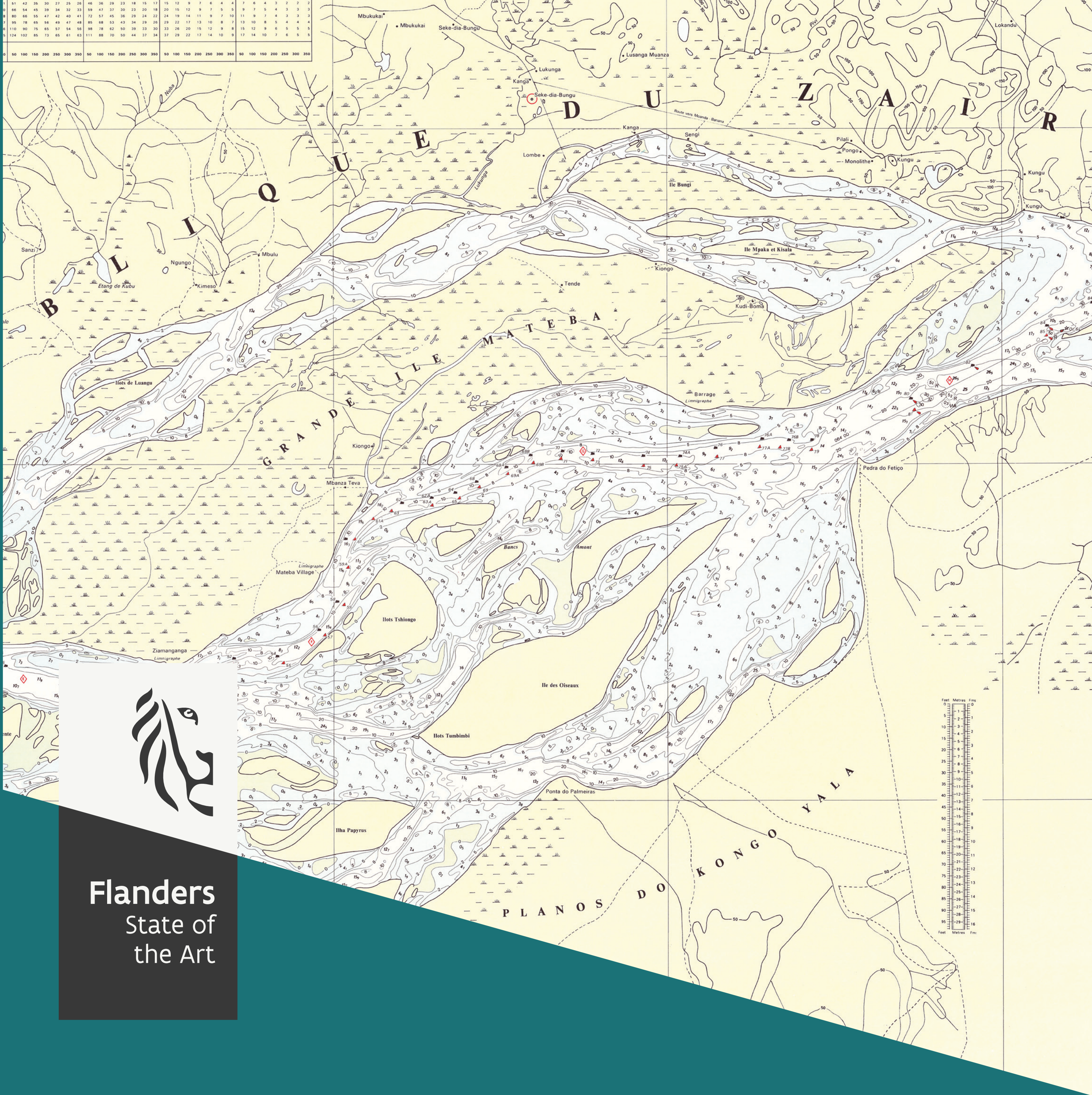


Flanders
State of
the Art

22_035_1
FH reports

Techno-economic study on the deepening and widening of the navigation channel in the maritime reach of the Congo river

A description of the hydro and sediment dynamics of the Congo river and the concept of morphological management to optimize the navigational depth

DEPARTMENT
MOBILITY & PUBLIC WORKS

www.flandershydraulics.be

Techno-economic study on the deepening and widening of the navigation channel in the maritime reach of the Congo river

A description of the hydro and sediment dynamics of the Congo river and the concept of morphological management to optimize the navigational depth

Meire, D.; Plancke, Y.; Kaptein, S.

Flanders Hydraulics
Flanders
State of the Art

Cover figure © The Government of Flanders, Department of Mobility and Public Works, Flanders Hydraulics

Legal notice

Copyright and citation

D/2024/3241/296

This publication should be cited as follows:

Meire, D.; Plancke, Y.; Kaptein, S. (2024). Techno-economic study on the deepening and widening of the navigation channel in the maritime reach of the Congo river: A description of the hydro and sediment dynamics of the Congo river and the concept of morphological management to optimize the navigational depth. Version 4.0. FH Reports, 22_035_1. Flanders Hydraulics: Antwerp

Document identification

Customer:	Haedes	Ref.:	WL2024R22_035_1
Keywords (3-5):	Congo river, sediment transport, hydrodynamics, morphological management		
Knowledge domains:	Hydraulics and sediment > Sediment > Dredging and dumping > Literature and desktop study Hydraulics and sediment > Morphology > Erosion and sedimentation > Literature and desktop study		
Text (p.):	45	Appendices (p.):	1
Confidential:	☒ No	☒ Available online	

Author(s):	Meire, D.; Plancke, Y.

Control

	Name	Signature
Reviser(s):	Kaptein, S.	Getekend door:Steven Kaptein (Signature Getekend op:2024-12-09 16:08:51 +01:0 Reden:Ik keur dit document goed Kaptein Steven Vlaamse overheid
Project leader:	Plancke, Y.	Getekend door:Yves Plancke (Signature) Getekend op:2024-12-13 13:11:08 +01:0 Reden:Ik keur dit document goed Plancke Yves Vlaamse overheid

Approval

Head of Division:	Bellafkih, K.	Getekend door:Abdelkarim Bellafkih (Sign Getekend op:2024-12-09 11:19:09 +01:0 Reden:Ik keur dit document goed Bellafkih Abdelkarim Vlaamse overheid

Abstract

In this report an overview is given of the available knowledge, tools and experience on the Congo river, especially near the zone of the “Région Divagante”, which were gathered over the course of the time. For the “Région Divagante”, which is the most critical region for navigation in the navigable part of the Congo river, an analysis has been performed on the following topics

- *hydrodynamics*: description on annual hydrology, fresh water discharges, tides and currents
- *sediment* : description of sediment characteristics and sediment transport
- *morphology* : description on the morphology and its evolution
- *morphological management* : description of basic concepts and applications

Contents

List of tables

List of figures

1 Introduction

In this report, an overview of data sources, knowledge and experience and research tools are described, which are available at Flanders Hydraulics Research and were gathered in the course of mainly the second half of the 20th century. This analysis focusses on the maritime reach of the Congo river, and especially on the “Région Divagante”. This desktop study, is performed making use of previous studies performed by Flanders Hydraulics on the maritime reach of the Congo river in combination with recent experience on sediment and morphologic management in rivers and estuaries. It is a guideline for the future application of the concept morphological management in the “Région Divagante”.

The “Région Divagante” is a morphological very dynamic reach of the river, with channels and sandbars moving significantly over the years. To guarantee an optimal port accessibility (ports of Boma and Matadi) the hydro-morphological situation is described and the concept of morphological management is explained and proposed. This concept was already successfully applied in large rivers and estuaries around the world, among which the Congo river and the Schelde-estuary.

First, we describe within this study (chapter 2) the geology, hydrodynamics, sediment dynamics and morphology of the “Région Divagante”. In chapter 3, a general description is given of the concept of morphological management, addressing not only the concept but also the research tools required to apply the concept successfully. In chapter 4 we describe “La méthode des dragages dirigés” a technique that was developed specifically for the Congo river. Finally, in chapter 5, we illustrate the concept of morphological management on a hypothetical situation, representative for the complex channel system of the Région Divagante.

2 Description of the “Région Divagante”

2.1 Introduction

The Congo River has an overall length of 4700 km and its drainage basin covers 4 * 10^6 km² (Figure 1). The sources of the Congo are in the highlands and mountains of the East African Rift, as well as Lake Tanganyika and Lake Moero (formerly Lake Mweru), which feed the Lualaba River. Further downstream, below Boyoma Falls, this becomes the Congo. The Congo flows generally toward the northwest from Kisangani just below the Boyoma Falls, then gradually bends southwestward, passing by Mbandaka, joining with the Ubangi River and running into the Pool Malebo (Stanley Pool). Kinshasa and Brazzaville are on opposite sides of the river at the Pool, where the river narrows and falls through a number of cataracts in deep canyons (collectively known as the Livingstone Falls), running by Matadi and Boma, and into the sea at Banana.

Lower Congo constitutes the ‘lower’ parts of the great river; that is the section of the river from the river mouth at the Atlantic coast to the twin capitals of Brazzaville and Kinshasa. Because of the vast number of rapids, in particular the Livingstone Falls, this section of the river is not operated continuously by riverboats.

Figure 1 – Catchment of the Congo river

The navigable part of the Congo River is the 150 km portion of the river between Matadi sea port and the mouth of the Congo River at Banana (Figure 2). A detailed map of the Region Divagante is added in Figure 3: Overview of the Région Divagante. 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 Congo River can be divided into three sections (Bujika, 1987).

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 m and even, locally, to 100 m. It consists of rocky walls particularly resistant to erosion. Its width ranges from 500 to 2000 m.

The second section covers 60 km between Boma and Malela. It is the so-called ‘Région Divagante’ 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 Congolaise des Voies Maritimes (hydrographic surveys, aids to navigation and dredging) are concentrated there.

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 (see section 2.3.4) and great depths of 400 m and more (geological deeps). The mouth of the Congo River is 10 km wide. From Bulabemba to Kisanga the width gradually decreases from 5 to 2 km.

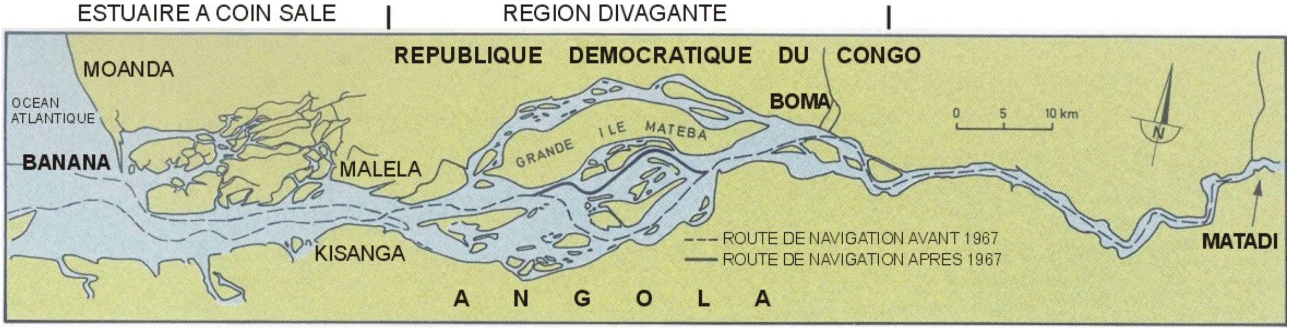


Figure 2 – Navigable part of the Congo river

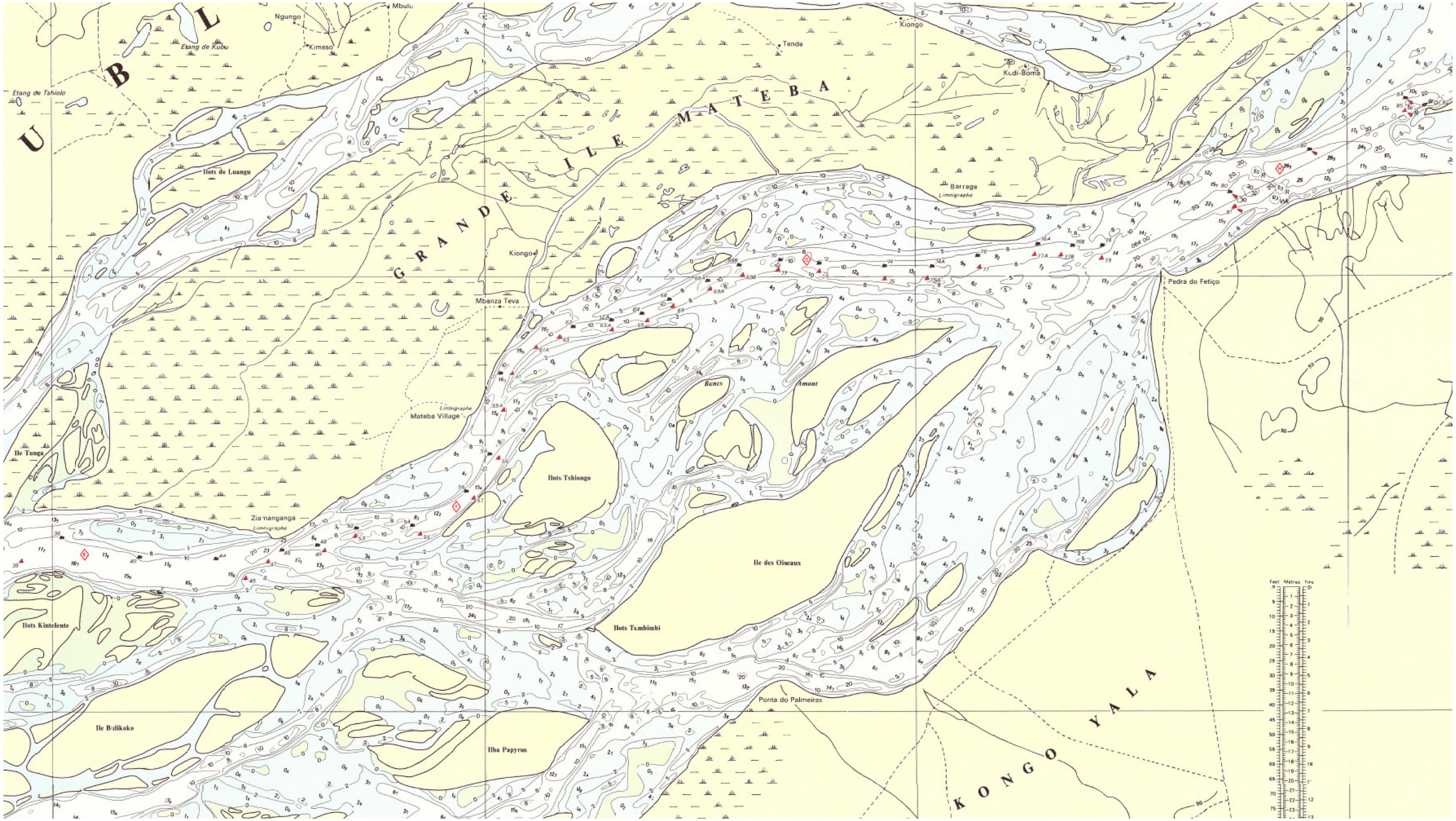


Figure 3 – Overview of the Région Divagante

2.2 Geology

The stream pattern of the Congo river in Lower-Congo is the specific result of different geological conditions (Steenstra, 1986). These are in the first place the selective erosion in the formations, but also the zones of tectonic deformation and brecciation.

Between Inga (upstream region of Lower Congo) and Banana (mouth area at Atlantic ocean) one can distinguish three major divisions:

1. A zone between Inga and the "Chaudron d'Enfer", where the river follows the direction of the layers, or cuts them nearly perpendicularly along zones of faulting (zigzag pattern);
2. A zone between Matadi and Boma, where the river follows the softer rocks surrounding hard domes of crystalline rocks (sinusoidal pattern);
3. A zone downstream of Boma, where the river is braided in the beginning ("Région Divagante") and afterwards perpendicularly cuts through the slightly westdipping formations.

While sections (1) and (2) are found in areas of Precambrian rocks showing intense deformations and often granitization, section (3) is found in an area with rocks from Cretaceous to Recent, mostly of marine origin. Due to a small shift of the whole area to the west, one finds rejuvenation in different affluents of the river. The intermediate zone between b and c is characterized by a zone with rather coarse clastic sediments ("Grès sublittoraux") of which the composition corresponds to the materials of destruction of the crystalline Precambrian rocks (arkoses, coarse sandstone, some shales). They are most probably of lagoon origin and they form a rather resistant rock. These "Grès sublittoraux" are deposited between and around protruding tops of an old relief of the crystalline rocks, but where they are cut by the river, one finds a zone with accumulation of finer sediments in which the river anastomoses into an interlacing system of channels (braided pattern, "Région Divagante"). The "Chaudron d'Enfer", a little downstream of Matadi, has its origin in a brecciated zone due to the meeting of different faults and to softer rocks below the hard rocks at the surface.

2.3 Hydrodynamics

2.3.1 Water levels

The Congo river basin is located on both sides of the equator. In the northern sub-basins, peak values are reached in October and November. In the southern sub-basins, peak values are recorded in the period of between February and March. This leads to a double annual peak in the discharge in the downstream part of the Congo river (Tourian et al., 2023). On the gauging locations of Kinshasa, Matadi and Boma (see Figure 5 to Figure 7 and combined in Figure 4), peak values can be observed around May ("la petite crue") and December – January ("la grande crue"). The peak in spring is much smaller compared to the peak in the winter season. The annual variation is higher in Matadi compared to Kinshasa and Boma, which is probably due to the shape of the local cross section area.

Within the Région Divagante the surface slopes are rather mild, ranging between 2 and 15 cm per kilometer, and on average 5 cm/km (Peters, 1971). Upstream of Boma, between Boma and Matadi, the hydraulic slope is about 8 cm/km.

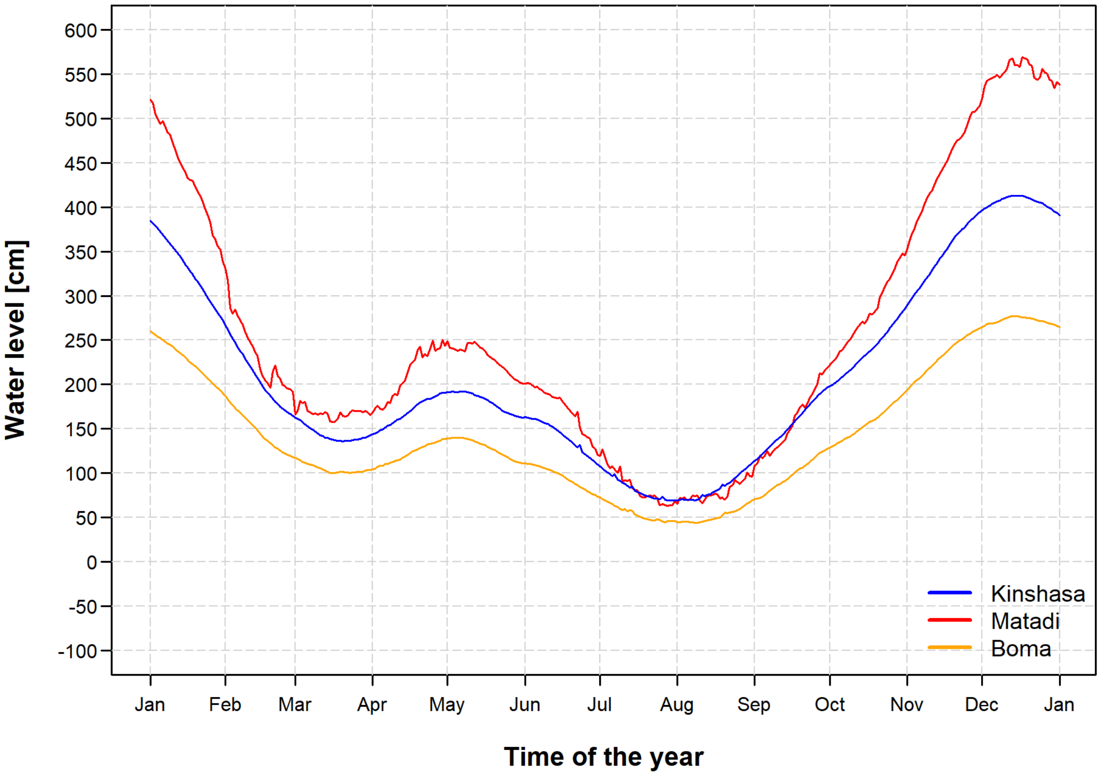


Figure 4 – Overview of an average yearly variation in the water levels (average of period 1984 – 2008)
[*water levels at each location are expressed to local reference level*]

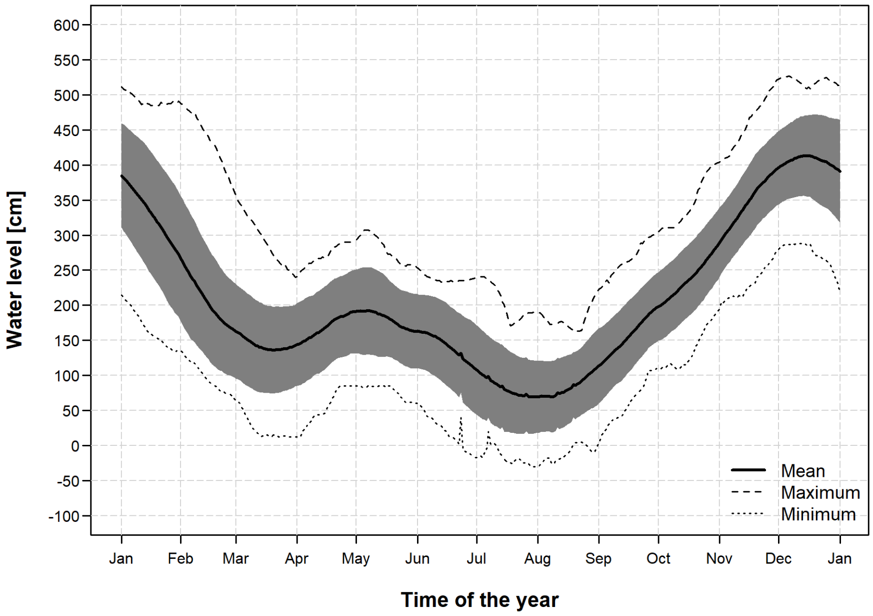


Figure 5 – Annual variation of the water levels (mean with standard deviation, minimum and maximum) at Kinshasa (period 1984 – 2008) [*water levels are expressed to local reference level*]

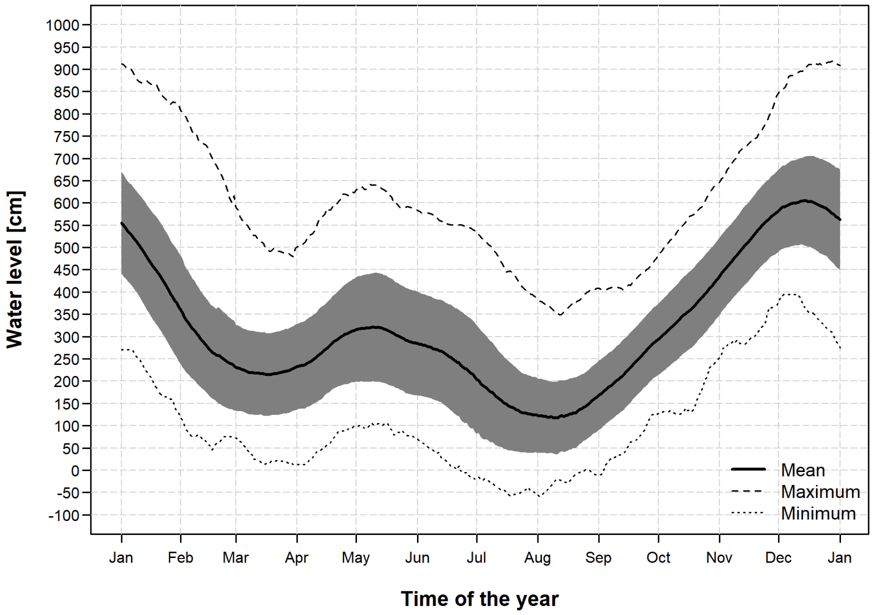


Figure 6 – Annual variation of the water levels (mean with standard deviation, minimum and maximum) at Matadi (period 1903 – 2010) [*water levels are expressed to local reference level*]

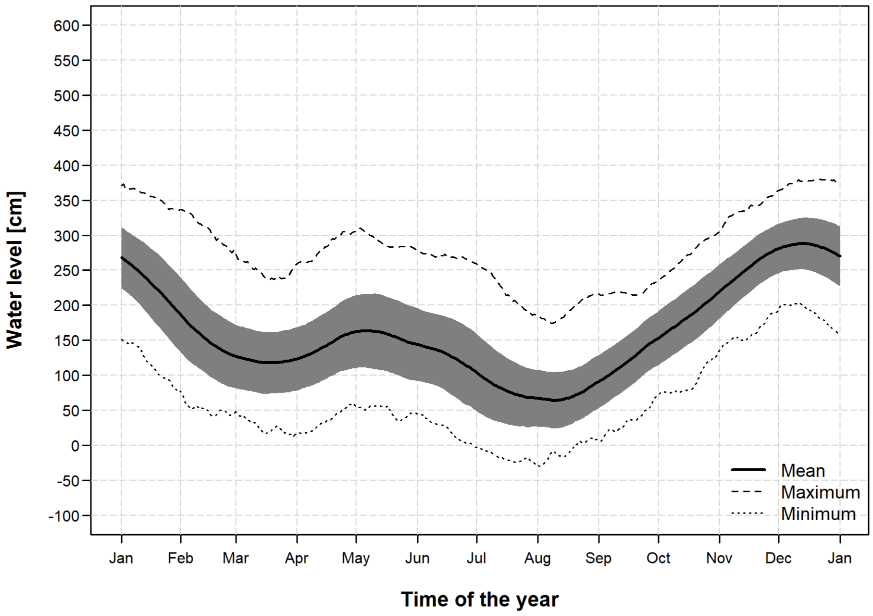


Figure 7 – Annual variation of the water levels (mean with standard deviation, minimum and maximum) at Boma (period 1903 – 2011) [*water levels are expressed to local reference level*]

2.3.2 Fresh water discharge

To translate the variation in water levels to discharges (Figure 8), the Van Nimmen curve (which gives a Q-h relation for the measured water levels of Boma) (Waterbouwkundig Laboratorium, 1968) is used. It is evident that the discharge follows the same pattern as the water levels. The average discharge over the considered period (1903 -2011) is 36000 m³/s, with maximal annual discharge of 46500 m³/s (in 1962) and a minimal annual discharge of 29000 m³/s (in 1992). Worldwide, the Congo river is the second largest river with regard to freshwater discharge, behind the Amazon. The annual discharge of the Congo river is more than 300 times larger than the annual freshwater discharge of the Schelde!

Maximal monthly discharges are recorded in December, with a monthly average of ca. 48100 m³/s and minimal discharges are recorded in August, with monthly average values of 28100 m³/s. The ratio between the extreme flows and the base flow is of the order of 2 to 3, which means that the peaks are relatively moderate. The small flood has, on average, a discharge of approximately 70 % of the large flood in December.

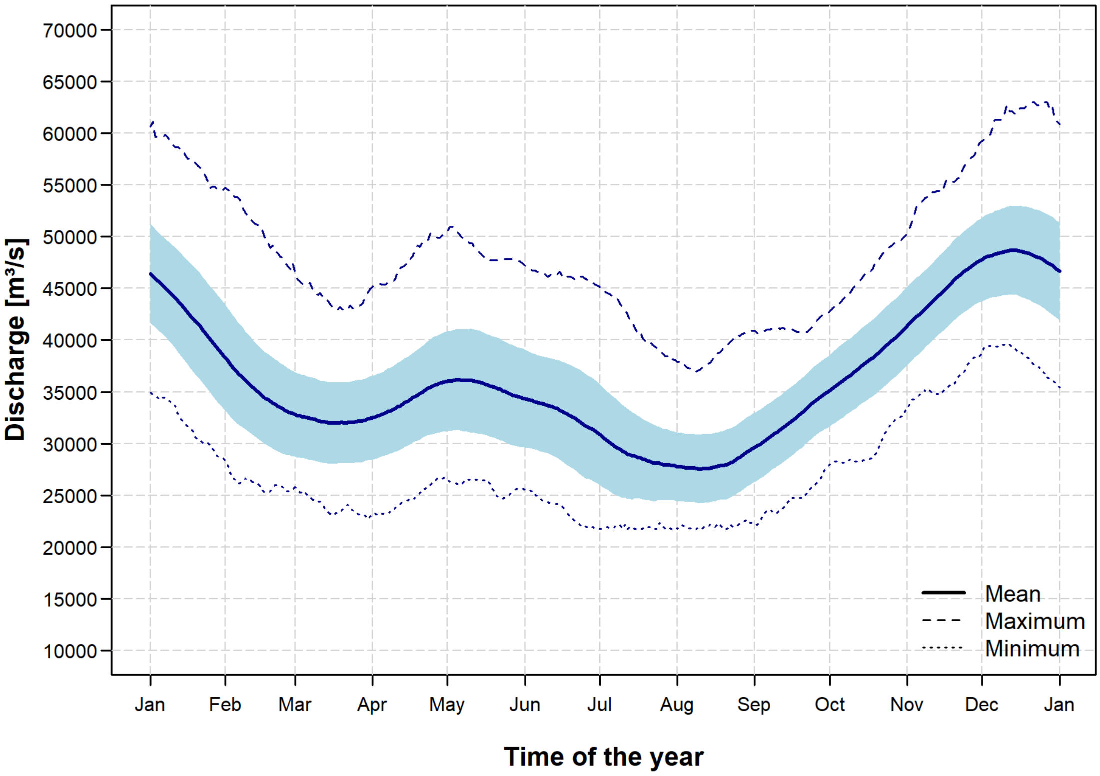


Figure 8 – Annual variation of the discharge at Boma (period 1903 – 2011)
[*water levels are expressed to local reference level*]

2.3.3 Currents

The section between Boma and Matadi is characterized by a relatively high gradient of the channel bed and its embankment, resulting in a rather high speed of the water : from 5 to 6 km/h (ca. 1.5 m/s) at low water level and from 9 to 10 km/h (ca. 2.5 m/s) at high water level. The concentration of currents enables the self-dredging capacity[1] 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 Congolaise des Voies Maritimes are limited to aids to navigation and dredging of harbors.

The section between Boma and Malela, the so-called 'Région Divagante', 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 Congolaise des Voies Maritimes (CVM) 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 of which the speeds vary as from 4 to 5 km/h (ca. 1 m/s) along the thalweg during lower water level and from 6 to 7 km/h (ca. 1.5 m/s) during the higher water level.

This spreading out of the currents (e.g. shown in Figure 9) recorded at the entrance of the area is due to a strong reduction of the 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 'buffer' of sediments near 'banc Ntua-Nkulu'. Because of the relatively slow main currents in this section, the self-dredging capacity is low resulting in a continuous deposit of sediments coming from upstream.

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 Région Divagante. In this respect, the navigation channel in the Région Divagante 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 9.29 km long, maintained with great efficiency by the Congolaise des Voies Maritimes in order to allow the safe access to the ports of Boma and Matadi to great tonnage vessels.

The section from Malela to the mouth of the river at Banana is characterized by both the predominance of tidal effects and great depths of 400 m and more (geological deeps). The mouth of the Congo 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.

---

[1] The self-dredging capacity of a river is the tendency of the flow to transport sediment. A high self-dredging capacity results in very low sedimentation rates, and thus limited need to dredge this part of the river.

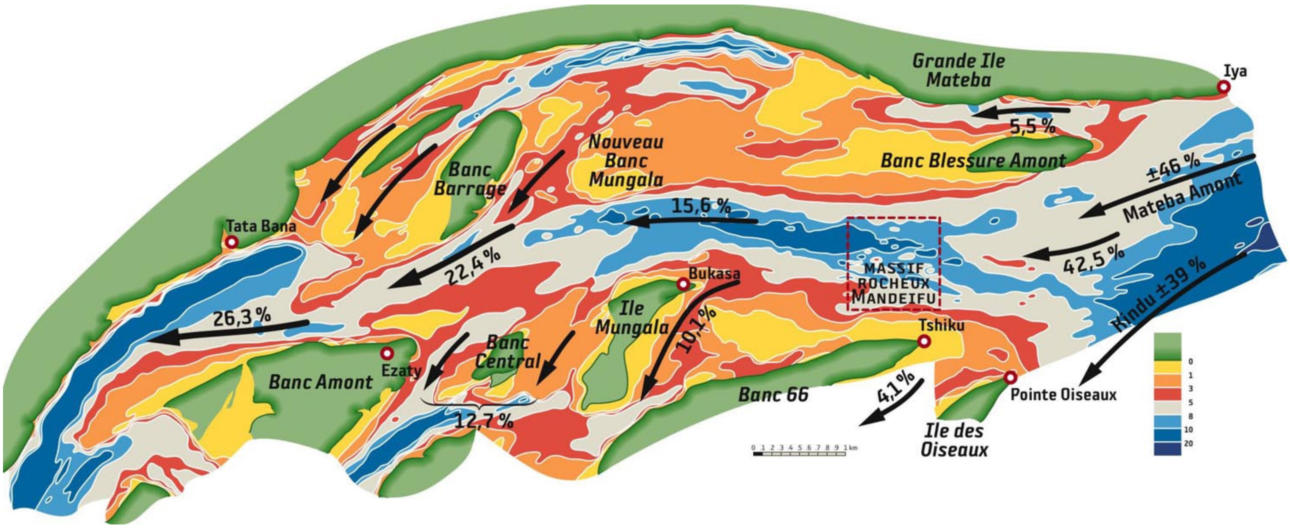


Figure 9 – Spatial variation of fresh water discharge distribution in the “Région Divagante”
Source: presentation on Congo river by JJ. Peters (www.potamology.com)

2.3.4 Tides

Besides the annual hydrographic regime of the Congo River, the currents in the “Région Divagante” are also influenced by the tide. At Bulabemba, approximately 5 km upstream of the mouth, the semi-diurnal tide has an average amplitude of 1.4 m during spring tide and 0.7 m during neap tide periods (Sterling, 1986b). The tidal wave propagates into the Congo river, where the intensity decreases with increasing distance from the mouth. The most upstream influence is felt up until Boma, approximately 80 km upstream of the river’s mouth. The influence of the tide on the currents is not very noticeable, slight modifications of the currents in magnitude and direction are perceptible in the downstream part of the ‘Région Divagante’ (Peters et al., 1971)

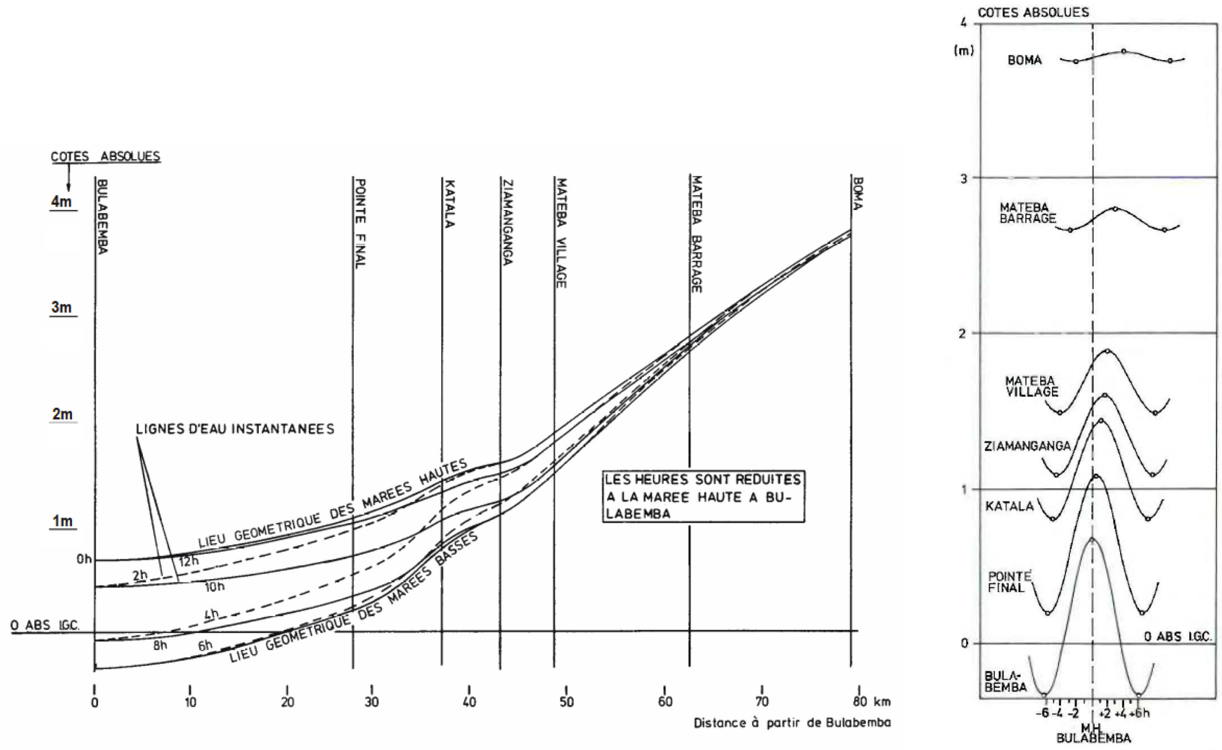


Figure 10 – Tidal influence along the “Région Divagante”: longitudinal profile (left) and tidal curves for different stations (right) (from Sterling et al., 1986b)

2.4 Sediment dynamics

2.4.1 Sediment characteristics

The average diameter of the sands collected ranges from 100 µm to 1000 µm, with a predominance of 300 µm. The sand is therefore most often fine sand. The clays are very difficult to erode even by very violent currents (Peters et al., 1971).

In the distribution of the sediment within the "Région Divagante", there are two main observations which can be summarised. First of all, it is noted that the sediment in the southern part is generally coarser than the sediment in the northern part. This observation is particularly observed in the region upstream of Ditadi-dia-Muingu (Fetish-rock). In Figure 11 the pathways of the fine and coarse sediment are sketched in this upstream region.

Secondly, there is a progressive decrease of the median diameters from upstream to downstream, both in the northern and southern axis. This phenomenon can be explained by the reduction of the transport capacity of the river, when approaching the ocean (Coen et al., 1983). This reduction of the median size (d50) is also shown in Figure 11 (left).

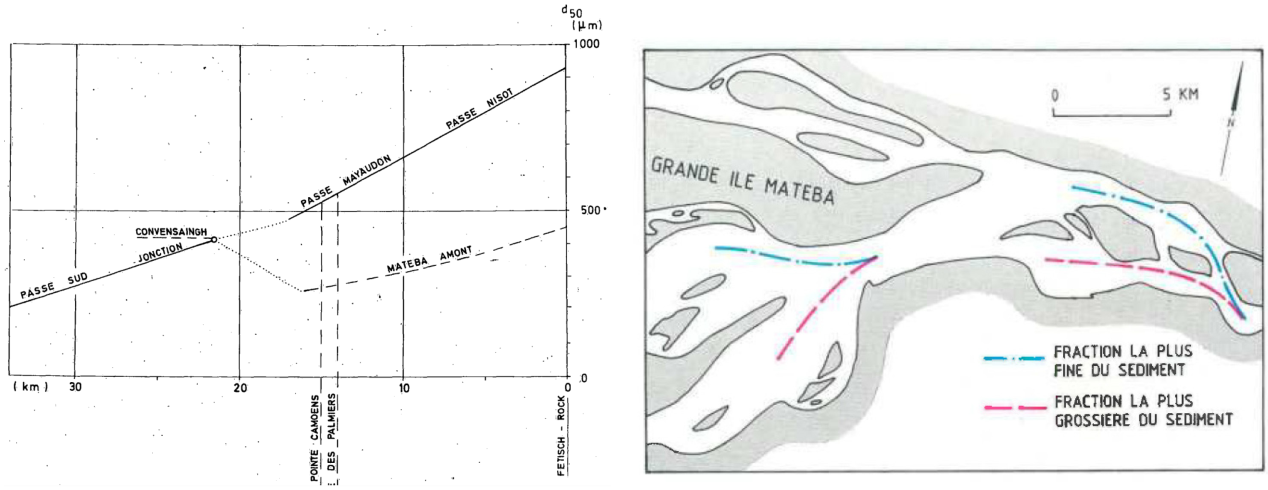


Figure 11 – Left: Evolution of the median grain size (d50) along the Région Divagante (Peters, 1971)
Right : Transport pathways of fine and coarser sediment in the upstream part of the Région Divagante (from Sterling, 1986)

2.4.2 Sediment transport

The Congo River, entering the Région Divagante, brings an appreciable quantity of sediment, depending on the discharge (or stream power). The relation between discharge and sediment transport is not linear. From a discharge larger than 44000 m^3/s, south of the grand isle of Mateba, the sediment transport increases very fast.

The flow entering the Région Divagante is measured in the gauging section of Ntua-Nkulu (formerly “banc d’Anvers”). In Figure 12 the changes in sediment transport capacity as a function of flow at Ntua-Nkulu are shown, based on the diagram of Richardson (1966). Here, the kink in the curve around 44000 m^3/s is clearly observable. It is clear that the transport capacity is very dependent on the discharge, and therefore can be very different on a year to year basis. In Figure 13 an example of the annual sediment transport capacity is shown for 3 different years. It is also clear that the height of the “petite crue” and “grande crue” (see section 2.3.1.) influences in great amount the annual sediment transport capacity. The calculated annual solid transport capacity for 1969, 1961 and 1958 is respectively $160 * 10^6$, $200 * 10^6$ an $42 * 10^6$ m^3/year.

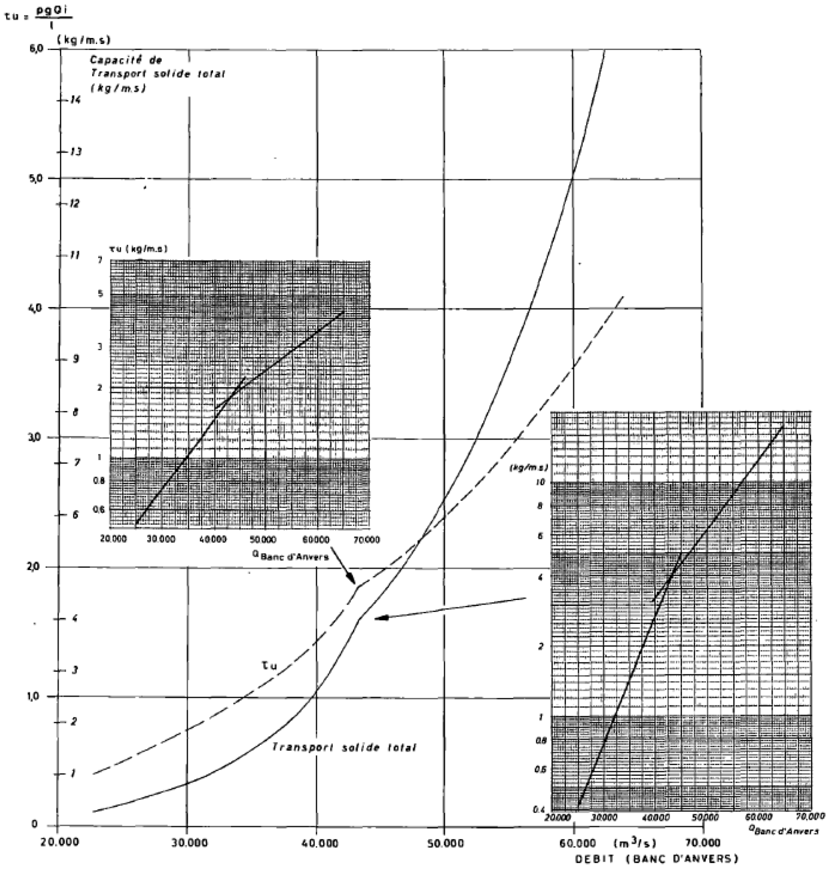


Figure 12 – Change in sediment transport capacity in relation to discharge at Ntua-Nkulu (from Peters, 1971)

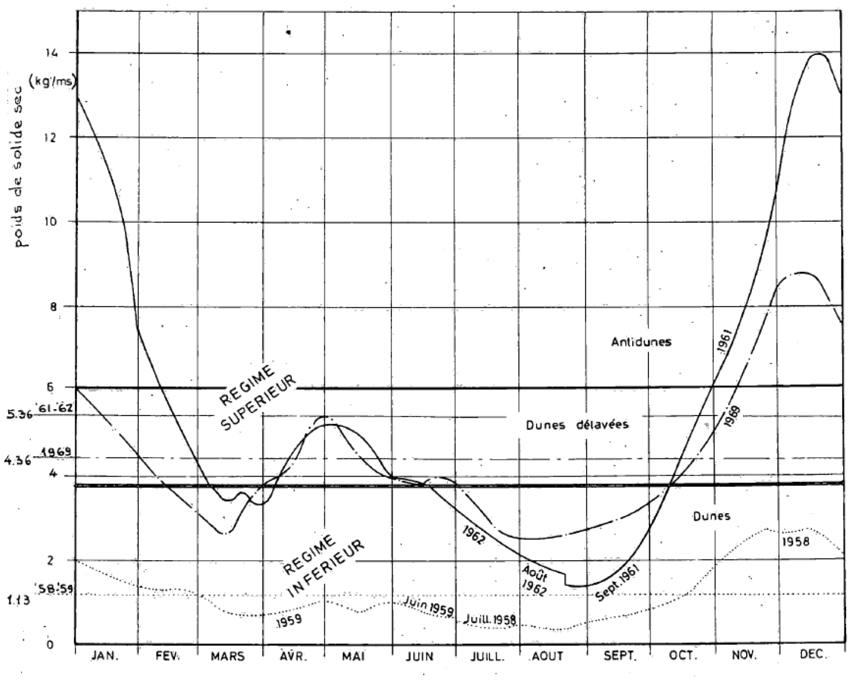


Figure 13 – Calculated sediment transport capacity in relation to the time of the year, for 3 different years (1958, 1969,1961) at Ntua-Nkulu (from Peters, 1971)

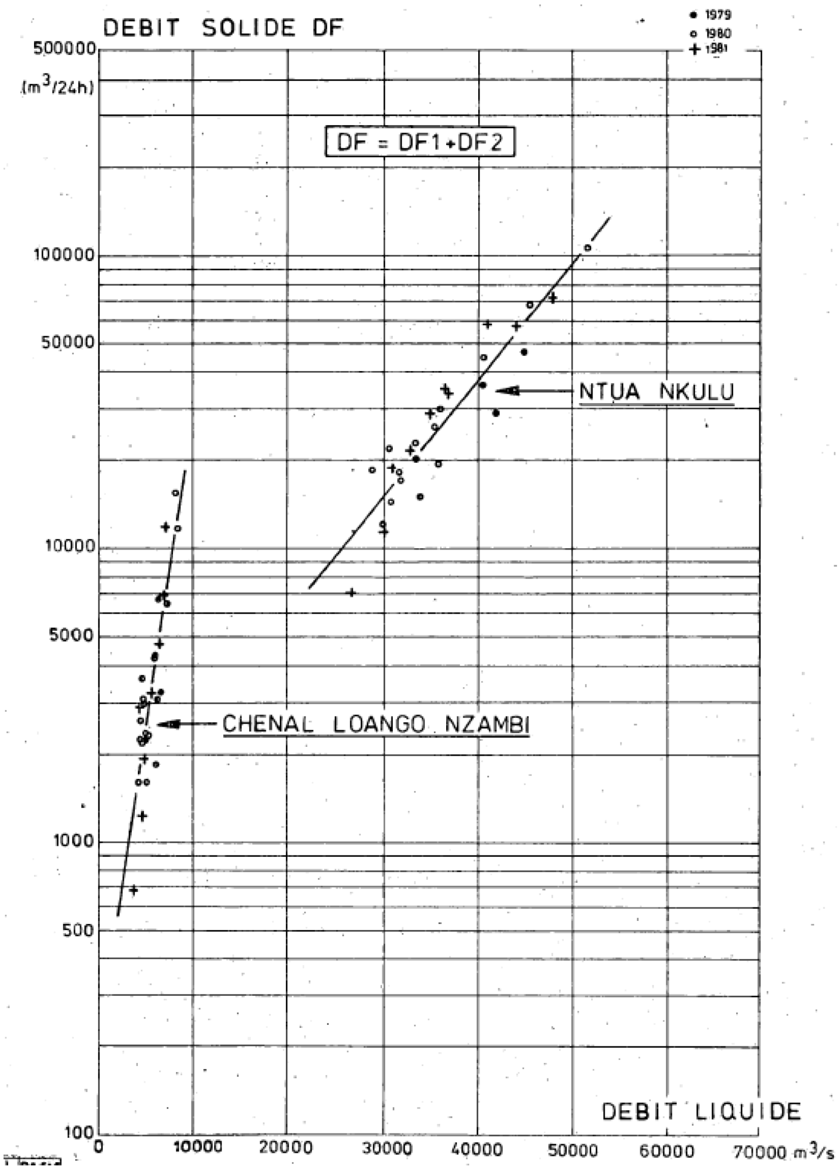


Figure 14 – Relation between measurements of sediment transport and discharge for some measurement campaigns in 1979, 1980 and 1981 (from Peters et al., 1982).

The actual sediment transport can be measured in the field, e.g. using a Delft bottle (see e.g. Figure 14 and Figure 15). In Figure 14 the total measured sediment transport [in m^3/day] at the measurement transect of Ntua-Nkulu is shown. This total transport is the combination of suspended transport (here measured by a cable-suspended Delft bottle above 40 cm of the bottom) and the bottom transport (measurement between 0 and 40 cm of the bed, measured using a frame-mounted Delft bottle). The relative importance of both measurements in the total sediment transport varies largely between different measurements.

In Figure 15 the measurements of the magnitude and the spatial variation of the sediment transport in the different channels (different measurement transects) is shown, which gives a lot of insight in the movement of sediment particles. However, this point measurements are very labour intensive. Nowadays alternative techniques, using acoustic or optical backscatter, can be used, giving a good indication of the sediment concentrations within the channels. However, these “indirect” techniques require calibration that leads to an uncertainty in the calculated results.

Besides the in situ measurements, sediment transport in the Congo river was also studied using scale models. This scale models gave more insight into the direction of the sediment transport, as the trajectories of the solid particles could be studied (see Figure 16). It is clear from Figure 16 that the flow patterns and the sediment trajectories can differ significantly, e.g. due to helicoidal flows. This knowledge was also used to study the most suitable dumping location for dredged material. This was done in regard to the efficiency of the dredging operation and on the possible negative effect on the navigation channel.

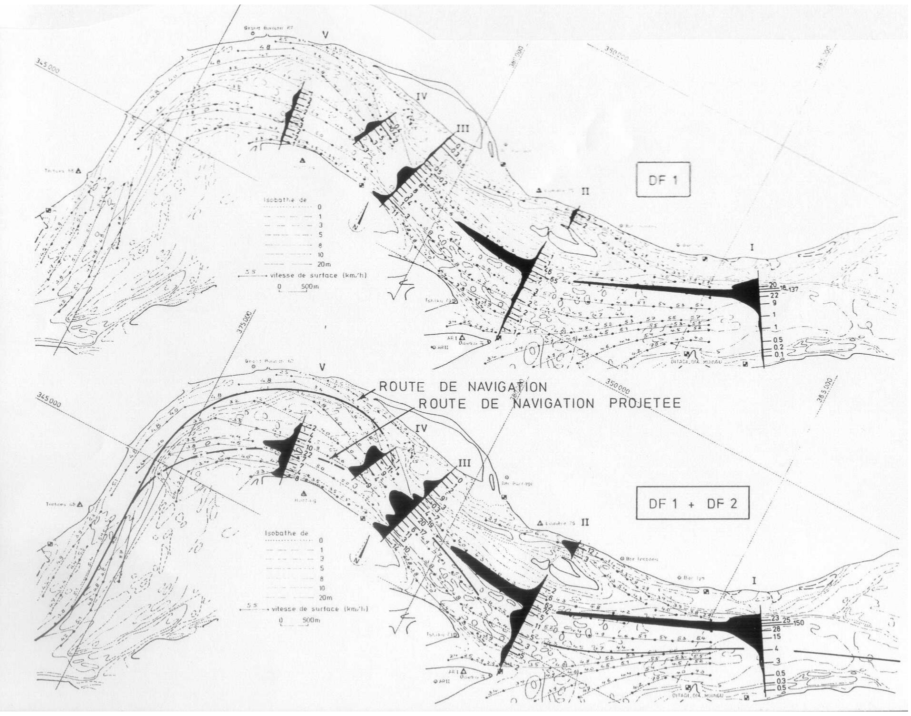


Figure 15 – Sediment transport in branches within the “Région Divagante”

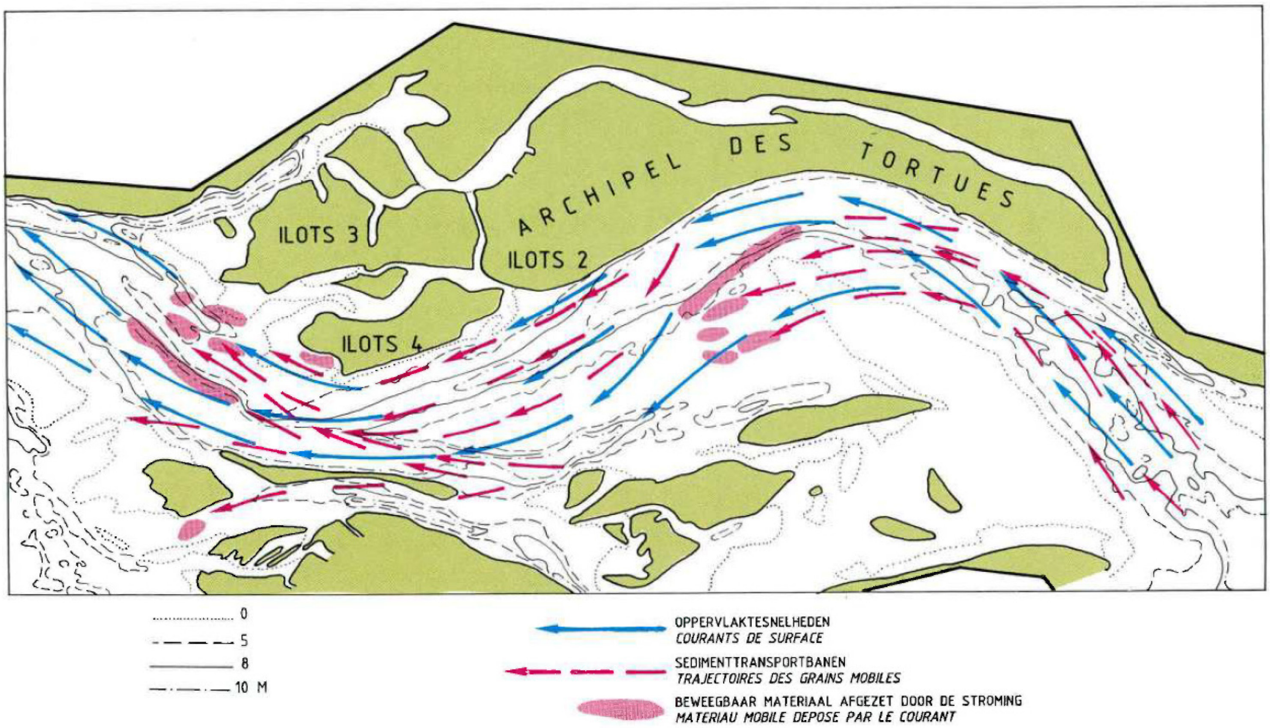


Figure 16 – Surface velocities, sediment trajectories and sedimentation zones (gray) in a scale model of the Région Divagante (Coen, 1986)

2.5 Morphology

Like any natural river with a gentle slope, the Congo river is a braided river (estuary) in the Région Divagante, where the different individual channels are meandering. As such, a succession of deep zones (pools) in the outer bends of the curves are observed, which are separated by sills in the straight sections (see Figure 17). As long as the river doesn't encounter any hard points, the natural evolution of this meander can continue, with a downstream movement of the system. However in the Région Divagante, a series of hard points have been identified, as can be observed in Figure 18. This hard points can be rock formations or very hard clay layers, which are not (easily) eroded, and limit the lateral migration of channels.

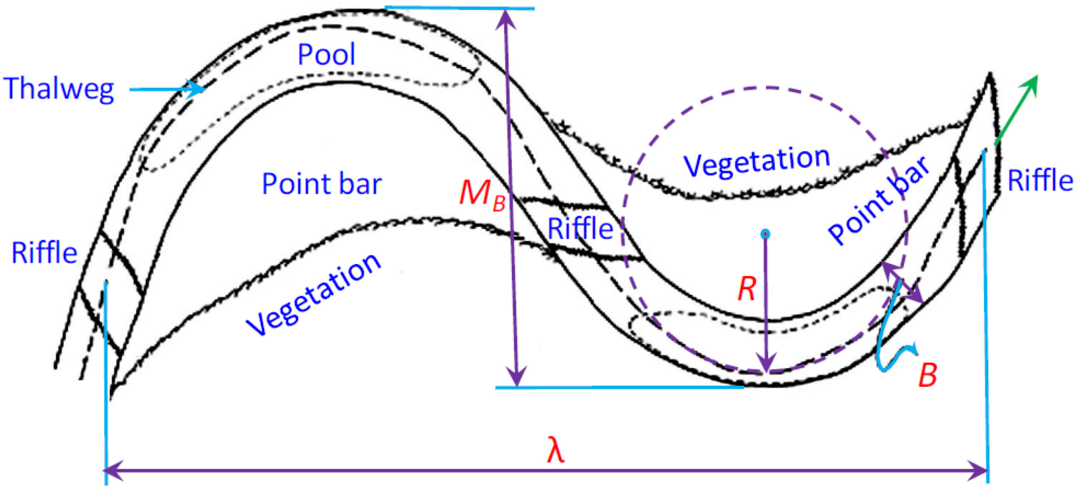


Figure 17 – Planform of a river meander (from Banda (2022), after Leopold & Wolman, 1957)

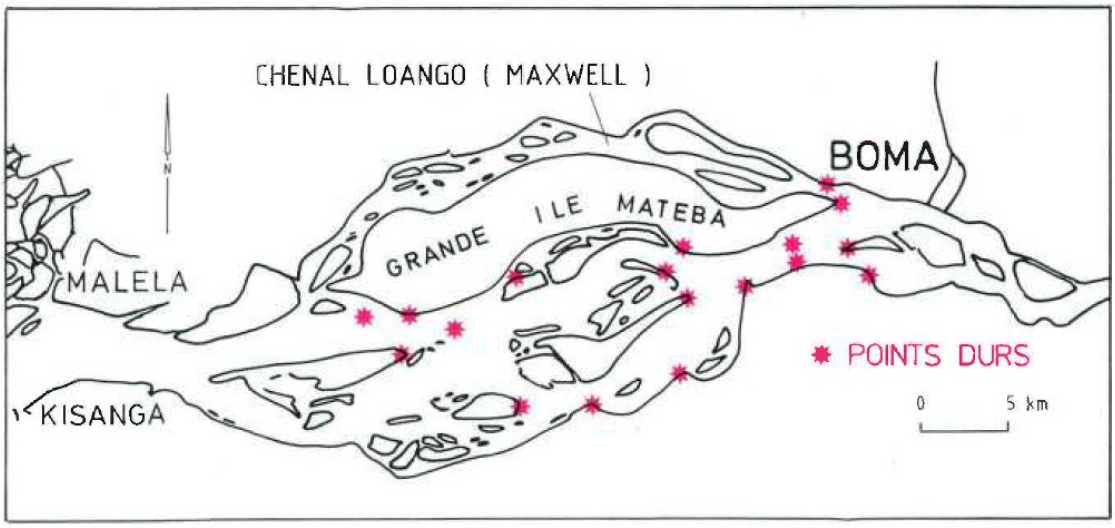


Figure 18 – Map of the Région Divagante with indication of hard points (from Sterling, 1988)

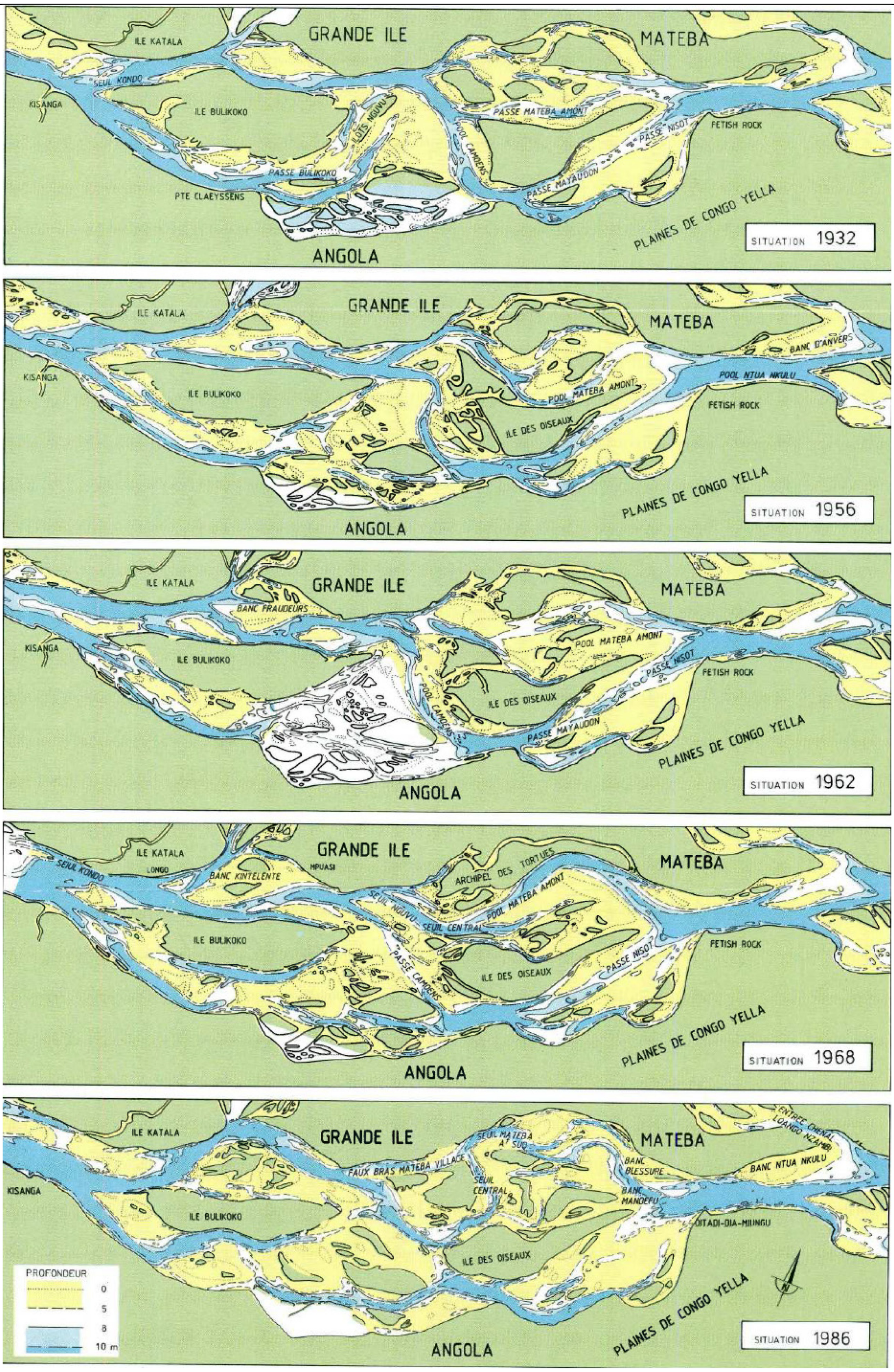


Figure 19 – Map of the Région Divagante over a period of ca. 50 years (1932 – 1986) (from Sterling, 1986)

Those hard points can influence the "free" morphological evolutions in several ways (Peters et al., 1975). It can block the movement of the meanders, lead to a channel on the opposite side of the hard points, be responsible for the creation of a bank downstream of the hard point or it can be responsible for the separation of currents, especially in the upstream of these hard points (Fetish rock – Ditadi-dia-muingu, Ditadi-dia-mandeifu, Point ile des oiseaux). The hard points influence the morphological evolutions heavily, together with the divisions of the currents, which on their turn influence the morphological development.

In Figure 19 the large scale morphological evolutions of the Région Divagante are shown, over the period 1932 till 1986. In the region, some islands can be distinguished, which remain more or less stable during the course of the time. In the north, the grand isle of Mateba divides the Région Divagante in 2 distinct zones (Peters & Sterling, 1971). In the north, the channel Loango Nzambi accounts for approximately 10 to 15 % of the total discharge (see Figure 20). South of the grand isle of Mateba, the "isle of Bolikoko" and the "isle des oiseaux" remain stable. The latter forms the division between the "Mateba amont" in the north and the "Fetish rock" pass in the south. At the downstream end of the "isle des oiseaux" part of the water passing south of the isle diverts again to the north, via the pass Tumbimbi (pass Camoens), while the remaining continuous south into the "passes Portugaises". The northern pass (at the downstream end of the Région Divagante) contains the discharge of the Mateba amont, pass Tumbimbi and Loango Nzambi channel. The southern pass respectively the water from the "pass Jonction" and "passes Portugaises". The division of the channels' discharges, and its evolution over time, is shown in Figure 20.

Besides the large scale morphological evolutions, also on the smaller scale continuous changes occur, which can also influence or hamper navigation. Dunes are the most widespread bed forms within the Région Divagante. Both the hydrodynamics (flow velocity, water depth) and sediment characteristics influence the characteristics of these dunes. Some of these characteristics are shown in Table 1, for both the northern channel (Mateba Amont) as the southern channel (Passe Bunia), the latter characterized with coarser sediment, as also depicted in section 2.4.1. The sediment transport by the proceeding of these dunes is as well location specific (for similar hydrodynamic conditions). When moving along a sill, the dune top can exceed the navigation depth and should be dredged. In this case dredging should be limited to removing the top of the dunes. In the case an overdepth is created, the top of the dunes can grow even larger.

Besides the effect on navigation (on a smaller scale), the bed forms also influence the bed roughness and as such the distribution of the currents. In case of (high) floods, the bed forms can change quickly from dunes to antidunes, resulting in different roughness. This again is a function of the local hydrodynamics and sediment characteristics. The "passe Mateba amont" will experience a transition from a bed with dunes below 45000 m^3/s to a flat bed or even antidunes above this discharge threshold (Peters & Sterling, 1971). The "passe Bunia" does not experience this transition, and as such the resistance to flow in the Mateba Amont region with high flows decreases compared to the passe Bunia. This induces an important increase of discharge and sediment transport and can trigger larger scale evolutions.

Table 1 – Characteristics of bed forms – dunes – in two different regions of the Région Divagante (from Peters & Sterling, 1971)

	Passe Mateba Amont		Passe Bunia	
	Mean	*Range*	*Mean*	*Range*
Amplitude (H_d)	2.00	0.5 – 5.0	1.5	0.7 – 3.5
Length(L_d)	100	30 – 400	60	30 - 100
Solid discharge [$m^3/d*m$]	6	0 – 11	2	0 - 4

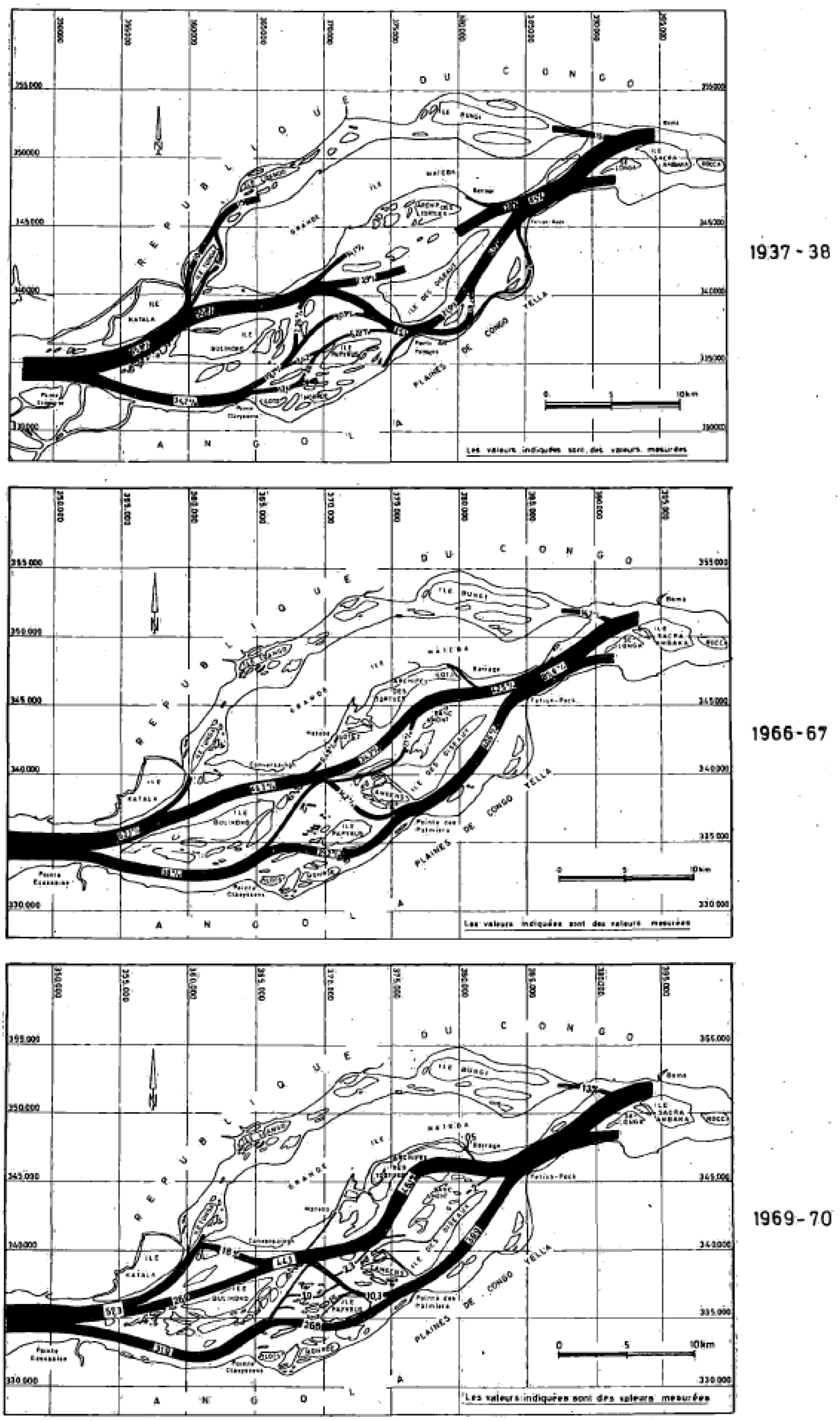


Figure 20 – Distribution of the discharge within the Zone Divagante over between 1937 and 1970
(from Peters & Sterling, 1971)

3 Morphological management

Morphological management of a water system (river, estuary, coastal area) aims at pursuing a morphology sustaining all its different functions (Antwerp Port Authority, 2012). Water systems support many important ecosystem functions: mitigation of floods, maintenance of biodiversity and biological production, port accessibility, etc. Morphology plays a crucial role in facilitating these ecosystem services. Channel geometry and depth in combination with sandbars influence safety against flooding, port accessibility and ecology (Meire et al., 2005; Smolders et al., 2015).

Managing the system taking only into account one of its functions, often resulted in human interventions with a benefit for the function that was aimed for, but also with a negative effect for some of the other functions. Where at first sight it seems that those different functions have nothing in common, it must be clear that all of them require a certain state of the morphology (Figure 21). However the required morphological state is or can be different for each function, and the most suitable morphology has to be determined taking into account all those functions. By such an integrative holistic management approach, taking into account all the functions, improving the accessibility of a port can e.g. result in a lower risk of flooding and a preservation or even an improvement of the natural values of the water system.

This should be based on a continuous analysis of the morphology. The big challenge is situated in the dynamics (hydrodynamics, sediment, …) of the environment, which should be maintained. Therefore it is necessary to define a long term vision of the system, against which the observed morphological evolutions can be evaluated.

In morphological management “steering the morphology” means working with nature as much as possible. If negative evolutions – impeding the long term vision of the system – are observed, one must attempt to curb this unwanted evolution. The engineering measures available to manage the morphology include morphological dredging and disposal strategy, modification of existing hard bordering and construction of soft structures.

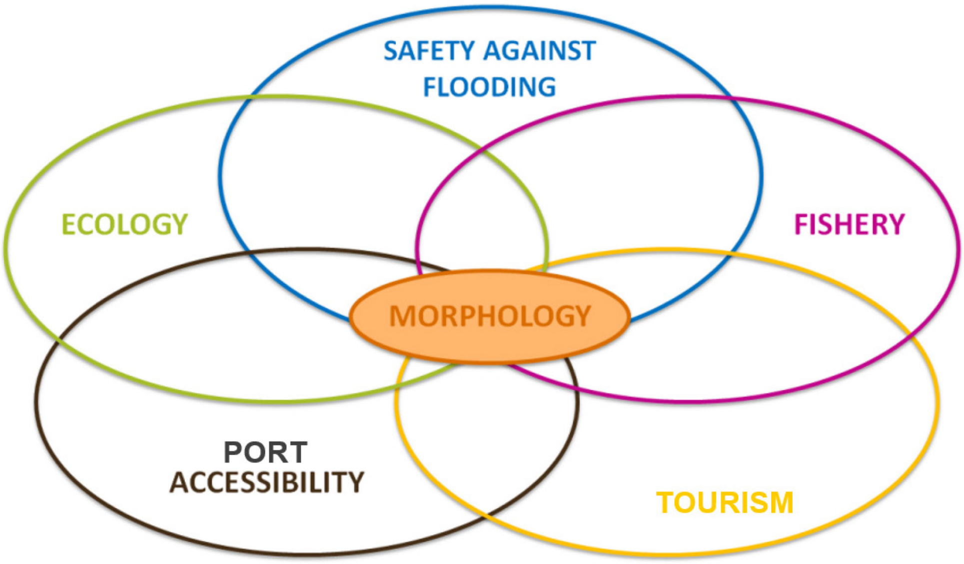


Figure 21 – The “morphological management” approach. The morphology is supporting all other functions.
(Source: Antwerp Port Authority, 2012)

3.1 The engineering measures

Engineering works in water systems are traditionally structural (such as groynes and spur dykes, jetties, bank revetments, guiding banks or guiding levees) and/or dredging. Obviously, engineers consider their works as influencing the morphology. However, this is more in the sense of controlling, sometimes even "taming" nature. For example the common technique of disposal of dredged material in the side channels of a multiple channel system – aimed at getting rid for some time of the sediment before it comes back to the navigation channel – is obviously affecting morphology but this is not what we understand by morphological disposal. Morphological management must be flexible, responsive and holistic. Local interventions or too rigid approaches have failed. Following paragraphs give a description of the possible measures for managing the morphology of a water system.

3.1.1 Morphological dredging

Dredging is used to create new channels or deepen and/or widen existing channels (capital dredging) or to maintain existing navigation channels (maintenance dredging). However, dredging can also be used as a tool to influence the morphological behaviour in the system. Morphological dredging is meant to trigger evolutions, so that the channels and sandbars become more adapted to the needs of navigation and ecology. This may include dredging to rectify channel borders or to initiate new channels, either a main channel or a secondary channel.

3.1.2 Morphological disposal of dredged material

Morphological disposal is not just getting rid of the dredged material. In the vision of morphological management, the disposal of the dredged material is seen as an opportunity to initiate certain desired evolutions. As an example disposal can be used to provoke wanted evolutions of sandbars, or to influence the lateral movement of channels.

3.1.3 Modification of hard bordering

In the past, hard bordering along water systems (including hard structures such as groynes, spur dykes, …) was often constructed without taking into account the morphology of the system. And if this was taken into account at the time of construction, the hard bordering might not have remained appropriate anymore in the present situation since the morphology – and as a consequence also the hydrodynamics – is changing all the time. Therefore, the hard bordering may influence its current morphology negatively, for example by orientating water flow in an unfavourable direction.

3.1.4 Construction of new (soft) structures

In order to guide the flow or to affect the erosion-transport-deposition process, one could build flow guiding structures. Since the morphology of water systems is changing all the time, the efficiency of a structure may decrease over time, possibly even causing negative effects after a while. Therefore preference should be given to soft structures, which can be removed or adapted easily if necessary. Structures built with concrete or riprap should be avoided if possible.

3.1.5 Navigation beacons

Besides adaptations of the system for navigation purposes, also the navigation channel can be shifted to follow morphological evolutions of the system. By moving or replacing of the navigations beacons following the geographical surveys, this can be implemented in the field.

3.1.6 Combination of the above works

In order to implement morphological management of a water system, one will most likely need a combination of all engineering measures mentioned above. However, the goal of these works is not to work against the natural evolution, but rather with the natural evolution. Extensive research is necessary in order to determine the most optimal morphology of the estuary, sustaining and if possible even improving all the functions of the system.

3.2 Research tools

River and coastal morphology remains an experimental science, in which theories are not yet well established and bring little help for solving engineering problems. If flow and sediment movements are key elements to the morphological behaviour of a water system, they are certainly not the only ones. The way the flow and sediment transport patterns are influenced by controls like harder river bed material and by hydraulic structures is also essential.

A sound morphological management starts in understanding its past morphology. This morphological analysis must be a continuous activity, based on analysis of topo-bathymetric maps from the past and the present situation. Information about hard geological controls is essential for understanding these processes. Monitoring of different parameters such as flow velocities, discharges, sediment transport, … is necessary to increase the knowledge about the local hydrodynamic and sediment transport processes. Analysis of such monitoring data will help in interpreting the observed evolutions on topo-bathymetric surveys.

Where monitoring data reveals information about local processes, models – numerical as well as physical – can be used to understand the processes on a larger scale. It is important that such models are accurately calibrated and validated using the monitoring data in order to be sure that the model is reproducing well the real physical processes. Where it is generally accepted that the physics of hydraulic models is very well understood, this is not the case for morphological models. Therefore hydraulic models are to be preferred, where the morphological predictions should be made based on expert judgement. From point of view of sediment transport, physical scale models can be used. However, full morphological modeling still has its limitations: where a lot of improvement has been made in recent years, the lack of knowledge on sediment transport processes causes rather poor results for this kind of models, both on short as well as on the longer term (Peters *et al.*, 2006; Peters & Plancke, 2010).

Where one is confronted with the fact that all research tools have disadvantages, it is believed that a multi-tool approach as suggested here (combining analysis of historical topo-bathymetric maps, field measurements, numerical and/or physical models and last but not least expert judgement) combines the advantages of all research tools, minimizing the uncertainties of the final result. Besides the research tools mentioned above, in situ tests – including an extensive monitoring program to detect all possible effects – can be used to give a maximum certainty. Especially for projects with a possible large negative effect this option can be preferred: the negative effects that might occur from the tests will be small and most of the time reversible due to its scale.

3.3 Examples of morphological management

3.3.1 The Schelde-estuary

A first example of morphological management of an estuary concerns the new disposal strategy used during the capital dredging works in 2010 in the Schelde-estuary. Before this project, the disposal of dredged material was rather seen as an inevitable consequence of dredging of the navigation channel. The disposal strategy was once oriented on getting rid of the dredged sediments, disposing sediments mainly in the secondary channels. Where one was happy that this strategy did not have negative effects on the system, there was a possibility that the multiple channel system could be jeopardized if disposed quantities would be too high. Therefore, the Port of Antwerp Expert Team – appointed to investigate the feasibility of a 3rd deepening campaign of the navigation channel in the Westerschelde – proposed a new strategy to dispose dredged material in the estuary (Plancke *et al.*, 2006).

By disposing the dredged sediments on strategically chosen sites, one could try to curb in a positive way unwanted morphological evolutions in the estuary. In the framework of the 3rd deepening campaign of the fairway in the Schelde-estuary, an environmental impact assessment and appropriate assessment (Consortium Arcadis & Technum, 2007) were carried out studying different scenarios. Based on the success of the disposal tests at the shoal of Walsoorden (Ides *et al.*, 2006), one scenario was defined where the dredged material was disposed along sandbars, using the dredged material to induce morphological positive evolutions. Besides the Walsoorden sandbar, 3 other locations in the Westerschelde were appointed to be reshaped and extended by disposing dredged material (Figure 22). From the assessment studies it was concluded that the scenario including the disposal along these 4 sandbars is the most valuable alternative, since this scenario could create benefits for nature.

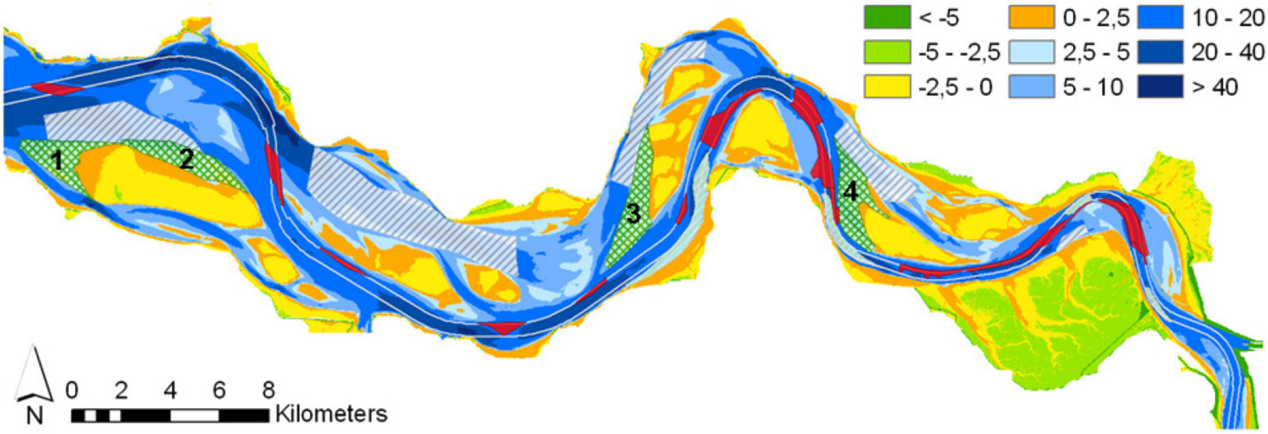


Figure 22 – Westerschelde with dredging locations (red), disposal locations near sandbars (green) and in channels (white hatch)

For every disposal location, a site specific strategy (Figure 23) was worked out (Plancke *et al.*, 2015). The objective of this research was to maximize the ecological benefits from the disposal, by increasing the area of low dynamic shallow water and intertidal zones. Besides this ecological objective, improving the sustainability of the multiple channel system was another aim. To evaluate the success of this new disposal strategy, an extensive monitoring program was set up and several criteria were defined.

Before the start of the deepening the reference situation was monitored. Since then, new measuring campaigns at all locations have been executed to evaluate the effect of the works. Results show different effects near different sandbars, both for sediment stability as changes in flow velocities. Nevertheless, ecological results are promising: initial results (2 years after start) showed an increase of almost 100 ha new low dynamic habitat, while at the end of the initial license period (2016) results showed an even further increase of almost 140 ha new low dynamic habitat near the 4 disposal locations.

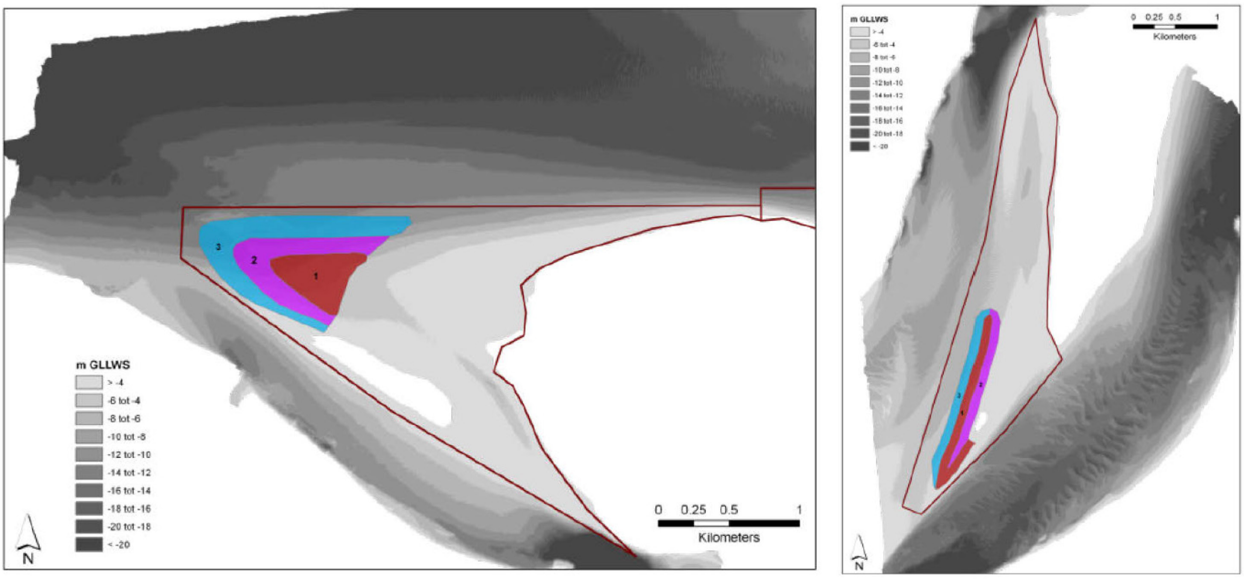


Figure 23 – Disposal concepts: megadune proposed at Hooge Platen West (left) and sand spit proposed at Baarland (right)

3.3.2 The Congo river

The concept of morphological management has been successfully applied in the Congo river (in the “Région Divagante”). The large fresh water discharge causes a lot of sediment transport in the river, making it a multiple channel system with channels and sandbars which are very mobile. The management of the navigation channel in this reach is done in a dynamic way, taking into account the natural dynamics of the system. Morphological evolutions are observed and if necessary (e.g. the navigation channel is located in a channel which is degenerating) the navigation channel is moved to another channel.

Figure 19 shows the topo-bathymetry between 1932 and 1986: where in 1932 the channel is located south of the large supratidal sandbar “Ile des oiseaux”, it is clear that in 1968 the channel north of this sandbar is used for navigation. The dredging works throughout the years have been minimized, trying to work with the natural evolution as much as possible. In this way the natural dynamics of the system are preserved, reducing the impact of human interference in the estuary from point of view of port accessibility.

As a case study, the recent evolution of the channel Canard – situated between the sandbar Kindu and Bunia in the southern part of the Région Divagante – is mentioned (see Figure 24). Due to sediment transport the Kindu sandbar had been shifting in western direction, the sandbar in fact moving into the Canard channel. Since the fairway was situated in this channel, high volumes of maintenance dredging works were required here in order to keep the necessary depth. Moreover measurements with GPS floats indicated that the discharge through the Canard channel had decreased over time, the flow preferring to go over the Bunia sandbar instead. Since the amount of discharge determines the flow velocities, and sediment transport is dependent on flow velocities, it was obvious that the Canard channel was naturally degenerating. On the other hand it was to be expected that a new channel would develop through the Bunia sandbar. Where one could keep the navigation channel in the Canard channel by intense dredging activities, in fact stopping the shift of the sandbar Kindu and thus the local morphodynamics, it was chosen not to do so. Instead the natural morphological evolution was fastened by dredging a channel through the Bunia sandbar, taking into account the local flow direction. Figure 24 clearly shows the position of the newly dredged channel, which coincides with the measured flow patterns. Due to a profound hydrodynamic and morphodynamic analysis, this new navigation channel didn’t experience sedimentation over time. The flow velocities in this newly dredged channel were high enough to keep the initial dredged channel depth, even causing gradual widening and deepening of the channel over time. As a consequence the maintenance dredging works in this part of the channel were very low.

Where this morphological management of the Congo river requires regular measurements to observe and analyse the natural morphological evolution, the advantages of such management are not small at all. Firstly, the dredging works to maintain the depth of the navigation channel are minimal. Secondly, the natural morphological dynamics of the system still remain resulting in a system where the human impact on morphodynamics is very limited.

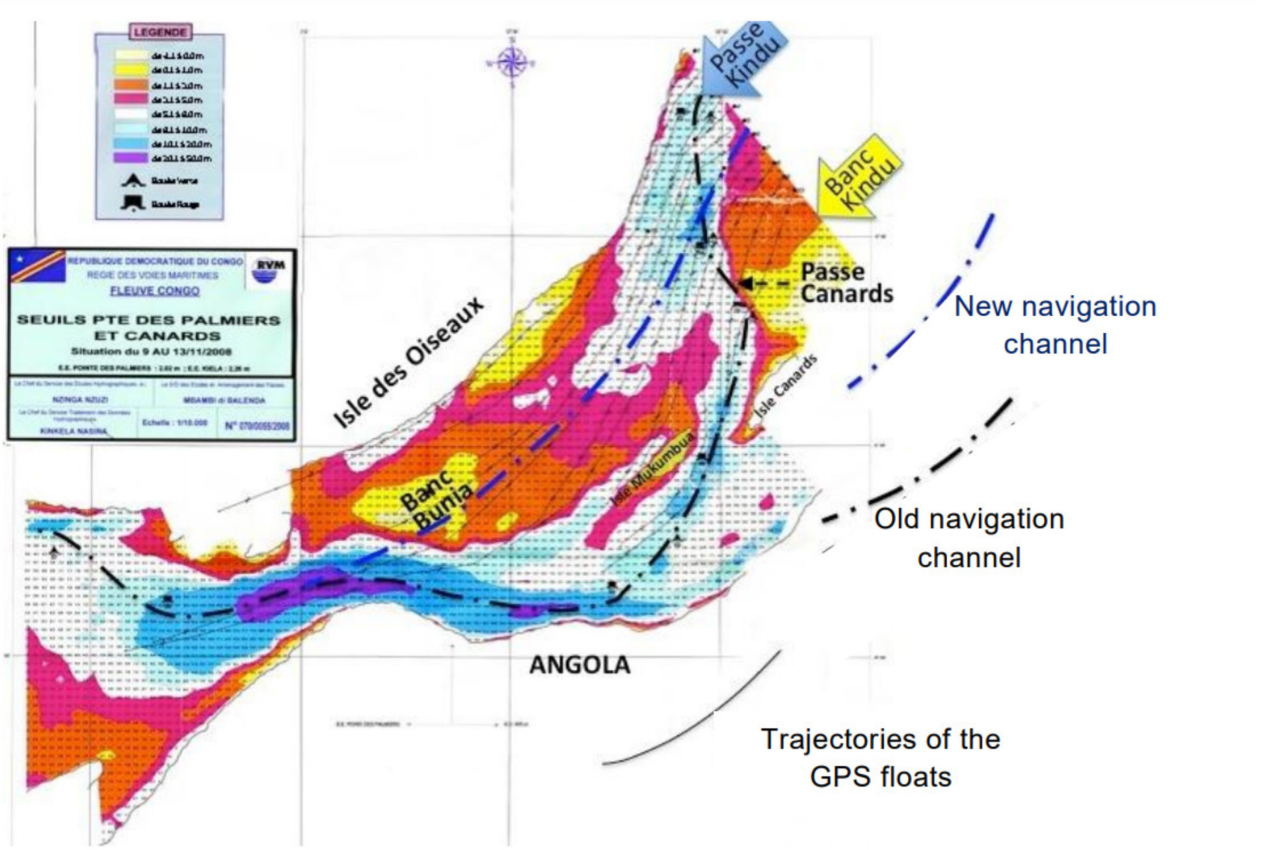


Figure 24 – Topo-bathymetric map of the region around the Canard channel with indication of the old and the new position of the navigation channel. The trajectories of GPS float measurement are also visualized (Source: Peters, 2010)

4 The method of controlled dredging

4.1 Introduction

La méthode des dragages dirigés ("method of controlled dredging") initially involved the processing of a certain amount of geometric and hydraulic information, as well as the application of empirical relations or rules (Peeters, 1986). Those in charge of hydrography and dredging had attempted, through repeated observations (maps, flow measurements, etc.), to detect trends in natural evolution. In some cases, comparison with similar developments in the past made it possible to improve the effectiveness of these forecasts and to organize dredging in such a way as to work 'with' nature rather than 'against' it. It was only later that the idea of using dredging to modify the direction of natural morphological evolution was born (see chapter 5 as an example).

The method can be divided into two phases:

Phase 1 : *Analysis phase*

In this phase, also called "forecasting method developments", the trends in the natural development are investigated. This phase leads to a diagnosis, but necessarily contains unknowns such as, for example, the evolution future floods

Phase 2: *Intervention phase*

In this phase the dredging and location of buoys are used, to improve the navigability, taking into account the trends of the natural evolution, but also in certain cases by trying to counter these natural developments if they are harmful

In the following paragraphs the different aspects of the analysis phase will be described (section 4.2). They will be illustrated by the case of the Mpuasi and Bulikoko channel, as is done in Peters et al. (1977). Before 1970 the Bulikoko channel was dominant and was the navigation channel. After 1970 the Mpuasi became dominant and the navigation channel shifted to this channel.

4.2 Field measurements

4.2.1 Topo-bathymetry

Bathymetric surveys provide information at different geometric scales: on a larger scale, the surveys describe the planform and depth of different channels; on a detailed scale, the survey gives information on the shape of sandbars and dunes. It should be noted that both an analysis on both scales is necessary, as large scale morphological evolutions also steer or influence the evolution on a smaller scale. In Peters & Sterling (1975) an annual survey of the Région Divagante is proposed, measured during the low water season. For the pools and meanders in the navigation route, a survey at the beginning and end of the low water season is proposed.

Comparisons between surveys (difference maps) visualize patterns of sedimentation areas, stable zones and areas of erosion. This technique provides both qualitative (erosion or sedimentation) and quantitative (amount of sediment/sediment balance) information.

Figure 25 shows the morphological evolution of the Mpuasi and Bulikoko channels over the period 1968 – 1973 (Peters et al., 1977). Initially, in 1968, the Bulikoko channel (southern) was dominant with water depths of more than 8 m. Gradually the water depth in the southern decreased and a sill started to form at the downstream end of the channel (1970, 1971). At the same time the northern channel (Mpuasi) started to develop: the shallow area at the upstream side gradually eroded from less than 5 m in 1968 to more than 8 m in 1973.

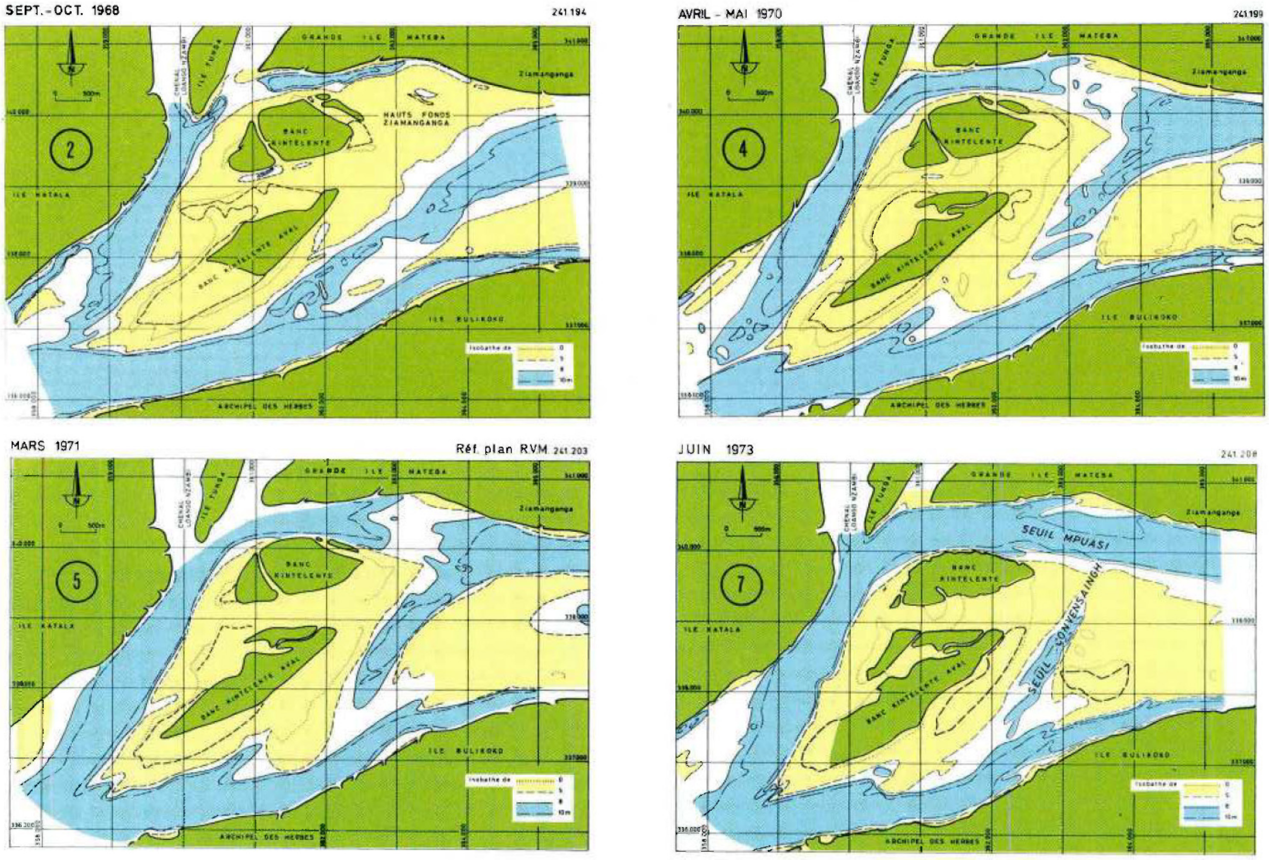


Figure 25 – Morphology of the Mpuasi and Bulikoko channels in the period 1968 – 1973 (from Peters et al., 1977)

Besides the sedimentation on the downstream end of the pass Mateba aval (Convesaingh sill), also the orientation of the principal currents changed over the time, as can be seen in Figure 26. This larger scale evolutions also influence the local developments mentioned above, and emphasize the importance of combining information on different spatial scales.

4.2.2 Water slope

The slope of the water (hydraulic gradient) can reflect local effects. An increase of the slope, under similar hydraulic conditions, indicates a tendancy of sedimentation of the channel (see also section 4.3.2). In contrast, a decrease of the gradient can be caused by the increase of the considered channel. To do this, we need to know the 'normal' gradients, measured in an equilibrium situation at different times during floods and along the entire longitudinal profile. The slopes gradually decrease as the river approaches the ocean, but increase or decrease overall as the water rises or falls during floods. The effect of the tides must be taken into account by calculating average slopes over the day or over a spring-neap cycle (14.5 days), depending on the application and the location within the Région Divagante.

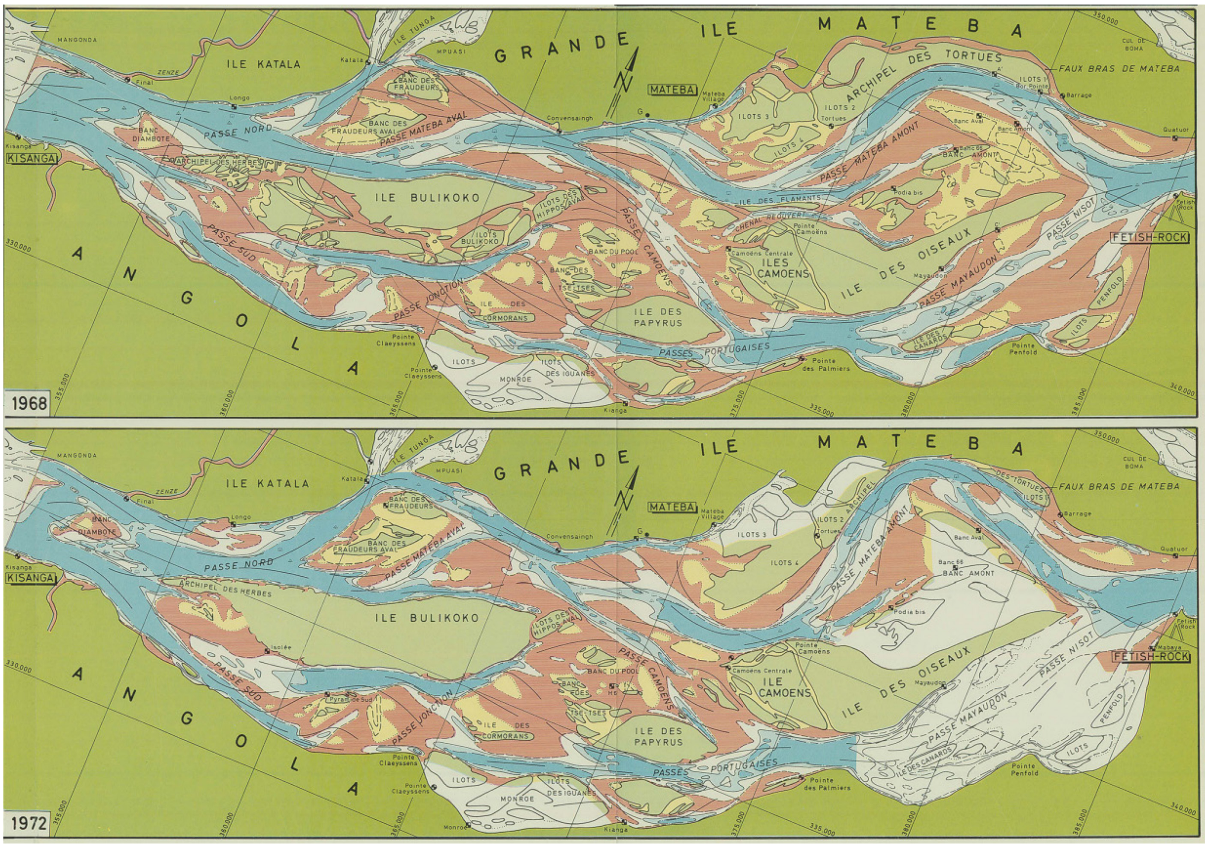


Figure 26 – Morphology of the Région Divagante, survey of 1968 and 1972 (Peters et al., 1977)

4.2.3 Water discharge and currents

By comparing fresh water discharges recorded at variable time intervals, it is possible to detect the closure or opening of the channels through which the water flows. Different time scales can be used depending on the objective. It is important to take into account the effects of tides (semi-diurnal time-scale) and floods (seasonal time-scale). Fortunately, floods are so slow that their effects can be considered negligible during a tidal cycle. Analysis of the currents, particularly their distribution/concentration in certain parts of the channel, provides valuable qualitative information on the tendency for the channel to deepen or aggravate.

Figure 27 illustrates the importance of the discharge distribution in relation to the morphological evolution: in §4.2.1 the shift from Bulikoko towards Mpuasi as dominant channel was described. This evolution can also be seen in the discharge distribution: until the 1960’s the Bulikoko channel transported more than 80% of the water, and had an increasing tendency (compared to 1930’s) due to a sedimentation of the Mpuasi channel. After the opening of the Mpuasi channel the contribution of the Bulikoko channel dropped to less than 50%.

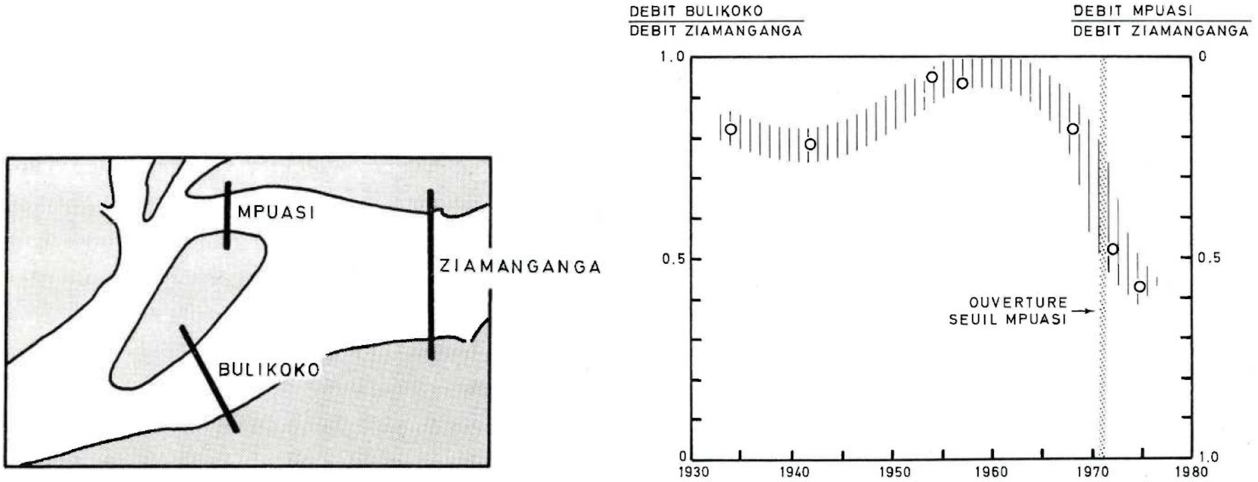


Figure 27 – Discharge distribution between the Mpuasi and Bulikoko channels between 1934 and 1977 (from Peters et al., 1977)

4.2.4 Sediment transport

Changes in morphology and channel geometry are the result of sand transport (see also section 2.4.2). This modifies the morphology of the river at different scales. During floods, and depending on the local characteristics of the flows and sediments, the river bed will be shaped in the form of a flat bed, ripples or dunes. Some ancient hydrographers, including A. Kholchloff, have observed the link between the appearance of certain types of bedforms and the difficulties of maintaining good navigability in these areas. Systematic observation of these bedforms is important. The interaction between river flow, sand transport and the nature and dimensions of the bedforms play an important role in the way the river bed changes and the banks and meanders move.

The overall movement of meanders is governed by multiple mechanisms. Systematic observation of (1) the movement of sandbanks, (2) measurements of sand transport, (3) analysis of sediment characteristics of both bed material and transported sediments and (4) the role of hard points on the movement of meanders, have already made it possible to identify laws and experimental rules. These are very useful, but complicated and difficult to apply.

4.3 Special techniques

Laboratory studies, based on field measurements and observations, have led to the development of analysis methods and tools for predicting future trends.

4.3.1 Trend maps ("La carte des tendances")

When, in the early 1970s, the influence of hard points became apparent near the entrance to the newly opened Mateba Amont channels, rapid channel changes occurred. The alternating opening and closing of the "Mateba Amont" (later called "Mateba Amont Sud") and "Barrage" demonstrated the need for a complementary tool to the scale model technique for forecasting short-term trends.

Although it appeared simplistic at first sight, an attempt was made to create a technique for predicting the trend towards erosion or silting at a given location, using simple, conventional measurements of depth and surface current. By analysing a large number of sediment transport measurements and comparing them with the changes in the riverbed observed at the locations where the measurements were taken, a graph was drawn up, as shown in Figure 28 (left).

If only the two parameters mentioned above are taken into account, it is clear that the forecast will not necessarily come true. But it is equally clear that the information thus provided can, in combination with the other tools developed in the evolution forecasting method, greatly improve the reliability of this method.

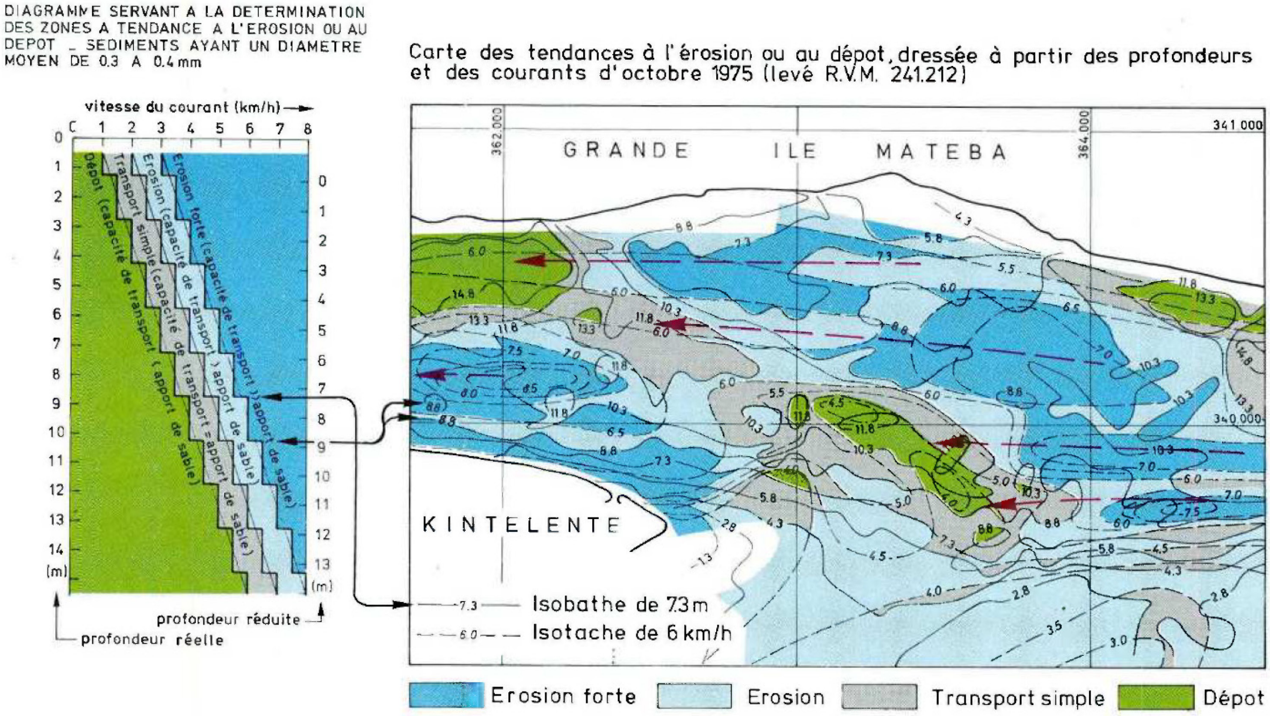


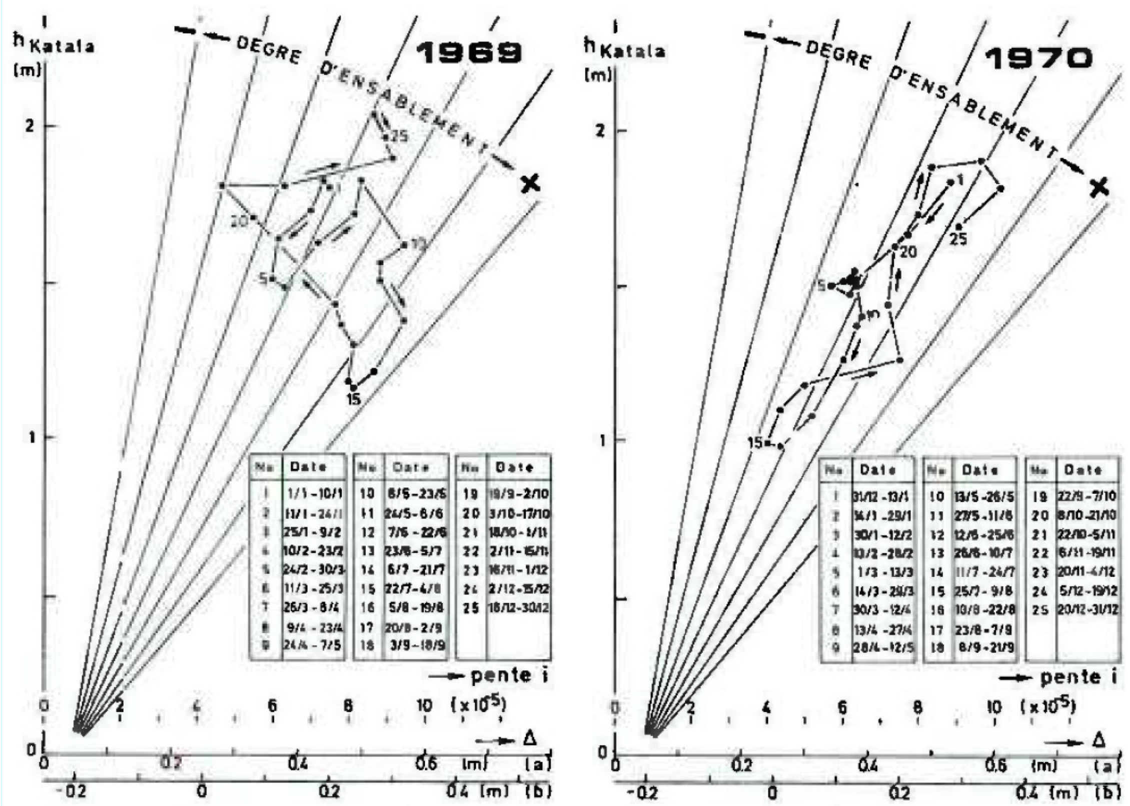
Figure 28 – Relation between water depth ("profondeur"), flow velocity ("vitesse") and morphological (blue = erosion, green = deposition) respons (left) and its application at the Mpuasi sill (right) (from Peters et al., 1977)

4.3.2 The law of the water slope ('La loi des pentes')

The slope of the water line, i.e. the gradient of the water level towards the Atlantic ocean, is determined by the resistance of the river. A river's resistance is greater if its shape is irregular (meanders, sills, dunes). A river with regular meanders, low curvature, deep sills and a single channel, with small dunes or a flat bottom has low resistance. As such, the slope of the water line will be small. A river with irregular meanders, strong curvature, high sills and two channels, with large dunes, has strong resistance. The slope of the water line will be steep. During a flood, the slope generally increases with the flow.

These slopes are known and recorded every week. If a sill silts up quickly, the slope of the water line will suddenly increase at the sill, causing the water level upstream to rise. This is demonstrated in Figure 29: in 1969 the slope increases to 10^{-5} which coincides with the silting up of the Bulikoko channel; with the increase of the water level at the end of the year (from 1 m to 2 m at Katala water level station), the slope decreases indicating the opening of the Mpuasi channel (Figure 29 - left). In 1970 a new morphological situation is formed, resulting in the normal pattern of higher slopes for higher water level can be seen in Figure 29 (right).

Precise measurements of the slopes of the various sills, using water level gauges located just upstream and just downstream of the sill, and the study of their temporal variation in relation to the downstream water level, make it possible to tell which sills are silting up. In the same way, you can tell whether the sill is eroding.



No	Date	No	Date	No	Date
1	1/1 - 10/1	10	8/5 - 23/5	19	19/9 - 2/10
2	11/1 - 24/1	11	24/5 - 6/6	20	3/10 - 17/10
3	25/1 - 9/2	12	7/6 - 22/6	21	18/10 - 1/11
4	10/2 - 23/2	13	23/6 - 5/7	22	2/11 - 15/11
5	24/2 - 10/3	14	6/7 - 21/7	23	16/11 - 1/12
6	11/3 - 25/3	15	22/7 - 4/8	24	2/12 - 15/12
7	26/3 - 8/4	16	5/8 - 19/8	25	16/12 - 30/12
8	9/4 - 23/4	17	20/8 - 2/9		
9	24/4 - 7/5	18	3/9 - 18/9		

No	Date	No	Date	No	Date
1	31/12 - 13/1	10	13/5 - 26/5	19	22/9 - 7/10
2	14/1 - 29/1	11	27/5 - 11/6	20	8/10 - 21/10
3	30/1 - 12/2	12	12/6 - 25/6	21	22/10 - 5/11
4	13/2 - 28/2	13	26/6 - 10/7	22	6/11 - 19/11
5	1/3 - 13/3	14	11/7 - 24/7	23	20/11 - 4/12
6	14/3 - 29/3	15	25/7 - 9/8	24	5/12 - 19/12
7	30/3 - 12/4	16	10/8 - 22/8	25	20/12 - 31/12
8	13/4 - 27/4	17	23/8 - 7/9		
9	28/4 - 12/5	18	8/9 - 21/9		

Figure 29 – Relation between water slope (Δ) and water depth (h) for different moments in 1969 and 1970 (from Peters et al., 1977)

4.4 Intervention phase

In section 4.2, the case of the Bolikoko and Mpuasi channel was shown as an example. In this case the morphological evolutions are quite straightforward and a clear change of the course of the navigation route. It is clear that from the moment that the Mpuasi channel become more dominant (deeper), around 1970 – 1971, as can be seen in e.g. the distribution of the discharge (Figure 27), the orientation of the navigation channel is changed.

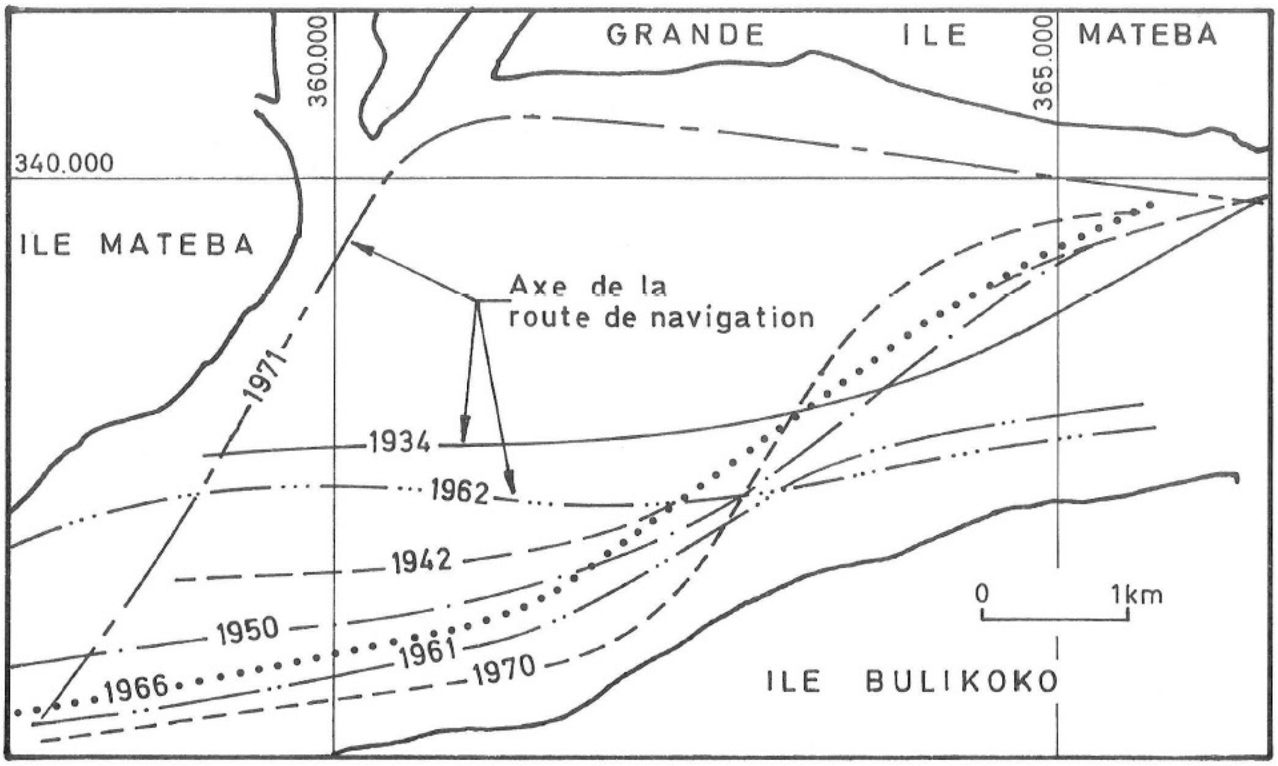


Figure 30 – Variation of the navigation route in the region of the Bolikoko and Mpuasi channel.

The change of the course of the navigation route can also change less dramatically. In Figure 31 the navigation route between 1976 and 1985 is shown around Mateba village. It can clearly be seen that the navigation route is following the natural, morphological changes, with a downstream movement of the meander, and an increase of the curvature of the bend. But also here, at a certain moment in time, another pathway was chosen for the navigation channel (Peters, 1986). The moment and course is determined by different morphological evolutions (sedimentation at the downstream end, hampering of the natural evolution of meanders by hard points) and hydrological opportunities (the occurrence of a larger flood event).

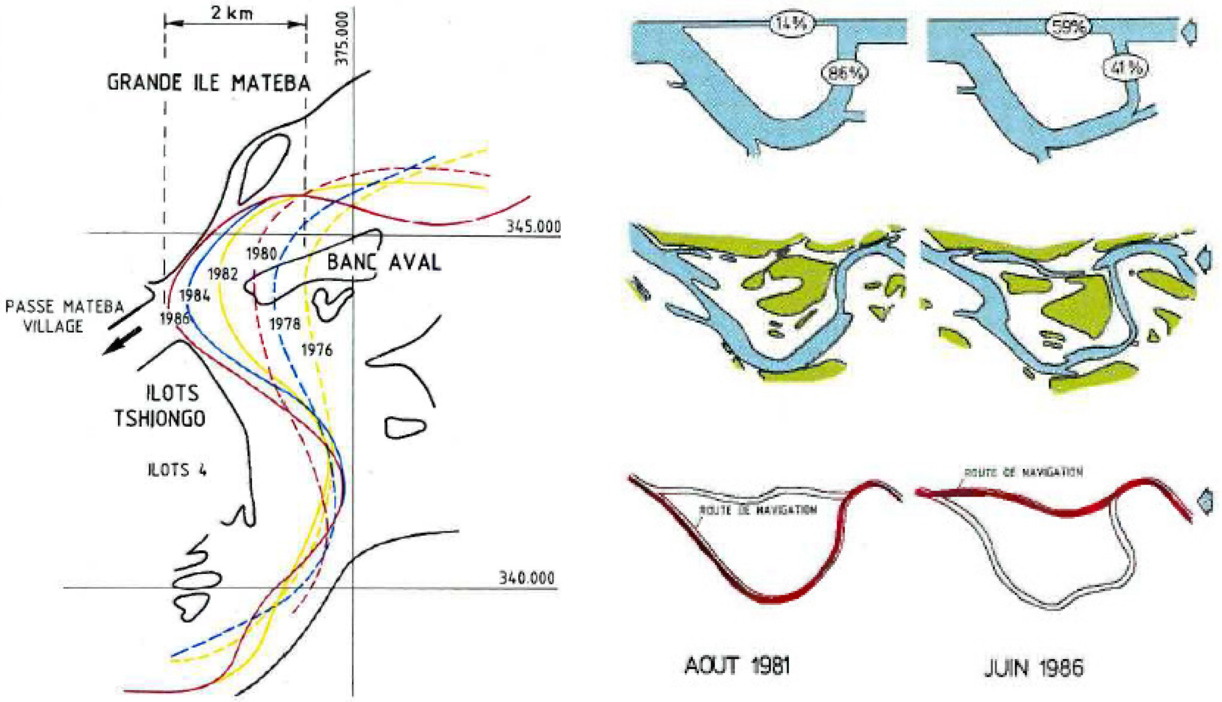


Figure 31 – Evolution of the navigation channel (left) around the ‘Central sill” for the period 1976 – 1985 and morphological changes (right) in that region (Sterling, 1986).

5 Application of morphological management on a hypothetical bifurcation

The “Région Divagante” is characterised by dynamic channels and sandbars, which make it challenging to define the optimal navigation channel. In the previous century the navigation channel has shifted regularly, in reaction to certain morphological evolutions. Without recent data[2] (topo-bathymetry, discharges, flow and sediment transport rates) it is impossible to present an applicable suggestion for the morphological management in the Région Divagante. In order to demonstrate the concept and the importance of good data-availability, a fictive case is presented. This case is applicable on a bifurcation in general, and as such not limited to a certain section within the Région Divagante.

In this case, the main channel has a bifurcation in a northern (initial small) and southern (initial large and therefore navigation) channel (Figure 32). For both channels annual measurements of discharge are available, and also annual dredging volumes are known. Initially, more than 70% of the total discharge flows through the south channel, while dredging volumes vary around 1 Mm^3/y (Figure 33). The disposal strategy does not take into account morphological consequences and dredged material is deposited in the south channel, just downstream of the dredging location.

Over the next years, a gradual increase in dredging volumes can be noticed, while also the discharge distribution changes. After 12 years, both channels transport similar volumes of water, indicating a trend that the south channel is degrading, while the north channel is becoming dominant. If good – i.e. executed well using state-of-the-art techniques and on a regular basis – measurements are available, this evolution can be detected. The concept of morphological management can then be applied in different ways. In this hypothetical case, two different strategies can be proposed:

1. *Anticipation*: the evolution is noticed and a strategy is applied trying to maintain the south channel as navigation channel
2. *Reaction*: the evolution is noticed (too) late, and a strategy is applied to switch from the south towards the north channel as navigation channel

In the first strategy “*anticipation*” (Figure 34, middle), a disposal strategy is used striving to maintain the south channel as the navigation channel. Dredged material is relocated upstream in the main channel, at a location near the northern border of the channel. The disposal is a soft measure and aims at guiding the flow more towards the south channel. If the deposited sediment is transported, it will move towards the north channel, reducing the cross-section of the channel. These two aspects, should lead to an increase in discharge for the south channel, in favour of the north channel.

In the second strategy “*reaction*” (Figure 34, bottom), a disposal strategy is used striving to allow the north channel to become the navigation channel. Dredged material is relocated upstream in the main channel, at a location near the southern border of the channel. The disposal is a soft measure and aims at guiding the flow more towards the north channel. If the deposited sediment is transported, it will move towards the south channel, reducing the cross-section of the channel. These two aspects, should lead to an increase in discharge for the north channel, becoming dominant over the south channel. This strategy follows the natural trend and can be seen as “working with nature”.

---

[2] Haedes was contacted to provide recent topo-bathymetric data, but they replied that no recent data was available for this project.

It should be mentioned that the choice between the proposed strategies is not trivial. Beside local aspects, also the broader picture should be taken into account. For this case, downstream of the bifurcation, a new system with multiple channels is present. Therefore the choice in one part, is influenced by and has an influence on the adjacent channels and sandbars.

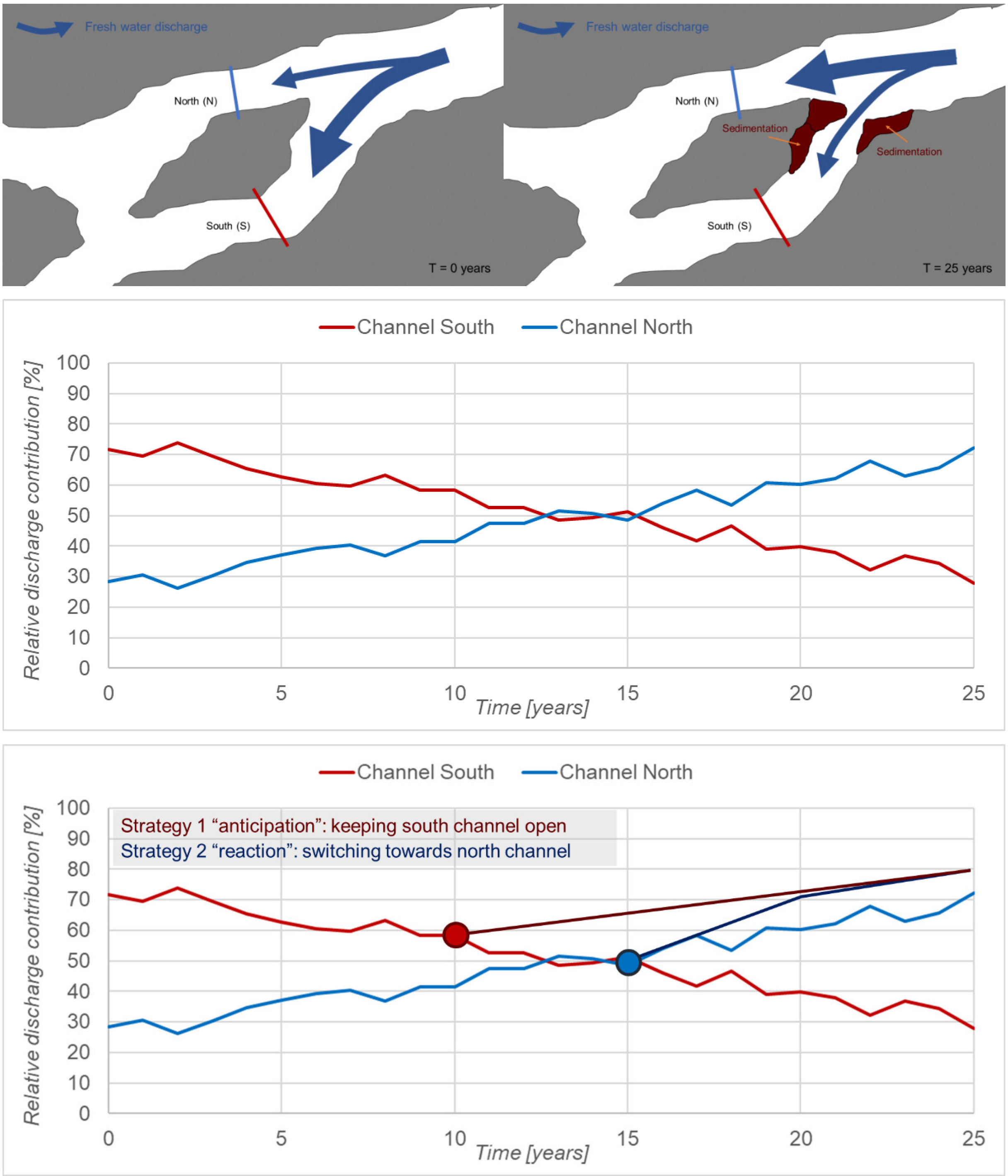


Figure 32 – Discharge distribution between north and south channel: initial (top-left) and final (top-right) situation without morphological management; evolution of discharge distribution without (middle) and with (bottom) morphological management

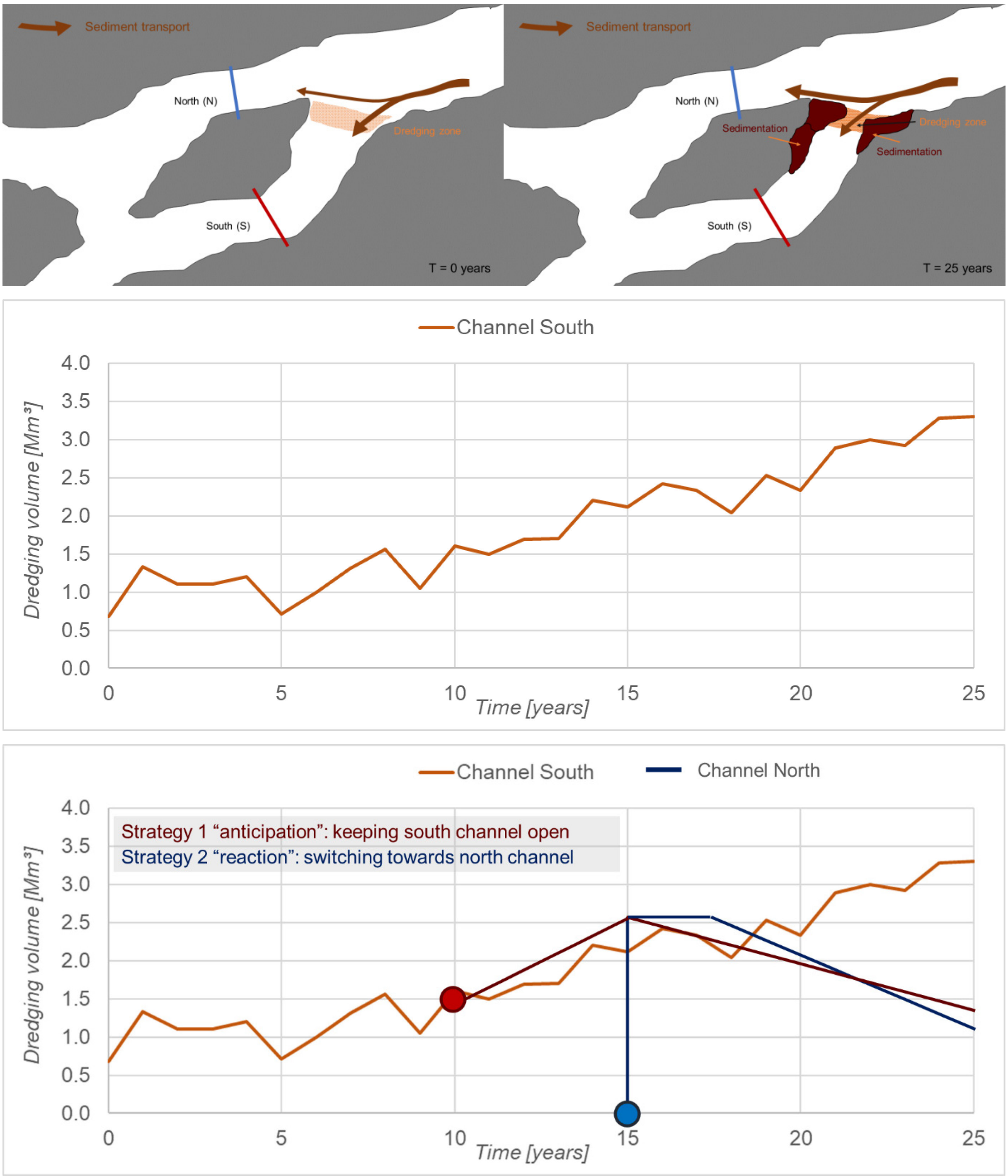


Figure 33 – Sediment transport for north and south channel: initial (top-left) and final (top-right) situation without morphological management; evolution of dredging volumes without (middle) and with (bottom) morphological management

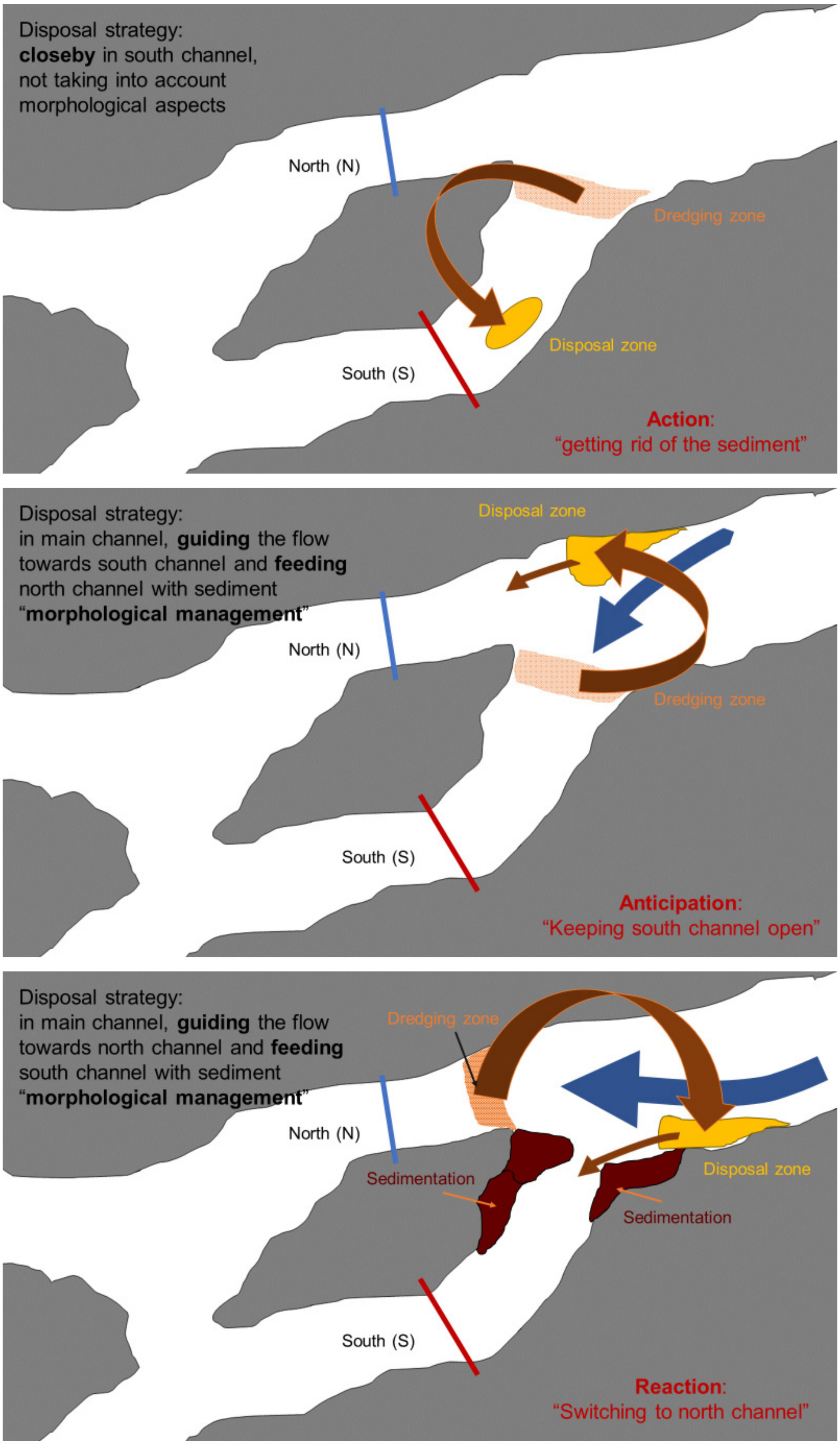


Figure 34 – Different sediment disposal strategies:
top: getting rid of the sediment by dumping it close to the dredging location
middle: morphological management: relocation of dredged sediment close to northern border in order to maintain south channel
bottom: morphological management: relocation of dredged sediment close to southern border in order to switch to north channel

6 Conclusion

In this report an overview is given of the Congo river, especially the Région Divagante, and its challenges for navigation. It should be emphasized that this is the most critical section and most of the activities of the Congolaise des Voies Maritimes (surveys, dredging) are concentrated there. The hydrology of the Congo river is characterized with two flood peaks during the course of the year. A larger peak ("la grande crue") is situated in the month December, a smaller peak ("la petite crue") is observed around April – May. During this peak events, a lot of sediment is imported into the Région Divagante, and the transport of sediment within this region is more intense, due to increased water currents (or stream power). At the downstream end, the Région Divagante is under tidal influence (without reversing the flow), which influences both hydrodynamics and sediment dynamics. As such, the Région Divagante is a very dynamic region from a morphological point of view.

In this desktop study, the resulting and observed evolutions in the morphology are explained, using existing studies from the 2nd half of the 20th century. Channels and sandbars have been shifting throughout the years, resulting in different morphological configurations. These evolution have their impact on the accessibility of the ports of Boma and Matadi, as different locations of the navigation channel were present over the last century.

Morphological management of a water system aims at pursuing a morphology sustaining all its different functions (recreation, navigation, safety against floodings,…). However the required morphological state can be different for each function, and the most suitable morphology has to be determined taking into account all those functions. Moreover, morphology is not static and "working with nature" is key in morphological management to "steer the morphology". Several options or measures can be taken, ranging from both dredging and disposal strategies to the creation of soft structures and the adaptation of hard structures. In complex (and realistic) situations, a combination of measures will be needed. The optimal strategy is also site specific, requiring insight in the crucial processes for the specific system.

On the Congo river the "méthode des dragages dirigés" (method of controlled dredging) is used in the past to steer some morphological evolutions and adapt the navigation route to this new conditions. This method is in the first place based on an analysis of the data, which is absolutely necessary. Both field surveys, water slopes, and discharge (current) data is indispensable. This data should be studied on a larger scale (considering the whole Région Divagante) to detect large scale evolutions and patterns, before zooming in on the specific region of interest (a local system with sills and pools, bend of a meander). Nowadays, efficient measurement techniques (e.g. ADCP) are available, nevertheless an appropriate consideration of the frequency, location and timing of the measurements is inevitable to obtain a useful database. The database should be a combination of long time monitoring data, making it possible to detect long term trends and short term project measurements, to answer specific questions on the zone of interest.

In the studies of the 2nd half of the 20th century special techniques were developed as the "law of the slopes" (section 4.3.2) and "tendency maps" (section 4.3.1) to respectively analyse certain morphological developments and predict trends toward erosion or sedimentation. The diagnostic phase is also complemented with general knowledge from physical laws describing the movement of meanders and a lot of knowledge was extracted from a physical scale model. On these models the pathways of the sand particles (bottom transport) could be observed and the effect of certain morphological measures (e.g. dumping of sediment material) could be addressed. Nowadays, also numerical models can be used as additional tool. Also here, a thorough calibration of the model based on measurements is important and limits of the applicability of these models, especially morphological models (e.g. Meire et al., 2019), should be taken into account. In any case, a combination of methods and tools is necessary to obtain a holistic, sustainable morphological management strategy.

6.1 A look ahead

However, due to climate change, also the driving forces for these morphologic evolutions could change in the (near) future. Nowadays, the tidal influence in the Région Divagante reduces quickly going upstream due to the dominance of the fresh water discharge. This region of influence will increase with sea level rise. In Figure 35 projections are shown for three scenarios of temperature increase (1°, 2° and 3 ° respectively), and 2 available locations closest to the mouth of the Congo river (source: project tool NASA: sealevel.nasa.go), namely Tema (Ghana) and Walvis Bay (Namibia). The regional sea level rise ranges between 0.4 and 0.6 m for respectively 1° or 3° global temperature increase by 2100.

Future projections of the hydrology are very uncertain (e.g. Karam, 2023), with a tendency for slightly lower annual runoff (approximately 5 %). However, especially the height of the floods are important for the evolutions within the Région Divagante, rather than the average values.

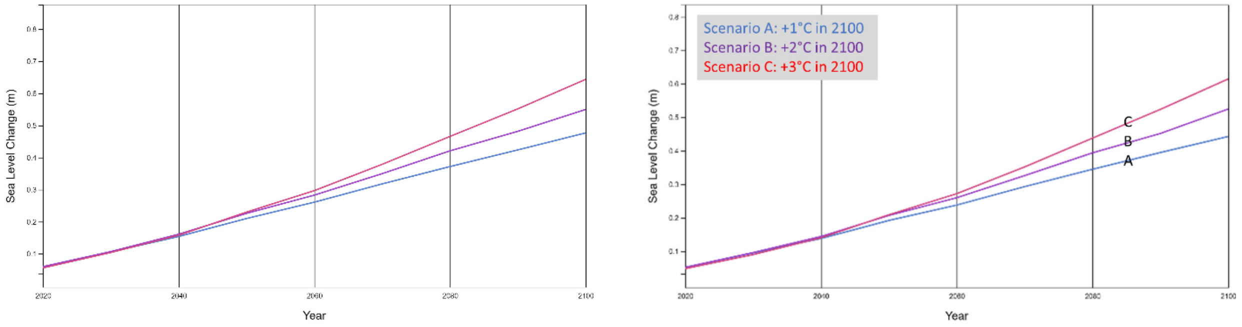


Figure 35 – Evolution of the sea level between 2020 and 2100 for Tema (left) and Walvis bay (right)
for scenario’s with 1, 2 and 3 degrees of warming

7 References

Bujika, N.M. (1987). HYDROGRAPHY IN THE NAVIGABLE PART OF THE ZAIRE RIVER, in: (1987). International Hydrographie Review. pp.23–33

Consortium Arcadis & Technum. (2007). Verruiming vaargeul – Hoofdrapport Passende Beoordeling. 130 pp.

Coen, I. (1986) Modelstudies Mateba. in: (1986). Symposium De Maritieme Toegang tot Zaire. pp. 77–87

Coen, I.; Peeters, A.; Van Hoeylandt, A.; Cumps, F.; Roovers, P.; Peters, J.J. (1983). Navigabilité du bief maritime du fleuve Zaïre: granulometrie des sédiments du lit de la région divagante. Mateba 21. *WL Rapporten*, 255_21. Laboratoire de Recherches Hydrauliques: Anvers. different pagination pp.

Ides, S.; Plancke, Y.; De Mulder, T.; Mostaert, F.; Peters, J.J. (2006). De stortstrategie ‘Walsoorden’: een nieuwe benadering voor het beheren van de morfologie en de ecologie van de Westerschelde [POSTER]. Waterbouwkundig Laboratorium: Borgerhout

Karam, S.; Zango, B.-S.; Seidou, O.; Perera, D.; Nagabhatla, N.; Tshimanga, R.M. (2023) Impacts of Climate Change on Hydrological Regimes in the Congo River Basin. ustainability 15, 6066. https://doi.org/10.3390/su15076066

Meire, D.; Plancke, Y.; De Maerschalck, B.; Mostaert, F. (2019). Agenda voor de toekomst - Morfologie Mesoschaal: deelrapport 3. Gevoeligheidsanalyse voor morfologische simulaties in de Westerschelde. Versie 3.0. *WL Rapporten*, 14_024_3. Waterbouwkundig Laboratorium: Antwerpen. 47 + 40 p. bijl. pp.

Peters, J.J.; Cunge, J.A.; Plancke, Y.M.G. (2006). Role of practinioners and hydroinformatics in the decision-making process for morphological management of an estuary, in: (2006). Proceedings of the 7th International Conference on Hydroinformatics

Peters, J.J.; Plancke, Y. (2010). Limitations in morphological modeling within the framework of the European bird and habitat directives., in: (2010). SIMHYDRO 2010: modèles hydrauliques et incertitudes, Nice, 2-4 juin 2010 [CD-ROM]

Peters, J.J.; Sterling, A. (1971). Etude de l'amélioration du bief maritime du fleuve Congo: la dynamique de la sédimentation de la région divagante du bief maritime du fleuve Congo. Mateba VII. *WL Rapporten*, 255_7. Laboratoire de Recherches Hydrauliques: Anvers. Vol. 1 (Text); Vol. 2 (Figures) pp.

Peters, J.J.; Sterling, A. (1975). Etude de l'amélioration du bief maritime du fleuve Zaïre: la méthode des dragages dirigés. Mateba 12. *WL Rapporten*, 255_12. Laboratoire de Recherches Hydrauliques: Anvers. 38 pp.

Peters, J.J.; Coen, I.; Roovers, P. (1977). Etude de l'amélioration du bief maritime du fleuve Zaïre: la méthode des dragages dirigés. Applications: Mateba 14. *WL Rapporten*, 255_14. Laboratoire de Recherches Hydrauliques: Anvers. 25 + annexes pp..

Peeters, A.; Van Hoeylandt, A.; Cumps, F.; Coen, I.; Roovers, P.; Peters, J.J. (1982). Navigabilité du bief maritime du fleuve Zaïre. Rapport général 1981: Mateba 20. *WL Rapporten*, 255_20. Laboratoire de Recherches Hydrauliques: Anvers. 36 + appendices pp.

Peters, J.J. (1986). Etude récentes de la navigabilité, in: (1986). Symposium De Maritieme Toegang tot Zaire. pp.21–42

Plancke, Y.; Peters, J.J.; Ides, S.; Plancke, Y.; Peters, J.J.; Ides, S. (2006). A new approach for managing the Western Scheldt's morphology and ecology, in: (2006). 31st PIANC congress, 14-18 May 2006, Estoril Congress Centre, Portugal: book of papers. PIANC = AIPCN: Brussels. ISBN 88-8940-506-6. pp.[1-13]

Plancke, Y.; Vos, G.R.; Schrijver, M. (2015). New disposal strategy in the Schelde-estuary: using dredged sediment to create benefits for nature, in: (2015). E-proceedings of the 36th IAHR World Congress 28 June – 3 July, 2015, The Hague, the Netherlands. IAHR

Antwerp Port Authority. (2012). Morphological management of estuaries – Case study of the Scheldt estuary. 39 pp.

Richardson, E.V.; Simons (1966) Resistance to flow in Alluvial Channels. U. S. G. P. O. 422-J.

Steenstra, B. (1986). De geomorfologie van Beneden-Zaire, in: (1986). Symposium De Maritieme Toegang tot Zaire. pp.21–42

Sterling, A. (1986b). Exposé introductif in: (1986). Symposium De Maritieme Toegang tot Zaire. pp.21–42

Sterling, A. (1986). Etude de la navigabilité, in: (1986). Symposium De Maritieme Toegang tot Zaire. pp.11–20

Tourian, M.J; Papa, F.; Elmi; O., Sneeuw; N.: Kitambo, B.; Tshimanga, R.M.; Paris, A.; Calmant, S. (2023) Current availability and distribution of Congo Basin's freshwater resources. COMMUNICATIONS EARTH & ENVIRONMENT | https://doi.org/10.1038/s43247-023-00836-z

Waterbouwkundig Laboratorium (1968). Etude de l'amélioration du bief maritime du fleuve Congo. Rapport général: Mateba I. WL Rapporten, 255_1. Laboratoire de Recherches Hydrauliques: Anvers. 67 + annex. pp.

8 Appendix

Table 2 – Overview of current names and former names in the Region Divagante

Current name	**Previous name**
Ntua - Nkulu	Banc d’Anvers
Passe Kindu	Passe Nisot
Passe Bunia	Passe Mayaudon
Passe Tumbimbi	Camoens
Ziamanganga	Convesaingh
pass Mateba aval	Convesaingh sill

DEPARTMENT **MOBILITY & PUBLIC WORKS**
Flanders hydraulics

Berchemlei 115, 2140 Antwerp
T +32 (0)3 224 60 35
F +32 (0)3 224 60 36
flanders.hydraulics@vlaanderen.be
www.flandershydraulics.be