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HYDROGRAPHY IN THE NAVIGABLE PART OF THE ZAIRE RIVER

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INTRODUCTION

This paper describes the navigable part of the Zaire River, the hydrographic surveys made in this lower part of the river and, finally, the tidal wave in the estuary.

It should be pointed out that maintenance of the navigation channel as well as piloting of ships in the navigable part of the Zaire River are part of the duties of the 'Régie des Voies Maritimes', a technical and commercial public firm.

This paper has been divided into four main chapters. The first one provides a general idea on the navigable part of the Zaire River. The second deals with hydrologic features (hydraulic, meteorological and sedimentological). The third encompasses all the hydrographic studies made in the navigable part of the Zaïre River, particularly topographic, limnimetric, hydraulic, sedimentological and hydro-meteorological as well as the hydrographic surveying. The fourth and last chapter describes the tide in the navigable part of the Zaire River.

I. — PRESENTATION OF THE NAVIGABLE PART OF THE RIVER

The navigable part of the Zaire River (see figure) is the 150 km portion of the river between Matadi sea port and the mouth of the Zaire River at Banana. It is characterized by a tide wave, the intensity of which decreases with increasing distance from the mouth.

Given the topographic, hydraulic and sedimentological parameters, namely the shape of the channel, the gradient of the river bed, the surface currents, etc., the navigable part of the Zaire River can be divided into three sections.

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The first section, between Matadi and Boma, is 60 km long. There, the river runs through a deep and narrow valley with great depths ranging from 20 to 50 metres and even, locally, to 100 metres. It consists of rocky walls particularly resistant to erosion. Its width ranges from 500 to 2 000 m.

Taking into account the relatively high gradient of the channel bed and its embankment, the speed of the water outflow is rather high (from 5 to 6 km/h at low level and from 9 to 10 km/h at high level).

The concentration of primary currents enables the self dredging in this section of the river and the gradient of the channel bed facilitates the transportation of sediments downstream. In the first section, the activities of the Régie des Voies Maritimes are limited to aids to navigation and dredging of harbours.

The second section covers 60 km between Boma and Malela. It is the so-called 'wandering area' which is 10 to 20 km wide with natural depths of 5 m. It is to be emphasized that this is the most critical section and all activities of the Régie des Voies Maritimes (hydrographic surveys, aids to navigation and dredging) are concentrated there. Indeed, as its name indicates, it is an alluvial wandering plain which is characterized by certain hydraulic and sedimentological phenomena, namely the spreading out of primary currents the speeds of which vary as an average from 4 to 5 km/h along the thalweg during the lower level and from 6 to 7 km/h during the higher level.

This spreading out of the currents recorded at the entrance of the wandering area is due to a strong reduction of the high gradient of the bed, enabling the formation of lateral channels during flood. It is to be noted that formation of these channels contributes to the reduction of current speeds in the navigation channel.

Moreover, the sediments coming from upstream are deposited at the entrance of that area, forming thus a 'reserve' of sediments known as 'banc Ntua-Nkulu'. Because of the relatively slow main currents in this section, there is a continuous deposit of sediments coming from upstream which decrease depths accordingly, chiefly during high level period.

In addition to the aforementioned sedimentation, other characteristics of that area are the wandering of meanders and instability of shoals, sand banks and small islands scattered across the wandering plain. In this respect, the navigation channel in the wandering area is characterized by numerous shoals: Oiseaux Nord, Mateba, Amont Sud, Central, Nguvu, Mpuasi, Longo and Kondo. Their occurrence is related to several hydrological parameters, especially the rises and falls of the river level. All these shoals characterized by shallow depths form a wide area approximately 9.290 km long, maintained with great efficiency by the Régie des Voies Maritimes in order to allow the safe access to the ports of Boma and Matadi to great tonnage vessels.

The third section is 30 km long and extends from Malela to the mouth of the river at Banana. Its characteristics are both the predominance of tidal effects and great depths of 400 m and more (geological deeps).

The mouth of the Zaire River is 10 km wide. From Bulabemba to Kisanga the width gradually decreases from 5 to 2 km. The marine canyon is filled with salt water. The fresh water runs towards the ocean in a relatively thin layer, on top of the salt water. The thickness of the water layer and the length of the salt water area vary according to the upstream flow and marine seasons. The average gradient of the water surface rises to 2.9 cm/km on average flood.

The average surface velocities, taking into account speed variations during tide, range from 4.7 km/h to 6 km/h at low water and from 6.4 to 8.5 km/h at high water.

It should be emphasized that the activities of the Régie des Voies Maritimes in this downstream portion of the navigable part are limited to specific hydrographical studies and aids to navigation.

II. — HYDROLOGICAL CHARACTERISTICS OF THE NAVIGABLE PART

II.1 Hydraulic characteristics

II.1.1 River regime

The Zaire River ranks second in the world after the Amazon River in South America for the quantity of water poured into the oceans. Stretching on both sides of the equator its river basin enjoys a privileged situation. Therefore, the flow discharge benefits, in turn, from the rainfall in each hemisphere, which produces two floods: the so-called 'small flood' from March to May, and the so-called 'large flood' from October to December. The ratio between the extreme flow discharges is significantly low (of the order of 3) which means that floods are relatively slow. Estimating the minimum and maximum discharge as 23 000 m^3/s and 80 000 m^3/s, respectively, the average variation of the quickest discharge could be approximately 10 litres/s. This shows that floods have no measurable dynamic effect further to accelerations.

It should be noted that the Zaire River is subject to three states: disturbed, transitory and stable.

The state is said to be disturbed when the discharge exceeds 44 000 m^3/s at the gauging section of Ntua-Nkulu, which is 2.50 m above the reference level at Boma. On the other hand, it is stable when the discharge is less than 40 000 m^3/s at Ntua-Nkulu, or 2.00 m above the reference level at Boma. However, the river regime may be considered as permanent.

II.1.2 Currents

In the navigable part of the Zaire River, a study of primary currents complements each hydrographic sounding operation. It aims to define the surface velocities both in magnitude and direction, as well as their concentration. It should be emphasized that velocity changes of the primary currents, both in magnitude and direction, as well as their concentration, depend on the river regime.

In the upstream portion of the navigable part between Matadi and Boma, velocities are high; they range from 5 to 6 km/h at low level and from 9 to 10 km/h at high level. It should also be noted that these high velocities are due to the steep embankment of the river in that section, as well as to the high gradient of its bed. However, between Boma and Kisanga the river spreads over a large alluvial plain; during the lower level, primary currents concentrate in the thalweg with surface velocities varying on average between 4 and 5 km/h.

On the contrary, during the higher level surface velocities of the primary currents in the thalweg are higher; on an average they vary from 6 to 7 km/h and may reach 9 km/h during an exceptional flood.

II.2 Meteorological characteristics

As for the whole tropical zone, seasonal variations in the navigable part of the Zaire River depend on the rainfall regime, temperature being relatively uniform all year round. The dry season is well defined from 15 May to 15 August and the rainy season is sometimes interrupted for 2 or 3 weeks in February. The annual rainfall varies between 800 and 1000 mm along the river. The absolute minima and maxima, under shelter, are respectively 16 °C and 37 °C at Banana and 17 °C and 38 °C at Matadi. The average monthly temperature is approximately 28 °C during the rainy season and 22 °C during the dry season.

Temperature falls of as much as 8 °C in fifteen minutes occur sometimes during the rainy season because of often violent storms. Along the navigable channel, winds are rather regular and the sea breeze can be felt till Boma and Matadi where it blows sometimes strongly for three or four hours after sunset.

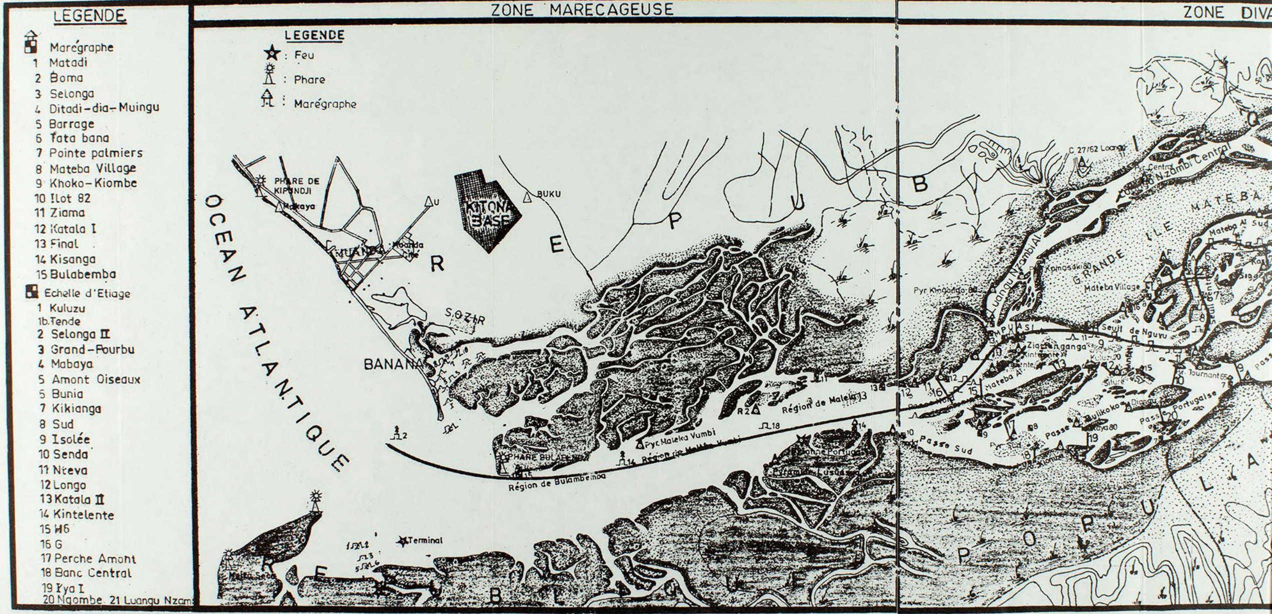
On the other hand, the direction and strength of the wind influence the average level and heights of high and low water and cause a rise higher than the predicted level when the wind is strong. At the river's mouth, around 5 p.m., the SW wind may reach a velocity varying between 22-29 km/h. The wind is less strong in June and July, but may reach 36 km/h in October in the afternoon.

The average monthly barometric pressure is 759 mm during the rainy season and 763 mm during the dry season. Observations have shown that the high and low water heights are linked to the atmospheric pressure. Indeed, in March, a high level at the mouth corresponds to a low atmospheric pressure. On the other hand, the high atmospheric pressure of July corresponds to a minimum water level at the mouth. Thus, the 6 mb difference between the minimum and maximum monthly average corresponds to a difference of 0.35 m in the monthly average of the water level.

II.3 Sedimentological characteristics of the navigable part

II.3.1 The sediments in the wandering area

Most of the sediments found in the navigable part of the wandering area are constituted of fine sands, sometimes associated with gross sands. The average


LEGENDE
Marégraphe
1 Matadi
2 Boma
3 Selonga
4 Ditadi-dia-Muingu
5 Barrage
6 Tata bana
7 Pointe palmiers
8 Mateba Village
9 Khoko-Kiombe
10 Ilot 82
11 Ziama
12 Katala I
13 Final
14 Kisanga
15 Bulabemba
Echelle d'Etiage
1 Kuluzu
1b. Tende
2 Selonga II
3 Grand-Pourbu
4 Mabaya
5 Amont Oiseaux
6 Bunia
7 Kikianga
8 Sud
9 Isolée
10 Senda
11 Nteva
12 Longo
13 Katala II
14 Kintelente
15 H6
16 G
17 Perche Amont
18 Banc Central
19 Kya I
20 Ngombe. 21 Luangu Nzam
ZONE MARECAGEUSE
ZONE DIVA
LEGENDE
: Feu
: Phare
: Marégraphe
OCEAN ATLANTIQUE
PHARE DE KIPUNDJI
Makaya
KITONA BASE
BUKU
MUANDA
Moanda Cite
S.O.Z.I.R
BANANA
R E P U B
Région de Maleia
R2
Pyr. Mateka Vumbi
Région de Bulambemba
PHARE BULABEMBA
Terminal
Passe Sud
Pyr. Kingonda 80
GRANDE ILE MATEBA
Mateba Village
Luangu Nzambi Al.
Luangu Nzambi Central
Mateba Al. Sud
C 27/62 Luango
Kamosaki 80
MPUASI
Ziamanganga
Seuil de Nguvu
Mateba Al.
Passe Portugaise
Pyr. Tournant 65
Bulikoko
Kaya 80
P O R T U G A L
Malta Seca

AGANTE | ZONE STA

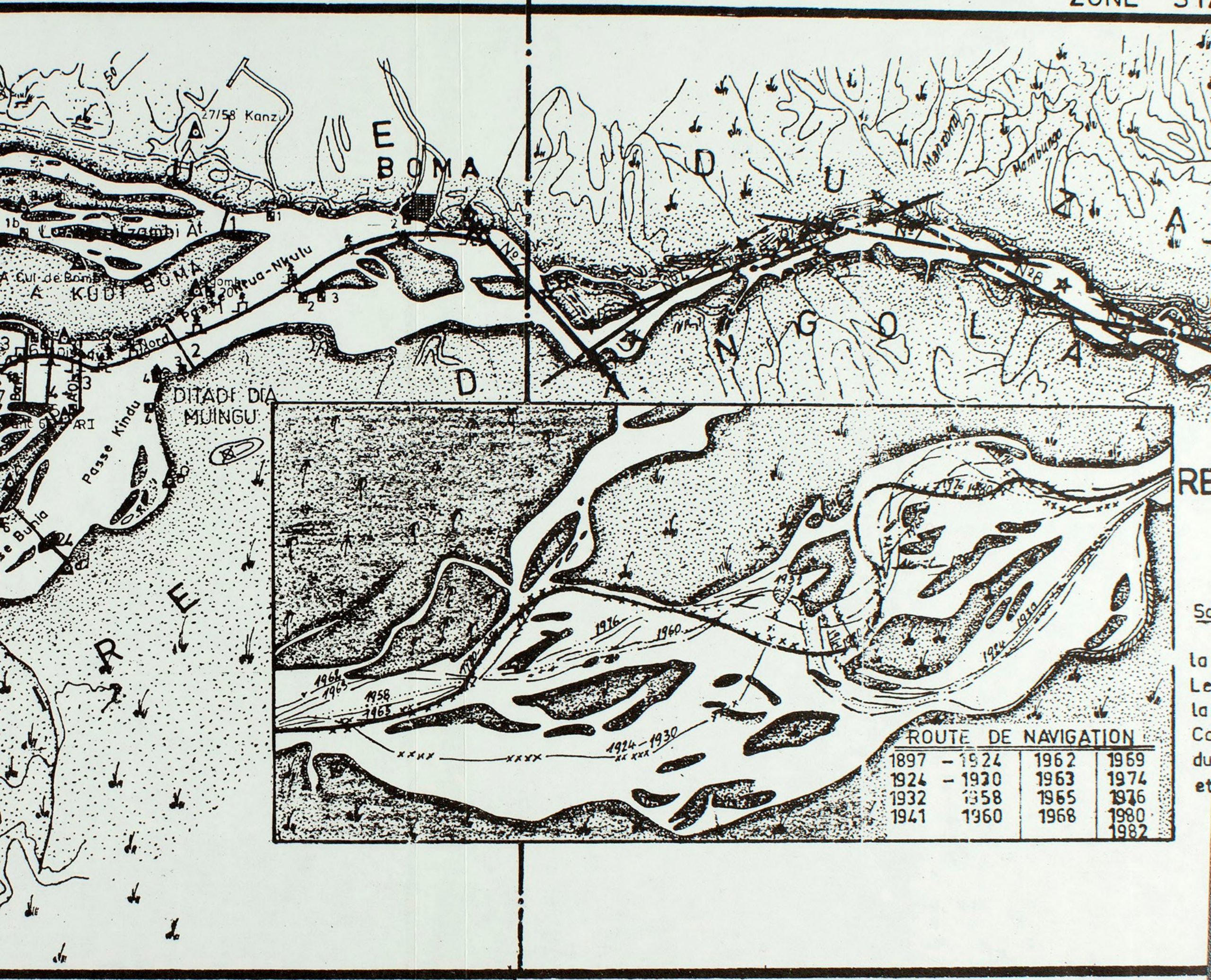
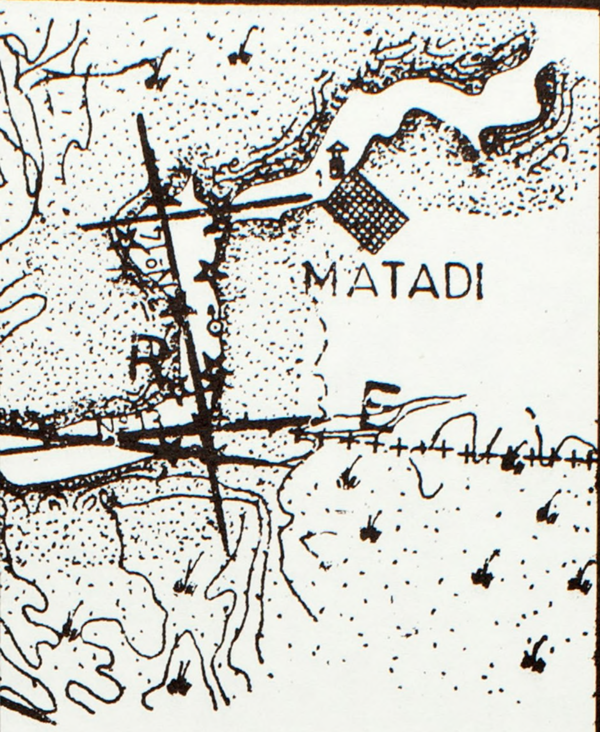


Figure 9



BLIQUE DU ZAIRE
S VOIES MARITIMES

EUVE ZAIRE

HELLE 1/200.000

1/50.000 levées et publiées par
pies Maritimes de 1980 à 1982
es criques entre Banana et Male-
la Sabena en 1929.
ler pour la rive sud à l'ouest
Banana, les criques portugaises
rofonde.

LEGENDE

Bancs de Sable

1 Banc Ntua-Nkulu
2 Banc Blessure At.
3 Banc Blessure Al.
4 Banc Barrage
5 Banc Rocheux
6 Banc Mateba At.
7 Banc Mateba Al.
8 Banc Central
9 Banc Ziamanganga
10 Banc Kintelente
11 Banc Kondo At
12 Banc Kondo Al
13 Banc Diambote

Sections de Jaugeages

1 Chenal luangu
2 Ntua Nkulu
3 At Oiseaux
4 Oiseaux Nord
5 Faux Bras Oiseaux Nord
6 Barrage
7 Faux Bras Sud
8 Faux Bras Mateba Village
9 Pointe des Palmiers
10 Tumbimbi A
11 Tumbimbi B
12 Silure
13 Bulikoko
14 Mpuasi
15 Kintelente
16 Passe Nord
17 Passe Sud I
18 Passe Sud II
19 Passe Portug. I
20 Passe Portug. II
21 Jonction
22 Mateba Amont Sud
23 Sortie Ilot Oiseaux
24 Canard

diameter of the sands sampled up to this day ranges from 100 microns to 1000 microns with a dominance of 300 microns. It should be mentioned that it is quartzous sand consisting of several types of quartz and, in particular, of rock-crystal which is the colorless type, of amethyst quartz which is distinctively purple and of smoky quartz which is dark. Moreover, these sandy sediments are always associated with cuttings of muscovite ('micros blancs') and of magnetite.

Regarding the morphoscopy of the quartz grains, it has been observed that some are round and others blunted and shiny or sub-angulous. It is worth noticing that sand is finer downstream than upstream. This upstream-downstream decrease of the average diameter is logical. It corresponds to the classification resulting from the spreading out of currents in the wandering area, fine sands being carried farther away than coarse sands. Moreover, it has been observed that sands from upstream split into two transportation axes at the entrance of the wandering area; medium sands follow the Mateba Amont 'pool' while the coarse ones drift towards the Ditadi-dia-Muingu 'pool' (see sea chart).

Although most of the sediments in the wandering area are sandy, one may find silt, clay, and even mud on certain islands which are often immersed and lying in almost still water. Clay is generally of the plastic or hard types.

It is worth specifying that several coherent rocks, commonly called 'hard spots', have already been listed in the wandering area. Each of them either supports the dynamics of the alluvial plain or stops the wandering of the meander, contributing thus to the natural changes of the river in that sector.

II.3.2 Topographical bottom features

In the wandering area, the topographical bottom features listed below can be observed during well defined periods. Their formation depends on the river regime. Chiefly there are ripples, dunes, antidunes and flat bottoms.

It is necessary to recall that the dynamics of sediments are related to each of the river regimes and that the various shapes of the river bed already listed are related to each of these three regimes too. In the wandering area the lower water level is sedimentologically characterized by the very slow transportation of sand in the form of dunes; the river bed consists of dunes, sometimes with superposed ripples.

The higher water level is characterized by the very fast transportation of sand in the form of small dunes, named antidunes, which, very often, are flattened when the transport is very strong. The transitory regime is characterized by changes in the configuration of the bottom, from dunes to flat bottom.

The Zaire River carries huge amounts of sediments which are deposited in the various branches of the wandering area, particularly in Mateba Amont through which almost half of the total water flow of the river passes. It should be noted that the present navigational route crosses the Mateba Amont branch.

Although the amount of sediments supplied to the wandering area is considerable, that quantity is very small compared to the magnitude of the water discharge. It results from this comparison that the Zaire River ranks second in the world for the annual water discharge and eleventh for the quantity of sediments carried annually.

There is a 0.99 billion of m^3 variation in the volume of water carried annually by the Zaire River, the average volume amounting to 1.25 billions of m^3 for the wandering area. Sediments carried annually amount to 50 gr/m^3. The low transportation capacity of the river, which has been explained above, plus the fineness of sediments (sand) account for the displacement of sediments by migrating dunes or ripples of large size. It has been observed that the progression of sandbanks depends on the river regime; the maximum velocity during the disturbed regime has been estimated 60 m per week. Sediments in motion can either move in contact with the bed or in suspension. It is worth noticing that some grains change path and often remain in the vicinity of the bed before falling to the bottom: this process is called siltation.

Moreover, this transportation of solids contributes to bottom changes. Yet, dissolved material carried by water in the form of ions, particularly sulphates, carbonates and colloidal clays, does not contribute to bottom changes. A billion cubic metres equals 10^{12} metres, i.e. 10^{18} litres or a trillion litres.

III. — HYDROGRAPHIC STUDIES

Recalling that the erosive and alluvial mechanisms of the navigable part of the Zaire River are best observed by the daily hydrographic studies, we have to perform:

- — Topographical studies
- — Limnimetrical studies
- — Hydraulic studies
- — Sedimentological studies
- — Hydrometeorological studies and hydrographic surveying.

The above mentioned studies allow us improved observations of changes and natural trends of the Zaire River as well as to manage the aids to navigation and dredging works efficiently.

III.1 Topographical studies

Topographical studies include horizontal and vertical control along the navigable part of the Zaire River. It is worth indicating that all these studies are the basis for all hydrographic studies carried out in the navigable part of the Zaire River to follow the natural evolution of the river.

III.2 Limnimetrical studies

They consist of determining the variation of the water surface in relation to flood and tide as well as their reciprocal influence. The analysis of the data resulting from these studies allows the hydrographic service to reduce soundings for the charts, as well as to follow the natural changes of the river.

III.3 Hydraulic studies

They consist in determining the discharge of liquids and solids of the various branches in the wandering area of the navigable part. They are used to assess the natural changes of the Zaire River as a function of the discharge measured in various branches of the river, particularly in the wandering area.

III.4 Sedimentological studies

In the navigable part, sedimentology consists in studying the dynamics of sediments, and in analysing those found in the Zaire River.

Dynamic sedimentology allows to evaluate the quantity of sediments carried into the wandering area and to determine the drifting axes of these sediments.

Static sedimentology is used to determine the type and properties of materials to be dredged to improve dredging efficiency.

III.5 Hydrographic surveying

Hydrographic soundings are carried out in order to follow the natural evolution of the bottom of the river. They allow to produce hydrographic charts necessary to improve the control of natural changes of the river.

These hydrographic charts enable us to execute a series of studies, in particular the comparison of surveys, charts of trends and isobath. Based upon the comparison the hydrographic service may assess the erosive and alluvial mechanism which just took place. Charts of trends allow one to predict tendencies of erosion or siltation of the navigable channels.

III.6 Hydrometeorological studies

Hydrometeorological studies in the navigable part serve to control, compare and supplement hydrographic studies. To ensure a better follow-up of the changes, these studies define the existing correlations between the variations of the hydrometeorological elements and the fluctuations of the water level on the one hand and, on the other hand, the variations of the discharge. Therefore, it is possible to predict the flood which is to be expected in the navigable part.

IV. — TIDES IN THE NAVIGABLE PART

IV.1 Description of the Zaire River estuary

The Zaire River flows into the southern Atlantic Ocean. The mean position of its estuary is: 12°20′ E, 6°00′ S. Its geomorphology is characterized by a submarine canyon with depths up to 500 m at the mouth and over 2 000 m at 150 km from the coast.

The range of tide in the estuary of the Zaire River is low. The volume of the upstream flow is such that sea water remains under the fresh river water.

The perpendicular position of the Zaire River estuary to the direction of the tidal wave in the ocean is such that the vertical tide determines the tidal propagation in this estuary.

IV.2 The tide at the mouth of the river

IV.2.1 Tidal observations at the mouth of the Zaire River

The present tide reference station in the Zaire estuary is the limnimetrical station of Bulabemba, 4.8 km upstream from the mouth. Data from this station are also used by the British 'Tidal Computation Section' for prediction of tides.

The tide is semi-diurnal with a relatively large diurnal inequality; this is the reason why the river has four tide extremes a day, with two high tides and two low tides, of six hours each. Semi-monthly periods with spring and neap tides and semi-annual periods with maximum tidal ranges can be observed around equinoxes too.

Systematic study of observations only started in 1976. The greatest tidal range observed was 1.82 m in 1976 and the smallest 0.45 m the same year.

IV.2.2 Variations of the mean water level at the mouth of the river

A noticeable fact concerning observations at the limnimetrical station of Bulabemba is the considerable fluctuation of the daily mean water level, in spite of the immediate proximity to the ocean. Many factors account for it, particularly:

— the atmospheric pressure
— the wind
— the upstream flow.

IV.2.2.1 Atmospheric pressure effect

It is generally accepted that the sea level may vary under the influence of atmospheric pressure and wind strength.

Indeed, a low atmospheric pressure in March corresponds to a high level at Bulabemba; on the contrary, the high atmospheric pressure of July corresponds to a minimum level at Bulabemba.

The difference between the minimum and maximum monthly average of the atmospheric pressure, which reaches 6 mb, corresponds to a difference of 0.35 m in the monthly average of the water level.

IV.2.2.2 Wind

At the river mouth, the regime of the winds is rather steady. A slight south/south-east breeze blows for a short time at sunrise (1 Beaufort corresponding to 4 to 7 km/h). Then, until about 11 a.m. wind decreases. Around noon a south-west wind rises which may reach, around 5 p.m., a velocity of 4 Beaufort (22-25 km/h). Finally, around 10 p.m., the wind again decreases. Prior to a storm there are brief gusts of wind with a strength of 7 or 8 Beaufort (43-58 km/h). In June and July the wind is less strong, but in October its velocity may go up to 5 Beaufort in the afternoon (29-36 km/h).

Prevailing winds are not oriented in the general direction of the river. Only the south-west wind could eventually explain a rise in sea level along the Zaire coast.

IV.2.2.3 Influence of the upstream flow

Studies of the navigable part of the Zaire River show that the influence of the upstream flow on the daily mean water level variation is negligible.

IV.2.3 Tidal currents at the mouth of the river

Fresh surface water leaves the estuary on the surface and is deviated north-west under the influence of the ocean currents (Benguela and Guinea currents) without notable effect from the submarine canyon. The tide only modifies the strength of the current, and not its direction. However, south of the submarine canyon facing the Angola coast, currents alternate.

Between Banana and Bulabemba the current runs only in the downstream direction. The only exceptions are creeks and bays which, filled and emptied with each tide, have currents of opposite directions.

Although the tide does not modify the direction of the water flow of the river, its influence is not to be disregarded since it slows the current so that the water level only fluctuates with the tide in the Atlantic Ocean.

IV.2.4 Determination of the datum

In Zaire, the datum recognized by the Institut géographique du Zaire (I.G.Z.) corresponds to the mean sea level which interacts the tide gauge at Banana at 0.85 cm.

Compared to this datum, tide gauge zero is to be found at —0.85 cm (low water spring tide of December 1915).

IV.3 Propagation velocity of the tidal wave

The velocity of the tidal wave varies according to the sections of the navigable part.

(a) It is more than 10 m/s in the section of the Zaire River between Banana and Kisanga (30 km).

(b) In the wandering area, where this wave encounters islands, islets and sandbanks and where meanders are numerous, velocity is reduced to about 4.2 m/s on average.

(c) Upstream of this area, the velocity which had been hindered by obstructions in the wandering area increases again and is of the order of 10.4 m/s.

The tidal wave is first recorded in Bulabemba (present reference station) and 15 km farther, it is last recorded in Matadi without, however, crossing a tributary.

CONCLUSION

This article may not have revealed particularly surprising features, but it is nevertheless hoped that it was an interesting description of the navigable part of the Zaire River of which the 'Régie des Voies Maritimes' is in charge.

As regards its characteristics, particularly in the middle section (the so-called 'wandering area') there is a predominance of continuously moving sediments: sandbanks, islands, islets and banks. It is this evolution which tends to deteriorate the navigability conditions of the navigable part, in general, and of the wandering section in particular. Thus, efficient dredging is impossible prior to the hydrographic surveys mentioned.

It is important to note that while the magnitude of tidal ranges in certain estuaries (such as the Scheldt River) facilitates navigation for deep draught ships, the same advantage does not apply to the navigable part of the Zaire River where the range is very small and never exceeds 0.80 m over the sandy sills of the wandering area.

To improve navigability in the navigable part of the river, it is worth mentioning that the Régie des Voies Maritimes appreciates the support of the International Hydrographic Organization.

This support is necessary to us, given the complexity of the hydrographic studies required in this part of the river as well as the age of the equipment and hydrographic vessels used. The situation just outlined explains why there are not national charts of the Zaire coast available.

It is also desirable that this support encompasses the training of hydrographers, either by attendance in various seminars or by granting of studies and training scholarships.

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