First International Symposium on Perspectives for Environmental Geochemistry in Tropical Countries

(Brazil - Niteroï - November 29 - December 3, 1993)

theme 7 : *Programmes of Environmental Quality and Monitoring in Tropical Countries*

EXPORT OF MATTER FROM THE CONGO RIVER (PEGI PROGRAMME)

by

(A.LARAQUE [1], J.P.BRICQUET [2], J.C.OLIVRY [3], M.BERTHELOT [4])

1 Hydrologist Hydrochemist - ORSTOM - BRAZZAVILLE - CONGO
2 Hydrologist - ORSTOM - BAMAKO - MALI
3 Director of research - Hydrologist - ORSTOM - BAMAKO - MALI
4 Hydrologist - ORSTOM - BRAZZAVILLE - CONGO

EXPORT OF MATTER FROM THE RIVER CONGO

SUMMARY

Six years of continious and regular observations (1987 - 1992) of the solid and dissolved transports of the Congo river, allowed to quantify and define their consistancies and origins.

This river, whose interannual discharge was from 37,700 m3/s during this period of study, has exported in interannual average 91,6 x 10^6 tons of matter distributed in 7,9 x 10^6 tons of sand and 22,8 x 10^6 of suspended matter (SM) and 61,1 x 10^6 tons of dissolved matter (DM).

6% of the SM is composed with particulate organic matter (POC) and 29,46% of the DM comes from the dissolved organic matter (DOM). The resting quotas correspond respectively to the particulate mineral matter (94% of the SM) or dissolved matter (70,54% of the DM).

The interannual average concentration of these transports (76,2 mg/l) is low compared to the one of the largest rivers of the planet.

The seasonal and interannual variations of the concentrations of the matter and of the discharges don't exceed respectively 14% and 28%, underlining then a large regularity of the solid and liquid discharges.

Therefore a more precise study of each category of the transported matter gives us a better understanding of the functioning of this ecosystem.

The specific export of matter is 26,3 tons/km2/year (without correction of the atmospheric contribution).

INTRODUCTION

The objective of the program PEGI-GBF (Programme d'étude de l'environnement et de la géosphère intertropicale - Opération Grands Bassins Fluviaux) is the study of the dynamics of the intertropical forested ecosystems and a better understanding of their operation.

The ten year old programme which commenced in December 1986 in the Congo basin and for which INSU-CNRS (*) and ORSTOM(*) are working together.

Here, we present the synthesis of a monthly observation over the last six years of dissolved solids and solute transport (yearly review, seasonal and interannual variations) at the outlet of the river.

---

* INSU = Institut National des Sciences de l'Univers
CNRS = Centre National de Recherche Scientifique
ORSTOM = Institut de Recherche Scientifique pour le Développement en Coopération

HYDROLOGICAL ASPECTS

Situated on the intertropical zone (9°N -13°S, 31°E-11°W) this river basin of 3,6 x 10^6 km^2 is the second largest in the world after the Amazon.

Despite an average rainfall of 1526 mm the runoff coefficient is low (24%). It is due essentially to the strong evapotranspiration (1000 mm/an) of the forest.
Its interannual discharge mean calculated over 90 years (1903 - 1992) from the Brazzaville-Kinshasa station (which controls 97% of the Congo river basin) is of 40 600 m3/s (see fig. 1).
The seasonal and interannual variations of its discharge are low respectively 1,74 and 1,64.
This regularity is due to the situation of the basin from both sides of the equator, which receives alternatively the flow from the northern hemisphere and that of the southern hemisphere (see rivers hydrogramme, see fig 2).

After the first six years of the programme PEGI, its stated that with an average discharge mean of 37 700 m3/s, the river has a deficite runoff from nearly 7% compared with the interannual discharge mean calculated over the last 90 years (see fig 2).

This deficite of the runoff since 1980 is due to the weak rainfall that has affected intertropical Africa, as emphasized by J.C. OLIVRY (1993).

PROTOCOLES AND METHODS

IN SITU SAMPLING AND ANALYSES

The objective is to estimate as precisly as possible the transport of matter of the river and study their fluctuation in course of time.

A standard stream gauging does not give a precise estimation of solid discharge, therefore, samples of water were collected on n points of x verticale profiles of the transverse section of the river where the *Vi* stream velocity is measured.
Knowing the concentration of transport matter *Ci* in each sample, a double integration of the multiplication of *CiVi* (on the verticals and on widths of the section) allows to evaluate the solid discharge.

$$Qs = \int_0^l \int_0^p Ci.\ Vi.\ dldp$$

l is the absiss, *p* is the river depth, *L* is the total width of the section and *P* is the total depth of the given vertical (BRICQUET 1987).
From *Q* the liquid discharge one can obtain an average concentration *Cm* in the section :

$$Cm = Qs/Q$$

However, these complete stream gauging (liquid and solid discharge) are complicated and long operations on site and in the laboratory for such a river like the Congo, with a width of 3 km and a depth over 30m during flood time.
Such operations are also delicate to do on a border river.
As MOLINIER (1979) showed that it gave very little variations of transport matter all along the width of the section, apart from the proximity of the steep bank, it was decided to carry out monthly water samples and the measure of velocity on a single vertical at 40 km upstream from Brazzaville and considered as a representative of whats happening in the section.

Monthly 40 liters of water are sampled at five different depths in order to calculate the average for a more precise calculation of the transported load.
The velocities are measured with an OTT current meter at the top of a 50 kg sounding weight.

This "representative" vertical profile signifies that we can assimilate the measured average concentration *Cm* with the real concentration of the section.
The multiplication of this average concentration *Cm* by the liquid discharge *Q* allows to obtain solid discharge *Qs*.
Q is calculated from a report of high discharge at the station of the Beach of Brazzaville.
The average concentration of transport is obtained with the arithmetical average of the single concentration which is multiplied by the ratio *K* (single velocity on the *i* point by the average velocity of the vertical profile):

$$Cm = 1/5 \sum_{1}^{5} K.Ci$$

or by integration of the parabole of *K.Ci*. The average velocity is calculated by the integration of the parabole velocity measured on the vertical profile (OLIVRY, 1986).

LABORATORY TREATMENTS AND ANALYSES

The filterization of each 40 litres sample with a 50μm pore size filter allows to seperate the sand. A filterization of one litre of each sample with a 0.45μm allows to seperate the suspended matter (SM). These fractions are then weighed (after drying in a steamroom) with the precision of 0,1 mg (balance Sartorius).
For the monthly samples, one liter of the fraction retained is then passed in the steamroom at 105°C to obtain dry residue. This one corresponds to the total dissolved solids (TDS) (either dissolved organic matter and dissolved mineral: DOM + TDS = DM).

A filterization of a surface gauging with pregrilled GFF filters of 0,2 m will be used to determine the Particulate Organic Carbon (POC).

The dosages of the dissolved minerals elements are realised by the "surface formation laboratory" of ORSTOM in Bondy (FRANCE).

Ca, Mg, Na, K by atomic absorbtion (detection limit of 0,01 mg/l).

Cl, NO3,SO4 by ionic chromatography (detection limit of 0,1 mg/l)

SiO2, Al2O3, Fe2O3 by plasma emission spectrometry (detection limit of 0,02mg/l) and finally the TAC is determinised by potentiometric dosage (detection limit of 0,5 mg/l).

TRANSPORT

The previous research done to try to evaluate the transport matter of the Congo river have mostly been done on the basis of few single measures from surface samples taken without regular periodicity. Therefore the published results are ill matched. The longest series of measurements done by GIRESSE (NKOUNKOU, 1985) cover nevertheless three hydrological cycles bewteen 1974 and 1976 with monthly sampling, but however with some lake of observation.

The report of the data obtained of the Congo river as part of the programme PEGI is the first of its kind by its regularity, periodicity, duration and precision.

Between 1987 and 1992, 73 in situ measurements have been taken, sampling treatments and dosages of monthly specimens covering these 6 years, that is to say 5 complete hydrological cycles.

We are privileging here the reasoning of the hydrological cycle rather than the calander year.

CONCENTRATIONS, FLUXES AND BALANCES OF ANNUALS EXPORTS (1987-1992):

The concentrations:

The totality of these transports (interannual average of 76,2 mg/l) is distributed like the following: 34% of particulate transports (25,8 mg/l) and 66% of disolved transport (50,4 mg/l).

These solid transports contain 6,54 mg/l of sand and 19,27 mg/l of suspended matter (SM), which correspond of the fraction retained between 50µm and 0,45µm (see fig 3).

The concentrations in SM are close to the one found by GIBBS (1967) and MOLINIER (1979), but differents from other authors, like VAN MIERLO (1926), DEVROEY (1941), NEDECO (1959), HOLEMAN (1968) and VAN DER LIDEN (1975), sometimes the differences can be from the single to the double.

The results of the dosages available for 1992, allows us to evaluate the particulate organic carbon (POC) proportion to nearly 6% among the SM. This low pourcentage agree with the 7% calculated by NKOUNKOU (1985) from the data of KINGA MOUZEO (1982). CADEE (1982) estimate this pourcentage at 4,66%.

The POC concentrations are therefore very low (average of 1,33 mg/l in 1987 and 1,63 mg/l in 1992). They are included in the value range of 1,1 mg/l and 2,5 mg/l presented by KINGA MOUZEO (1986) calculated on the basis of samples taken on the river Congo in 1976 and 1983.

The 50,4 mg/l of the average Dissolved Matter (DM), contain 72% of mineral matter (or Total Dissolved Solid TDS, that is to say 36,5 mg) and 28% (that is to say 14,13 mg/l) of Dissolved Organic Matter (DOM). Most of the organic matter is then under the dissolved form.
This DOM is calculated for each water sample, by the difference between dissolved matter (DM), which corresponds to the 105°C dry residue and the the total dissolved solids (TDS).
This TDS is composed of 73,3% of ionic dissolved elements (CTD = sum of cations and anions dosated in laboratory). The rest, 26,1% is composed of neutral mineral oxydes in solution, where the silica (9,49 mg/l of SiO_2) exclusively dominates on negligeable quantities of Fe_2O_3 and Al_2O_3.

The fluxes:

In terms of flux, we obtained a total discharge of 2914 kg/s of matter, distributed respectively in 975,2 and 1938,7 kg/s of solid and dissolved transports.
The solids are composed with 250,6 and 724,6 kg/s of sand and SM, while the dissolved matter are subdivided in 1327,7 and 611 kg/s of mineral and organic matter.
Solidogrammes and hydrogrammes of the Congo are similar. The low values of solids and dissolved concentrations and their low seasonal variations, not always synchronized with the discharge variations, are in fact controled and occulted by the very high values of discharges.

The Balances:

The 91,8 x 10^6 tons of annual exported matter is composed of 33,5% of solids, that is to say 30,7 x 10^6 tons whose 7,9 x 10^6 tons of sand (SAN) and 22,8 x 10^6 tons of suspended matter (SM), and of 66,5% of dissolved matter (DM), that is to say 61,1 x 10^6 tons distributed in 42,1 x 10^6 tons of total dissolved solids (TDS) and 18 x 10^6 tons of dissolved organic matter (DOM).
These values of solid transports agreed with 31,2 x 10^6 ton/year from GIBBS (1967), while the other authors have always found higher values.

In this way, if the river Congo comes in average each hydrological year in second place for its liquid exportation (1188 x 10^9 m^3), it is only found in ninth place for its total exportations of matter (91,8 x 10^6 tons) compared with the other twelve largest rivers in this planet (GAC,1980).
During this period of study, 544 x 10^6 tons of matter have been exported of which 181 x 10^6 of solid matter and 363 x 10^6 of dissolved matter, for the liquid volume of 7100 milliards of m3.

SEASONAL AND INTERANNUAL VARIATIONS.

If the interannual variations of discharge in this period of study (1,16) are lower than the ones recorded over 90 years (1,65), on the contrary the seasonal variations are a little higher for that period: average of 1,90 against 1,74. These last figures are due to the abnormal mimimum flow which are closer to the minima observed during the last 90 years, while each main flood corresponds approximatily to the interannual average flood.

In this way the annual variations of the other values which ratios of the extreme intercycles averages are lower than the seasonal ratios (maximum monthly average/mimimum monthly average) 1,13 against 1,86 for the total concentrations, 1,19 against 2,51 for the total flow and consequently for the balance of matter (fig. 5).
Within the **solid transports**, the sand concentration fluctuated a little bit more than that of the SM.

The **particulate organic carbon** (POC) remains almost the same during the year, around 6% of the SM.

We will keep in mind for the period 1987-92, a variation of the particulate concentrations going from 18,2 to 41,9 mg/l around an interannual average of 25,80 mg/l.
For the dissolved matter, this variation is included between 39 and 87 mg/l (average: 50,4 mg/l).
At last for the total transport, the values fluctuate between 60,66 and 110,83 mg/l (average 76,2 mg/l).

In accordance with the regular hydrological discharge of the river, these seasonal and annual intercycles ratios are on the whole low and charaterized also a regular flow of transport. This results from the combination of different complementary contributions coming from various drained soils, which are themselves subjected to various hydrological cycles depending on their northern or southern positions in this huge basin.

However, the fluctuations of few concentrations during the hydrological cycles gives information on certain aspects of the functioning of this huge tropical forest ecosystem.

Then we established a synchronous evolution between the **dissolved organic matter** concentrations curve and the discharges curve (fig 6), this one by contrary is opposite of the dissolved mineral matter evolution curve.
The largest seasonal fluctuations (ratio from 1 to 32!) are generally found for the DOM with the maximum concentrations (around 30 mg/l) and observed in December or January at the main flood of each cycle. The minimums with a concentration lower than 5 mg/l are observed in July and August by the main lowest water level. Such fluctuations and organic concentrations have been already recorded for some tributaries of the left river side by CLERFAYT (1956).
During the flood period, the congolese flooded basin, release a large quantity of organic matter. The river is then covered with water hyacinth and vegetation islets floating, extracted from the bank because of a higher water level and a stronger current which explains such an enrichment in organic matter of the water. This is in contrary accompanied with a dilution of the **dissolved mineral matter** by rise of the liquid mass.

Indeed for the TDS concentrations, it is the opposite phenomenon which happened with reversed tendencies compared to the discharge curve (fig.6). Therefore depending on the hydrological year, we obtained 1,33 to 1,87 times less TDS during flood than during lowest water level. Dilutions and concentrations of dissolved mineral matters are hence generated by the alternances of flood and lowest water level.

If some significant seasonal variations could be noticed for the dissolved matter; it gives by contrary very few interannual variations for the distribution of the various transports and their seasonal variations recurring from one year to another.

CORRELATIONS

It doesn't give any relation between the discharges and solid transports (correlation coefficients inferior at 0,3), therefore, the dissolved transports could have been linked to the discharge and the electrical conductivity with relatively good correlation coefficients (r > 0,75) (see tab 1).

These equations are similar to the ones of DERONDE and SYMOENS (1980), KINGA MOUZEO (1986), NKOUNKOU and PROBST (1987), NKOUNKOU and al (1990), PROBST and al (1992).

Consequently we can estimate the discharge by the conductivity measurements taken with simple portable soundings by the relation: $Q = 221{,}33 \times 10^4 \times EC^{-1{,}13}$ with r = 0,87.

TAB 1 - SIGNIFICANT CORRELATIONS OF TRANSPORTS OF THE CONGO IN BRAZZAVILLE (after 62 couples have been given)

CORRELATIONS	R	units
$TDS = -4{,}90 \times 10^{-4} \times Q + 54{,}42$	0,80	mg/l-m³/s
$TDS = -4{,}77 \times 10^{-3} \times Q^{-0{,}46}$	0,81	mg/l-m³/s
$CTD = 3{,}90 \times 10^{4} \times Q^{-0{,}69}$	0,84	mg/l-m³/s
$DOM = 7{,}90 \times 10^{-4} \times Q - 16{,}60$	0,68	mg/l-m³/s
$TT = 9{,}47 \times 10^{-3} \times Q^{1{,}19}$	0,92	kg/s-m³/s
$EC = 4{,}48 \times 10^{4} \times Q^{-0{,}67}$	0,87	uS/cm 25°C -m³/s
$TDS = 2{,}63 \times EC^{0{,}71}$	0,83	mg/l-uS/cm
$CTD = 0{,}56 \times EC^{1{,}05}$	0,86	mg/l-uS/cm
$DOM = -1{,}15 \times EC + 56{,}66$	0,74	mg/l-uS/cm
$TT = 34{,}45 \times 10^{4} \times EC^{-1{,}34}$	0,87	kg/s-uS/cm
$Q = 221{,}33 \times 10^{4} \times EC^{-1{,}13}$	0,87	m³/s-uS/cm

Key :

Q = discharge in m^3/s

TT = total matter transports in kg/s

R = correlation coefficient

The evolutions of the different solid transport concentrations with the discharge don't show well definite cycles, like the one we find for tropical river like Oubangui, second tributary coming from the northern hemisphere (OLIVRY and al 1988) and don't always have similar cycles from one to an other.

The seasonal variations of the solid transport concentrations are low and independant of the discharges (fig.7), that confirms the origin of multiple sources and the complex association of the hydrological cycles with the different and complementary particulate transports.

This same figure shows however that the peaks of flood are preceeded by some more or less big peaks of the SM, which correspond to the renewal of the erosive phase.

The decomposition of the dissolved transports (Fig.8 - Cycle example 1989-90), allows to draw some trends and shows that this one is mostly controled by the total dissolved solids (TDS) whose average concentrations are two times more important than the one of the DOM.

TDS and DOM have reversed behaviours during the hydrological year: The first one (fig. 8a) decreases in flood (dilution) and rises during the lowest-water level (concentration). That is more noticable for the main discharge and less for the secondary, where we verify just a reducing of the augumentation of the TDS concentration, during the small May flood. In August a decrease of the concentration went at the same time, with a beginning of the main flood of the hydrological cycle.

The DOM (fig. 8b) increases in flood under the effect of more intense washing of the forest cover and largely decreases sometimes up to being inexistant in the lowest water level (ratio of the extremes = 15,87).

EXTRAPOLATIONS

Owing to the low concentrations, the flux and exports of matter stay controlled by the strong river discharge and consequentely evolve concurrently (fig.4). The Figure 9 shows a perfect relation between the tonnage of matter and exported liquid volumes: $Y = 0{,}13 \times X - 64{,}29$ with $r = 0{,}92$.

These observations realized on five complete hydrological cycles, allows us already to calculate the interannual means of the 90 years of which the river discharge is known.

This interannual discharge of 40 600 m3 /s (that is to say 1280 x 10^9 m3/year), by applying the previous relation the annual average export of matter to 102 x 10^6 tons. This corresponds to a total flux of 3240 kg/s and hence to a specific export of 29,14 t/km2/year.

The particulate flux represents 33,4% and the dissolved matter 66%.

It seems possible then with the history of the discharges to reconstruct the history of the matter discharges.

SPECIFIC ALTERATION

The specific total export of matter with an average of 26,3 tons/km2/year is stable from one year to the other with an interannual variation of 1,20. The interannual variation of solid and dissolved exports are similar.

This is the chemical alteration, stable from one year to an other (ratio of the extremes = 1,14), which hence dominates the mecanical erosion with 12,1 t/km2/year of elements put in solution. Then come the organic matter exports with 5,39 t/km2/year which fluctuates a little bit more from one year to another (ratio of the extremes = 1,55).

With a mecanical erosion of 8,8 t/km2/year (value close from the one of GIBBS,1967), the Congo river comes in to the thirty-third position of the forty largest rivers in the planet (river basin > 400 000 km2 and discharge >5 000 m3/s), which have much higher values: Yellow river (2150), Brahmaputre (1370), Colorado (870), Gange (537), Mekong (435), Amozon (79), etc...... (MEYBECK, 1976 and 1984). Within the African continent, it is just before the Senegal (GAC,1980).

This flattened basin, protected by its dense forest cover; is no longer subjected to an intense mecanical erosion (33,5% of the gobal specific exportation), but is more subjected to a biogeochemical alteration (66,5%). It is the chemical alteration (46%) which dominates "relatively" (because it stays low, the soils have already released most of their soluble elements), with a significant part of the dissolved organic matter (20,5% of the specific export) which comes from the forest.

This dynamic is comparable to the one of the Rio Negro, the main tributary of the Amazon which flows mostly through the Amazonian forested basin. However, the functioning of the Congo differs from the one of the Amazon whose water carries a large quantity of matter (four to five times more MES), issued essentially from the intensive erosion of the eastern side of the Andes.

Its specific mecanical erosion (79t/km2/year), nine times more than the one of the Congo finds its origin mainly in the young Cordillera in continuous surrection.

After all of that, the contribution of the Congo river is large, it totalises half of the african contribution in fresh water in the Atlantic Ocean. For the whole continent, its hydrous exports represent 38%, its dissolved contribution 40% and the suspended matter only 7%.

REFERENCES

BRICQUET J.P, 1987, "Mesure des matières en suspension : le Congo à Brazzaville. Rapport ORSTOM, Brazzaville, 13 pa, multigr.

CADEE G.C, 1982, "Organic carbon and phytoplankton in Zaïre river, estuary and plume". In : Transport of carbon and minerals in major world rivers, Part I, ed E.T DEGENS, pa 429-432.

CLERFAYT A, 1956, "Composition des eaux de rivières du Congo - Influence des facteurs géologiques et climatiques". Centre belge d'étude et de documentation des eaux, v.31, n° 31, pa 26-31.

DERONDE.L et SYMOENS.J.J, 1980, "L'exportation des éléments dominants du bassin du fleuve Zaïre : une réévaluation". Annls Limnol. 16(2) : 183 - 188.

DEVROEY E, 1941, "Le bassin hydrographique congolais, spécialement celui du bief maritime". Inst. Roy. Col. Belge, Sec. Sc. Tech. Mém. - Coll 8°, III (3) : 3 - 160.

GAC.Y, 1980, "Géochimie du bassin du lac Tchad" - Travaux et documents de l'ORSTOM, 123, 251 pa.

GIBBS.R, 1967, "The geochemistry of the Amazon river system. Part 1 : the factors that control the salinity and the concentration of suspended solids", Geol Soc of Amer. Bull., 78, pa 1203-1232.

HOLEMAN J.N, 1968, "The sediment yield of major rivers of the world. Wat. Resour. Res., 4(4) : pa 737-747.

KINGA MOUZEO, 1982, "Les suspensions organiques et minérales du fleuve Congo. Première approche d'un bilan. Rapport DEA, Univ de Perpignan, 54 p.

KINGA MOUZEO, 1986, "Transport particulaire actuel du fleuve Congo et de quelques affluents; enregistrement quaternaire dans l'éventail détritique profond (sédimentologie, minéralogie et géochimie)" - Thèse de doctorat - Univ de Perpignan - 251 pa.

MEYBECK.M, 1976 "Total mineral dissolved transport by world major rivers" - Hydrological Sciences - Bulletin des Sciences Hydrologiques, XXI, 2 6/1976.

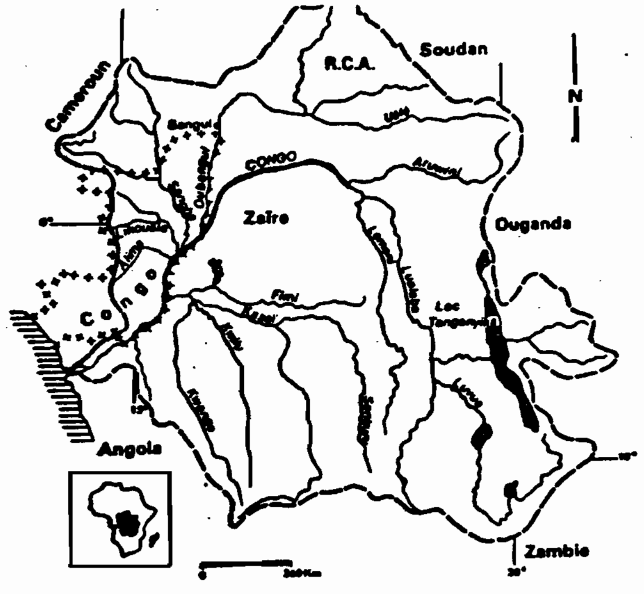


Fig 1 Basin of Congo River

Fig 2 CARACTERISTIC HYDROGRAMS OF THE CONGO

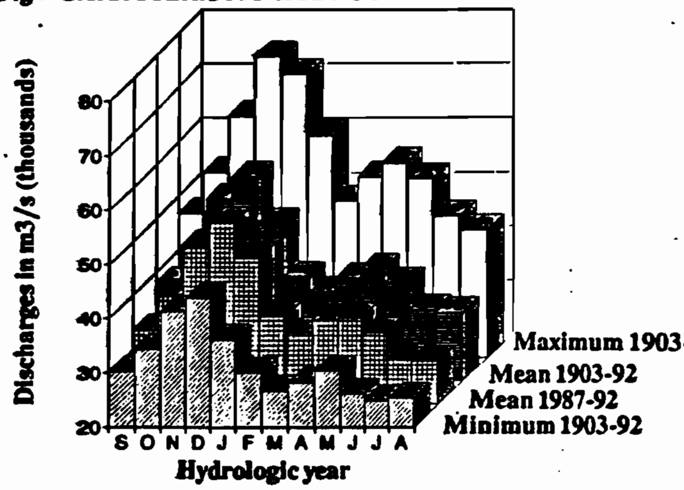
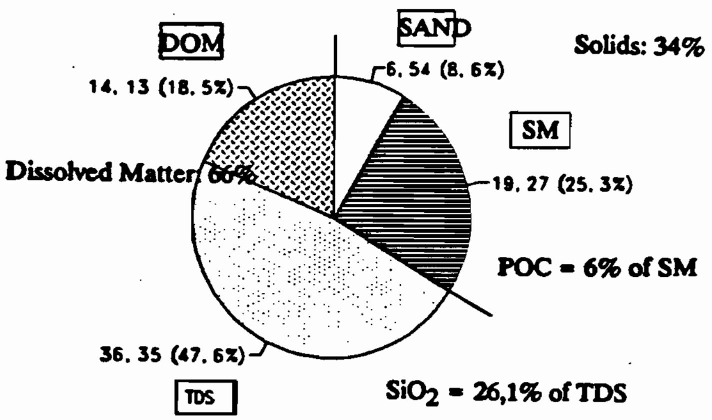


FIG.3 - TRANSPORT DISTRIBUTION OF MATTER /hydrological years (Average 87-92)



TOTAL = 76,2 mg/l

FIG.4 - SOLIDS, DISSOLVED MATTERS AND LIQUIDS DISCHARGES OF THE CONGO IN BRAZZAVILLE.

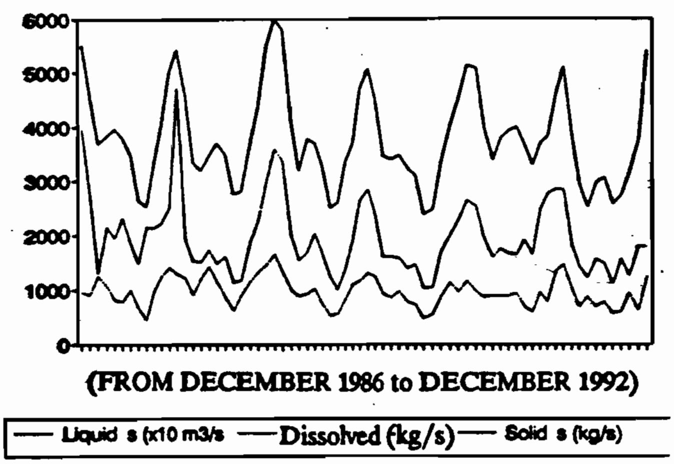


Fig 5 EXPORTATIONS DISSOLVED SOLID LIQUID ANNUAL MEANS IN 10^6 t and 10^10 m3

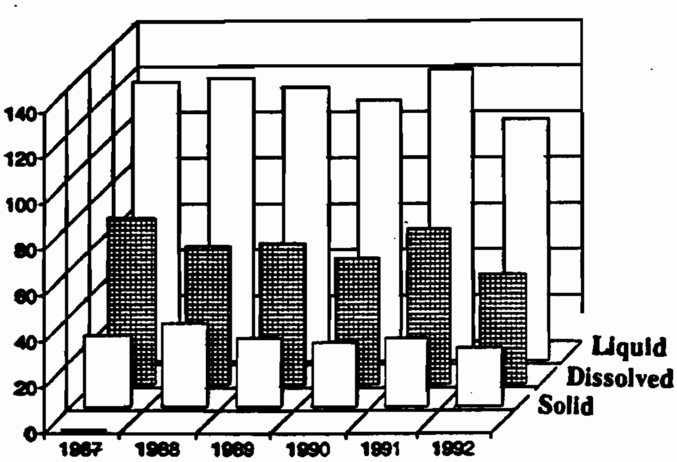


FIG.6 - CONCENTRATIONS AND DISCHARGES VARIATIONS OF CONGO IN BRAZZAVILLE

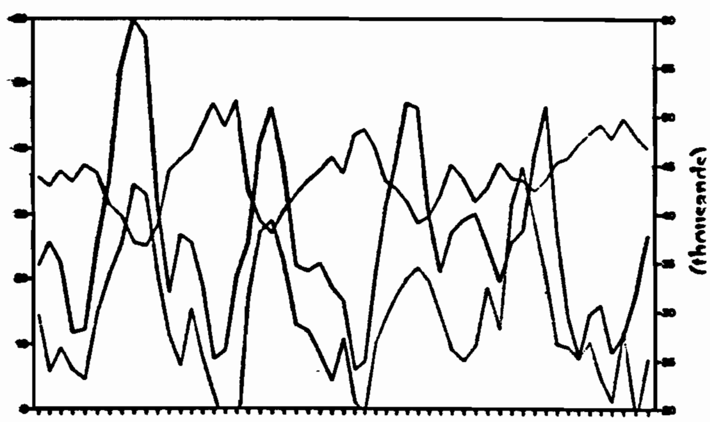


FIG.7 - VARIATED CONCENTRATIONS OF SAND, SM AND DISCHARGE OF THE CONGO IN BRAZZAVILLE

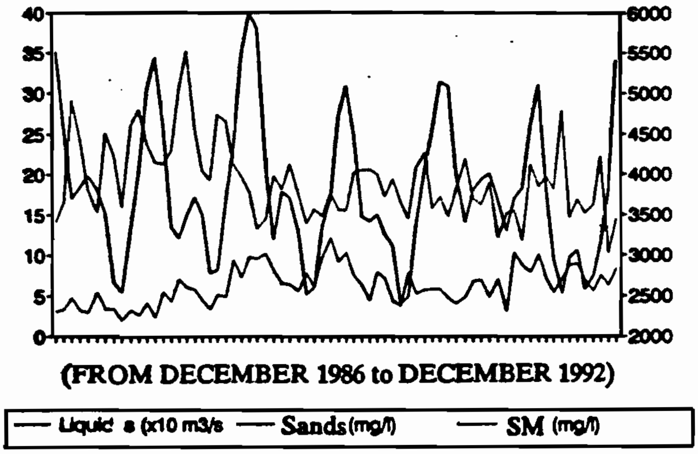


FIG.8a - DISSOLVED MINERAL MATTER
Congo in Brazzaville 1988-1989

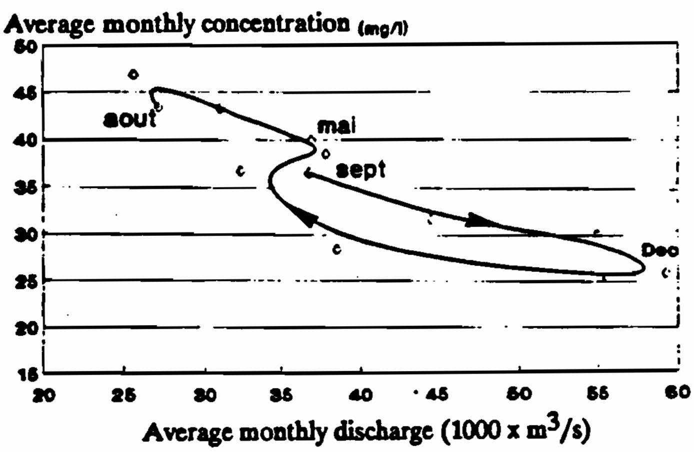


FIG.8b - ORGANIC DISSOLVED MATTER
Congo in Brazzaville 1988-1989

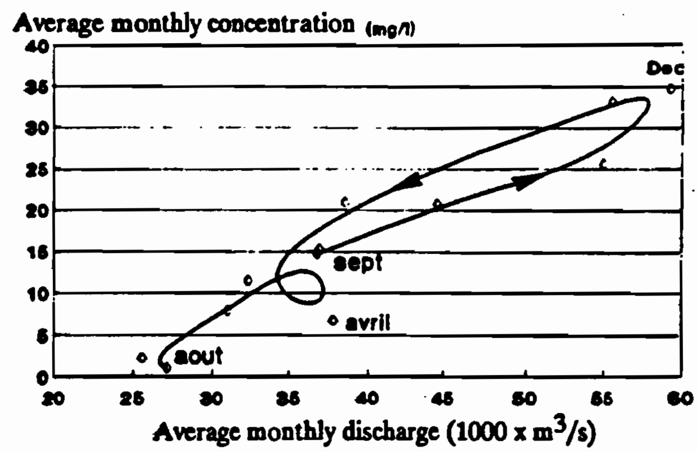


FIG.9 - ANNUAL EXPORTS FROM 1987 to 1992

(Y = 0.13 x X - 64.29   r = 0.92)

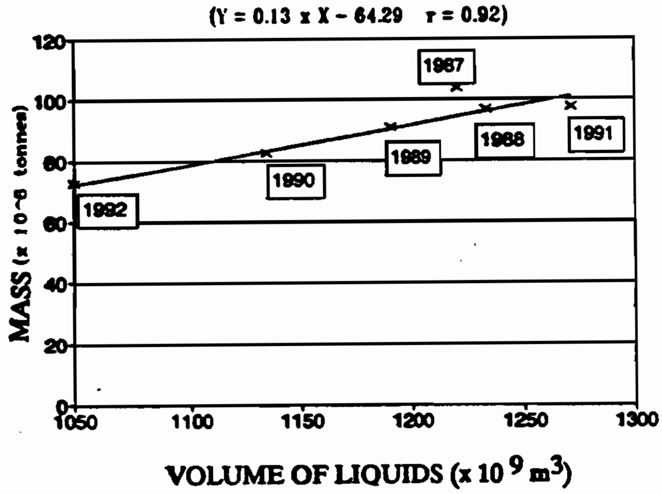


FIG.10 - MEAN CHEMICAL COMPOSITION OF THE CONGO FROM 1987 TO 1992 (in mmoles/l)