C

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THE DEMOCRATIC REPUBLIC OF THE SUDAN

# HYDROLOGY STUDY OF THE KONGOR AREA

## *P R E L I M I N A R Y   R E P O R T*

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## - Preliminary report -

In a letter of the 13rd February, 1980, the Office for Projects Execution (OPE) of the United Nations Development Programme (UNDP) asked the Hydrology Department of the Office de la Recherche Scientifique et Technique (ORSTOM) in France to undertake an hydrology study of the KONGOR area situated in the south of the Sudan in the right bank of the WHITE NILE (Bahr el Jebel).

This study aimed at defining the shape of the water level curve and the role played by the flood of the WHITE NILE in the zone liable to inundation and situated west of KONGOR ; thus making it easy to set-up a system of dikes which would reduce the area flooded by the NILE.

This study which was undertaken by Mr Jacques CALLEDE, an hydrological engineer, was based on :

- measurements of the water level and rainfall through satellite telemetry,
- remote sensing techniques (LANDSAT satellite) and a photo reconnaissance in high water,
- isotopic analyses of water in order to determine the nature (rainfall or NILE) of water in the flooded zone.

For this purpose, J. CALLEDE accomplished two expeditions in the Sudan :

- the first one which took place from March 30th to April 26th 1980 aimed at setting up the telemetry network and taking samples of water in order to make the isotopic analysis.
- the second one which took place from October 20th to November 3rd, 1980 consisted of an air reconnaissance during which aerial photographs were taken.

The object of this report is to give briefly the first conclusions of this work.

## 1 - PROGRESS OF THE STUDY

### 1.1 - Results of the Telemetry network

Telemetry makes use of the ARGOS system whose messages are intercepted at Toulouse (France) and are sent by Telex to Paris through the Global Transmission System (GTS). Moreover, once a month, the ARGOS system sent us a tape file containing all the messages which were intercepted during that period.

There are three stations :

- at PENGKRO (50 km east of BOR), the station was set up on April 18th 1980 and its geographic coordinates are latitude 06°17' North and longitude 032°00' East.

- at KONGOR (6km west of KONGOR), the station was set up on April 15th 1980 and its geographic coordinates are latitude 07°08' North and longitude 031°17' East.

- at DUK FAIWILL, the station was set up on April 16th 1980 and its geographic coordinates are latitude 07°30' North and longitude 031° 31' East.

Transmission was achieved until December 15th 1980 when data processing was deliberately stopped at Toulouse. Unfortunately, it should be noted that the station at KONGOR stopped transmitting from July 17th and could not be put again under operation because no boat was available to go there during the flooding period.

4951 messages were transmitted, which represents 4951 values of the water level in the plain and 4951 values of rainfall.

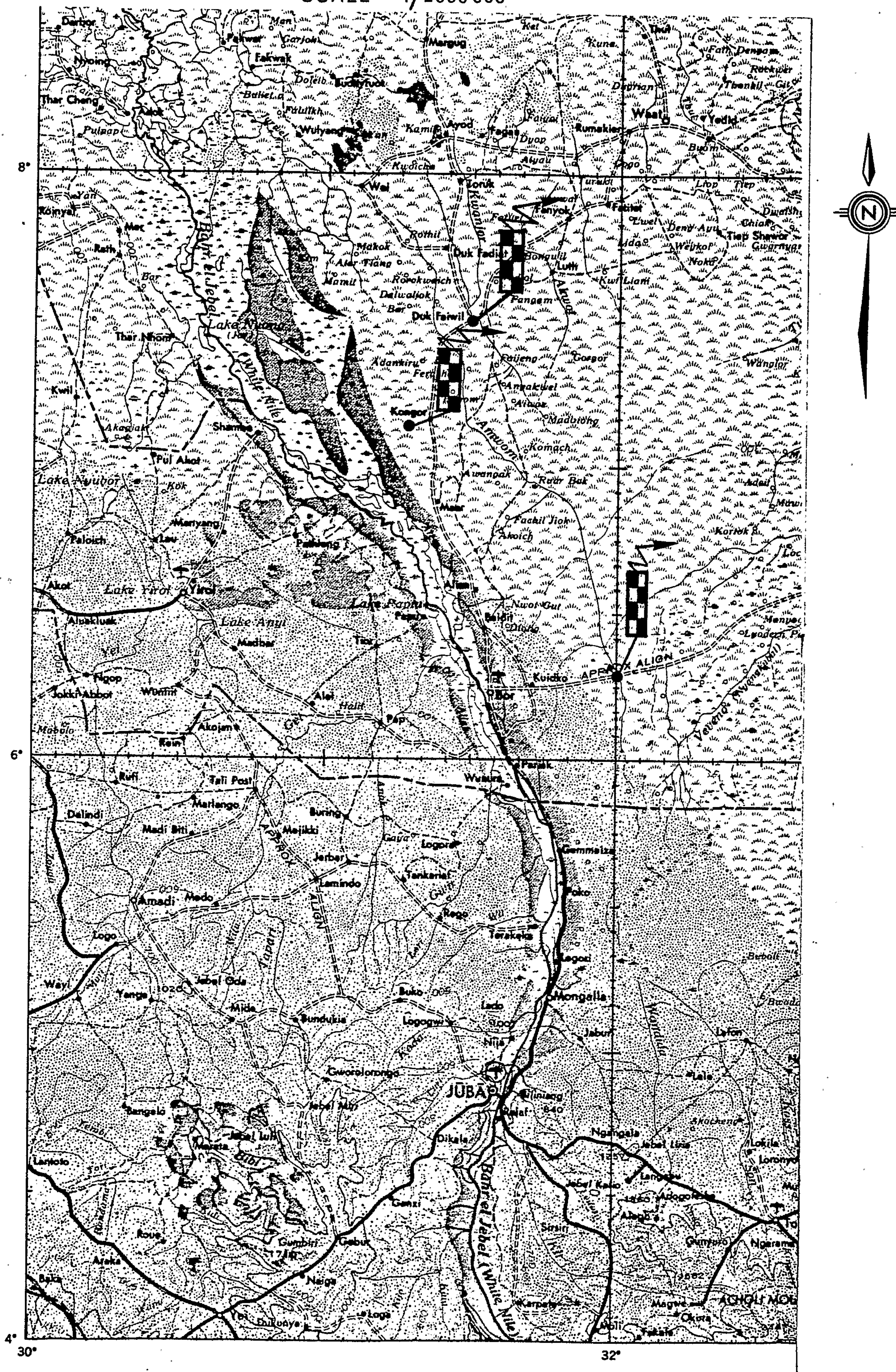
Theoretically, we had to receive 7,5 messages per day on an average (value given by the ARGOS system). In fact, we received 8,6 of them, that is to say 15 % more. A few aberrant messages had to be eliminated because they were transmitted under bad conditions (the satellite was very low on the horizon). However, the rate of accurate transmission is very good amounting to 98,9 %, which shows that the rate of data gathering amounted to 114 % in relation to the standards of the ARGOS system.

### 1.2 - Air reconnaissance and remote sensing

An air reconnaissance had been planned accompanied by photographs which were taken obliquely. For this purpose, we worked with an hand mount which made it possible to take photographs of the same zone using simultaneously two cameras 24x36. One camera was loaded with a film Kodachrome, while the other was loaded with an Infrared film Ektachrome (false colour).

# SATELLITE TELEMETRY NETWORK IN KONGOR AREA

SCALE 1/2000 000



Although I planned to use the aircraft Cessna 206 of the CCI Company in order to perform this work as soon as mid-June, a succession of unlucky events prevented me from using it. Therefore, my work consisted in flying over the plain of BONGOR (at too high an altitude) when going from KHARTOUM to JUBA (in a bi-motored Cessna 402 with low wings) and back (in a bi-motored De Haviland TWIN OTTOR with high wings). We could realize the magnitude of the flooding in the plain and take a series of photographs through the hatches of the aircrafts. If the Cessna 206 had been used as planned, the work should have been carried out at an altitude of 3000 to 6000 feet and through an open hatch because photographs were taken with an infrared film.

UNDP/OPE sent us three photographs of the plain which were taken by LANDSAT satellite in 1979 respectively in March, May and October. These photographs are digital and appear in magnetic tapes 1/2".

These tapes will be analysed in February 1981 but the photographs themselves give already useful data. It is to be pointed out that remote sensing will be used in cooperation with the FAO Remote Sensing Office in Rome. For instance, Mr LANGERAAR, Remote sensing officer must send us three panchromatic photographs SSB of the KONGOR area at the scale of 1/250 000.

### 1.3 - Isotopic analyses

About 90 samples were collected at :
- BOR (samples in the NILE waters)
- PONGKO (rainfall and water in ditches)
- KONGOR (rainfall and water in the zone flooded by the NILE).

These isotopic analyses are in progress.

### 1.4 - Bibliography and Data gathering

The UNDP/OPE was supposed to provide us with :

- available aerial photographs of the region,
- hydrometric data of the NILE in BOR (or vicinity) and KONGOR,
- monthly pluviometric data of the KONGOR area.

A meeting about this question was held between Mr CALLEDE, Mr BOS (ILACO), Mr HYLAND (UNDP) and Mr YATH (Jonglei Executive Organism) as soon as I arrived at KHARTOUM on April 1st 1980. The result of this meeting was the production of a technical publication ILACO containing a few hydrometeorological data previous to 1977 but no aerial photographs. Up to now, I could get neither the water level of the NILE nor pluviometric data.

On the other hand, despite the statements made by some experts of the Jonglei Executive Organism, it seems that the BOR Stream gauging station has disappeared from its old site since 1975 and in October 1980, there was no station in the new site (25m upstream or downstream from the pumping station).

We asked unsuccessfully Mr G. BOS (ILACO - Netherlands) to send us the technical publications which are likely to help us in our work.

Finally, thanks to Mr H. GRUTZMACHER, Director of the PENKGRO Pilot Project in BOR and his assistant, Mr R.J. ROWBOTTON, we could consult a certain number of records and above all, the results of measurements (infiltration, evapotranspiration and creeping flood) which were made in the area of this Project.

## 2 - DATA INTERPRETATION. HYDROLOGY IN THE KONGOR PLAIN

The following text gives a first idea of hydrology in the KONGOR plain. We will give a brief summary of the physical environment and we will analyse the flow in the zone situated east of the dyke which protects the plain against the NILE flood. Finally, we will study the flooding of the western zone by the NILE waters.

### 2.1 - The physical environment

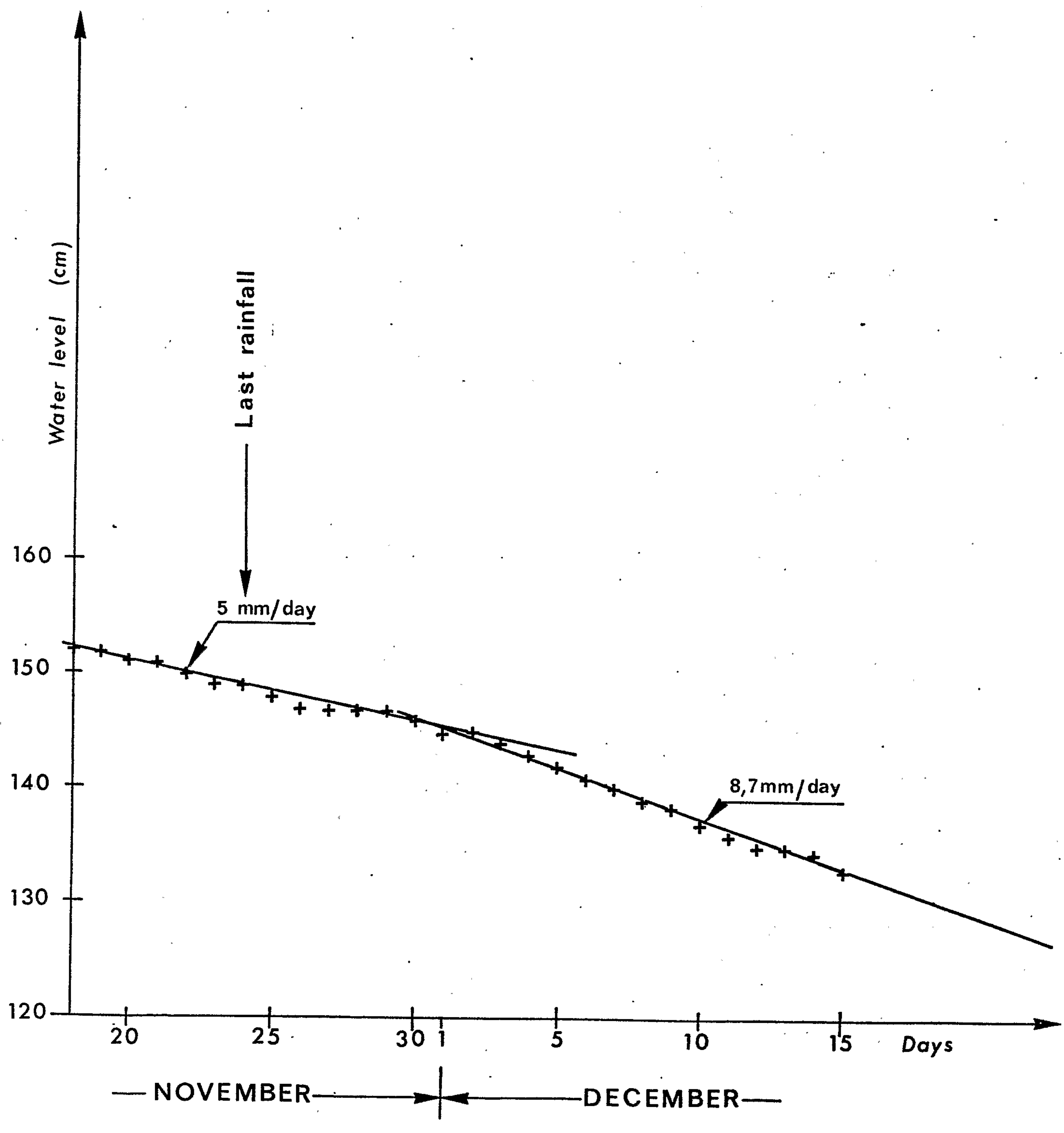
The KONGOR plain is almost flat without any marked thalweg or surface water divide. The longitudinal slope amounts to 10cm/km (0,1°/ooo while the cross slope is almost equal to zero (according to the topographical records found in the ILACO report).

Soils are practically impervious : the water levels which were transmitted at the end of the rainy season show a decrease in the level ranging from 5 to 8,7cm a day. Given the rate of evaporation, losses by infiltration range from 2 to 4mm a day (2 to $4.10^{-8} m.s^{-1}$), which is really typical of an impervious soil. Moreover, inhabitants store water in holes which are dug right in the soil ("hafirs") during the dry season. We observed this

Annex 2

# PENGKO TELEMETRY STATION

## DROP IN WATER LEVEL AFTER RAINY SEASON



phenomenon in April 1980 when water began to be pumped in the UNDP camp at KONGOR : people living in the vicinity came and took water for them and their cattle and began to dig holes of 30cm in depth and 2m in diameter. We observed that, when filled with water, these holes kept their water and the decrease in the level was practically equal to zero (during the night).

### 2.2 - Pluviometric data

According to the available data, the annual rainfall amount to 903mm at Bor, while they amount to 924mm at KONGOR. They are low values compared to those which are prevailing far in the west and at the same latitude :

YALINGA (situated at 900km) = 1561mm
BRIA (situated at 1020km) = 1584mm
CRAMPEL (situated at 1350km)= 1326mm

This situation can be accounted for by the fact that the watershed divide CONGO/NILE delays the arrival of the humid monsoon from the Gulf of Guinea. But the most likely explanation lies in the fact that the inner delta of the WHITE NILE (which includes the KONGOR plain) is a privileged zone as far as the formation of storm lines is concerned. These lines whose orientation is North-South move from the East to the West and are found in Central and Western Africa. They give rise not to the highest point rainfall but to the highest flows of rain water over a region, which is revealed by the ten-year-frequency rainfall amounting to 103mm according to the same documents. This value is similar to those observed in the three above-mentioned stations in Central African Republic. Teletransmission of rainfall also shows that the space distribution from one station to the other is governed only by random. Finally, this hypothesis concerning the genesis of storm lines is corroborated by investigations which were made with Sudanese meteorologists, aircraft pilots and various organisms.

The first conclusion is that the building of the JONGLEI Channel may reduce the area and the mass of water which, when evaporating, gave rise to storm lines. This phenomenon can have unfortunate consequences for the African countries situated west of the Sudan.

### 2.3 - Evapotranspiration

The measurements which were made on the "class A" evaporation pan of the PENGKRO Pilot Project show an evaporation amounting to about 2050mm. Although these measurements can be underestimated (owing to a netting with too fine meshes whose purpose is to protect the pan against birds), we obtain a potential evapotranspiration amounting to about 1500mm, after pan coefficients have been applied. This value is similar to this observed far in the West, which is corroborated by the empirical relation between potential evapotranspiration and the monthly average maximum temperature which was defined by RIOU as far as Africa is concerned.

In the KONGOR plain, we can accept a potential evapotranspiration ranging from 3mm/day (from June to August) to 5mm/day (from January to March).

### 2.4 - Hydrology of the zone situated east of the dike which protects it against the NILE flood

The rain flow can be compared to a vertical application of water on a sheet steel which is practically horizontal. Water will stagnate on this sheet or will flow out using the surface micro-thalwegs.

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 ($I_t$) 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 :

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

The difficult observation of the creeping flood lies in the fact that :

- rainfall are distributed in space at random,
- it is difficult to evaluate the storage volume over a zone,

- the preferential channels of the creeping flood are badly defined.

Some measurements which were made by R.J. ROWBOTTON show water speeds amounting to 0,1 $m.s^{-1}$ as far as the creeping flood is concerned. The thickness of the rainfall excess can easily reach 30cm. Then, this flow without any recharge spreads in the plain and will be absorbed more or less quickly by evapotranspiration. Mr R.J. ROWBOTTON also set up a runoff plot with an area amounting to 1,3 ha on which he measured the runoff volume. Therefore, the runoff coefficient (that is to say the proportion of creeping flood) ranges from 10 to 64 % according to the conditions of surface storage. We must point out that the measurements refer to only six rainy periods (therefore it is not a very representative sample) and that the year 1980 was not very prolific as far as the creeping flood is concerned.

In October 1980, the KONGOR plain with or without any creeping flood was submerged in numerous places where the ground is situated about ten centimetres below the normal level. The inhabited zones where countrymen know that water will not reach them (protective dykes are built) are the only to emerge.

There is no doubt about the nature of water : it is rain and only rain. It seems that a possible water supply by the NILE is not very realistic, despite the fact that fishes are caught in ponds as soon as rainfall appear. As a matter of fact, there are here like in the Chad basin fishes belonging to the species "Lepidosirenidae" and the genus "Protopterus aethiopicus" (Dipneusti) which succeed in hibernating in the soil of dried up ponds during the dry season and get a half aquatic and half aerial respiratory system. Moreover, no fish was caught in the ditches of PENKGRO.

This hydrological balance corroborates the following hypothesis : rainfall amounting to 900mm from May to October are absorbed by infiltration and evapotranspiration from May to January, that is to say within 9 months (or 270 days), which represents a total (infiltration + evapotranspiration) of 900mm/270 = 3,3mm, being thus an entirely adequate value in relation to what was mentioned above.

## 2.5 - Hydrology of the western zone

When rain begins to fall, it is the same problem, which was corroborated by transmissions from the station at KONGOR (until the failure which occurred on July 17th).

As the NILE is overflowing, the flooding of our zone by rainfall is increased by a flooding from the NILE. It seems that the NILE flooding is prevailing and governs the maximum water level in this zone.

On the other hand, it seems rather unlikely that the hydrological regime has suffered modifications since 1961. In fact, 1961 is the year when floods were observed with a fifty-year-frequency, Such is the case, especially of the Ubangi (BANGUI), Congo (Brazzaville) and the Chari (N'Djamena). The role of the regulation dam which is situated on the NILE downstream from Lake Victoria must be considered.

Currently, it is not possible to establish a correlation between the level of the NILE (at which station ?) and the level of the flooding because we get no measurement.

As soon as we returned to France, in November 1980, we sent three stage gauges at KONGOR (UNDP/OPE) so that the level 1980 could be identified and an approximate evaluation of the level in the previous years could be made by asking questions to the countrymen. This method along with the knowledge acquired about the NILE flood should make it possible to define the level of the ten-year-frequency flood or, may be, the fifty-year-frequency flood at the foot of the dyke.

Here, water results from rainfall and the river. Remote sensing and, especially, the isotopic analysis should give some valuable information.

## 3 - SUGGESTIONS FOR FURTHER STUDY

The results of measurements which were made in 1980 correspond to what was expected, so it seems a priori useless to undertake a second series of measurements.

Nevertheless, a certain number of new studies must be achieved or avoided.

3.1 - Studies which must be avoided

The Deft Hydraulic Laboratory intends to study through tele-transmission the cross backwater curve of the NILE between its major bed and the dike at KONGOR.

On the one hand, it is necessary for this work to know the base level whose evaluation must be better than the centimetre in each station (which is difficult over a distance of nearly 40km between the dike and the major bed). Then the sensor must be more accurate than the centimetre, which is not the case. Finally, given the insignificant value of the cross slope, the results will never be significant and will be in no way consistent with the expenses incurred.

3.2 - Studies which must be undertaken

Nearly all the works must be performed either by the UNDP/OPE/PISU or by the station of the PENGKRO Pilot Project. The different studies which must be undertaken are the following ones :

3.2.1 - to try to know, in relation to an arbitrary level, the different levels of the flooding west of the dyke, which involves the knowledge of the maximum value of the NILE flood (BOR, JONGLEI, etc). Such a work can be performed by UNDP/OPE/PISU.

3.2.2 - to go on making measurements on runoff plots and to improve them through the installation of a rainfall recorder and a flume (with water level recorder).

3.2.3 - to go on making observations on the creeping flood with, if possible, a few water level recorders and a raingauge network. It will be essential to evaluate the speed of water.

3.2.4 - to study the influence of the Jonglei Channel on the genesis of stormlines. The points 3.2.2 and 3.2.3 could be performed by the PENGKRO Pilot Project. The point 3.2.4 requires the participation of a meteorologist who would be a specialist in the question, such as Mr H. DHONNEUR, Engineer in the French Météorologie Nationale. The satellite telemetry stations could be either used again in the KONGOR plain (measurement of the flooding along the dyke and measurement of the creeping flood) or used in the hydrometric Sudanese network or elsewhere.