egypt, Caïro, 1951, 178 p., 94 fig., 8 ph., 134 réf.

22 - HURST (H.E.) - 1954 - "Le Nil description générale du fleuve, utilisation de ses eaux". PAYOT, PARIS, 1954, 302 p., 19 fig.

23 - LANDSBERG (H.E.) - 1972 - "World survey of climatology climates of Africa". Elsevier, Amsterdam - London - New-York, 604 p., 39 tab.

24 - OMAR (M.H.) EL BAKRY (M.M.) - 1981 - "Estimation of evaporation from the lake of ASWAN high dam based on measurements over the lake", in Agricultural Météorology, Amsterdam, vol. 23, n° 4.

25 - RIOU (E.) - 1975 - "La détermination pratique de l'évaporation. Application à l'Afrique Centrale". Mémoires ORSTOM, n° 80, PARIS, 235 p.

26 - SHANIN (M.) - 1975 - "Hydrology of the Nile basin". International courses in hydraulic and sanitary engineering, delft, 140 p., 13 tab., 17 réf.

27 - SUTCLIFFE (J.V.) - 1974 - "A hydrogical study of the southerm sudd region of the Upper Nile". A.I.S.H. in Bulletin des Sciences hydrologiques, vol 19, n° 1, pp 237 - 255, 3 tab., 10 fig., 9 réf.

28 - TOUCHEBEUF DE LUSIGNY (P.) - 1974 - "Note sur les crues et les étiages du ZAIRE à Kinshasa" EDF-DAFECO, PARIS, 5 p., 5 tab.

29 - TSCHIRHART (G.) - 1959 - "Les perturbations atmosphériques intéressant l'A.E.F. Méridionale". Monographies de la Météorologie Nationale, n° 13, PARIS, 32 p., 35 f., 4 réf.