The Niger, a lifeline

Effective water management in the Upper Niger Basin

Leo Zwarts (RIZA), Pieter van Beukering (IVM),
Bakary Kone (Wetlands International), Eddy Wymenga (A&W)

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This multidisciplinary study has been carried out in the framework of the interdepartmental Dutch Partners for Water programme "Water for food and ecosystems" and the PREM-programme (Poverty Reduction and Environmental Management) of the Dutch Ministry of International Cooperation. The project has been executed during 2002-2004 in narrow co-operation with the Malian authorities and institutions.

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Preface

Water, a source of life, forms a unique resource as well for several concurrent exploitations.

Considering this, the complexity of basin management appears to be a challenge in view of which the soundness of decisions whether taken by administrators or communities involved constitutes the best guarantee for stability and harmonious development.

The Niger River Basin covering practically all administrative and economical regions, represents for Mali what a vascular system means for the human body.

In view of this, every study which helps to understand an economic, social and cultural phenomenon in this geographical area, is considered by the Malian Government as a contribution to national edification.

In this context the present work describing the life of certain Niger River communities in detail, comes as a contribution by a Son of Mali, to the joint management of this major resource.

Therefore, in my capacity as executive water manager, we appreciate this quality achievement as a contribution to obtaining the objectives and to the investigation of interactions between the ecosystem and the socio-economic activities in the Niger River Basin.

Hamed Diane SEMEGA
Ministre des Mines, de l'Energie et de l'Eau du Mali

1 INTRODUCTION

Leo Zwarts
Pieter van Beukering
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Water shortage has been identified by the United Nations Environment Programme (UNEP) as one of the most serious problems of the new millennium. For many decades, however, it has already been a dire problem for millions of people living along the southern fringe of the Sahara desert. For the communities living in the semi-arid, western Sahel zone the Senegal and the Niger rivers are a lifeline. Indeed, Mali is a classic case of a 'river-dependent economy' that is subject to enormous seasonal variation in rainfall and river flow. A popular solution to this climate dependency in the western Sahel zone has been the development of hydroelectric and hydro-agricultural irrigation schemes (Fig. 1.1).

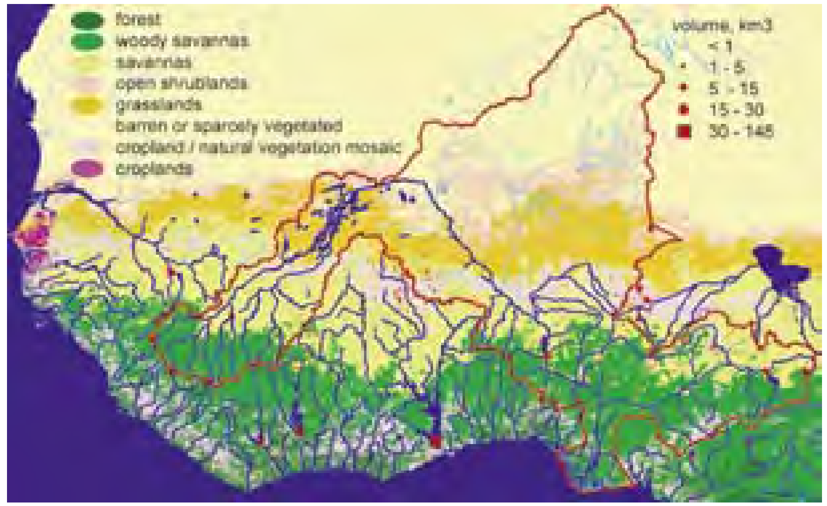


Fig. 1.1. The Niger Basin (red outlining) and the existing dams in western Africa (red dots).

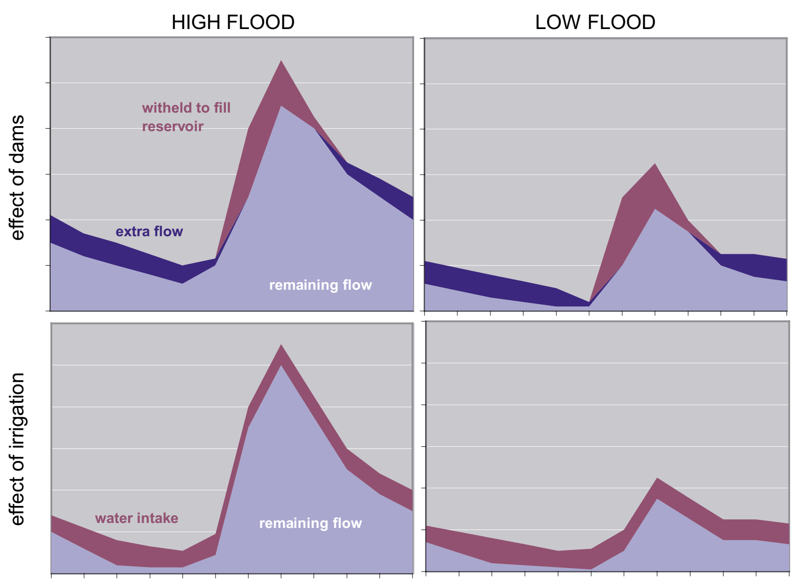


Fig. 1.2. Schematic hydrological effects of dams and water intake for irrigation during the flood cycle in years with a high and low flood. The flood cycle in the Western Sahel zone runs from June to December. Lowest flood levels occur from March to May.

Poverty Reduction Strategy Paper

The Poverty Reduction Strategy Paper (PRSP) of Mali constitutes the sole framework for Mali's development policies and poverty reduction strategies (GoM 2002). This influential document highlights the need to exploit the country's hydroelectric potential in the order of 5,000 GWh/annum. So far, high costs of both energy equipment and distribution networks have prevented expansion on such a scale. Mali's potential hydro-agricultural capability is also substantial, estimated at 2 million hectares. A review of the PRSP by the International Development Association (IDA) and the International Monetary Fund (IMF) confirms this, stating that "further development of Mali's untapped hydrological potential for agriculture and drinking water purposes is a critical need, as it directly addresses one of Mali's core vulnerabilities, that of the temporal and spatial variability in rainfall, as well as the uncertainty of climatic conditions" (IDA & IMF 2003).

Although Mali's hydroelectric and hydro-agricultural potential has yet to be fully realised, it is widely questioned whether the costs and benefits of such mega-investments are properly estimated. Besides the economic feasibility (i.e. direct costs and benefits) of additional dams, it is still unclear what the indirect effects of hydroelectric and hydro-agricultural schemes are on downstream beneficiaries of rivers. These beneficiaries include fishermen, cattle breeders, shipping companies and farmers, as well as the biodiversity of the river and connected floodplains.

Balancing interests

Hydrological interventions (i.e. dams and irrigation schemes) aim to increase economic independence and food security in the unstable Sahel environment. Tapping the Niger's flow, however, is not without consequences. Fig. 1.2 shows how irrigation takes a fixed amount of water throughout the year, while hydroelectric structures store water at peak flood levels and subsequently release it. The hydrological effects of both are felt most profoundly during the dry season and in years with low floods.

The following explanation helps to illustrate this: a natural river discharge of 10 to 20 km3 varies annually by a factor of 2. When extracting 5 km3,

the downstream discharge fluctuates between 5 to 15 km3, in other words, by a factor of 3. Would this increasing downstream instability also lead to a decrease in food security? A long-term, sustainable management of the water system and it surrounding should be based on an integrated approach, where the trade-off between water quantity and reliability are taken into account.

Especially in the Sahel where water is so scarce, it is essential to optimise the use of the water, since nearly each use has an effect on the (potential) use downstream. Wise use of water would be even more important if the newly planned dams in the Upper Niger (Fomi), the Bani (Talo) and the Niger downstream of the Inner Delta (Tossaye) would be operational (Fig. 1.3).

Fig. 1.3. The Upper Niger Basin with three existing dams (Sélingué, Sotuba, Markala), one in construction (Talo) and three still in study (Fomi, Djenné and Tossaye).

Scope of this study

The merits and shortcomings of costly hydrological structures have to be carefully balanced. In this study we incorporate downstream interests into our analysis. Downstream outcomes are inherently difficult to quantify, and are therefore often omitted in similar enquiries.

The aim of this study is to develop a decision-support system for effective river management in the Upper Niger, in which ecological and socio-economic impacts and benefits of dams and irrigation systems can be analysed in relation to different water management scenarios. Multidisciplinary in nature, this study draws on the fields of hydrology, ecology and environmental economics.

To assess the impact of the three man-made structures in the Upper Niger region, four hypothetical scenarios were simulated and analysed. These scenarios are used as central reference points throughout this study:

- Scenario 0. Without Office du Niger (ON) & Sélingué (Sél): In this scenario, neither Sélingué nor Office du Niger are present in the Upper Niger. This hypothetical situation acts as a 'baseline', illustrating the natural hydrological state more than 50 years ago;

- Scenario 1. Without Office du Niger & with Sélingué: In this scenario, Sélingué is still present but Office du Niger is absent;
- Scenario 2. With Office du Niger & with Sélingué: This scenario reflects the present situation, in which Sélingué and Office du Niger are in full operation in the Upper Niger;
- Scenario 3. With Office du Niger, Sélingué and Fomi: This scenario is similar to the present scenario but includes the existence of the proposed Fomi dam. The main purpose of this scenario is to evaluate the impact of this planned dam.

In this stage, the study will ignore three other dams: Talo, Djenné and Tossaye (Fig. 1.3).

Impact pathway approach

To determine the costs and benefits, a wide range of information is required. A consistent way to organise this information is to pursue the sequence of underlying processes, starting with the cause of an impact, on to the physical impact and ending with the social, economic and ecological effects. This so-called "impact pathway approach" is a methodology that proceeds sequentially through the pathway, linking causes to impacts, and valuing these impacts subsequently. The framework of the impact pathway represents the physical and socio-economic processes resulting from water management in the Upper Niger.

The evaluation of the physical effects of the dams is possible since the daily variation in water level and river discharge has been registered at many different stations along the Upper Niger for many decades. In combination with remote sensing data, this allows for statistical analyses to reveal the downstream effect of the dams and irrigation. The same data are also entered into a water balance model. These results permit to approximate the main effects of each scenario on the various benefit categories and evaluate the changes for the various stakeholders (i.e. local, national and international agents) and the involved regencies (i.e. upstream and downstream).

Having established and tabulated the full range and significance of the effects, changes are valued in monetary terms. The main impact pathways that will be covered include agriculture, fisheries, livestock, biodiversity, energy supply and transport.

Outline of the report

The impact pathway approach requires a substantial input of data from various disciplinary. In that sense, the study can be considered to be truly multidisciplinary. This is reflected in the outline of the report (Figure 1.3).

Chapter 2 summarizes the available hydrological information on seasonal and annual variation in river discharge and rainfall patterns. The chapter includes a model simulating the behaviour of the river basin under various hydrological conditions and infrastructures and in this way offers a tool to evaluate a variety of measures related to infrastructure. The information from Chapter 2 is used in Chapter 3 to describe the effect of the infrastructures on the flooding of the Inner Niger Delta. The flooding itself is described in detail, using remote sensing techniques.

The next six chapters describe the relationship between, on the one hand, the flooding of the Inner Niger Delta and, on the other hand, people (Chapter 4), fisheries (Chapter 5), vegetation (Chapter 6), livestock (Chapter 7), agriculture (Chapter 8) and ecological values (Chapter 9). The collected data are used to indicate the impact of upstream infrastructures.

The following two chapters deal with the existing upstream infrastructure itself. The chapters describe the economic and ecological values of the Sélingué reservoir (Chapter 10) and the irrigation area of Office de Niger (Chapter 11).

All information from chapter 9 to 11 is combined for an ecological evaluation of the direct and indirect impact of the man-made infrastructures (Chapter 12). One of the side effects of the hydropower reservoir and irrigated rice fields is the creation of an artificial wetland. Chapter 12 investigates whether this gain is sufficient to compensate for the evident ecological losses downstream.

Chapter 13 analyses the effect of the infrastructures on the transport and integrates all information given

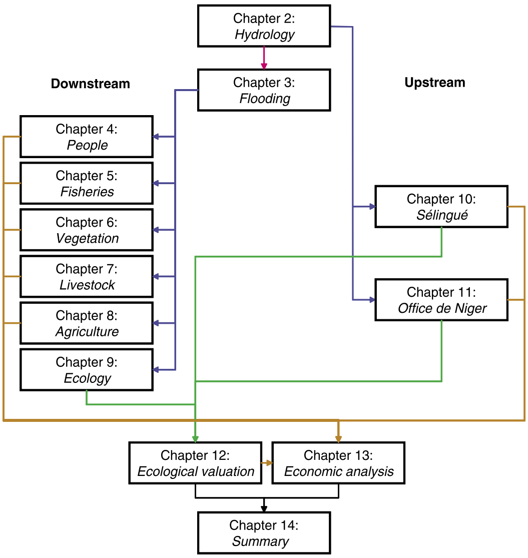


Fig. 1.4. Outline of the study.

in the previous chapters. The monetary values are calculated and the economic values of existing and planned dams evaluated, using financial information, such as initial investment and maintenance costs.

Chapter 14 gives the summary, the main conclusions and a number of policy recommendations.

Acknowledgements

The *Water & Ecosystems* programme, financed by the Dutch interdepartmental *Partners for Water* programme, gave RIZA the opportunity to set up a study on the possibilities for an integrated water management of the Upper Niger and to commission DNH and WL|Delft Hydraulics to develop a water balance model of the Upper Niger and Wetlands International and Altenburg & Wymenga to analyse the ecological gains and losses of the man-made infrastructures.

Another programme of Partners for Water, *Food for Water*, enabled Wetlands International to study the problem of the food security in the Upper Niger Basin, together with different Malian organisations. The added value of the PREM-programme of the Dutch Ministry of International Cooperation was a further elaboration of these socio-economic aspects by IVM. From the beginning, we worked closely together and already soon it was obvious that we should make a common, integrated final report.

Vincent van de Berk (LNV) initiated both Partner for Water projects and was from the beginning our stimulator. We are grateful to Andrea Almasi (LNV), Albert Beintema (Alterra), Hans Drost, Bart Fokkens and Willem Oosterberg of RIZA, Nicoline van den Heuvel and Gerard van der Kolff of Partners for Water. We also appreciate the support of the Dutch Embassy (Bamako) and the assistance of the Direction Nationale de la Conservation de la Nature (Bamako) and the Direction Régionale de la Conservation de la Nature (Mopti). Moreover, we thank Annemiek Roeling (RIZA) and three students of the master course Environmental Resource Management (ERM), Ernst Eisma, Kim van der Leeuw and Elena Sultanian, for their assistance in the research. We are also grateful to the following persons for carefully reading the draft text: Annebelle Aish (Chapter 1, 14), Luke Brander (Chapter 13), Daan Bos (Chapter 12) and Rob Bijlsma (Chapter 2-10, appendix 8).

During the study we worked closely together with Direction Nationale de l'Hydraulique (DNH), Opération Pêche Mopti (OPM), Office de Niger (ON) and Office de Développement Rural de Sélingué (ODRS). This study heavily relies on their data. A lot of data were also found in the annual reports and other data sets of the following Malian authorities: CPS-MDR, DGE, DRAMR, EDM, IER, ORM, ORS; see appendix 12 for their full names. We thank them all for their help and hope this study will be the start of a fruitful cooperation in the future.

2
HYDROLOGY OF THE UPPER NIGER

Leo Zwarts
Navon Cissé
Mori Diallo

2.1 Introduction

La Grande Sécheresse – the Great Drought in the early eighties – was a major catastrophe for the people in the Sahel. The rainfall was poor, but the decline of the river flow was even greater. Many people in Mali were convinced that the Sélingué dam built in that decade was the cause of the low discharge of the Niger River. Environmentalists used the same argument in international debates about dams. Hydrologists, on the other hand, reasoned that it was impossible that the relatively small reservoir had such a large impact. The question remains who was closer to the truth.

The water discharge of the Niger River in Mali fluctuates significantly. The reasons for these fluctuations are natural as well as man-made. The aim of this chapter is to develop a model that simulates the hydrology of the Upper Niger River, which captures natural variations as well as the impact of man-made structures. The hydrological model provides the first tool that leads to the explanation of the overall ecological and economic effect of dams and reservoirs in the Upper Niger.

The structure of this chapter is as follows. After the introduction (Section 2.1), the hydrological regime will be explained in terms of climate influences, the role of groundwater, seasonal variation in the river discharge, and the presence of reservoirs and dams in the Upper Niger (Section 2.2). Next, this latter aspect is addressed in more detail, focussing specifically on Sélingué, the Markala Barrage, Sotuba, and the planned structures at Fomi, Tossaye, Talo and Djenné (Section 2.3). The human impact on river discharge is estimated by means of the water balance approach and the statistical analysis in Section 2.4. Scenarios for further analysis of the impact of dams in the Upper Niger are presented and explained in Section 2.5. Finally, main lessons learned are summarised (Section 2.6).

2.2 The hydrological regime

The Niger River basin belongs to the largest river basins in Africa. The total length of the river is about 4,200 kilometres. The river basin of the Niger covers 7.5% of the continent and spreads over ten countries. Rising in Guinea, the river flows northeast into Mali. East of Tombouctou, it bends to the southeast, flowing across western Niger and forming part of the international boundary between Niger and Benin. From there, the Niger enters Nigeria and flows predominantly south, finally entering the Atlantic Ocean through an extensive delta (Fig. 2.1).

Information on the Niger River Basin provided by FAO indicates that most of the Niger River basin is located in Mali (25.5 %) and Niger (24.8 %). Table 2.1 gives general information on the extent of the Niger River Basin and the various countries that form part of the basin. The area of the Niger River basin in Guinea and Ivory Coast together is only 5.3% of the total area of the basin. However, because the sources of the Niger River are located in these countries this part is crucial for the basin. The quantity of water entering Mali from Guinea and Ivory Coast (i.e. about 40 km^3/yr) is actually greater than the quantity of water entering Nigeria from Niger (i.e. 36 km^3/yr), about 1800 km further downstream. This reduction is due to, among other reasons, the enormous decline in runoff in the Inner Delta in Mali through evaporation combined with absence of runoff from the left bank in Mali and Niger (the Sahara desert region).

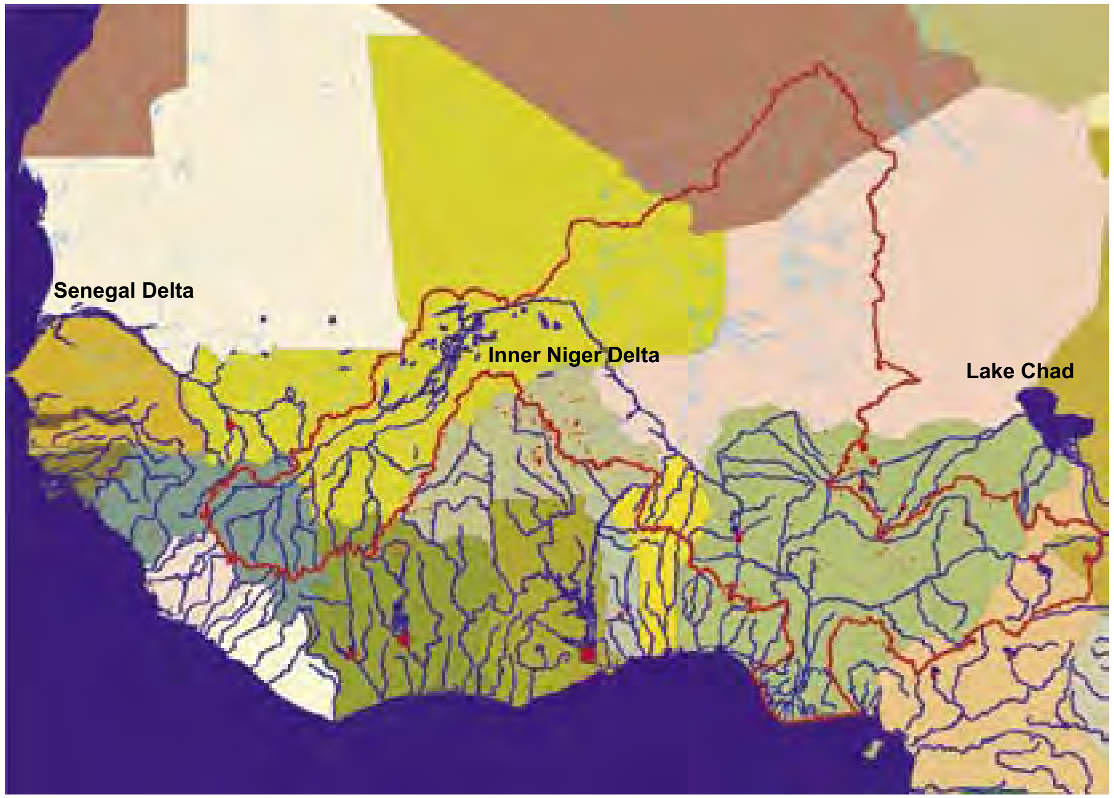


Fig. 2.1. The Niger Basin (red outlining). The Niger originates in Guinea and Ivory Coast, passes Mali, Niger and enters the Atlantic Ocean in Nigeria. The Niger Basin also extends over Algeria, Burkina Faso, Benin, Chad and Cameroon.

Table 2.1. The surface area of the Niger basin (2,273,946 km^2) split up for the 10 countries. These figures are compared to the surface per country. The average annual rainfall in the basin area is presented to give an idea of the contribution of each country to the river system. Source: FAO (internet site).

Country	Total area of the country (km²)	Area of the country within the basin (km²)	As % of total area of basin	As % of total area of country	Average annual rainfall in the basin area		
					min.	max.	mean
Guinea	245 857	96 880	4.3	39.4	1240	2180	1635
Ivory Coast	322 462	23 770	1.0	7.4	1316	1615	1466
Mali	1 240 190	578 850	25.5	46.7	45	1500	440
Burkina Faso	274 000	76 621	3.4	28.0	370	1280	655
Algeria	2 381 740	193 449	8.5	8.1	0	140	20
Benin	112 620	46 384	2.0	41.2	735	1255	1055
Niger	1 267 000	564 211	24.8	44.5	0	880	280
Chad	1 284 000	20 339	0.9	1.6	865	1195	975
Cameroon	475 440	89 249	3.9	18.8	830	2365	1330
Nigeria	923 770	584 193	25.7	63.2	535	2845	1185
Niger basin		2 273 946	100.0				

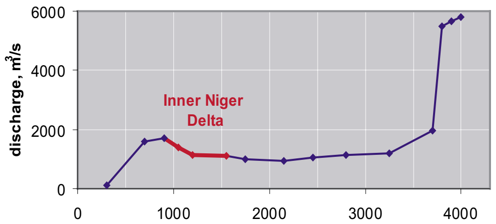


Fig. 2.2. Average annual river discharge of the Niger as a function of the distance from its origin. The Inner Niger Delta (indicated with a red line) is situated between Ségou (900 km) and Tombouctou (1500 km).

The Niger River enters Mali through various tributaries from Guinea. The main tributary, the Bani, originates from Ivory Coast and SW Mali. The total catchment area of the Bani (129,000 km^2) is nearly as large as the rest of the Upper Niger basin upstream of the Inner Niger Delta (147,000 km^2).

This study focuses on the hydrology of the Upper Niger River. The Upper Niger is defined as the Niger basin up to and including the Inner Delta. The total inundated area covered by the Inner Delta, which is a network of tributaries, channels, swamps and lakes, can reach around 30,000 km^2 in the flood season. As shown in Fig. 2.2, after a rapid increase in discharge due to abundant rainfall in Guinea, Ivory Coast and southwestern Mali, reaching values in the order of 1000 m^3/s at Koulikoro, the flow through the Inner Delta results in a gradual decrease in the discharge. The river 'loses' a part of its potential flow between Ségou, at 900 km from its source, and Tombouctou, at 1500 km, due to evaporation caused by the hot climate. The water supply from the Bani tributary, which flows into the Niger River at Mopti, at 1150 km from the source, does not compensate for the 'losses' in the Inner Delta. For a long stretch afterwards there is hardly any inflow and the discharge remains rather stable, until another humid region is passed in the lower reaches of the Niger River shortly before entering the Atlantic Ocean.

A number of factors cause the discharge levels of Upper Niger River to vary significantly. These include:

- Climate
- Groundwater
- Seasonal variations
- Dams and reservoirs

In the following sub-sections, these factors will be discussed subsequently.

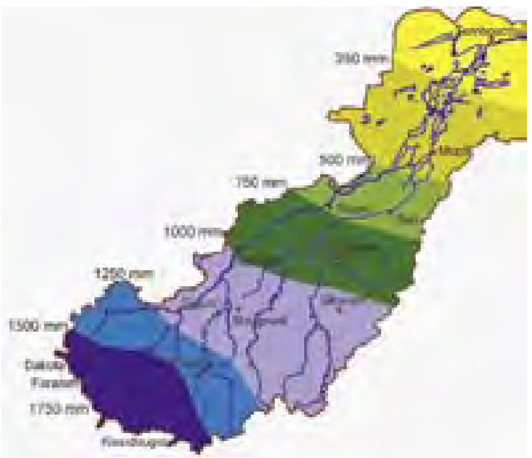


Fig. 2.3. Annual precipitation (mm/ year) in the basin of the Upper Niger shown as five different zones (Source: Quensière et al. 1994a). Thirteen meteorological stations are indicated with red dots.

Climate

The annual rainfall in the Upper Niger varies between less than 250 mm in the North-East and over 1750 mm in the South-West (Fig. 2.3). In general the climate of Mali is semi-arid to arid with a clear dry season (December – May). The rainy period covers three months in the semi-arid zone, 5-7 months in the Sudan zone and 8 months in the Guinean zone. As shown in Fig. 2.4, in all zones the rainfall reaches its peak in August. Fig. 2.4 gives the average rainfall per month over a period of 30 years. Between years the variation is large, especially in the semi-arid zone. As a consequence of this natural variation there is also a large fluctuation in the river discharge.

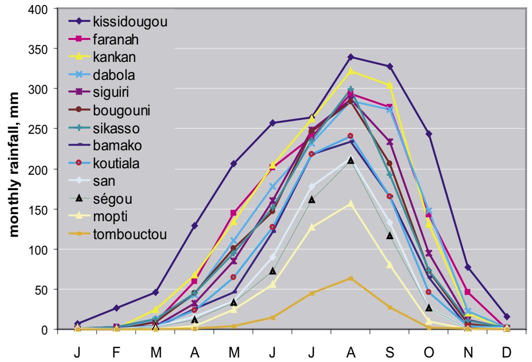


Fig. 2.4. Average monthly rainfall (mm) in the period 1961 - 1990 at 13 sites situated in the Upper Niger Basin (see Fig. 2.3).

Long series of rainfall measurements are available for the Inner Delta and surroundings.[1] The longest series originates from Tombouctou where rainfall has been recorded since 1897. From 1926 onwards there are near-complete series for Bandiagara, Djenné, Gao, Goundam, Ke-Macina, Markala, Mopti, Niafunke, San and Ségou. At another seventeen stations within the Inner Delta rainfall has been measured since 1981 by the Institut d'Economie rurale (IER), Opération Riz de Ségou (ORS) and Opération Riz de Mopti (ORM).

Fig. 2.5 shows the variation in rainfall calculated over eleven stations where the rainfall has been registered since 1926 at least. The figure also shows the maximum water level in the Inner Delta, as measured in Mopti. There is no causal relationship between flood level in the Inner Delta and local rainfall, since

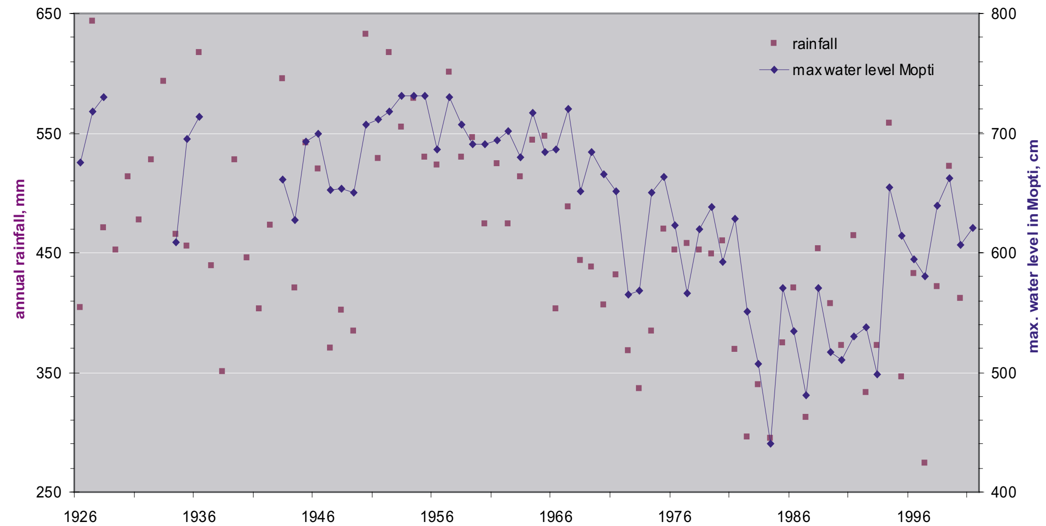


Fig. 2.5. Variation in annual rainfall in Inner Delta and maximum water level in Mopti (cm). Rainfall is averaged over 11 stations: Bandiagara, Djenné, Gao, Goundam, Ke-Macina, Markala, Mopti, Niafunke, San, Ségou and Tombouctou.

[1] There are many studies on the variability of rainfall in the Sahel. The data from all meteorological stations in the world are collected by the World Meteorological Organisation (WMO). There are more than hundred of such WMO-stations in the western Sahel. Several of these stations measure rainfall for more than 100 years. Since data are increasingly lacking in long series of annual rainfall, indices are calculated after which missing values have been "imputed" using data from neighbouring stations.

flooding of the Inner Delta is largely determined by the river discharge of the Niger and the Bani. It is obvious, however, that high flood levels, such as occurring from 1950 to 1960, coincide with abundant local precipitation. Vice versa, years with low floods (1980-1990) coincided with limited rainfall. The relationship between local rainfall and flood level is further illustrated in Fig. 2.6. The two series shown in Fig. 2.5 are plotted against each other. This figure shows that the flood level is almost by definition high if annual rainfall in the Inner Delta exceeds 500 mm. When there is not much rain, flood levels are generally substantially lower. Yet, the level of flooding in dry seasons varies as much as 200 cm.

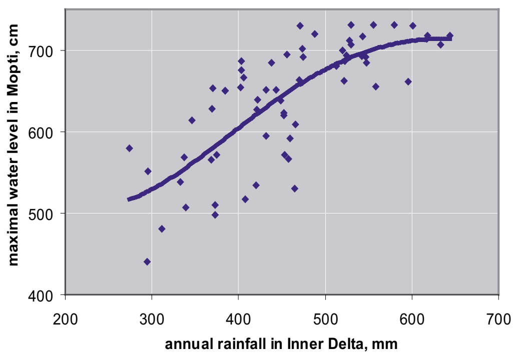


Fig. 2.6. The relationship between local rainfall in the Inner Delta and the maximum water level in Mopti.

Groundwater

Besides rainfall, groundwater aquifers also play an important role in the level of discharge of the Niger river. Fig. 2.7 shows the river discharge at Koulikoro and the average rainfall in seven upstream meteorological stations: Dabola, Dinguiraye, Faranah, Kankan, Kouroussa, Kissidougou and Siguiri (see Fig. 2.3 for the location of these stations). Rainfall data are collected at different stations since 1922. The river discharge of the Niger is measured in Koulikoro since 1907. At that site, the annual river discharge has been as high as 2308 m^3/s (1925) and as low as 637 m^3/s (1989).

Clearly, there is a relationship between rainfall and river discharge in Koulikoro, yet the variation in river discharge is larger than the variation in precipitation. The river discharge is very low after a series of dry years (i.e. the period around 1940 and especially since 1970) and it is high after a period of wet years (e.g. the early fifties). Hence Mahé *et al.* (1997) conclude that rainfall shortage causes a reduction of the groundwater. This was confirmed by later studies on the groundwater level (Mahé *et al.* 2000).

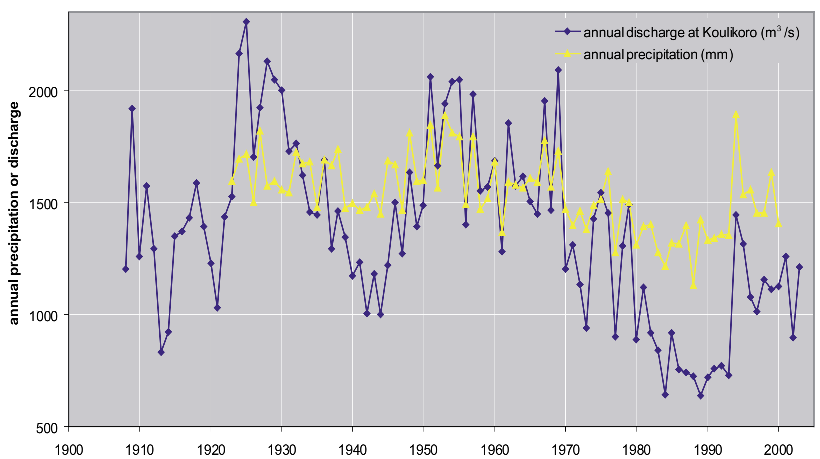


Fig. 2.7. The annual river discharge at Koulikoro (m^3/s), 60 km downstream of Bamako, and the annual rainfall (mm/year) in the Inner Niger basin upstream of Bamako.

The effect of rainfall shortage on groundwater is not everywhere the same within the Upper Niger. Mahé *et al.* (1997) studied this relationship in five different sub-basins in the Upper Niger: Bani, Sankarani, Tinkisso, Milo and Niandan. Fig. 2.8 summarises their work and shows the average yearly river discharge and rainfall during 39 years. In all basins, the relative standard deviation is much larger for the river discharge than for the rainfall, but the discrepancy between river discharge and rainfall is particularly large for the Bani. This implies that groundwater storage in the Bani basin has a larger effect on the river discharge than in the other basins. If this were true, one might expect that the river discharge is not only dependent on the rainfall in the foregoing months, but also in the preceding year(s).

A multiple regression analysis was performed to reveal to what degree the river discharge would be dependent on the rainfall in the foregoing years. The river discharge of the Bani is a function of the rainfall in the preceding three years. For each additional mm of rain, the discharge increases with 1.1 m^3/s in the same year. Independent of rainfall in the same year, the discharge increases with 0.6 m^3/s for each mm of rain in the the foregoing year. The effect of two year before is even still significant with 0.4 m^3/s. In contrast to the Bani, the rainfall in the foregoing years has no effect on the river discharge of the Sankarani. Mahé *et al.* (1997) suggest that the groundwater storage in the Sankarani basin is less variable due to the dam in the Sankarani, where the Sélingue reservoir works as a kind of buffer. More detailed results of the multiple regression analysis are given in Appendix 1.

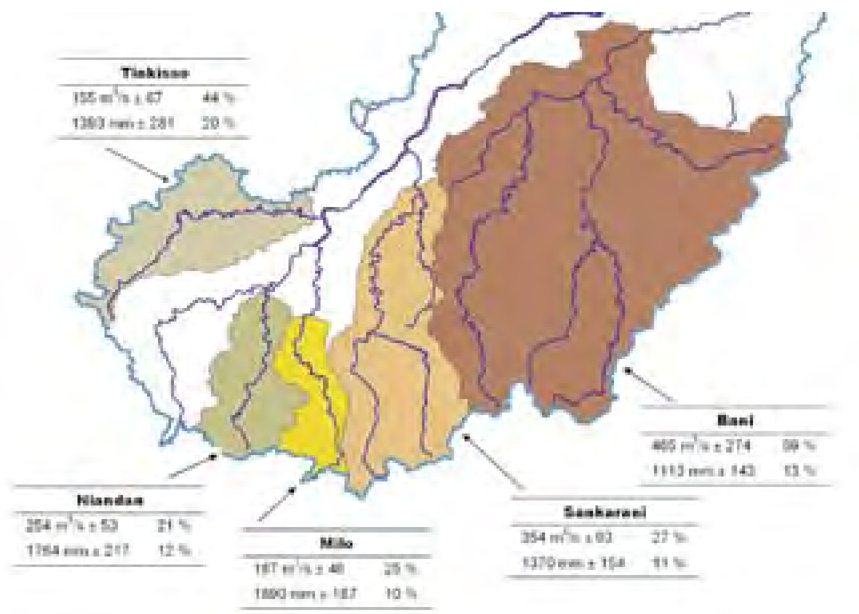


Fig.2.8. Average ± standard deviation of the rainfall (mm/year) and the river discharge (m^3/s) in five different basins in the Upper Niger. The right column in the tables gives the relative standard deviation (SD as % of the mean). Source: Mahé *et al.* (1997).

Seasonal variation in the river discharge

There is huge variation in the river discharge within a year. This follows from the large seasonal variation in rainfall (see Fig. 2.9). During the dry period, the flow of the Niger River is only a fraction of the maximum. The rainfall in the Upper Niger reaches its peak in August, but it takes time for the flood to come down. The river discharge in Koulikoro is at its highest level in September and that is also true for Douna in the Bani River. Since it takes only some days then before the water has reached the Delta, the flood also arrives in September.

The Inner Delta of the Niger River has a major influence on the type of flood wave coming from the Upper basin in Guinea and from the Bani River. The flood wave has an initial time basis of 2-3 months that changes downstream in an attenuated flood wave with a basis of about 7 months. The hydrological regime of the Inner Delta is determined by the extension of the floodable area. The Inner Delta is very flat, so a larger area is inundated during a high flood. But when a larger area is flooded, evaporation increases too. Thus, water loss increases with flood level. Another effect of a high flood is the longer period during which the water remains in the Inner Delta. Fig. 2.9 compares the flood wave before and after passing the Inner Delta in two extreme years: a very high flood (i.e. 1954/1955) and a very low flood (i.e. 1984/1985).

Reservoirs and dams

The flow in the Niger River is partially regulated through dams. Since many dams have been built in Nigeria, this is certainly the case in the Lower Niger. The most important dam is the Kainji dam with a reservoir of 15 km^3. Also in the Upper Niger there are a number of dams that influence the discharge level of the Niger River. Further details on the existing and planned dams are provided in the following section.

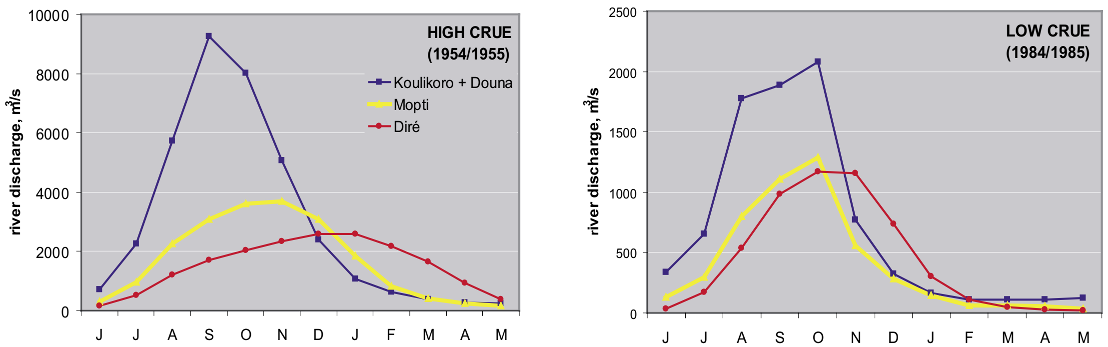


Fig. 2.9. Monthly discharge of the Niger River (Koulikoro) and the Bani River (Douna) combined, compared to the discharge at Mopti in the southern Inner Delta and Diré in the north-eastern part of the Inner Delta.

2.3 Dams, reservoirs and other water users

The Upper Niger has three dams, and four more dams are currently considered for construction (See Table 2.2). The Sélingué dam on the Sankarani River is used for hydro-power since 1982. The reservoir has a total volume of 2.2 km^3. The Sotuba dam, which is in operation since 1929, is another, very small hydropower plant, located directly downstream from Bamako. Because of the limited storage volume of the Sotuba dam, this reservoir does not have a significant hydrological impact on the Niger river basin. The Markala dam, which opened in 1947, is a diversion dam just downstream of Ségou. It is used to irrigate the area of the Office du Niger. In addition to the existing dams, several dams are considered for construction. These include the Fomi, Talo, Djenné and the Tossaye dam.

Sélingué

The Sélingué dam is located in Mali on the Sankarani tributary of the Niger River, not far from the border with Guinea. The Sélingué dam is mainly used for hydropower, but also permits the potential irrigation of about 60,000 ha under double cropping. Until now 1,350 ha is irrigated. Some of the main characteristics of the Sélingué dam are given in Table 2.3.

Table 2.2. Existing and planned dams in the Upper Niger.

Name of Dam	Year	Type	Storage volume	Water use & loss
		Existing dams		
Sélingué dam	1982	Power & irrigation	2.2 km^3	0.83 km^3
Sotuba dam	1929	Power & irrigation	-	0.22 km^3
Markala dam	1947	Irrigation	-	2.69 km^3
		Planned dams		
Fomi dam	Planned	Power	6.4 km^3	?
Talo dam	Planned	Irrigation	0.2 km^3	?
Djenné dam	Planned	Irrigation	0.4 km^3	?
Tossaye dam	Planned	Power & irrigation	4.5 km^3	?

Table 2.3. Main characteristics of the Sélingué dam.

Characteristic	Value
Surface of reservoir	34.2 km^2
Crest length	2600 m
Height	23 m
Total volume	2.1667 km^3
Effective volume	1.9287 km^3
Dead storage	0.238 km^3
Design flood discharge	3600 m^3/s
Minimum working level	340 m
Normal level	349.0 m
Exceptional low level	339.5 m

The water level in the reservoir varies during the season (Fig. 2.9). The water is high from September to January, decreases gradually from February to June and increases from June to August. There is hardly any variation in water level between the years. In nearly all years the water level decreases with about 7 meter between January and June. There were two events that deviated from the usual annual pattern. In the first two years after establishment of the dam, 1982 and 1983, the water level in the period of September to January was one meter below the average level of following years. In 1999 the water had

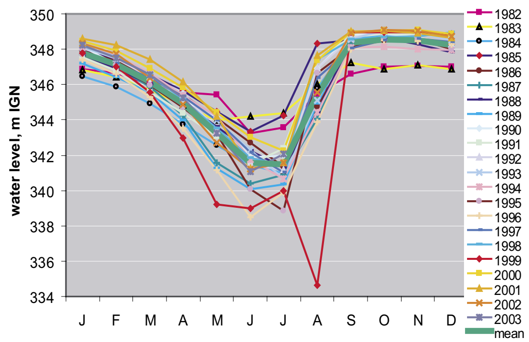


Fig. 2.10. Seasonal variation in water level (m IGN) in the Sélingué reservoir. Source: EDM.

gone down 14 metres, some four metres below the lowest gate level.

Table 2.4 gives the relationship between the surface and the volume of the reservoir. The surface area of the reservoir varies as a consequence of the variation in water level. Note that the reservoir is full at a level of 349 meter. The dead storage level, i.e. the level of the lowest gate, is around 338.5 meter. The relationship between surface and volume is confirmed by satellite images, which clearly show the variation in the shape of Lake Sélingué parallel to variation in the water level.

Table 2.4. Sélingué reservoir: the relationship between water level (m IGN) and the surface area of the reservoir and the volume.

Level (m)	Area (km²)	Volume (km³)
338	0	0
341	110	0.08
342	132	0.20
343	165	0.36
344	201	0.58
345	250	0.76
346	300	1.05
347	340	1.38
348	390	1.67
349	450	2.14

The variation in water level of the reservoir is due to a difference between inflow and outflow. Appendix 2 provides the inflow and outflow per months starting from January 1982. The average inflow and outflow per month are shown in Fig. 2.11. Note that that the outflow and the variation in water level are actually measured by EDM, but that the inflow is estimated from the (change in) water level in the reservoir. Although the estimated inflow is low between November and July (Fig. 2.11), it seems likely that the values are possibly still too high for these months. Actual measurements are needed to verify a possible overestimation of the inflow in the dry period. For the time being, we will use the inflow data as given by EDM.

It is clear that part of the flood water is used to fill the reservoir and that this water is released in the dry period. The inflow is reduced in August and September by 61% and 36%, respectively. In contrast, the outflow is 2.5 times higher than the inflow in February and April and even 3.3 times higher in March.

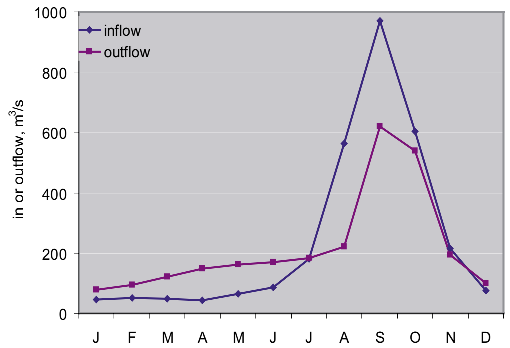


Fig. 2.11. The monthly inflow and outflow of the Sélingué reservoir, averaged over the period 1982 – 2003. Source: EDM.

The inflow and outflow data allow for the calculation of the absolute water loss of the reservoir. Fig. 2.12 shows how the inflow is larger than the outflow in the period of Augustus to October because the reservoir is filled. The net-inflow over that period accumulates to 2.04 km^3. During the rest of the year, the outflow exceeds the inflow due to gradual release of the water from the reservoir. This leads to a net-outflow of 1.21 km^3. Taken over the entire year, the reservoirs perform a water loss of 0.83 km^3 (i.e. 2.04 km^3 minus 1.21 km^3). The average inflow for the period 1982 – 2002 has been 7.76 km^3/year and the outflow 6.93 km^3. An average water loss of 0.83 km^3 is equivalent to 10.7% of the total yearly discharge of the Sakanrani. Several causes explain this loss of water. First, Hassane *et al.* (2000) estimate that the annual water loss due to evaporation in the reservoir is 0.569 km^3, which is equal to roughly a quarter of its total volume. Second, as already suggested by Mahé *et al.* (1997) a part of the water in the reservoir disappears in the surrounding as ground water.

Fig. 2.13 shows the seasonal variation in inflow and outflow, based on values averages over 21 years. The levels of inflow and outflow vary significantly

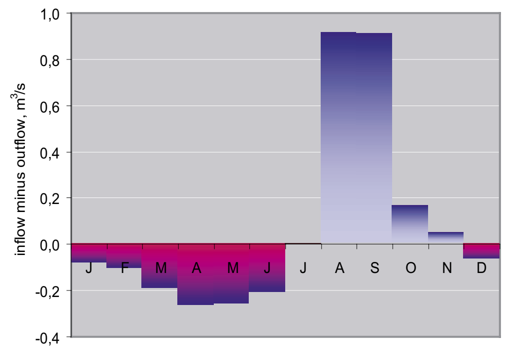


Fig. 2.12. The difference as m^3/s between monthly inflow and outflow in the Sélingué reservoir (average for 1982 – 2003). Source: EDM.

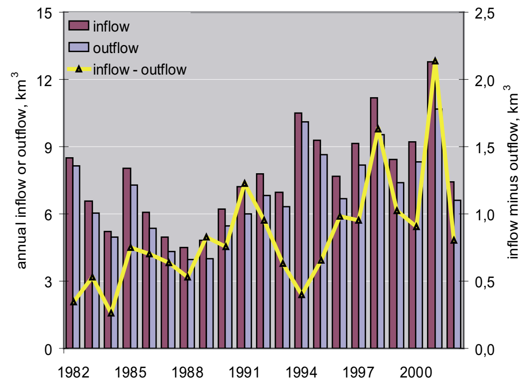


Fig. 2.13. The yearly inflow into and outflow from the Sélingué reservoir (km^3, left scale) and the difference between both, the 'water loss' (km^3, right scale. Source: EDM.

over time. The lowest inflow level (i.e. 4.50 km^3) was measured in 1988. The highest inflow was recorded in 2001 (i.e. 12.80 km^3). Each year, the outflow is lower than the inflow. Yet, the difference between the inflow and the outflow, the water loss, is only weakly related to the river discharge. Fig. 2.13 shows that water losses in recent years exceed those in the eighties. The explanation is a gradual shift in the water management of the reservoir by which the electricity production is now twice as high as 20 year ago (Appendix 2).

Another possible explanation of the increase in water losses is the expanding demand for irrigation. The irrigated area close to the Sélingué dam takes water from an inlet in the reservoir. However, until now the surface area being irrigated has not been larger than 1,350 ha. Therefore, the irrigation inlet consumes on average only 1.07 m^3/s. This is only 0.44% of the entire discharge of the Sakanrani. Yet, the ambition is to expand the irrigated area.

Markala dam

Markala Barrage

The Markala barrage was built in the Niger between 1937 and 1945, nearly 40 km NNE of Ségou. The Markala barrage is managed by Office du Niger. In the original planning the dam would permit the irrigation of 9600 km^2. Until now only a fraction of this surface is irrigated. The surface area of the irrigated rice fields accumulated to approximately 350 km^2 in the period of 1978 to 1985. In the period 1985 to 2003, the irrigated rice fields gradually expanded to 567 km^2. At present, the total irrigated area measures 740 km^2 (chapter 11). Office du Niger has the ambition to extend the irrigated area significantly more (Keita *et al.* 2002).

The Markala dam is a weir with a width of 2450 m. It creates a kind of reservoir in the natural river valley. The hydrological impact of the Markala dam is limited. This is due to the small change in water level and the absence of a significant storage reservoir. The water is only stored in the main bed of the river, confined by dikes. Satellite images clearly show that the river upstream of the dam is several kilometres wide, while the downstream river bed measures less than one kilometer.

The impact of the intake by the Markala dam varies substantially over the year. Fig. 2.14 shows the variation in the level of intake by Office du Niger. The monthly water intake since 1987 is given in Appendix 3. From August to November about 100 m^3/s is taken from the river. In the period December to April the intake is reduced to approximately 60 m^3/s. However, the average monthly river discharge varies naturally from 3200 m^3/s in September to as little as 100 m^3/s in March. Thus, the water use as fraction of the available water is relatively small in August to November, but extremely high from March to June. In this latter period, half of the river water is diverted to the irrigation fields. Fig. 2.14 also shows that a clear trend in the water intake during the last 15 years is lacking. The total intake for irrigation has varied between 2.50 km^3 in 1994 to 2.85 km^3 in 1999, with an average of 2.69 km^3 per year. The recent expansion of the irrigated area did not lead to additional use of water. This is due to the fact that

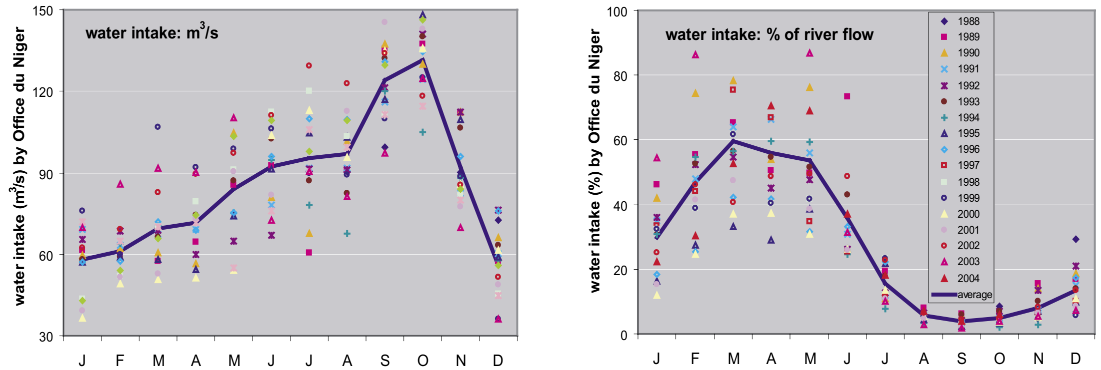


Fig. 2.14. Monthly water intake by Office du Niger at the Markala barrage since 1989 (left graph) and the monthly water intake as % of the river discharge at Koulikoro in the same month (right graph).

Office du Niger is still able to meet its own standard of 2.4 l/s per ha (Keita *et al.* 2002).

Sotuba

A very small hydropower plant is located in the Niger, directly downstream from Bamako at Sotuba. The dam was built in 1929, but the run-of-river power plant is operational since 1960. It has a capacity of 5.2 MW. The estimated head between intake and outlet is 4 metres. The plant can pass a maximum of 60 m^3/s and is able to continue to work at a minimum discharge in the river of 95 m^3/s. The structure itself is not important for this study as it has no important storage volume and as such does hardly have any impact on the hydrology of the Niger River. However, the same canal that feeds the plant also feeds a canal for irrigation that is able to pass 10 m^3/s with a minimum river level of 316 meter, but because of the power production, the maximum amount of water diverted for irrigation is 6.37 m^3/s. The water is used to irrigate the area of Baguinéda (3500 ha). According to Hassane *et al.* (2000) the average intake is 0.215 km^3 per year.

Sotuba dam

Fomi (planned)

At present, the Fomi reservoir is seriously being considered. The reservoir is planned to be constructed in the Niandan tributary in Guinea (see Fig. 2.8). The reservoir is meant for hydropower in combination with irrigation and flood control. The reservoir is planned to contain almost three times as much water as Lac Sélingué (see Table 2.5). Compared to the Sélingué lake, the Fomi reservoir will be 2.5 times deeper (i.e. 12 m, on average).

Table 2.5. Fomi reservoir: the relationship between water level (m IGN) and the surface area of the reservoir and the volume The reservoir is full at a level of 390.5 m. The dead storage level (lowest gate level) = + 380 m.

Level (m)	Area (km²)	Volume (km³)
351	0	0.00
360	100	1.00
370	200	1.80
380	450	2.46
390.5	507	6.16

Talo and Djenné (planned)

Building the Talo dam is already considered for a long time. The dam would be situated in the Bani River, 40 km downstream of Douna, NE of Bla, halfway between Ségou and San. The prime use of the dam is irrigation. Although the planned reservoir is rather small (Table 2.6), there is still a lot of debate about the Talo dam. People living along the Bani, downstream of the planned dam fear the negative impact of water diversion. That is why there is also a plan for a 'Djenné reservoir', in the lower regions of the Bani tributary, upstream of the Inner Delta. However, there is no official information about these plans. Experts involved claim the volume of the 'Djenné reservoir' to be in the order of 0.4 km^3. This would be more than twice the size of the Talo reservoir.

Table 2.6. Talo reservoir: the relationship between water level (m IGN) and the surface area of the reservoir and the volume. The reservoir is full at a level of 274.5 m. The dead storage level (lowest gate level) = + 269 m.

Level (m)	Area (km²)	Volume (km³)
268.3	0	0.00
269.3	20	0.02
270.3	30	0.05
271.3	35	0.08
272.3	40	0.11
273.3	45	0.14
274.3	50	0.18

Tossaye (planned)

The Tossaye dam is also still under consideration. The dam is planned to be built in the Niger near Bourem, 90 km NNW of Gao and 270 km east of Tombouctou (see Box 2.1). The dam is estimated to create a reservoir up to 4.5 km^3. This would make the Tossaye reservoir larger than Sélingué but smaller than Fomi. The planned Tossaye dam has more than one function: (1) hydro-power production of 150 GWh/year; (2) irrigation of up to 830 km^2; (3) possible feeding of Lac Faguibine, which is 550 km upstream from the dam, amounting to 2,6 km^3; (4) improvement of the low flow situation with a guaranteed cross-border flow to Niger of at least 75 m^3/s; and (5) improvement of navigation. The planned dam is a joint venture of Mali, Niger and Burkina Faso.

During incoming and high water, the Tossaye reservoir would have no impact on the Inner Delta. The impact in the dry period, however, may be considerable, especially for the northern part, where Lac Faguibine and other lakes in the northern and eastern part of the Inner Delta may be filled up again. Kuper *et al.* (2002b) discussed the effect of the Tossaye dam on the Inner Delta and concluded that the effect might be positive as well as negative. The impact will be more pronounced depending on the variation of the total river discharge over time.

Other water users

Compared to the water use by Office the Niger, the other water users take hardly any water from the Niger River. There are many small irrigation schemes along the Niger River in Mali. Two small irrigation systems were already mentioned: the annual water intake of 0.034 km^3 at Sélingué to irrigate 1,350 ha and 0.215 km^2 at Sotuba to irrigate 3,000 ha near Baguinéda. Nearly all other schemes are found in the Inner Delta (see Box 2.1). The most recent annual reports of Direction Régionale de l'Appui au Monde Rural (DRAMR) in Mopti and Tombouctou mention 93, 96 and 113 km^2 of irrigated rice fields in the region of Tombouctou and Mopti. They are mainly fed by small motor pumps. Van 't Hof (1998) is

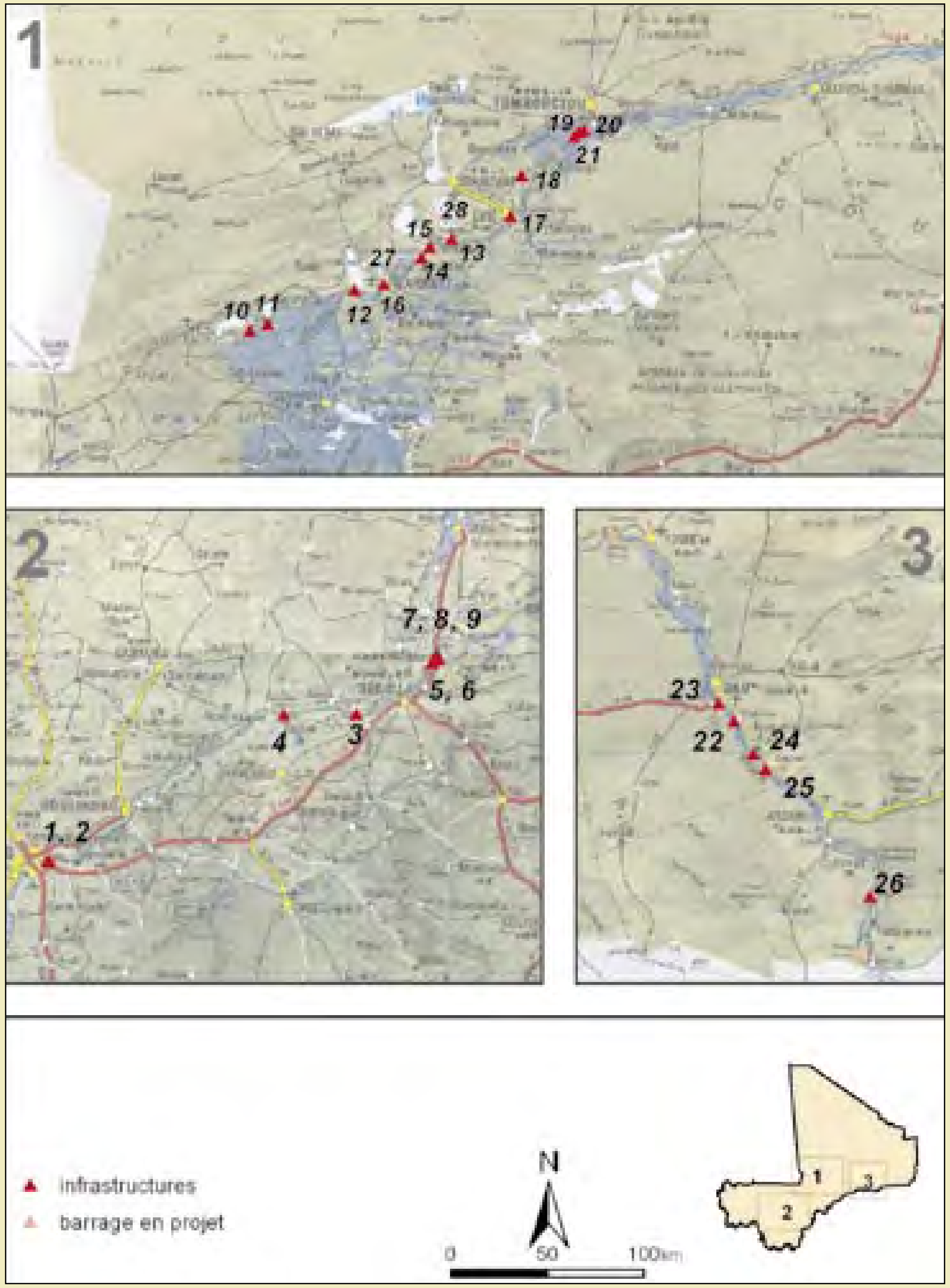
one of the few sources of information on these small-scale schemes. From August to December the potential evapo-transpiration of rice changes from 9 mm/day to 5.7 mm/day. The percolation shows more variation, but is normally in the order of 5.5 to 7 mm/day. This implies that the water demand for the irrigated agriculture in the region of Mopti is 13 – 14.7 mm/day. Based on a daily time of pumping of 11-12 hours (no pumping at night), the discharge per hectare is about 3 – 3.8 l/s. Taking into account losses in the system, it is reasonable to assume an irrigation value of 4 l/s/ha or for all 100 km^2 together 40 m^3/s. Given an irrigation period of four months, this would correspond with an annual water intake of 0.21 km^3. Note that this number may even be smaller since the calculation ignores the rainfall in August.

There are also many small structures that influence the entrance of water into the inundated areas. This applies to the entrance of water into the irrigation region under the Opération Riz de Ségou (ORS) and the Opération Riz de Mopti (ORM). ORS manages, eastern of Ségou, 354 km^2 in three areas: Markala (53 km^2), Dioro (150 km^2) and Tamani (152 km^2). The total area of ORM measures 270 km^2. ORM and ORS do not actively take water from the river. In fact, there are only dikes and sluices to keep the water at a certain level after inundation. When the water level does not rise enough, the area remains dry and rice growing is limited. Therefore, in dry years no rice is harvested at all. Since the polders ("casiers") of the ORM and ORS hardly have any effect on the natural inundation system, the overall impact on the Niger water regime can be ignored.

Several lakes around the Inner Delta are filled by the Niger, at least at high water levels. Small dikes have been built to regulate the water level in several of these lakes (Box 2.1). More details will be provided in chapter 3. The effect of these structures on the hydrological regime must be considered to be very small.

Finally, urban water demand may theoretically affect the water regime of the Niger river. Bamako is a large city with a fast growing population of more than 1 million people. The public water demand of Bamako has recently been estimated at 0.036 km^3 per year (Palangié 1999). The effect on the flow of the Niger is therefore extremely low.

Box 2.1.



26 infrastructures along the Niger in Mali, downstream of Bamako (from Diarra & Diallo 2003). Also the planned Tossaye dam, upstream of Bourem, (map 3) is indicated.

INFRASTRUCTURE	MANAGER	YEAR
1. Sotuba dam: hydro-power	EDM	1920
2. Baguinéda: passive irrigati on3000 ha	OPIB	1920
3. Doni (Farako): passive irrigation	ORS	1982
4. Tamani: passive irrigation	ORS	1982
5. Tien: passive irrigation	ORS	1970
6. Markala dam	ON	1943
7. Canal du Sahel	ON	1943
8. Canal du Macina	ON	1943
9. Canal du Cost - Ongoiba	ON	1980
10. Dianké: keep water within Lac Tanda	DRAMR-Tbt	1987
11. Sambari: keep water within Lac Kabara	DRAMR-Tbt	1987
12. Diré: pumping station; irrigation 200 ha	DRAMR-Tbt	1994
13. Marigot Kondi: keep water in Lac Faguibine/Télé	PSLF	1989
14. Pumping station for irrigation: Korioumé	CdK	1980
15. Pumping station for irrigation: Daye, 400 ha	PAHAPDA	1993
16. Pumping station for irrigation: Hamadja 750 ha	PAHAPDA	1994
17. Keep water; irrigation Bagoundié	DRAMR-Gao	1979
18. keep water; irrigation Tacharane	DRAMR-Gao	1979
19. Keep water; irrigation Haoussafoulane	DRAMR-Gao	1979
20. Keep water; irrigation Gargouna	DRAMR-Gao	1979
21. Keep water; irrigation Bara	DRAMR-Gao	1984
22. Keep water; irrigation Ansongo (Tobon)	DRAMR-Gao	1984
23. Active irrigation: Forgho 400 ha	DRAMR-Gao	1984
24. Keep water in Lac Takadji (Dabi)	PDZL	1991
25. Keep water in Lac Horo (Tonka)	UNSO	1994
26. Keep water in Lac Danga (Arabédjé)	PDZL	1993
27. Pumping station; irrigation 200 ha Niafounké	PDZL	1995
28. Keep water in Lac Fati (Tindirma)	PDZL	1991

EdM	Energie du Mali
OPIB	Office Périmètre irriguée de Baguinéda
ORS	Operation Riz Ségou
ON	Office du Niger
DRAMR-Tmt	Direction Régionale de l'Appui au Monde Rural – Tombouctou
PSLF	Projet Système du Lac Faguibine
CdK	Coopérative de Korioumé
PAHAPDA	Projet d'Aménagement Hydro-agricole des Périmètres de Daye Hamadja
DRAMR-Gao	Direction Régionale de l'Appui au Monde Rural –Gao
PDZL	Projet de Développement zone Lacustre, Niafounké
UNSO	Projet UNSO Tonka.

2.4 Human impact on river discharge

The study followed two approaches to determine the impact of the above mentioned human activities on the river discharge. The first approach is a relatively straightforward statistical analysis of the interaction between dams, reservoirs and the river flow in the Inner Niger Delta. The second approach is based on the application of an existing model package, RIBASIM (RIver BAsin SIMulation; Passchier *et al.* 2004) by WL/Delft Hydraulics and Direction Nationale de l'Hydrauligue (DNH). Because the two approaches concentrate on different aspects of the human impact on river discharge, both models can be used in a complementary manner.

The statistical approach

From the above description, one may conclude that there are at present only two large effects on the hydrological regime of the Upper Niger: the Sélingué reservoir (0.83 km^3/year) and the water intake by Office du Niger to irrigate the area of the Delta mort (2.69 km^3/year). There are two moderate effects: the irrigation at the Sotuba dam and in the Inner Delta (0.22 and 0.21 km^3/year); the effect of three other schemes combined amounts to only 0.07 km^3/year. Fig. 2.15 provides a schematic overview of the average discharge of the Upper Niger as well as the water loss due to hydropower and irrigation. To make all data comparable, the average river discharge has been calculated over a similar period (1970 – 1998). Fig. 2.15 also shows the position of the planned dams: Fomi, Talo and Tossaye.

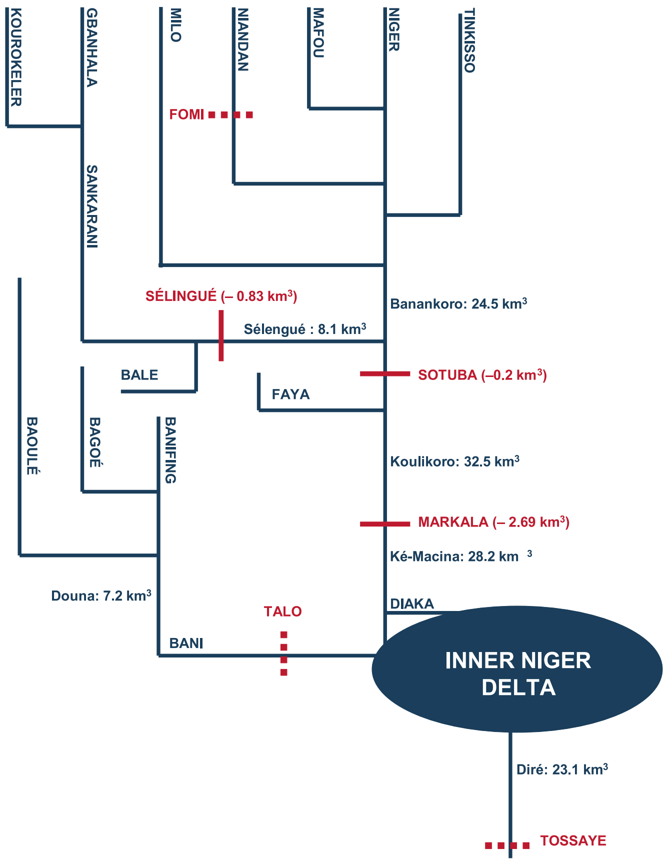


Fig. 2.15. Average river discharge (km^3/year) in the Upper Niger averaged over 29 years (1970-1998).Note: The tributaries are indicated in blue, the dams in red and the river discharge in black; Fomi, Talo and Tossaye are newly planned dams. Source: modified after Hassane *et al.* 2000.

The average annual inflow of the Sankarani into the Sélingue is 8.9 km^3. The water loss of 0.83 km^3 at Sélingué is equal to 9.3 % of the yearly inflow. The inflow from the other tributaries, measured at Banankoro is 24.5 km^3/year, while the total at Koulikoro is 32.5 km^3. This implies that the average volume of the Sélingué reservoir represents about 8.6% of the yearly average flow at Koulikoro and that the relative water loss at Sélingué is 2.6% of the river flow at Koulikoro. The water loss at Sotuba (i.e. irrigation Baguinéda) is only 0.6% relative to the river discharge at Koulikoro. Before the Niger enters the Inner Delta, 2.69 km^3/year is taken for irrigation at the Markala dam or 8.3% of the total flow of the Niger. The flow of the Bani is around a quarter of the discharge of the Niger before entering the Inner Delta. The average accumulated inflow into the Inner Delta from the Niger and the Bani is 34.5 km^3. The outflow from the Inner Delta at Diré amounts to 23.1 km^3. Therefore, the water loss, which is mainly caused by evaporation, is 11.4 km^3 (i.e. 33%). The water loss in the Inner Delta varies from year to year, depending on the area being inundated (Olivry 1995, Mahé *et al.* 2002, Orange *et al.* 2002a, 2002b; see also Fig. 2.9).

Fig. 2.15 shows that the average combined impact of reservoirs and irrigation on the river discharge still is relatively limited. Before the Niger and the Bani enter into the Inner Delta 3.7 km^3 (i.e. less than 10%) is taken of the 39.1 km^3 that would flow into the Inner Delta if there would be neither dams nor irrigation. The seasonal impact of the reservoirs and irrigation, however, may be much more pronounced. Therefore, special attention is paid to seasonal variation in the river discharge in Ké-Macina as well as the fluctuations over a longer period of years.

The seasonal effect of Office du Niger and Sélingué on the flow at Ké-Macina can easily be determined. To estimate the flow at Ké-Macina without the water intake at the Markala-dam, the irrigated amount by Office du Niger (see Fig. 2.14) is added to the current discharge levels. The downstream effect of the Sélingue dam is determined by the difference between the inflow of the Sakanrani and the outflow (see Fig. 2.11 and Fig. 2.13). The discharge at Ké-Macina without irrigation and without Sélingué is given by: the current discharge + the irrigated water by Office du Niger + the difference between the inflow and outflow of Sélingue.

Fig. 2.16 shows the effect of Sélingué and Office du Niger on the monthly flow at Ké-Macina over a period of seven years. At first glance, the effect seems to be limited, because the general pattern of incoming and rising water has not changed. A closer look shows that the peak flood is reduced and the water level is higher in the dry period. If there would be no irrigation of Office du Niger, the water level would be considerably higher in the dry period. The Sélingué reservoir has an opposite effect in the dry period, due to the water releases. The water intake by Office du Niger is less than the additional water releases from Sélingué, so the overall effect is that in the current situation the water level in the dry period is higher than if there would be no dam and no irrigation. Fig. 2.16 also shows that the effect of irrigation and the reservoir on the peak flood level is not the same in each year. The effect was large on the low flood of 1993 and hardly visible on the high peak of 1994.

Fig. 2.17 shows the average seasonal effect of Sélingué and Office du Niger. The negative effect on the flood is large in August and September, low in October and absent in November and December. From January till June, Office du Niger has a negative effect on the water level while Sélingué has a positive effect.

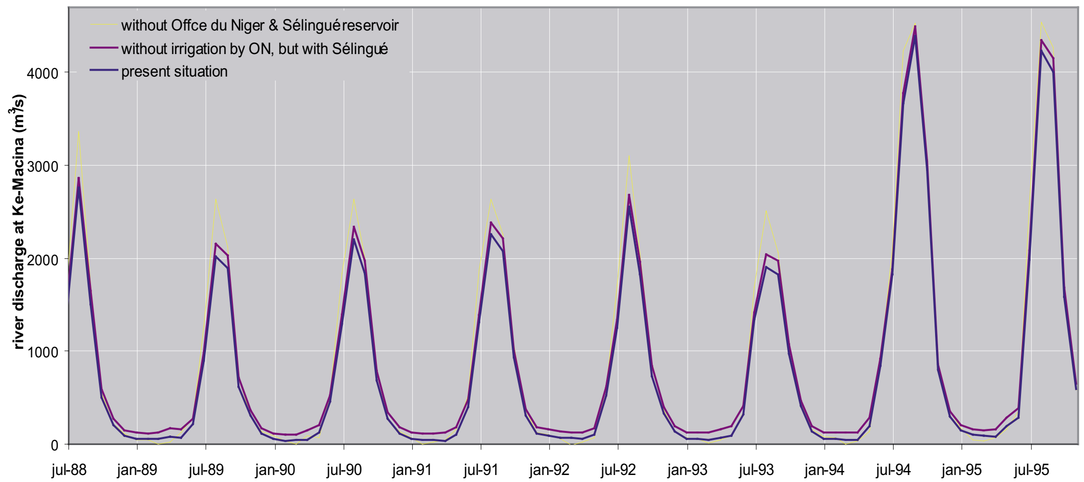


Fig. 2.16. Variation in monthly river discharge (m^3/s) at Ké-Macina (the entrance of the Inner Delta) between July 1988 and December 1995. Note: The actual variation is shown with a yellow line. A blue line gives the flow if there would be no irrigation by Office du Niger and a purple line the combined effect of Office du Niger and the Sélingué reservoir.

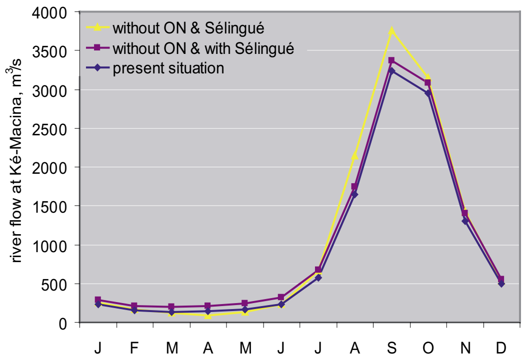


Fig. 2.17. The average monthly effect of Office du Niger and Sélingué on the river discharge at Ke-Macina. For further explanation, see Fig. 2.16.

Fig. 2.18 show how much higher the river flow would have been without Office du Niger and Sélingué. Clearly, the water storage has a larger impact if the river discharge is low. The absolute amount of water withheld in the reservoir and the irrigation are independent of the river discharge. As a consequence, the relative amount of water used for irrigation and for filling the reservoir is twice as large when the flow is twice as small. In the dry year 1993, as much as 40% of the flow in August and 30% of the flow in September has been diverted from the river. Fig. 2.18 also shows that Sélingué contributes much more to the reduced river discharge in August and September than Office du Niger. Therefore, although the overall impact of Office du Niger on the annual flow is 3.2 times larger than the Sélingué reservoir (see Fig. 2.15), Sélingué has a much larger effect on the river system in August and September (i.e. just before and during the peak river discharge).

Water-balance model

WL|Delft Hydraulics and Direction National de l'Hydraulique (DNH) entered a significant amount of hydrological data of the Upper Niger into the RIBASIM model (Passchier *et al.* 2004). A short summary of this work, focused on the downstream effect of the irrigation, the Sélingué dam and the Fomi dam, is provided in the following.

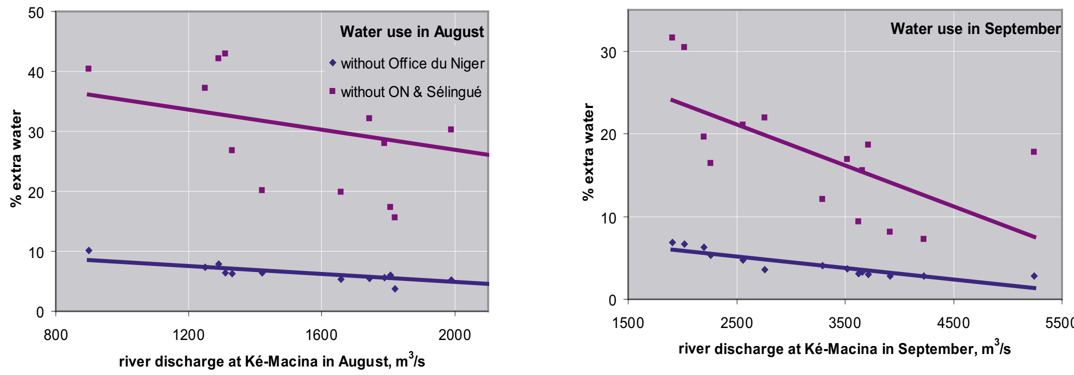


Fig. 2.18. The relative effect (%) on the river discharge in Ké-Macina in August (left graph) and September (right graph) of Office du Niger and Office du Niger plus Sélingué as a function of the total river discharge.

The RIBASIM model is based on a water balance approach for the Upper Niger, using a time step of one month over the period January 1980 to December 2001. The monthly river discharge upstream of the various structures is known:

- The inflow into the Sélingué reservoir has been estimated by EDM on site.
- The inflow into the future Fomi reservoir is derived from several Guinean hydrological stations (FRIENDS database; Sangare *et al.* 2002).
- The river discharge at Koulikoro was taken to estimate the flow at the Markala dam.
- The river discharge at Douna could be used to estimate the inflow into the future Talo reservoir.

As explained in section 2.2, the physical characteristics of the three reservoirs are known. The net-evaporation for each reservoir is entered into the model, based on average monthly precipitation and average monthly evaporation. Hence, the water loss varies on a monthly basis and not between years. The water demand of the irrigation systems (i.e. Sélingué, Baguinéda and Office du Niger) is also entered into the model. The water demand for irrigation differs per month but is kept constant for the different years. The outflow from the reservoirs depends on the operation rule.

Two operational rules are applied on the Sélingué reservoir. Operational rule '1' is to do nothing. As a consequence, the reservoir is filled most of the year. The inflow nearly coincides with the outflow. The only water loss is caused by net-evaporation. Operational rule '2' is to empty the lake as much as possible during the dry season to maximize the annual production of electricity. In this model run the operation rule at Sélingué is an energy demand of 18 Ghw.

Model run 1: irrigation by ON but no hydropower

The monthly flow into the three reservoirs is known. As mentioned, this run assumes the absence of manipulation of the water level in the reservoir. The only water loss taken into account is evaporation. The relationship between water level and water surface is known for Sélingué (Table 2.4), Fomi (Table 2.5) and Talo (Table 2.6). The net-evaporation varies on a monthly basis. The net-evaporation is highest in the period from November to April. Rainfall between July and September is larger than the evaporation, so net-evaporation is negative.

The outflow from the reservoir is calculated from inflow minus the monthly water loss due to evaporation. Since there is no outflow in the dry period, most of the year the reservoirs are rather full, implying a relatively high water loss due to evaporation.

Due to its great depth, the volume of the Fomi Lake is expected to be 2.9 times larger than Sélingué.

The surface of the Fomi reservoir is scheduled to be only 10% larger than of Sélingué. Hence, the water loss due to evaporation for both reservoirs does not differ much. The evaporation in the future Talo reservoir will have a limited effect on the flow of the Bani downstream of the dam. Therefore, the effect of the Talo reservoir is negligible for the entire Upper Niger River system.

Model run '1' ignores the water demand of irrigation near Talo. The average monthly water demand for the existing irrigation system of Office du Niger, however, is entered into the model. The water demand in May and June is set at 100 m^3/s, but since this level was not reached in various years, at least in this model run without hydropower in Sélingué, the average water intake over 21 years is low in these months.

Fig. 2.19 shows the effect of evaporation in the two reservoirs and irrigation by Office du Niger on the flow of the Niger before entering the Inner Delta. The effect is small in August till October and large from December till June. Fig. 2.19 also shows that irrigation by Office du Niger has a larger impact downstream than the net-evaporation in the reservoirs.

Model run 2: irrigation and hydropower

Obviously, the purpose of the dams is not to create a large lake but to produce electricity. In most years, the water level in the Sélingué reservoir drops 7 meters between February and June and is filled up again in July and August (see Fig 2.10). Because the water of the peak flood is partly withheld for release in the dry season, this has a substantial impact on the river flow. The direct downstream effect is a reduced river flow at the crue and a higher river flow during the dry period. As a result of this management strategy, the lake is smaller during the dry season. This leads to less evaporation in the dry season, compared to model run 1. According to run 1, the flow from the reservoir is reduced in the dry months because of evaporation. In run 2 there is not less but (much) more water. Hence, Office du Niger can take the water for irrigation as demanded in May and June.

In run 2, the energy demand at Sélingué is set at 18 Gwh. As shown in Fig. 2.20, this level can be reached without problems from Augustus to January. The period from April till July is a more problematic period as shortages can occur. Taking the average across the entire year and assuming a maximum production of 18 Gwh, the generation of electricity

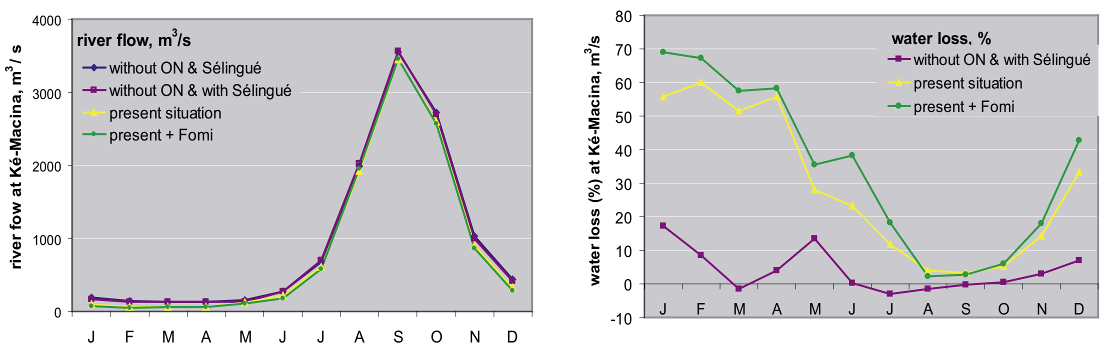


Fig. 2.19. Model run 1: The average monthly flow of the Niger at Ké-Macina (left panel), calculated over the period of 1980-2001. Four conditions are compared: (1) the natural situation (no dam, no irrigation), (2) only the Sélingué dam, (3) Sélingué + irrigation by Office du Niger (current situation), (4) Fomi+ Sélingué + irrigation by Office du Niger. The effect of the dams is limited, because in the calculations only the net evaporation in the reservoirs is taken into account (see text). Since the effects are hardly visible, the % reduction of the river flow due to the dams and irrigation are shown in the right panel. Source: DNH, WL|Delft Hydraulics.

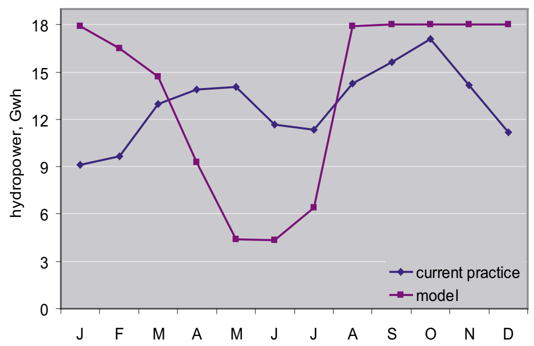


Fig. 2.20. Hydro-power produced at Sélingué in the present situation averaged over 22 years (1982-2003; see Appendix 2) compared to a model in which the total annual electricity production is maximized, given a demand of 18 Gwh. Source: EDM and WL|Delft Hydraulics.

arrives at 13.63 Gwh. The actual energy production amounts to 12.93 Gwh (Appendix 2) and therefore is slightly less than theoretically possible. However, compared to the model the current electricity production is more stable.

The river flow in model 2 is almost similar to the present situation: the total amount of water stored in the reservoir during the crue is equal to the amount released in the dry period. There is one small difference, however, between the present situation and model run 2. The modelled outflow in January and February is twice as high as in the actual situation, while the opposite occurs in May and June where the outflow in current situation is twice as high as in model run 2. This difference is entirely due to the decision of the manager of the Sélingué reservoir to give up a small part of the theoretical maximum production to guarantee a minimum power production of 9 Gwh (Fig. 2.20).

Due to the uncertainty with regard to the management options of the Fomi dam, model run 2 did not explicitly include the effects of this planned dam. By assuming that the hydro-power is maximised, the monthly downstream impact on the river flow resembles the impact of the Sélingué dam. Yet, because the water volume of Fomi is planned to be 2.9 times larger than Sélingué, a rough estimate would be that the effect of Fomi for each month is equal to 2.9 times the effect of Sélingué.

The yellow line in Fig. 2.21 shows the monthly variation in the river discharge at Ké-Macina. The effect of the Sélingué dam is clearly visible and does not deviate from the description provided earlier. The same is true for the downstream impact of irrigation. Fig. 2.21 clearly demonstrates that the Fomi dam can potentially have significant impact on the discharge of the Niger. Note that Fig. 2.21 is based on a model which maximises the production of electricity. If the water level in the lake is not managed with the purpose to produce as much hydropower as possible, the downstream effect of the Fomi dam will be smaller. However, since the prime goal of the Fomi dam is to produce electricity, it is likely that the downstream effect on the river discharge is better illustrated by Fig. 2.19 than by Fig. 2.21 It is also plausible that the applied operation rule at Fomi is similar to Sélingué: maximise energy production, but aim for a certain minimum level for the period from December to June. As a consequence, the water releases do not decrease but remain more or less constant from December to May.

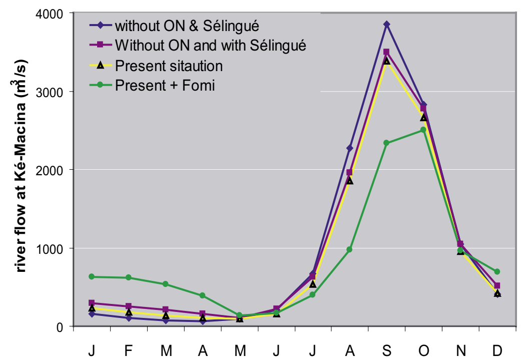


Fig. 2.21. Model run 2: The average monthly flow of the Niger at Ké-Macina, calculated over the period 1980-2001. The four condition are the same as in Fig. 2.19, but in contrast to model run 1, the two reservoirs are used to produce electricity. Source: WL|Delft Hydraulics & DNH.

2.5 Scenarios

To capture the impact of the main existing and planned structures in the Upper Niger on the water discharge in the Inner Delta, several scenarios have been developed (Table 2.7). These scenarios will also be used to determine the subsequent effects of changes in the water flow on the level of inundation and the ecology and economy of the Inner Niger Delta. The scenarios include:

- Scenario 0. Without ON & Sélingué: In this scenario a situation is imitated in which Sélingué nor Office du Niger are present in the Upper Niger. This is representative of the natural hydrological situation of more than 50 years ago;
- Scenario 1. With Sélingué & without ON: In this hypothetical scenario, a situation is simulated in which Sélingué is still present but Office du Niger is non-existent;
- Scenario 2. Present situation: In this "baseline" scenario, the present situation is mimicked, implying Sélingué and Office du Niger to be in full operation in the Upper Niger;
- Scenario 3. Present plus Fomi: This scenario is similar to the present scenario but imitates the existence of the Fomi dam. The main purpose of this scenario is to evaluate the impact of this planned dam.

The just mentioned run 1 was helpful to understand the role of evaporation, but will not be studied as a separate scenario. Also the effect of the three planned dams will not be considered as separate scenarios. Although the Talo dam and the water taken for irrigation will have a large impact directly downstream on the Bani itself, its effect on the Inner Delta will probably be very small. The effect of the planned Djenné dam is difficult to quantify since the necessary data are not yet available. Finally, the Tossaye dam also provides ample reason to evaluate its pros and cons scenario, yet, the means required to conduct such a time-consuming evaluation are lacking. Therefore, we decided not yet to include this dam into the analysis.

Table 2.7. Scenarios.

Scenario	Irrigation by Office du Niger	Hydropower Sélingué	Hydropower Fomi
Scenario 0. Without ON & Sélengué	No	No	No
Scenario 1. Without ON & with Sélengué	Yes	No	No
Scenario 2. Present situation	Yes	Yes	No
Scenario 3. Present plus Fomi	Yes	Yes	Yes

2.6 Conclusions

The analysis of the hydrology of the Inner Niger Delta and its upstream tributaries has generated a wide range of information. Much of this information can be used for the evaluation of the impact of natural variations and man-made structures on the inundation regime in the Inner Niger Delta. This evaluation will be presented in the next chapter. However, some of the findings are also relevant as stand-alone results. Therefore, the main conclusions of the hydrological analysis are summarised in the following points:

- Due to the fact that the annual rainfall is largely limited to three months (i.e. July-September), there is an enormous seasonal variation in the river flow of the Niger. The annual rainfall in the catchment area of the Upper Niger varies between 1100 and 1900 mm with an average amount of 1500 mm. Although the river discharge of the Niger is determined by rainfall, its variation between 600 and 2300 m^3/s is much more pronounced than for the annual rainfall. This is explained by the fact that the peak river flow is not only dependent on the rainfall in the preceding months, but also on the groundwater aquifers. Because groundwater level is determined by rainfall during previous years, the river flow declines during a series of dry years. This is what occurred during the period of dry years known in Mali as La Grande Sécheresse (the Great Drought) during which the flow of the Niger River declined to unprecedented low levels.
- So far, there is only one hydropower reservoir in the Upper Niger, Sélingué. With its size of 2.2 km^3, equivalent to 6.8% of the average river discharge of 32.5 km^3/year, the volume of the Sélingué reservoir is limited. Due to evaporation in the lake, measuring 34.2 km^2, approximately 0.5 km^3 of water flow is lost annually.
- The water stored in the Sélingué reservoir in the wet season is gradually released in the rest of the year. On average, 1.8 km^3 of the flow is withheld in the period of August to September. In years with high river discharge, this equals to 10-20% of the peak flow of the Niger. In years with low discharge, however, this fraction increases to as much as 20-30%.
- Without the releases of Sélingué the river discharge in the dry period declines to about 0.2-0.4 km^3 per month. The releases of Sélingué add about 0.2 km^2 per month to the river system. Especially in years with a low flood, the flow of the river in the period of March to May is largely dependent on the water management of Lac Sélingué.
- The Fomi dam is still under consideration. Its reservoir is planned to be 2.9 times larger than Sélingué. If water management of the Fomi dams is similar to the management of the Sélingué reservoir, we expect that the impact on the flow during the wet and dry period is similar to Sélingué, yet its magnitude will be around 2.9 times larger.
- Three other dams are also planned: the Talo dam and Djenné dam in the Bani tributary and the Tossaye dam downstream of the Inner Delta between Tombouctou and Gao. Due to lack of knowledge on these future infrastructures, it is difficult to determine the impact on the river system.
- There is only one large water user in the Upper Niger. To irrigate more than 700 km^2 in the "Delta mort", Office du Niger takes 2.7 km^3 water per year. This is equal to 8.3% of the total annual river flow. The water intake does not vary much from year to year. As a result, the annual water use of Office du Niger declines to 4% in a year with a large flow, but increases to 15% in a year with a low flow.
- Office du Niger takes about 100 m^3/s from August to November and about 60 m^3/s from December to April. That is equivalent to only a few percent in the flood period, but 50-60% in the dry period.

The current irrigation in the dry season is thus largely dependent on the additional water released from the Sélingué reservoir.

- The river discharge downstream of Office du Niger is evaluated for four scenarios to be used throughout this report. These include Scenario 2 or Present situation; Scenario 1, without Office du Niger but with Sélingué; Scenario 0, without Office du Niger and without Sélingué; Scenario 3, present situation plus the Fomi planned dam. These scenarios are considered to generate the most relevant results for policy makers in Mali.
- Some of the scenarios have been analysed with a water balance study. The river discharge data of the Upper Niger were entered into a model package, RIBASIM (RIver BAsin SIMulation), developed by Delft Hydraulics. This model study reveals that the management of the reservoirs has a significant impact on the entire river system.
- The data summarised in this chapter will be used in the next chapter to describe the effect of Sélingué and the irrigation of Office du Niger on the flooding of the Inner Delta. Similar efforts will be made to determine the impact the Fomi dam on the Inner Delta.

3 FLOODING OF THE INNER NIGER DELTA

Leo Zwarts
Ion Grigoras

3.1 Introduction

During the Great Drought, *La Grande Sécheresse,* in the early 1980s, the flooding of the Inner Delta shrank to less than one third of area inundated in the decades before. The inhabitants of the Inner Niger Delta dug channels and built dams and sluices to keep the water in the lakes and on the floodplains. Unfortunately, their efforts were mostly in vain because the flood level was insufficient during most of the recent years to cover the higher floodplains and fill the lakes.

The river flow of the Niger reaches a peak in September, bringing about the inundation of the Inner Delta. Chapter 2 already described how the peak flow of the Niger was rather minimal during the last decades and how part of this depression was due to irrigation by Office du Niger and management of the Sélingué reservoir. The analysis showed that about 6% of the peak flow in September is taken for irrigation of Office du Niger and about 20% is used to fill the Sélingué reservoir. What is the impact of this on the flooding of the Inner Delta? What will be the additional effect of the planned Fomi reservoir, which is nearly three times larger than the Sélingué reservoir? Before these questions can be answered, we have to describe how the flooding in the Inner Delta depends on the flood level and how both are related to the river flow. So far, the relationship between flooding and water level in the Inner Delta has only been quantified in an indirect way. Alternatively, satellite images can be used to directly measure the surface of the flooded area and link these data to the local water level.

The chapter is structured as follows. Section 3.2 elaborates on the existing estimates of inundated area in the Inner Niger Delta. For this purpose, various indirect methods, such as topographical maps, aerial photographs and agro-ecological models, are discussed. Next, remote sensing methods are applied to directly estimate the flooded area (Section 3.3). Specific issues discussed in this section are the selection procedure of satellite images, the distinction between land from water, and the coverage of the Delta. In Section 3.4 water maps are created for incoming and receding water, respectively. On the basis of these water maps, a digital flooding model is developed for different algorithms and elevations (section 3.5). Ultimately, the constructed models can be used to determine man-made impact of irrigation and reservoirs on the flooded surface of the Inner Delta, applying both the water balance and the statistical approach. (section3.6-3.8). Finally, conclusions are drawn in section 3.9.

3.2 Existing estimates of the surface area of inundation

Topographical maps and aerial photographs

The topographical maps of IGN (scale 1/200,000) clearly indicate the inundation zone and the zone being permanently covered by water. Fig. 3.1 shows this digitalised information. The inundated area and the permanent water bodies amount to 31,130 km² and 3,840 km², respectively. Since also the isolated depressions and lakes, such as Lac Korarou, are indicated as inundation zones, we assume that areas temporary covered by rainwater are indicated as inundation zone on the topographical maps as well. Most topographical maps from the Inner Niger Delta were published in 1956 and based on aerial photographs from the preceding years. During this period, the flooded areas were very extensive.

Ponchet & Troubat (1994) compared the inundated areas in 1955-1965 (36,100 km²) with the situation in 1970-1990.[1] Their map shows that the inundated area in most years in this period measures 12,400 km². When the areas irregularly flooded since 1970 are added to the inundation zone, the surface area increases to 18,500 km². Without the lakes east of the Inner Delta, which are only occasionally filled with water, the area amounts to 17,600 km². Regardless of the extent of inundation, the Ponchet and Troubat estimate is still half of the area being inundated in the sixties. Although Ponchet and Troubat did not explicitly indicate the inundated surface in extremely dry years on their map, they suggest it must have been as low as 8,000 – 10,000 km².

Fig. 3.1. The inundation area (light blue) and permanent water bodies (dark blue), such as indicated on 11 topographical maps published by IGN in 1956.

[1] Note that we assume that their estimate of 36,100 km² included all dry areas within the inundation zone

Hydrological model based upon evaporation

Information on the level of evaporation can assist us in determining the actual inundation area in the Inner Niger Delta (Quensière *et al.* 1994a, Olivry 1995). To determine this relationship, information is required on water losses in the Delta as well as on the amount of water entering and leaving the Inner Niger Delta. The relationship between river discharge (m^3/s) and water level has been determined for several hydrological stations along the Niger and can therefore accurately be described with third degree polynomials. Given these relationships, the amount of water entering and leaving the Inner Niger Delta can be derived.

The water loss between Ké-Macina and Douna at the entrance and Diré at the other side varies from year to year. This variation can be attributed to the total amount of the water brought by the flood, known as the "crue". The total annual river discharge entering the Inner Delta varies between 22 and 81 km³. If the crue is poor, 15 km³ leaves the Inner Delta. Therefore, 7 km³ or 32% of the river discharge at the entrance of the Inner Delta is lost to evaporation. In contrast, when the crue is very large, 40 km³ (i.e. 50%) of the total river discharge is lost to evaporation. In other words, the water loss increases more than proportional with the amount of water entering the delta. The main reason for the disproportional relationship between size of the crue and water loss is the fact that in years with a high crue a larger area is covered by water, subsequently leading to more evaporation. Evaporation varies between 160 and 240 mm per month, depending on temperature and sunshine, with an average of 200 mm per month.

The final factor to be taken into account before we can derive the total surface of the area where evaporation takes place, is the duration of the transport of Niger water from the entrance to the exit of the Inner Delta. This duration varies between 5 and 7 weeks, depending whether the crue is high or low. By combining the above information on water loss by evaporation and the transport time of Niger water, it is possible to estimate the inundated area each year from the water loss data. According to this relationship, the maximally inundated area varies between 9,500 km² in 1984 and 44,000 km² in 1957.

The maximally inundated area (derived from evaporation) can be described accurately as a function of the annual maximum water level in Akka:

$$km^2 = 102.84\ cm - 24675 \qquad \textbf{3.1.}$$

where:

km² = total of the inundated area in the Inner Niger Delta

cm = maximal water level in Akka (within the range of 325 and 625 cm).

The relationship behaves rather well but still has some shortcomings. As already noted by Olivry, his model is not realistic at a high water level, since the predicted surface area of the inundation zone surpasses the maximal inundated area of 30,000 – 35,000 km².

Agro-ecological model

Cissé & Gosseye (1990) followed yet another approach to determine the inundation area in the Inner Niger Delta. They based their analysis on the map of the PIRT (1983) where six different habitat types are distinguished. Since the occurrence of these habitats is determined by the inundation (duration of coverage by water and/or maximal water depth at an average crue), the map of PIRT can directly be used to estimate the average inundated area for different water levels. Cissé & Gosseye used the water level in Mopti as reference level and assumed a water level of 660 cm as the maximum level.

Orange *et al.*(2002a) evaluated the model of Cissé & Gosseye and concluded that the model behaves relatively well, but they detected a systematic underestimation of the inundated area. Therefore Orange *et al.* used a maximum water level of 610 cm at Mopti. By doing so, the model simulates variations of the inundated area between 6,000 km^2 in 1984 and 25,000 km^2 in 1955.

3.3 Remote sensing methods

Satellite images offer an opportunity to measure directly the inundated area. Mariko *et al.* (2002) analysed four NOAA-images from 1999. Although the resolution of NOAA-images is low with 1 x 1 km, a comparison of a series of images might be used as a direct measurement of the variation in the inundated area. Using a large number of Landsat images (resolution 30 x 30 m), Zwarts *et al.* (2003) conducted a similar approach for the Inner Niger Delta. This section is based on their work.

Separate land from water

Fig. 3.2 shows how Lac Débo looks like on a satellite image for two different days: February 1985 and February 2001. A selection has been made of three spectral bands (blue, red, green). The True Colour Composite clearly reveals where the ground is bare and where is vegetation. The image of February 1985 shows unmistakably what is water and what is land. This is not the case for the image of February 2001 because it remains unclear whether the green area is covered by water or not.

Land and water can be distinguished by selecting Landsat TM band 5 and 7. Water implies an algorithm of band 5 between 100 and 135 and band 7 between 70 and 90. All other values are land. This rule appears to work well. As shown in Fig. 3.2, most of the green area on the image of February 2001 must be considered as water which colours green because of floating vegetation.

Coverage of the Delta

A Landsat scene covers an area of 180 x 180 km. To cover the entire Inner Niger Delta, one needs one image from the area between Djenné and Lac Débo (path 197/row 50) and another north of Lac Débo up till Tombouctou (path 197/row 49). To get data from Lac Faguibine a third image (path 197/row 48) is required and two additional images from path 196 and 198 to cover the SW part near Ké-Macina and the NE part, east of Tombouctou. Fortunately, it was possible, at least for the images before 1999, to get a shift within the path. That is why image 197/49 and 197/50 with a shift 20% to the north was purchased. In this way, we are able to cover the upper northern part of the Inner Niger Delta, including Lac Faguibine, although part of the southern section had to be sacrificed. Fig. 3.3 shows the coverage of the two images without the shift of 20% northwards.

The Landsat satellite follows a track SSW – NNE. It does not always exactly produce the same images. There was a deviation of maximally 12 km to the west or the east. A zone of 178 km wide was always covered and all 23 images together covered a zone of 195 km wide. Row 49 + 50, including the 20% shift to the north, give a coverage of 380 km long.

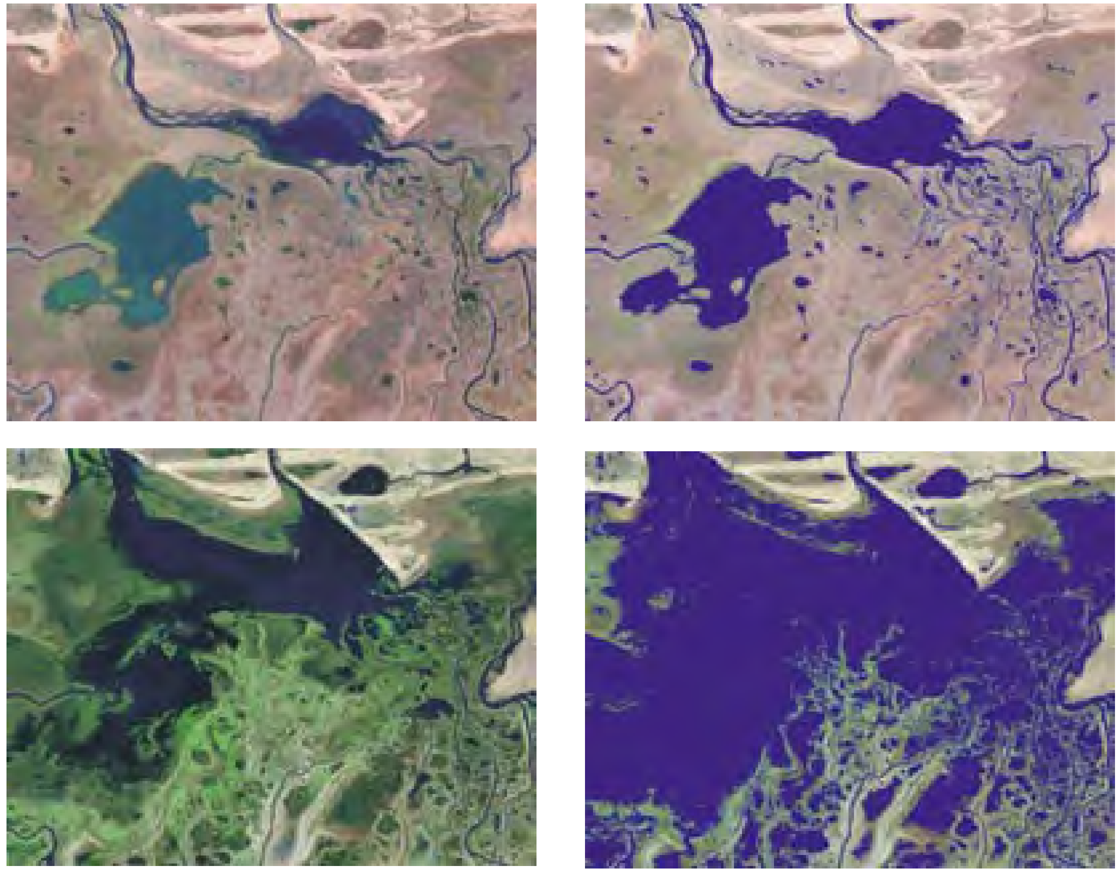


Fig. 3.2.True Colour Composite (left) and water map (right) of Lac Debo and Lac Walado on two different dates. Blue is water according to an algorithm (with the left picture as background). The four maps cover exactly the same area and measure 64.9 x 74.4 km. UTM Coordinates of NW-corner 333.7 x 1701.5 and of SE corner 407.1 x 1636.6.

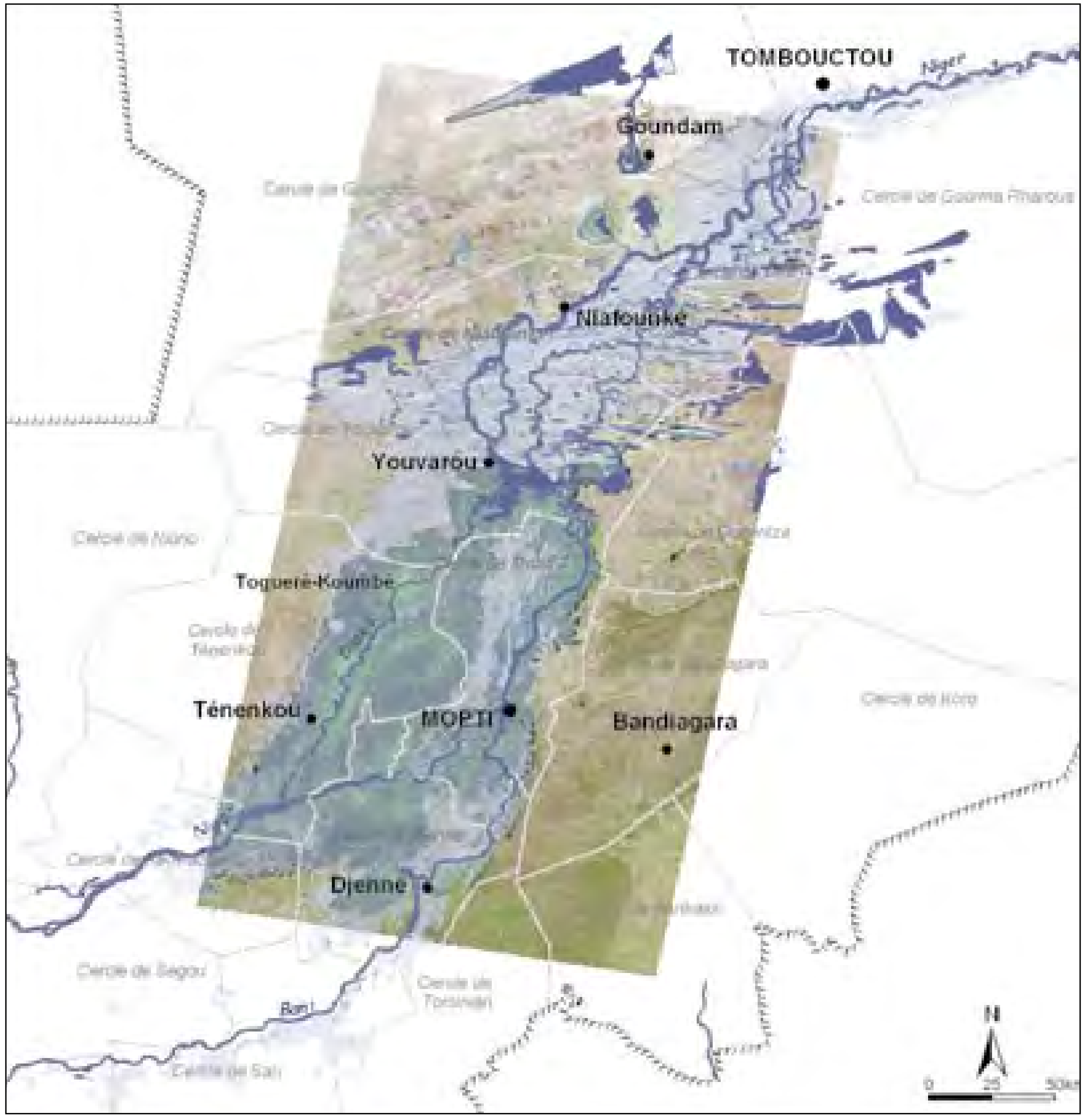


Fig. 3.3. Coverage of the Inner Delta by two Landsat scenes (d.d. 16-10-2001) without the shift of 20% northwards.

Selection of images

Because the quick-looks (free available images with a low resolution) indicated that the north revealed less variation in the flooded area than in the south, less data were needed for the northern part of the Delta to arrive at a full digital flooding model. Consequently, 24 images of the southern half of the Inner Delta, and 19 from the northern part have been obtained. The digitalized versions of the 24 water maps are presented in Fig. 3.5.

In principle, only images without clouds were purchased. However, to also cover images from the rainy season, we had to accept some images with scattered clouds. This led to problems in the construction of the water maps, because clouds and water bodies could not be distinguished well with the applied rule. To counter this problem clouds were removed by hand. Where this was not possible, we compared the cloudy images with another image without clouds and with a higher water level, and used the added image to mask the clouds.

The aim was to have a similar number of images from incoming and decreasing water with at least one image per 50 cm difference in water level. This appeared to be difficult. Fig. 3.4 plots the water level in Akka per image against the date of the image. The images are from eight different years. The daily measurements of the water level in Akka are also provided.

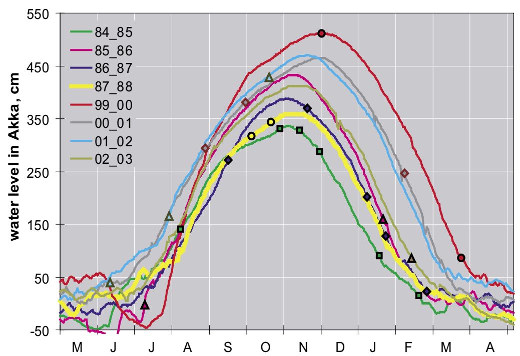
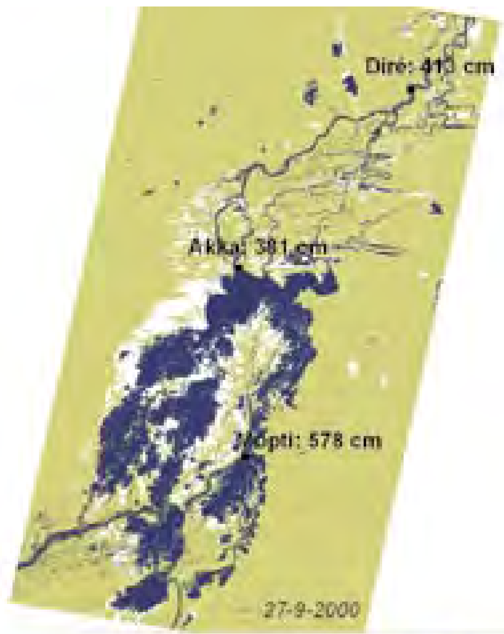
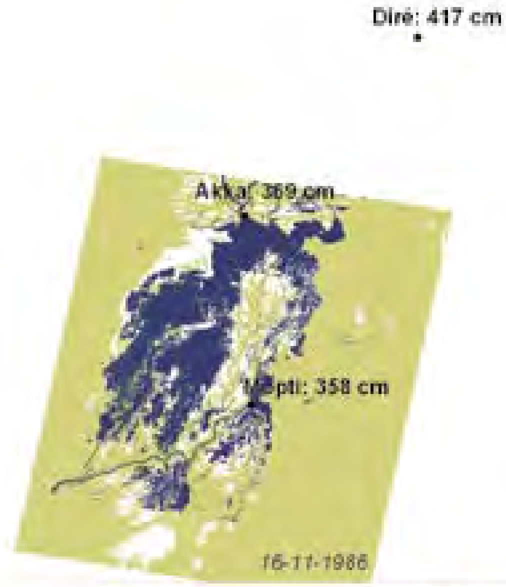


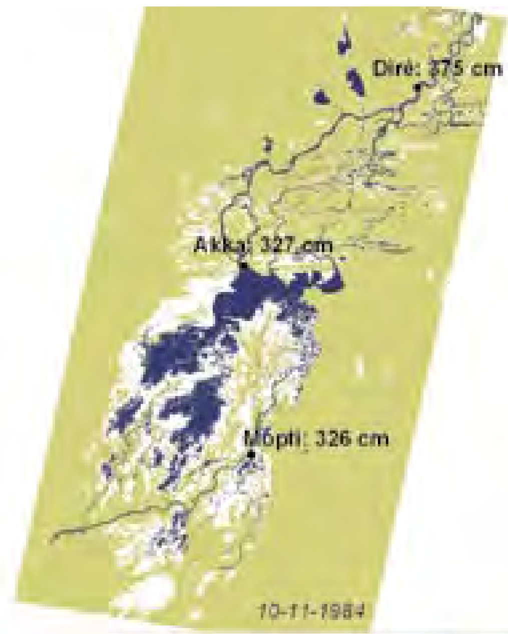
Fig. 3.4. Relationship between water level in Akka and the day number during 8 years. The 24 symbols along the curves concern the days from which Landsat scenes were selected. The horizontal axis refers to the hydrological year, i.e. from 1 May and 30 April the next year.

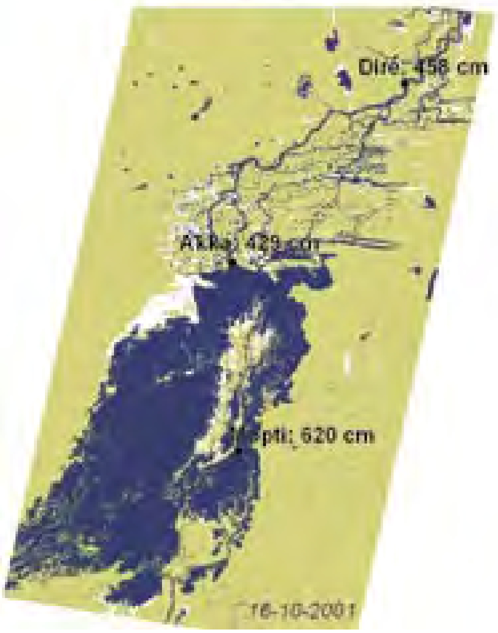
Fig. 3.5. Water maps of the Inner Delta for 24 dates, based on 24 satellite images of the southern half and 19 images of the northern part. The water levels at Mopti, Akka and Diré are indicated. The maps are ranked by increasing and decreasing water level in Akka for incoming and receding water, respectively.

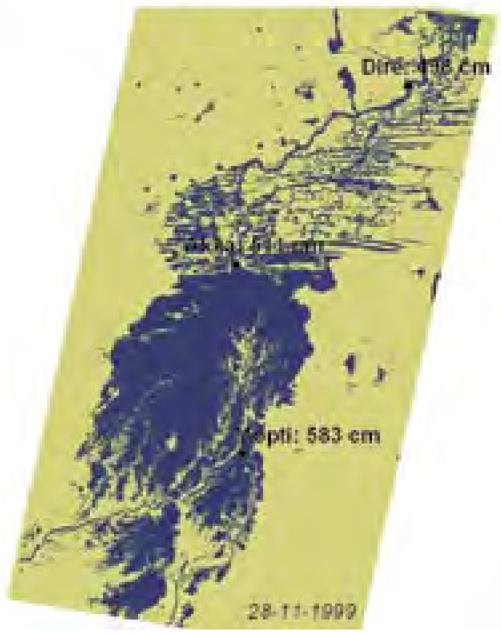

Diré: 387 cm
Akka: 343 cm
Mopti:481 cm
18-10-1987

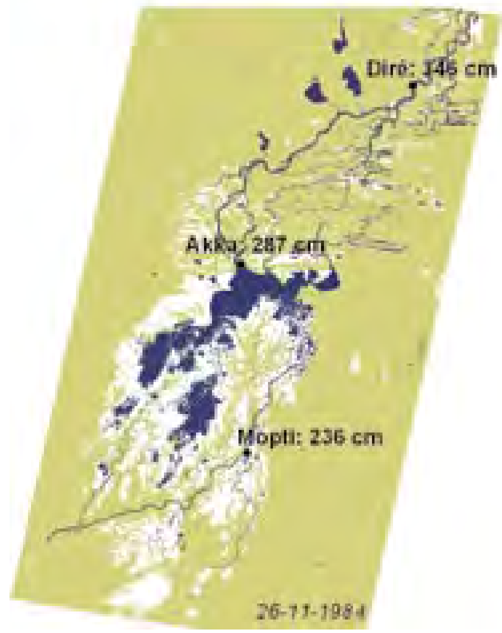

Akka: 381 cm
Mopti: 578 cm
27-9-2000

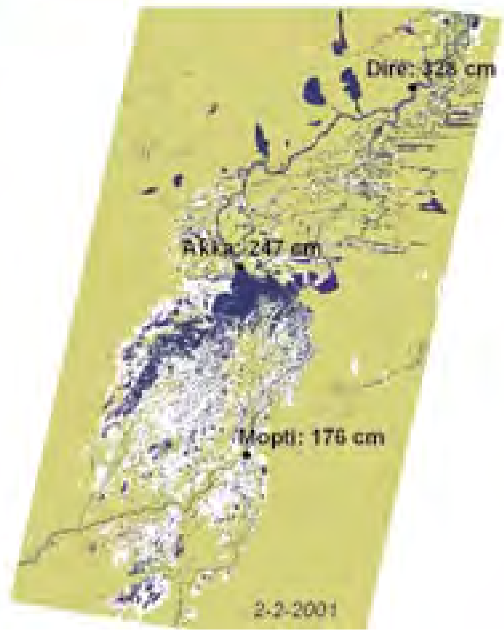

Diré: 417 cm
Akka: 369 cm
Mopti: 358 cm
16-11-1986


Diré: 375 cm
Akka: 327 cm
Mopti: 326 cm
10-11-1984


Mopti: 620 cm
16-10-2001


Mopti: 583 cm
28-11-1999


Diré: 346 cm
Akka: 287 cm
Mopti: 236 cm
26-11-1984


Diré: 328 cm
Akka: 247 cm
Mopti: 176 cm
2-2-2001


Diré: 281 cm
Akka: 202 cm
Mopti: 178 cm
3-1-1987
Diré: 244 cm
Akka: 160 cm
Mopti: 138 cm
16-1-1986
Diré: 167 cm
Akka: 86 cm
Mopti: 128 cm
19-3-2000
Diré: 166 cm
Akka: 86 cm
Mopti: 126 cm
8-2-2003
Diré: 206 cm
Akka: 122 cm
Mopti: 133 cm
19-1-1987
Diré: 167 cm
Akka: 90 cm
Mopti: 146 cm
13-1-1985
Diré: 104 cm
Akka: 23 cm
Mopti: 99 cm
20-2-1987
Diré: 89 cm
Akka: 14 cm
Mopti: 78 cm
14-2-1985

3.4 Water maps

The 24 water maps have been ranked by water level in Akka: rising for incoming water (Table 3.1) and decreasing for falling water (Table 3.2). At the extreme low water level of –2 cm in Akka (8 July 1985), large water bodies were only found in Lac Debo and Lac Korientzé in the central part of the Delta. Lac Walado fell nearly completely dry with little water left in the northern and southern part of this lake. In the north, Lac Horo still contained water. The situation was not much different at a water level of 77 cm (10 June 2001) and 140 cm (6-8-1984): Lac Debo and Lac Korientzé were slightly larger, while Lac Walado and Lac Fati were already (partly) filled with water. The southern Delta started to be flooded at a water level of 166 cm (28-7-2001) and more so at 271 cm (13-9-1986) and 294 cm (26-8-2000). However, even at a water level of 381 cm (27-9-2000) still large parts of the southern Delta were not yet covered, while the northern Delta was still dry at 429 cm (16-10-2001).

Nearly the entire southern and middle part of the Inner Delta was covered by water as well as parts of the northern region, at a water level of 511 cm in Akka (28-11-1999). Within the southern half, only the highest terrains, the levees along the Niger itself, the Diaka and the several Mayos were dry. When the water level had decreased to 369 cm (16-11-1986), water was still found around Pora, between the Niger and the Bani and along the Niger north of Mopti. The most extensive areas still covered by water were found in the central part of the Inner Niger Delta: west of the Diaka (Plaines de Seri), east of the Diaka (along the Mayel Kotia, Mayo Togoro and the Diarenndé) and further north the entire zone around Lac Débo, Walado and Korientze. At a still lower water level of 202 cm on the scale of Akka (3-1-1987), the majority of the floodplains were dry, except for the Plaine de Seri, and the adjacent Walado-Débo-Korientze complex. At a further decrease of the water, the Plaine de Seri got dry at a water level of 122 (19-11-1987) or 90 cm (13-1-1985), by which only Débo-Walado and Lac Korientze were still covered by water. During a water level of 23 cm (20-2-1987) and 14 cm (14-2-1985), Walado and Korientzé were still about the same size, but Lac Débo had become much smaller..

Table 3.1. Satellite images during incoming water. The water level in Mopti, Akka and Diré is given, as well as rainfall in Mopti (data IER): the number of foregoing days without rain, the rainfall (mm) in the fortnight before and the cumulative foregoing rainfall (mm) in the rainy season.

Date	water level (cm)			rain in time before		
	Mopti	Akka	Diré	dry days	rain in 14 days	total rain
8-jul-1985	137	-2	20	1	63.2	137.3
10-jun-2001	132	40	86	2	4.5	14.6
6-aug-1984	269	140	170	0	50.7	168.4
28-jul-2001	339	166	191	1	85.2	182.4
13-sep-1986	473	271	300	2	49.6	269.8
26-aug-2000	478	294	320	0	84.2	252.2
2-oct-1987	444	317	357	32	0.0	231.5
25-oct-1984	435	331	367	24	0.0	330.7
18-oct-1987	481	343	378	48	0.0	231.5
27-sep-2000	578	381	413	3	58.6	316.7
16-oct-2001	620	432	458	6	0.7	301.7

Table 3.2. Satellite images during receding water. Water level in Mopti, Akka and Diré is given, as well as the date and water level at which the flood reached its peak level.

date	water level (cm)			maximum water level (date)			maximum water level (cm)		
	Mopti	Akka	Diré	Mopti	Akka	Diré	Mopti	Akka	Diré
28-nov-1999	583	511	498	26-oct	23-nov	27-dec	662	511	515
16-nov-1986	358	369	417	8-oct	29-oct	2-nov	534	388	424
10-nov-1984	326	327	375	19-oct	30-oct	9-nov	440	336	375
26-nov-1984	236	287	346	19-oct	30-oct	9-nov	440	336	375
2-feb-2001	176	245	328	23-oct	22-nov	27-nov	608	465	486
3-jan-1987	178	202	281	8-oct	29-oct	2-nov	534	388	424
16-jan-1986	138	160	244	13-oct	3-nov	12-nov	571	433	460
19-jan-1987	133	122	206	8-oct	29-oct	2-nov	534	388	424
13-jan-1985	146	90	167	19-oct	30-oct	9-nov	440	336	375
19-mar-00	128	86	170	26-oct	23-nov	27-dec	662	511	515
8-feb-2003	126	86	166	8-oct	1-nov	15-nov	445	411	445
14-feb-1985	99	23	104	8-oct	29-oct	2-nov	534	388	424
20-feb-1987	78	14	89	19-oct	30-oct	9-nov	440	336	375

A comparison of the 24 images clearly shows that the flooded area, during the crue as well as during the décrue, is closely related to the water level. The only exceptions are the lakes in the north where dams were built between 1987 and 1994 in order to control the water (see chapter 2.3 and Fig. 3.1 for the location of the lakes). These dam-supported lakes include Lac Tanda (1987), Lac Kabara (1987), Lac Faguibine (1989), Lac Fati (1991), Lac Takadji (1991) and Lac Horo (1994).

A comparison of the images of northern lakes shows that Lac Horo was and still is a permanent lake, even in very dry years. Also Lac Fati was (nearly) always filled with water. Lac Télé was only dry on three images from June and July. Since 1984 Lac Faguibine was never completely filled with water. There were only three images on which the SE part was covered by water (16-1-1986, 3-1-1987, 19-3-2000). Lac Faguibine was fully dry on 2-2-2001. That is remarkable, because the maximal water level in Diré in the preceding months had been higher than during the crue of 1985 and 1986 (Table 3.2), when the SE part was covered by water. Apparently the water level must be higher than in the past to fill Lac Faguibine.

The lakes on the west side (Lac Tagadji, Mare de Soumpi, Lac Kabara, Lac Tanda and Gatié Loumo) are visible on all images from 1999 – 2003. They even contained water in June and July. Therefore, the lakes on the west side can be considered as small but permanent lakes. In the extremely dry years 1984 –1987, they were all fully dry, however.

Four lakes on the east side (Lac Haribongo, Lac Garou, Lac Do, Lac Niangaye) are not covered by the selected image, but two (Lac Aougoundou and Lac

Korarou) were fully visible on the northern image. During normal rains, Lac Korarou is a temporary lake from July till October. Yet, after an extremely wet year (1999) there was still water in March. Lac Aougoundou is a permanent lake, but it fell dry during the crue of 1984 and 1987.

Can a single map be constructed where the flooded area for different water levels are indicated? Table 3.3 shows that two maps are required: one for incoming and one for receding water. Both conditions reveal distinctly different outcomes. Table 3.3 shows the difference in water level at Mopti, Akka and Diré. To make this comparison, all measurements have been converted to water levels relative to sea level. The absolute difference between the water level at Mopti and Diré appears to be almost 5 metres during incoming water and just over 3 metres during receding water.

The importance of making a distinction between incoming and receding water is illustrated by comparing the flooded zone at 16-10-01 (429 cm in Akka) with those at 28-11-99 (511 cm in Akka) (Fig. 3.5). With a level of 511 cm, the crue reached its peak in Akka. Yet, the water level in Mopti had already fallen during four weeks, from 662 cm on 26-10-99 to 583 cm on 28-11-99. In contrast, the water level was at its peak in Mopti in 2001 with 621 cm while the water level was still rising in Akka, reaching a water level of 429 cm on 16-10-01. Therefore, although the water level in Akka on 28-11-99 was 82 cm higher than on 16-10-01, the situation was exactly the opposite for the water level at Mopti, which turned out to be 38 cm lower on 28-11-99 compared to 16-10-01. As a consequence, the décrue had started already in the southern Delta on 28-11-99 while the crue was still going on in the northern Delta.

Table 3.3.The absolute difference in water level between Mopti and Akka, between Akka and Diré and between Mopti and Diré during incoming water (left) and receding water (right). The difference has been calculated using the water level measurements (Table 3.1 and Table 3.2), taking into account that a water level of 0 cm at Mopti, Akka and Diré corresponds to 260.62, 258.38 and 256.85 m IGN.

crue	difference in water level (cm)			décrue	difference in water level (cm)		
Date	Mopti-Akka	Akka-Diré	Mopti-Diré	date	Mopti-Akka	Akka-Diré	Mopti-Diré
08/07/1985	363	131	494	28/11/1999	296	166	462
10/06/2001	316	107	423	16/11/1986	213	105	318
06/08/1984	353	123	476	10/11/1984	223	105	328
28/07/2001	397	128	525	26/11/1984	173	94	267
13/09/1986	426	124	550	02/02/2001	155	70	225
26/08/2000	408	125	533	03/01/1987	200	74	274
02/10/1987	351	113	464	16/01/1986	202	69	271
25/10/1984	328	117	445	19/01/1987	235	69	304
18/10/1987	362	118	480	13/01/1985	280	76	356
27/09/2000	421	121	542	19/03/2000	266	72	338
16/10/2001	412	127	539	08/02/2003	264	73	337
				14/02/1985	300	72	372
				20/02/1987	288	78	366

Combining water maps for incoming water

The construction of a common map with different water levels for incoming water is straightforward in a situation where land is turned into water during high water while the opposite process, water turning into land, does not occur simultaneously.

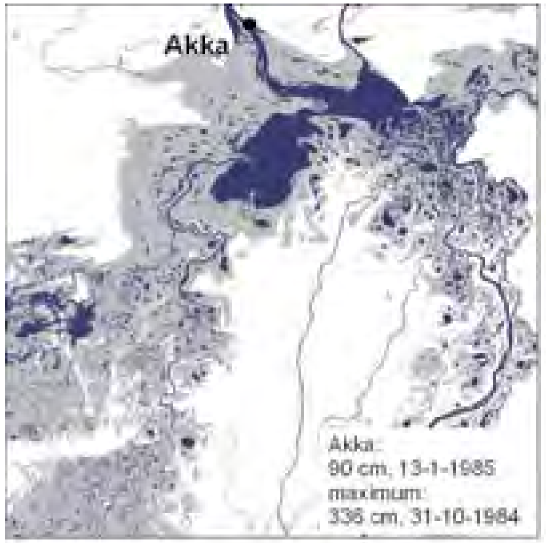
By comparing the available water maps in detail, Zwarts *et al.* (2003) concluded that isolated lakes are (partly) filled by rainwater during the crue and that this complicates combining satellite images during the rainy season since the rainfall differed between years. That is why Table 3.1 also provides information about rainfall preceding the dates of the satellite images.

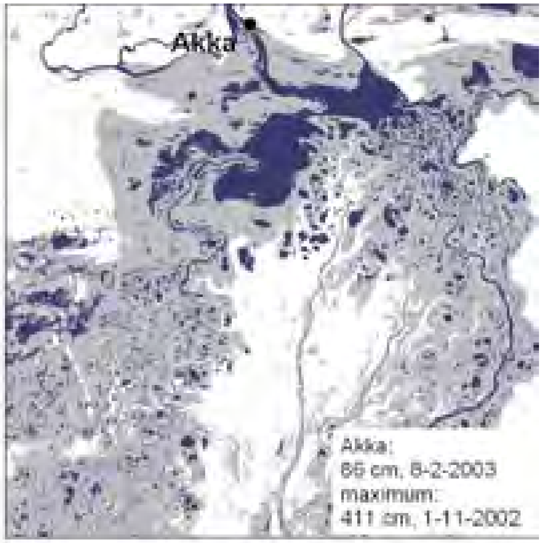
The effect of rainfall can even be seen on the small scale at which the water maps are printed in Fig. 3.5. For instance, due to local rainfall significantly more depressions were still filled by rainwater on 8-7-1985 (Akka: -2 cm) than on 10-6-2001 (Akka: 40 cm), despite the higher water discharge in 2001. The importance of rainwater is also illustrated by comparing maps with water levels of 294 cm (26-8-2000) and 317 cm (2-10-1987). There was no rain in the weeks before 2-10-87, but abundant rain in the fortnight of 26-8-2000. As a consequence, large areas along the periphery of the Inner Niger Delta had been covered by rainwater. There was no rainfall preceding 2-10-1987 (Akka: 317 cm), 25-10-1984 (331 cm) and 18-10-1987 (343 cm). In contrast, there was a lot of rain preceding 27-9-2000 (381 cm), leading to numerous small blue dots on the maps, indicating areas covered by water.

Combining water maps for receding water

Due to the absence of rain during receding water, modelling of the flooding during the décrue was more straightforward. However, another problem occurred in the modelling of the décrue: the maximum water level. The river water fills isolated lakes if the crue exceeds a certain level. That is why one might expect that the higher the maximal water levels, the more lakes and depressions are being filled. This implies that the flooded surface during the décrue not only depends on the water level itself, but also on the maximal water level reached in the preceding months. To facilitate the comparison between the images during the décrue, the highest water levels for the different years have been included in Table 3.2.

The expected problem related to the maximal water level did not show in the comparison of the images at a high water level (511 vs. 369 vs. 327 vs. 287 cm), since the maximal crue was about the same for those four images. However, when the images of 287 vs. 247 cm and 247 vs. 202 cm were compared, the image of 247 appeared to deviate from the 287 and 202 cm. The 247 cm image was from 2-2-2001, when the preceding maximal water level had been relatively high at 465 cm. This explains why many areas – in the north as well as in the south - were covered with water at 247 cm but not at 287 cm. In the latter case the maximal crue had been 149 cm lower than in the 247 cm-image (maximal crue: 336 vs. 465 cm).





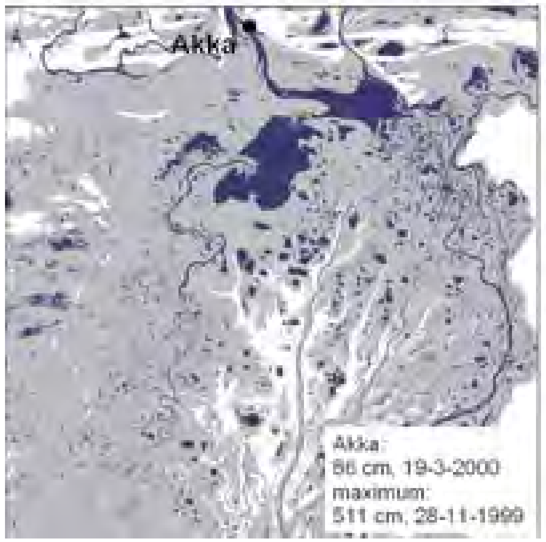


Fig. 3.6. Area covered by water in Lac Débo and Lac Walado and the area south of it on three different days when the water level in Akka was the same, but the maximal water level in the months before amounted to 336, 411 and 511 cm and the time passed since the water level was maximal amounted to 75, 99 and 117 days, respectively. The presented area measures 39 x 30.5 km. UTM-coordinates: NW-corner: 333.8 x 1705.5 and SE-corner 406.9 x 1632.4.

Another complication in modelling the decrue is caused by the shallow lakes and depressions which are no longer connected to the flood system. In other words, the model needs to account for the period between the moment that the lake lost connection with the hydrological system and its disappearance due to evaporation. Evaporation amounts to 7 mm per day.

The combined effect of maximal water level and time of evaporation can adequately be illustrated with three images during receding water with nearly the same water level at Akka (i.e. two of 86 cm and one from 90 cm). Fig. 3.6 provides the same information as Fig 3.5. but at a much larger scale for Lac Débo and surroundings.

Fig. 3.6 shows that the higher the flood, the more isolated lakes come into existence. This can for example be observed for the area south of Lac Débo and Walodo. As shown in Fig. 3.5, this area only floods at high water levels. However, the inundated area in the Plaine de Séri, west of the Diaka and south-west of Lac Walado, was already nearly dry on the 2000 image (after the water level had been high) and was still covered by water on the 1984 image (when the maximal water level had been very low). The explanation for this phenomenon is that the Plaine de Séri is found low in the inundation zone and is also covered by water in the dry year. However, the time passed since the water level had reached its peak level was 75 days in 1984 compared to 117 days in 2000. Therefore, from the moment the low-lying lakes were isolated, more water evaporated in March 2000 than in January 1985.

Combining all the above information, the flooding during the décrue can be confidently described with the 13 available images. However, when the water level at retreating water is lower than 300 cm, it becomes more difficult to compare images from different years. In such conditions, the maximal water level as well as the time passed since the water level has reached its peak, determine where isolated and temporary lakes with water can be found.

3.5 Digital flooding model

The inclusive and exclusive model

To produce a composite water map, on the basis of the water maps shown in Fig. 3.5, the complications explained in the previous sections need to be solved. The problem of rainfall during the crue and the problem of the maximal water level and evaporation time during the décrue boil down to the same issue: how to deal with areas being covered with water while at a higher water level they remain dry? Or to put it the other way around, how to deal with areas being dry while they were covered with water at a lower water level? In this study, two different algorithms (i.e. the inclusive and the exclusive) are used to deal with isolated lakes and other problems related to maximal water level and evaporation.

In the "inclusive algorithm", an area is considered water if it is covered by water at this water level AND at a lower level. The "exclusive algorithm" is less strict: an area is considered water if it is covered by water at this water level OR at a lower water level. The effect of the applied rule on the composite map is shown in Fig. 3.7 for the central part of the Inner Niger Delta for incoming water and receding water. On average, the exclusive algorithm clearly underestimates the flooded area while the inclusive algorithm evidently overestimates the level of flooding. The same is illustrated in Fig. 3.8, which plots the flooded areas against the water level in Akka according to both models, and also shows the measured inundation areas (see Fig. 3.5) as yellow triangles.

The inundated surface for which we had no northern image is shown as open triangles: this surface is of course always underestimated. The composite model also predicts the entire inundated area without the northern image. This is done using a

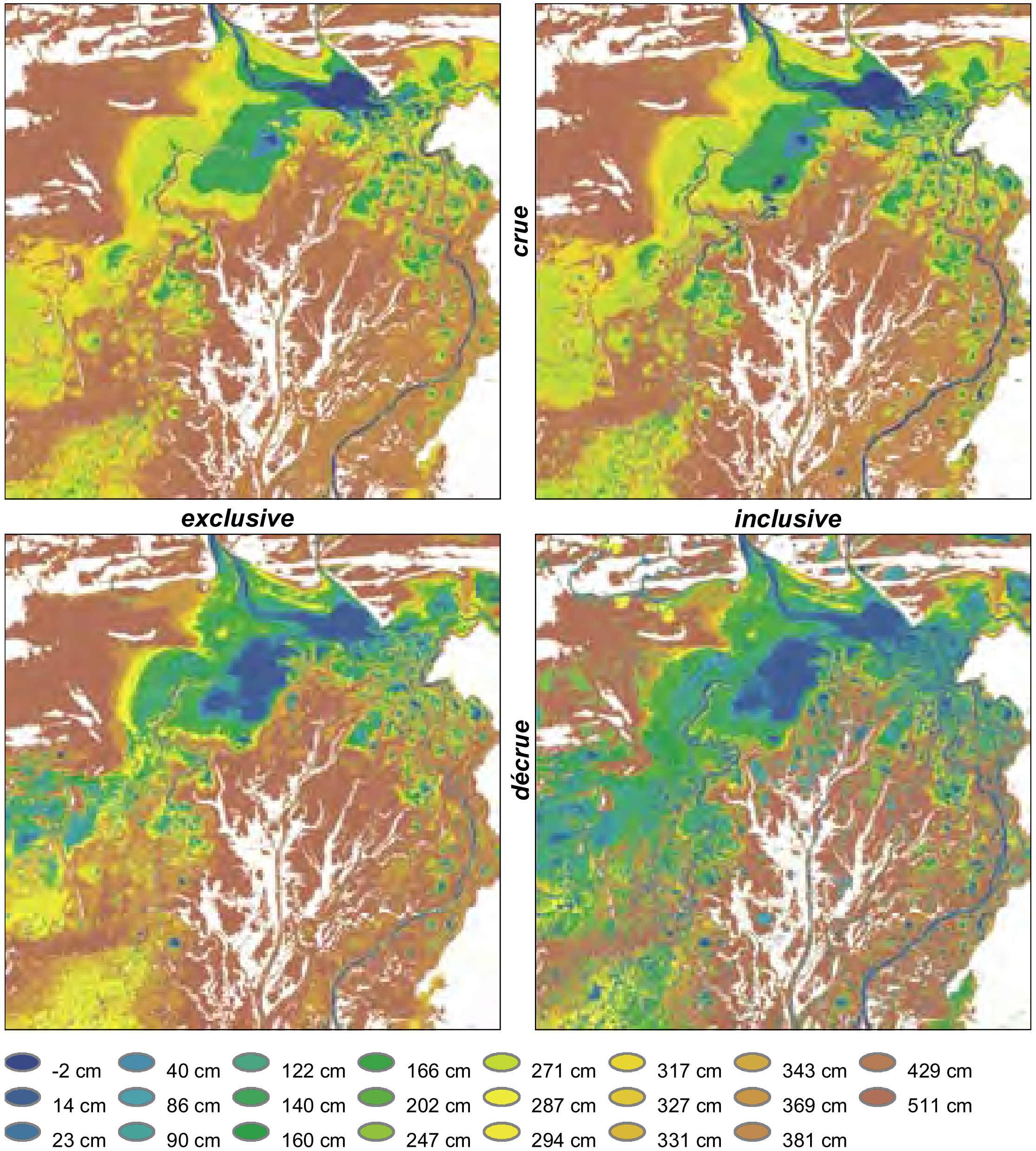


Fig. 3.7. Composite water maps of Lac Débo and Lac Walado and the area south of it (same area as shown in Fig. 3. 6), based on the water maps (Fig. 3.5), given separately for incoming water (up) and receding water (down) and according to the exclusive model (left) and inclusive model (right).

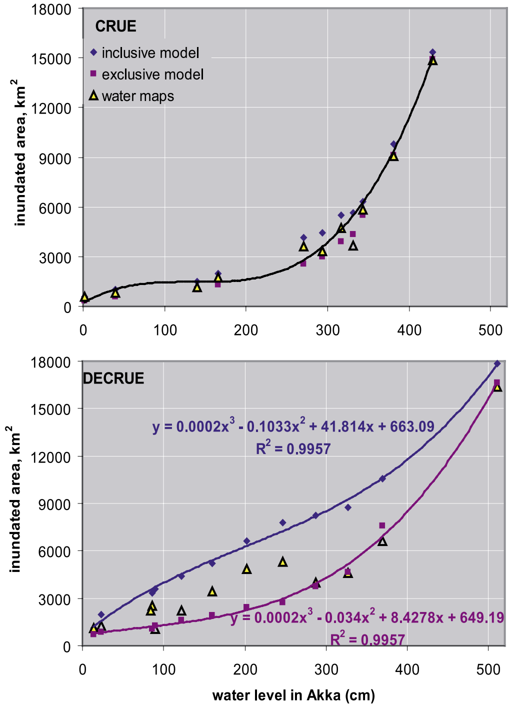


Fig. 3.8. Inundated area (km²) as a function of the water level during incoming water (up) and receding water (down). The inundated area, such as derived from the satellite images (Fig. 3.5), is shown with yellow triangles (full coverage) and open triangles (only southern part of the Delta). The surface areas according to the inclusive and exclusive mode are given. The deviation between the two models is small during incoming water, but large during receding water. The regression line is based on the average of both models. The exclusive model for incoming water describes the situation with little local rain. If there has been a lot of rainfall in the Inner Delta, the inclusive model is more appropriate. The exclusive model for receding water refers to years with a very low peak level of the flood, during which many isolated lakes have not been filled by water. The inclusive model refers to a year with a high flood, but will always be an overestimation of the flooded surface. The regression equations of both models are shown.

separate algorithm, in which images with a comparable water level are used to estimate the area being covered by water in the northern Delta.

Fig. 3.8 shows that the surface area being flooded is about the same for incoming and receding water, at least according to the exclusive model. This model shows the flooded area connected to the river and considers nearly all area not connected to the river as dry. The difference between inclusive and exclusive is small for the crue. This suggests that the effect of rainfall is, generally speaking, limited. A common equation based on the average values of both models results in:

Incoming <511 cm:

$km^2 = 0.0005cm^3 - 0.215cm^2 + 28.807cm + 194.36$

$(R^2 = 0.995)$ **3.2**

where:

km^2 = total inundated area in the Inner Niger Delta

cm = water level in Akka.

In contrast, the difference between the inclusive and exclusive model is large for the décrue. This shows that many more areas remained covered by water if the water level was high in the months before. Zwarts *et al.* (2003) determined the surface area being connected and disconnected to the river system for each satellite image. Their analysis shows that during the décrue about 50% of the inundated area is disconnected to the river by the time the water declined to a level between 100 and 300 cm at Akka. In a dry year, with a low maximum water level, such as in 1984, most of these areas remained dry all year round. Fig. 3.9 shows that the actual surface measurements of 1984 coincide with the surface area according to the exclusive model. For all recent images, however, the actual surface measurements are in between the inclusive and exclusive model estimates. In other words, the surface area is always overestimated in the inclusive model, even when the water level has been very high. Hence the best average prediction of the flooded surface at receding water would be to take the mean of both models:

Receding <511 cm:

$km^2 = 0.0002\ cm^3 - 0.0687\ cm^2 + 25.121\ cm + 656.14$

$(R^2 = 0.995)$ **3.3**

where:

km^2 = total inundated area in the Inner Niger Delta

cm = water level in Akka.

For our selection of satellite images the maximal water level in Akka is 511 cm, but it has been as high as 625 cm. Therefore, we assume that at such a high water, the inundation area is as extensive as indicated on the topographical maps, i.e. 31,000 km^2 (Fig. 3.1). Still, the area being inundated at a certain moment must have been smaller because a part of the inundation area in the southeast will already be dry while the flood is still covering the areas in the northeast. Possibly, the inundation area never exceeded 25,000 km^2 at a level of 625 cm in Akka.

When equation (3.3) of incoming water is extrapolated to a water level of 625 cm in Akka, the predicted water level is 56,300 km^2, thus 2.25 times higher than the expected 25,000 km^2. The exponent is less steep for receding water (equation 3.4), but even here the extrapolated surface at 625 cm, would be 38,300 km^2, thus 1.53 times too high. When a flooded area of 25,000 km^2 at a water level of 625 cm is added to the data of the incoming water, it is clear that the relationship have to be described with a S-curve. When the same is done for receding water, equation (3.3) change not much into:

Receding <625 cm:

$km^2 = 0.00007cm^3 - 0.0032cm^2 + 13.408cm + 1044.2$

$(R^2=0.997)$ **3.4**

Equation (3.4) was used to derive the surface of the surface of the inundation zone for the peak water level in Akka since the start of the measurements in 1956. Fig. 3.9 shows the variation in the peak water level and the corresponding surface of the inundation zone. Since the relationship between flood level and inundated surface is not linear, the variation in surface is larger than in water level. The maximal water level since 1956 was measured in 1957 (i.e. 625 cm) and the lowest peak level occurring in 1984 was nearly twice as low (i.e. 336 cm). The inundated surface in 1957 amounted to 25,000 km^2 and was more than three times lower in 1984 (i.e. 7,800 km^2).

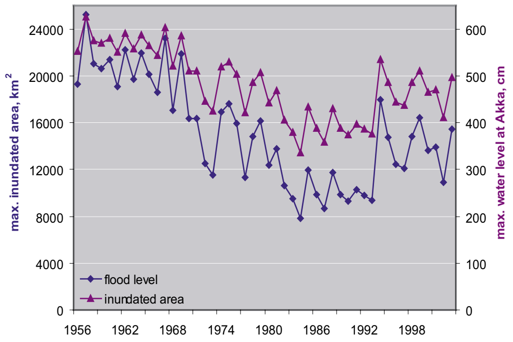


Fig. 3.9. Year-to year variation in peak flood level (Akka, cm; right scale) and maximal inundated surface (km^2, left scale)

The digital elevation model per 10 cm

The disadvantage of the given composite water maps as presented in Fig. 3.7 is that the intervals between the different water levels are unequal. To make a water map with equal intervals, the water line is interpolated at a water level of each additional 10 cm (i.e. 10, 20, 30 cm, etc.), using a pycnophylactic interpolation technique (Tobler 1992). The script can be downloaded from the website of ESRI (http://arcscripts.esri.com). A nice image of how the algorithm is working can be found on: http://www.ncgia.ucsb.edu/pubs/gdp/pop/pycno.html. Some other applications can be seen on: http://mywebpages.comcast.net/ldecola/baltwash/autocarto/. We ran the interpolation with 60 iterations and generated composite water maps per 10 cm. Fig. 3.10 shows the water map per 50 cm for incoming water. Fig. 3.11 and Fig. 3.12 present the same type of water map for receding water according to the inclusive and exclusive model, respectively.

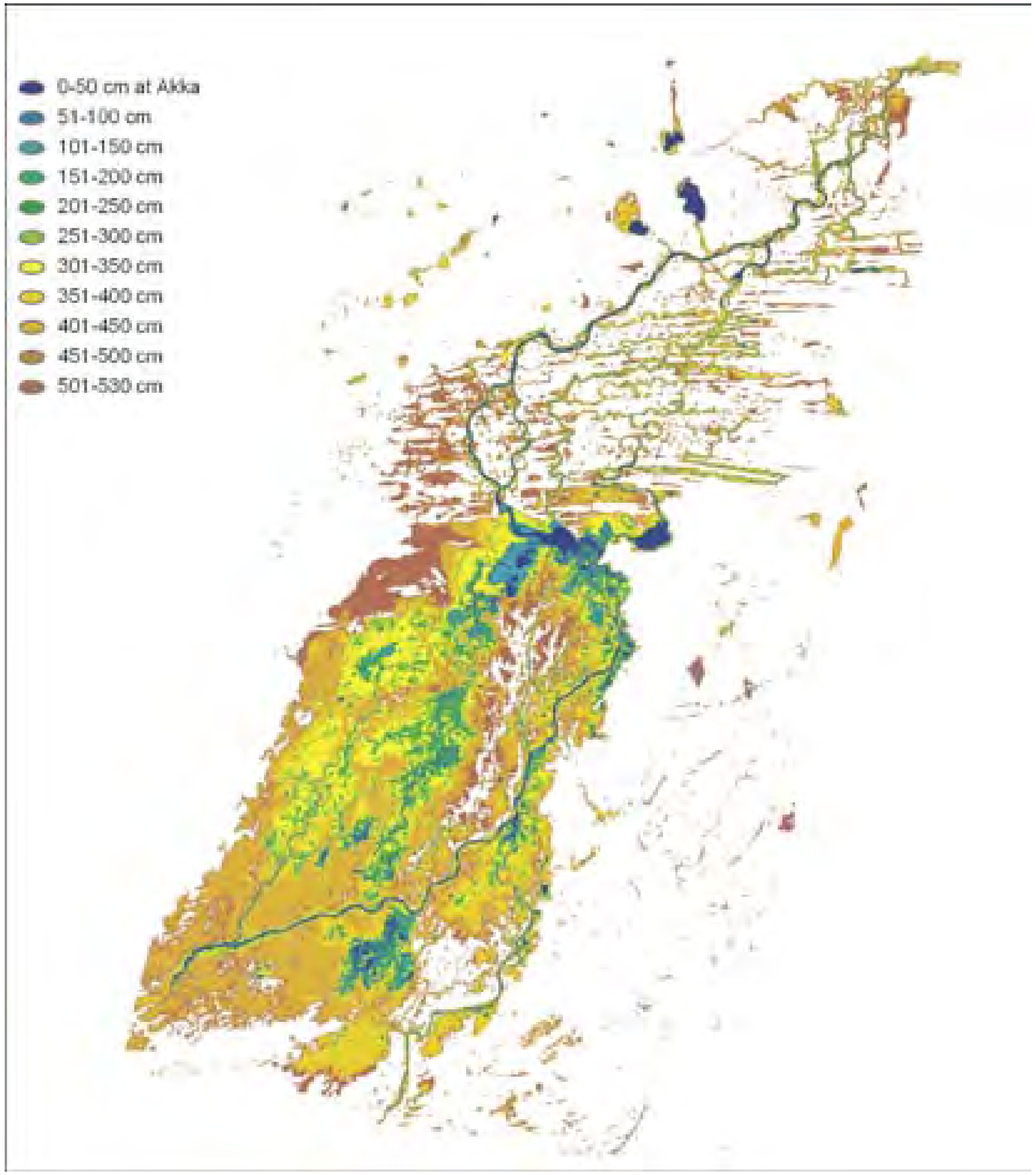


Fig. 3.10. Flooded area in the Inner Delta during incoming water as a function of the water level in Akka, based on the water maps given in Fig. 3.5, using the inclusive model to combine the maps and an interpolation technique to construct the flooded area per 10 cm. The map shows the change in flooded area per 50 cm.

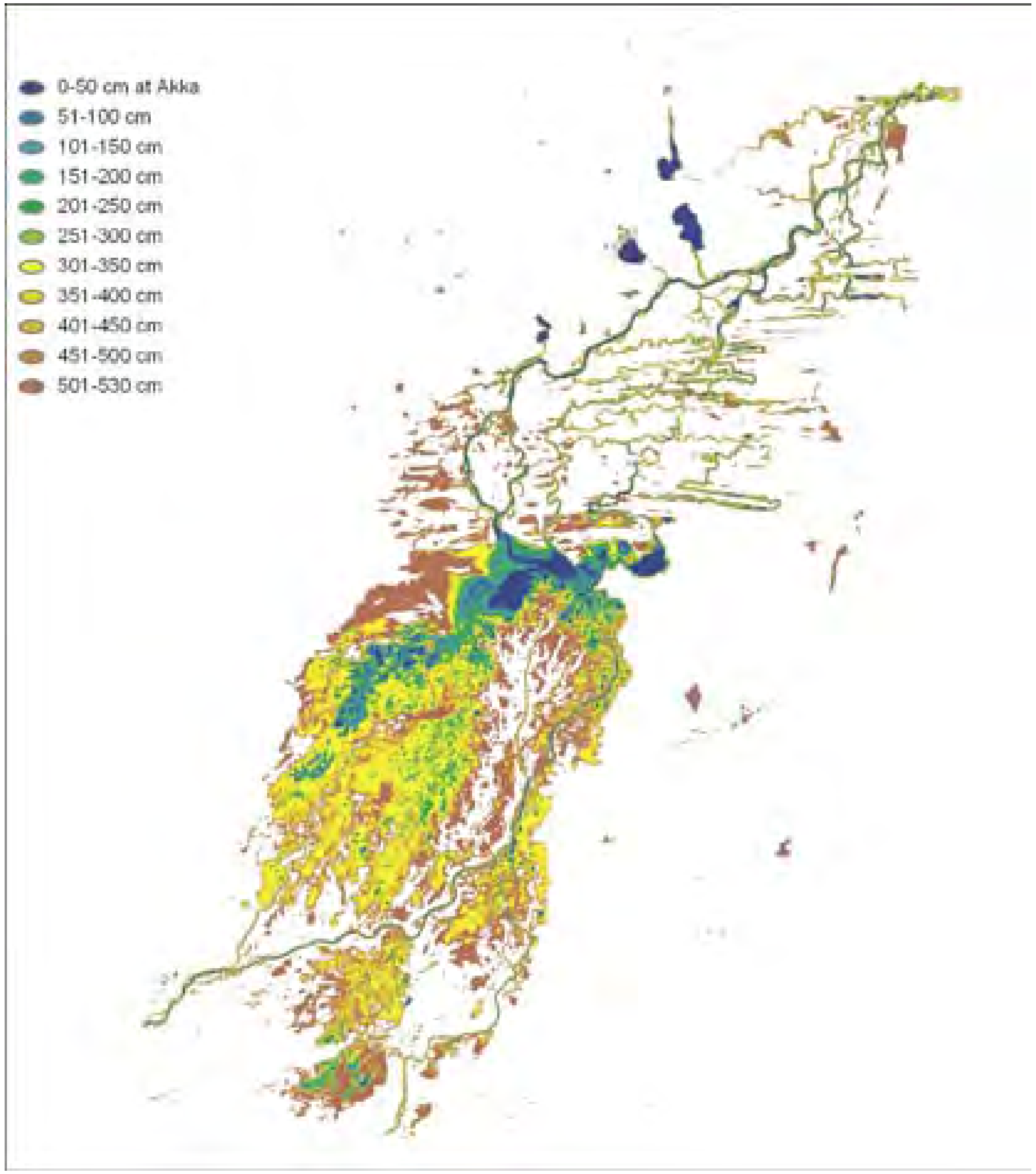


Fig. 3.11. Same map type as Fig. 3.10, but for receding water, using again the exclusive model to combine the water maps. This is the situation when the maximal water level has been very low.

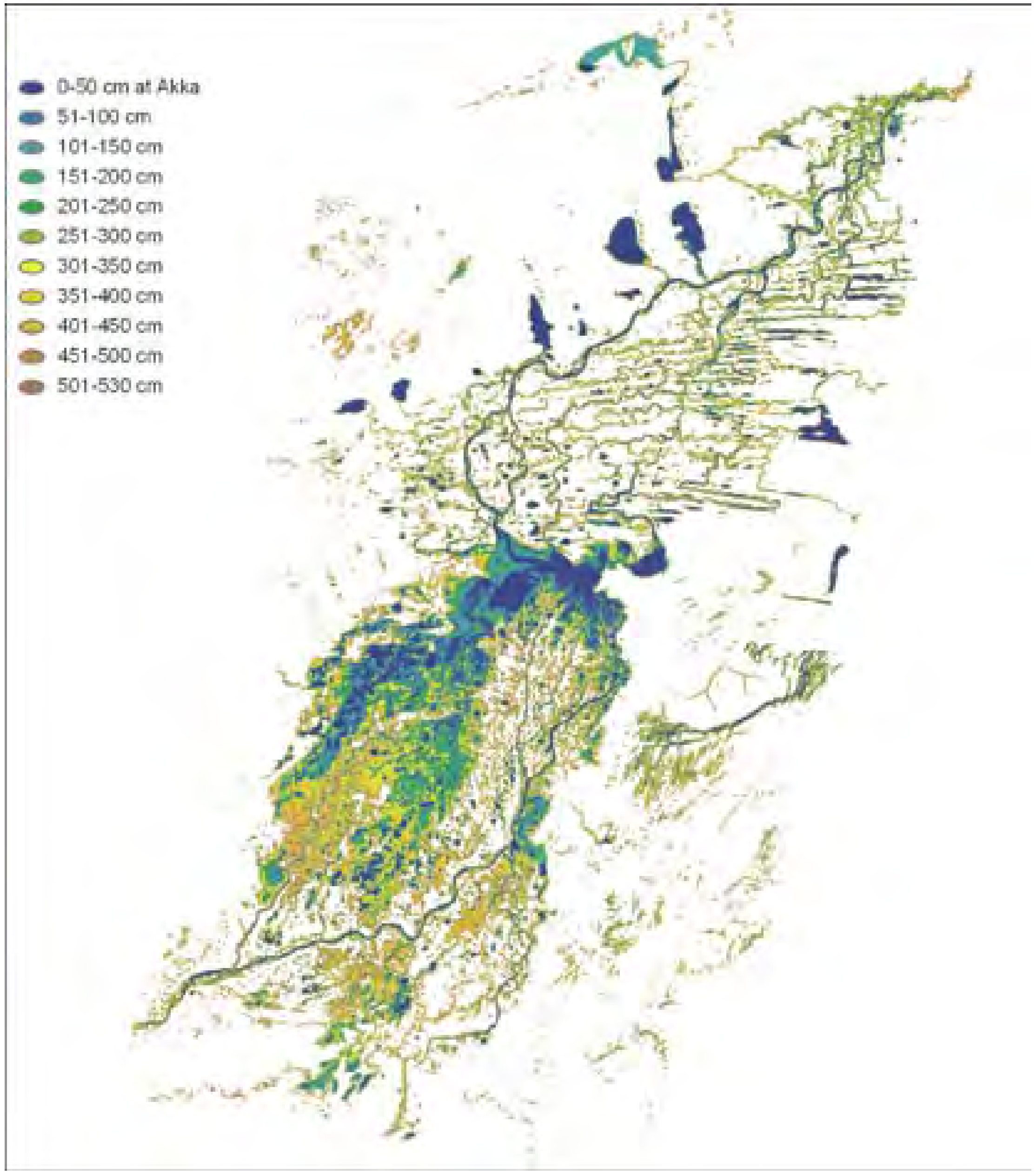


Fig. 3.12 Same map type as Fig. 3.10 and Fig. 3. 11 for receding water, but using the inclusive model to combine the water maps. This is the situation when the maximal water level has been very high.

3.6 Impact of irrigation and reservoirs

Similar to chapter 2, the study followed two approaches to determine the impact of the above-mentioned human activities on the river discharge. The first method is based on the water balance approach of the RIBASIM model. The second approach consists of a statistical analysis of the interaction between dams, reservoirs and the river flow in the Inner Niger Delta. Both models can be used in a complementary manner.

Water balance approach

As explained in chapter 2, irrigation and storage reservoir affect the river flow into the Inner Delta. Irrigation by Office du Niger reduces the river discharge. The effect of the Sélingué dam is seasonal and therefore less straightforward. The river flow is reduced during the crue while river discharge is larger during the dry period (see Figures 2.17 to 2.19). Figure 2.22 indicates that the future Fomi dam is expected to have a much larger impact on the river flow than the Sélingué dam.

The effect of the reduced river flow into the Inner Niger Delta can be analysed in two ways. Since the water level and river flow are measured at different hydrological stations, it is possible to do a statistical analysis to predict the downstream water level and river flow from upstream data. This analysis will be described in the section 3.7. The second approach is to use the water balance model RIBASIM. This approach is described in this section.

The SW part of the Inner Delta is inundated 1 to 2 months earlier than the NE part. This seriously complicates a water balance study for the entire area. That is why Passchier *et al.* (2004) split up the Inner Delta into eight zones (Fig. 3.13). In this stage, the areas west and north of basin called "South of Diré" have been ignored. Passchier *et al.* (2004) used the water maps derived from the satellite images shown in Fig 3.5 to calculate the relationship between water level and water surface during incoming and receding water for each of the eight zones (Appendix 4). Subsequently, this information is used to derive the relationship between water level and water volume.

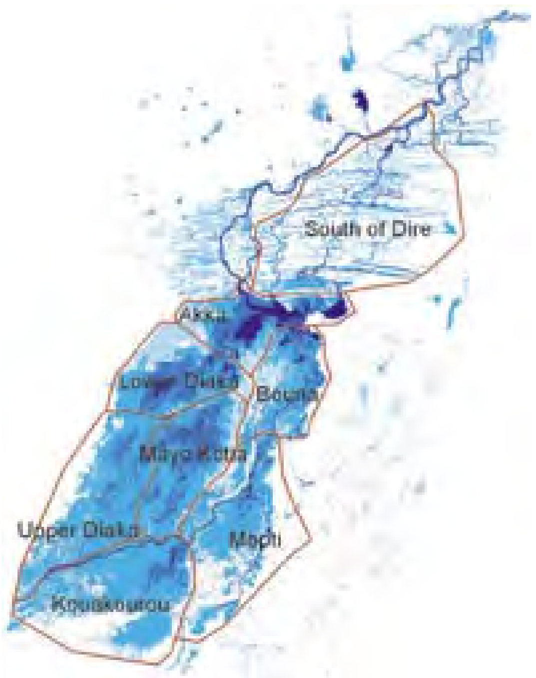


Fig. 3.13. Flood plains of the Inner Niger Delta, split up in eight regions. The different blue tints show the flooded area during incoming water at 23,140, 317, 429, 511 cm (see Fig. 3.5).

The most difficult part of the water balance study is to estimate the actual flow between the eight zones. The delay of the high water wave through the Delta depends on the flood level. If the flood is low the delay is 1 to 2 months, but it may be a month longer if the flood is high (Quensière et al 1994a, Orange *et al.* 2002a, Picouet *et al.* 2002, Zwarts & Diallo 2002). The model calculates the discharge by multiplying a fixed cross section with varying average flow velocities. Finally an average flow velocity of 0.08 m/s results in a delay of ca 1.5 month.

The next step involves the estimation of how the water flow through the different zones is divided. The final bifurcation ratios were: 25% of the water flows through the Diaka, 30% through the Moya Kotia and the rest through the Niger. Moreover it is assumed that 20% of the Bani flow bifurcated into the inundation area between the Bani and the Niger, near Kouakourou.

On the basis of the above estimates (see also Appendix 4), the inundation process can be simulated. Among others, the simulation allows for the approximation of the effect of a reduced river flow into the Niger. The reservoirs upstream of the Inner Delta are also taken into account in the RIBASIM model.

As described in chapter 2.5, two runs of the RIBASIM model have been included in this study. Run '1' describes an unrealistic situation in which no management of the water level in the reservoir will take place. Therefore, this chapter only evaluates run '2', which describes the effect of the dams during firm production of electricity and thus full management of the reservoir.

Fig. 3.14 shows the effect of the Office du Niger and the combined effect of Office du Niger and Sélingué on the flood level. The flood level is reduced by 5 – 25 cm due to the irrigation by Office du Niger. The impact of Office du Niger is most distinct in January and February. Due to the releases of Sélingué, the water level is raised more than 50 cm between January and April. Therefore, the combined effect of irrigation and the Sélingué is that the water level is 30 cm higher in these months. Sélingue lowers the flood level in the period of August to October with an additional 10-20 cm. As shown more explicitly in Fig. 3.15, the impact of both structures varies across the year. Without the presence of Sélingué and Office du Niger, the flood level would be 20 cm higher in August and September and 30 cm lower in the period January to March.

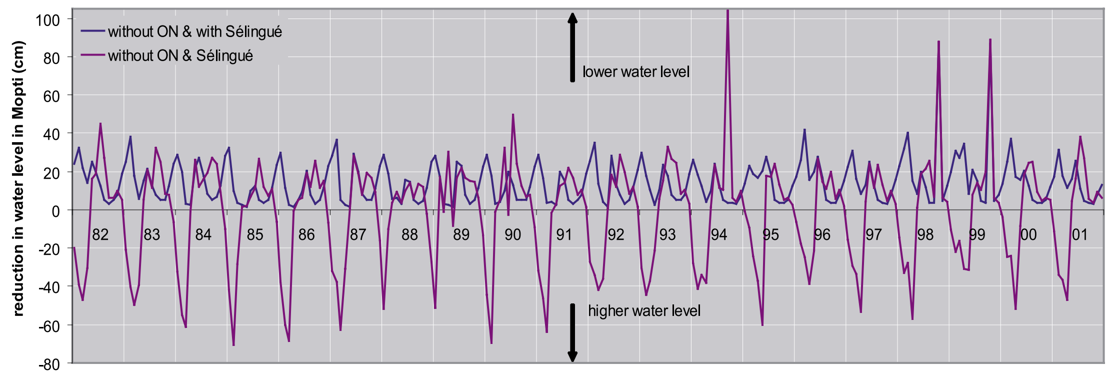


Fig.3.14. Reduction of the flood level at Mopti (cm) due to irrigation by Office du Niger and the combined effect of this irrigation and the Sélingué reservoir. Note that a decrease of the water level is positive and an increase negative. Source: WL|Delft Hydraulics.

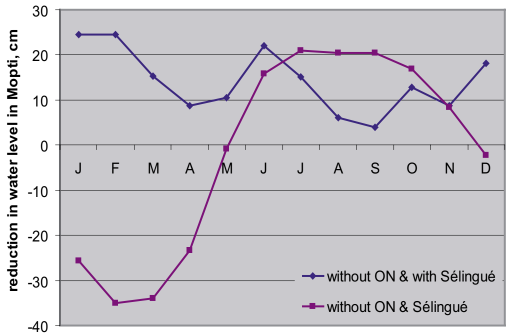


Fig. 3.15. Seasonal variation in impact of Office du Niger and Office du Niger + Sélingué on the flood level at Mopti; same data as Fig. 3.14.

Statistical approach

The flood level in the Inner Delta can accurately be predicted from the flow of the Niger and Bani into the Inner Delta using statistical analysis. These predictions are based upon a comparison of different time series of river flow and water level. This information will be used to check the water balance model described above.

River flow and flood level

To indicate the effect of irrigation and reservoirs on the Inner Delta, it is crucial to capture the relationship between river flow into the Inner Delta and water level in the Inner Delta itself. Since Akka is situated in the middle of the Delta, this hydrological station is selected to describe the fluctuation in water level.

It takes approximately one month before the water entering the Inner Delta reaches Akka. Therefore, we compare the average water level per month in Akka with the average monthly flow of the river entering the Inner Delta. The flow is determined by the sum of the river discharge at Ké-Macina along the Niger at the entrance in the Inner Delta and at Douna along the Bani.

When the monthly water level in Akka is plotted against the river flow of Niger+Bani the month before, a cloud of dots appears which reveals no relationship whatsoever. By splitting the data by month, however, the relationship between water level and river flow becomes distinct. Yet, the relationship differs by month (Fig. 3.16). Because the power function for August, September and October is the same, these three months are joined together. The regression shows a very close fit. Therefore, the water level during the crue can be predicted accurately from the river flow.

Fig. 3.6 also shows the relationship between river

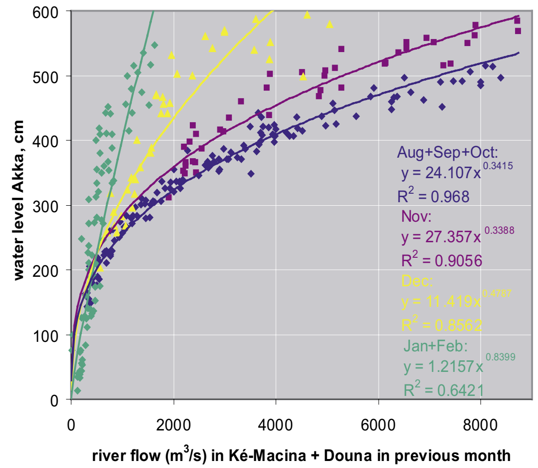


Fig.3.16. Water level in Akka as a function of the river flow in Ke-Macina and Douna in the preceding month. All data are based on daily measurements, but are averaged per month. The figure shows the relationship separately for four periods. The regression equations of the power functions are also given, as well the explained variance (R^2).

discharge and water level for other months. The fit is not as good as for the period August-October. The graph seems to indicate that later in the year, the same river flow goes with a higher water level than earlier in the season. The explanation is that the flow in the preceding months has already flooded the Inner Delta and that the river flow in a later month only adds little extra water to the large existing water body. In other words, the water level in Akka depends on the flow entering the Inner Delta one, two, three, four, or more months ago. A multiple regression revealed that the water level in October can perfectly be predicted from the flow in September. The flow in July and August has no effect on the water level in October. In contrast, the water level in November depends on the river flow in August, September and October. The same holds for the water level in December, which depends on the water flow in September, October and November. The equations that represent the relationship between the water level in Akka in November or December (cm) and the river flow of Bani+Niger (m^3/s) in three foregoing months, are given below. Note that the very high R^2 shows that the fit is very good.

November

$$cm = \exp(2.775 + 0.164*\ln(O) + 0.173*\ln(S) + 0.066*\ln(A))$$

$$(R^2 = 0.969), \qquad 3.5$$

December

$$cm = \exp(0.793 + 0.216*\ln(N) + 0.122*\ln(O) + 0.306*\ln(S))$$

$$(R^2 = 0.970) \qquad 3.6$$

where:

cm = The water level in Akka in November or December

A, S, O or N = The river flow of Bani+Niger (m^3/s) in August, September, October or November.

Impact of irrigation and reservoirs on flood level

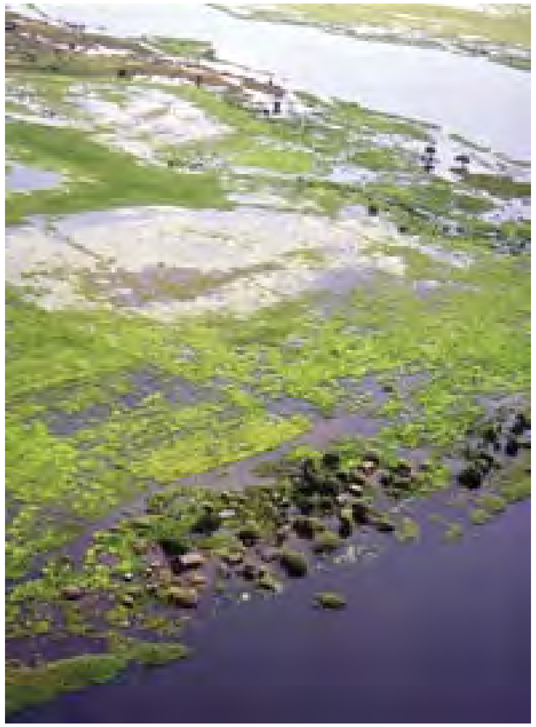
The power function of August to October as shown in Fig. 3.16 and the two separate functions of November and December presented in equations (3.5) and (3.6) can now be used to calculate the water level from the river flow in the preceding month. The calculation is carried out for the actual monthly river flow data as well as for the reconstructed river flows representing the different scenarios introduced in chapter 2. These scenarios include the river flows in the absence of irrigation, without the dam at Sélingué and with the presence of the Fomi dam. Subsequently, the three reconstructed series of monthly water levels are plotted against the actual monthly water levels. The results are shown in the first few columns of Table 3.4 The fit of the regression analysis is extremely good.

The regression equations can now be used to indicate the effect of the irrigation and the Sélingué and the future Fomi reservoir on the water level in Akka. The impact of the three structures, which have been depicted on the right hand columns of Table 3.4, depends on the water level, but also varies between the months:

- Office du Niger: Office du Niger reduces the water level in Akka by about 10 cm if the water level is 250 cm and this gradually decreases to 5 cm if the water level is as high as 550 cm. The water balance study described in the previous section showed that Office du Niger lowered the water level by 5 –10 cm, thus in full agreement with the statistical prediction.
- Sélingué: Sélingué reduces the flood level in September- December by another 15-20 cm, again exactly the same outcome as the water balance study (Fig. 3.15). The months do not differ for moderate and high flood level, but if the water level is low, the impact of the Sélingué is twice as large in September as in December. Such a difference is to be expected since the amount of water withheld by the reservoir is large at the start of the flood wave and gradually decreases in later months (Fig. 2.18).
- Fomi: The effect of the Fomi reservoir has been simulated by assuming that the flow reduction

Table 3.4 The water level in Akka (cm) with no irrigation by Office du Niger and no Sélingué reservoir ('without ON & Sél'), with no irrigation by Office du Niger but Sélingué still present ('without ON & with Sél'), and with irrigation by ON, and two dams Sélingué and Fomi dam ('present + Fomi') as a function of the present water level in Akka (cm). The linear function is given for four months (a = constant, b = slope); R^2 = explained variance. The deviation between the predicted water and the present water level, according the regression equation, is shown in the right columns; no values are a given if the water level is out of reach of the actual measurements

Scenario	**Month**	**a**	**b**	**R^2**	**Water level Akka (cm) present situation**			
					250	350	450	550
Without ON & Sél	Sept	43.5	+0.939	0.938	28.3	22.2		
	Oct	43.2	+0.937	0.981	27.5	21.2	14.9	
	Nov	43.5	+0.942	0.999	29.0	23.2	17.4	11.6
	Dec	32.1	+0.974	0.998	25.6	23.0	20.4	17.8
With ON & without Sél	Sept	13.4	+0.974	0.999	6.9	4.3		
	Oct	14.7	+0.975	0.999	8.4	5.9	3.4	
	Nov	16.9	+0.975	0.999	10.7	8.1	5.6	3.1
	Dec	19.8	+0.975	0.999	13.6	11.1	8.6	6.0
Present + Fomi	Sept	-155.6	+1.231	0.938	-97.9	-74.8		
	Oct	-119.2	+1.178	0.839	-74.7	-56.9	-39.1	
	Nov	-106.4	+1.130	0.974	-73.9	-60.9	-47.9	-34.9
	Dec	-48.4	+1.020	0.974	-43.4	-41.4	-39.4	-37.4



would be in agreement with Sélingué, but than 2.9 times larger. Note that 2.9 is the ratio between the water volume of Fomi and Sélingué. The impact of Fomi on the flooding of the Inner Delta is significant. Even at a flood level of 450 cm and higher, the water would be reduced by 35 - 40 cm. The reduction would increase to 50 – 100 cm at a lower flood level and earlier in the season.

3.7 Annual flooding statistics

There is a large year-to-year variation in the flooding of the Inner Delta. The next chapters will investigate to what degree the ecological and economical values of the Inner Delta depend on the degree of flooding. By determining this relationship, we can estimate the downstream impacts for the economy and the ecology in the Delta of a decline in river flow caused by upstream irrigation and reservoir management.

To determine the link between flooding and downstream impacts, we first need to find out which measure of flooding can be used. There are at least five ways to describe the annual fluctuation in flooding: (1) maximum flood level, (2) maximum inundated surface, (3) duration of flooding, (4) annual or (5) maximal flow of the river entering the floodplains. Each of these measures can be described in several ways. For instance, the flood level of the Inner Delta has been measured at several hydrological stations. All these variables are highly correlated, since the river flow determines the maximal flood level as well as the surface of the flooded area.

Second, we also need to find out which flooding measure reveals the strongest link with the annual production of fish, livestock or rice. This measure is likely to differ between the various sectors. Fish production, for example, is probably best explained by the surface of the inundated area and the duration of the flooding. Rice production, on the other hand, is expected to depend mostly on the maximal flood level and the time of year at which the rice fields are flooded. Finally, the production of cattle may depend mainly on the production of a species of floating grass (i.e. 'bourgou'), which in turn depends on the maximal flood level and the duration of flooding.

This section provides a short overview of the interrelationships between the different flooding statistics. In the next section, the effect of Sélingué, Office du Niger and the planned Fomi dam on the different series of data will be indicated. An overview of all measurements and derived values is provided in Appendix 5.

River flow and flooding

Fig. 3.16 already showed how the flood level in September and October was determined by the amount of water entering the Delta one month earlier. Later in the season, the flood level is highly dependent on the river discharge in the three foregoing months (Table 3.4). The maximal flood level is also closely related to the water flow in the preceding months. When the maximal water in Akka is plotted against the river discharge of Niger and Bani combined, the best fit is generated by taking the flood level as a function of the river flow in September (see Equation 3.7):

$$cm = 17.762 * flow^{0.3872} \quad (3.7)$$

(R^2 =0.8902)

where:

cm = maximal water level in Akka

flow = river discharge (m^3/s) for Ké-Macima + Douna in September.

The fit improves even further if the flood level is plotted against the average river discharge in August, September and October:

$$cm = 16.801 * flow^{0.4038} \quad (3.8)$$

(R^2 = 0.9313)

where:

cm = maximal water level in Akka

flow = average river discharge (m^3/s) for Ké-Macina + Douna in August-October.

The flooded surface is closely related to the flood level (section 3.4). When the inundated maximal surface for the different years is plotted against the river flow, the function becomes:

$$km2 = 24.497 flow^{0.7651} \quad (3.9)$$

(R^2 = 0.9245)

where:

km^2 = inundated surface on the area indicated in Fig. 3.9-3.11;

flow = average river discharge (m^3/s) for Ké-Macina + Douna in August-October.

The annual peak river discharge, flood level and flooded surface are highly correlated. In a statistical sense, the three variables describe the same process.

Flood level and flood duration

The flood level is closely related to the duration of the flooding period. In a year with a high peak flood level in the Inner Delta, the flood lasts four months longer than in a year with a low flood. As shown in Fig. 3.17, the wave comes one month earlier and continues for an additional three months. To construct this figure, all daily measurements since 1944 were subdivided into six categories on the basis of the highest water level in each year. There are three years with a maximum flood between 450 and 500 cm (1984/5, 1987/8, 1993/4). For these three years the average water level per date is calculated. The same is done for the other categories: 500 – 550 cm (n = 6), 550 – 600 cm (n = 9), 600 – 650 cm (n = 7), 600 – 650 cm (n = 20) and 650 – 700 cm (n = 12). Besides the fact that the flood wave lasts longer with a higher flood, Fig. 3.17 shows that the peak level is reached more than a month later if the flood is high. Note that Appendix 5 provides the maximum water level per year for two stations (i.e. Akka and Mopti) as well as the specific date of this peak level. Details about of the annual variation in the dates of inundation are presented by Zwarts & Diallo (2002).

A surface area in the central Inner Delta at a level of 300 cm, relative to the gauge of Akka, is covered by water for 41% of the year. Due to variations in flood level, however, the coverage by water varies between 15% and 65% of the year (Zwarts & Diallo 2002). Fig. 3.18 shows the relationship between flood duration and maximum water level for areas at a level of 100, 200 and 300 cm, respectively. The data are calculated for Akka in the central Delta, using the daily measurements of the water level. The positive slope of the three curves indicates a strong relationship between the maximum water level and the flood duration. In years with an extremely high flood, a part of the Inner Delta is still flooded at the beginning of the next hydrological year, which starts on May 1st. Therefore, the water level in the previous year partly explains the variation along the regression lines shown in Fig. 3.18. This variation is small, however. Hence, the conclusion remains that the maximal flood level and the flood duration are statistical interchangeable.

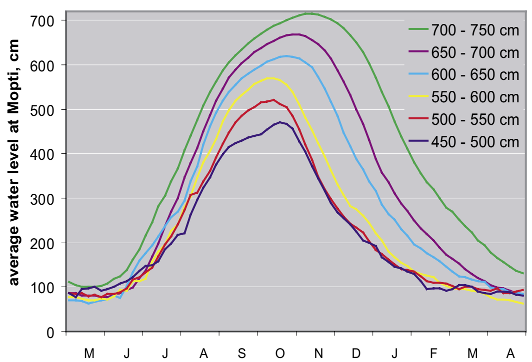


Fig. 3.17. Average daily water level in Mopti during the hydrological year (1 May - 31 April) for six different flood levels

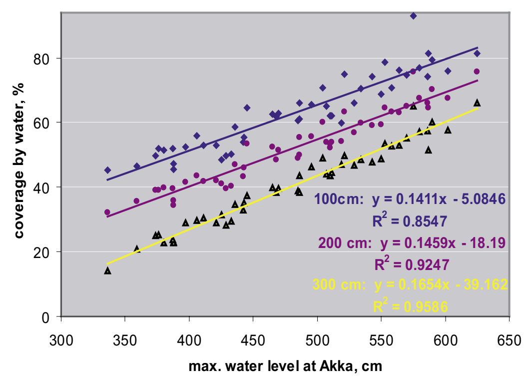


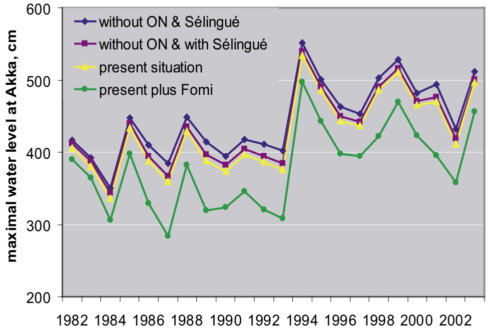
Fig 3.18. Relationship between maximal water level and flooding period of the floodplain at three different levels, 100, 200 and 300 cm, relative to the gauge of Akka (% of the hydrological year: 1 May – 30 April the next year). Data is based on all daily measurements in 1956-2004; each dot represents a year.

3.8 Scenario analysis on inundation area

Section 3.5 described the effect of irrigation and reservoirs on the flood level. The outcome of water balance calculations coincides with the statistical analyses regarding the effect of the irrigation and the Sélingué reservoir on the flood level in the Inner Delta. Because the two approaches do not differ, only the statistical analysis will be applied in the forthcoming chapters.

Besides the original data on the flood level, the river flow and the water use, Appendix 5 also provides an overview of the equations used to predict the monthly water levels and the maximum water level. When the monthly water use by Office du Niger and the Sélingué reservoir is added to the current river discharge, the reconstructed discharge can be entered into the equation of flood level against river flow to derive the flood level. In this way the average water level in October and November for the four scenarios is calculated. Although these details are not provided in Appendix 5, flood levels can be calculated with the described equations. The same Appendix also describes how the maximum water level in the four scenarios is derived from the predicted water levels in November.

The relationship between the water level in Akka and the flooded surface in the Inner Niger Delta has been estimated in section 3.5 (see equation 3.4). This equation is now used to calculate the surface of the inundated area for the four scenarios. Fig. 3.19 shows the impact of irrigation and reservoirs on the maximum water level at Akka and the maximally inundated area. Without Office du Niger the inundated area would be 300 km^2 larger and without Sélingué another 600 km^2. The absolute reduction in surface is about the same in September, October and December. The Fomi dam has a much larger impact. Compared to the present situation, the inundated surface declines by 2,000 to 2,300 km^2, implying a reduction of the flooded area of 48% in September and 25% in following months.



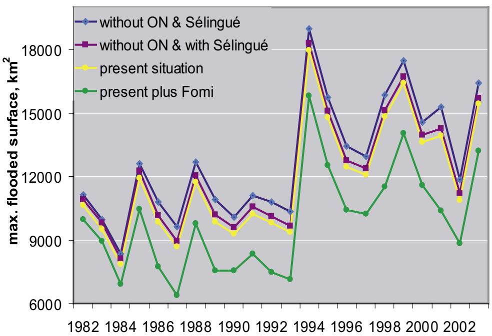


Fig. 3.19. Year-to-year variation in the maximum water level in Akka (top) and the surface of the maximum inundated area in the Inner Delta (bottom). The effect of the irrigation by Office du Niger and the Sélingue and future Fomi reservoir are indicated

3.9 Conclusions

The above analyses of the flooding regime of the Inner Niger Delta provides us with a reliable range of estimates for the calculation of the ecological, social and economic impact of man-made structures in the Upper Niger. These separate analyses will be presented in the next chapters. To recap the main lessons learned, the conclusions of the flooding analysis are summarised in the following points:

- Satellite images clearly reveal the flooded areas of the Inner Delta. By comparing images from different dates with different flood levels, it is possible to describe the flooding as a function of the flood level. The relationship differs for the crue and the décrue.
- Rains can temporary fill depressions between June and September. This potentially complicates the distinction between flooded areas versus areas that are filled by rainwater. The analysis proved, however, that the significance of local rain is limited and only plays a role in the description of the flooding during incoming water.
- The flooded surface during receding water is dependent on the flood level itself as well as on the maximum water level reached during a particular year. During the décrue, about half of the more isolated depressions and lakes that are filled at high floods, are no longer connected to the river. The time it takes for these water bodies to disappear, depends on the water depth and the time passed since these water bodies lost contact with the river system.
- One map of the flooding process of the Inner Delta during the crue is provided. Different colours indicate the flooded area at different flood levels. Two maps are provided for the décrue. One represents the situation after a high flood, the other after a low flood.
- The strong correlation between the flooded area and the flood level, allows for the estimation of the area being inundated at a maximum during the last half century. The inundation area varies between 8,000 and 25,000 km^2.

- The RIBASIM water balance model revealed that the water level in the Inner Delta in August - October was reduced by 5-10 cm due to irrigation of Office du Niger and another 15 cm due to the management of the Sélingué reservoir.
- The statistical analysis supplemented these estimates by comparing different long-term series of hydrological measurements. The analysis accurately predicts the water level in the middle of the Inner Delta, on the basis of information on the river flow of the Niger and Bani during the previous months. According to this analysis, the Fomi dam will reduce the peak flood level with another 45 cm.
- The impact of irrigation and reservoirs on the flooded surface has been indicated as well. The management of the Sélingue reservoir leads to a decline of the maximum inundation of 600 km^2. Office du Niger and the Fomi dam cause an additional decline of 300 and 2000 km^2, respectively.

4 PEOPLE IN THE INNER NIGER DELTA

Leo Zwarts
Bakary Kone

4.1 Introduction

All over the world, floodplains are extremely productive biological systems. This is one of the reasons why floodplains in the Sahel attract so many people. The Inner Delta of the Niger forms no exception. The Delta accommodates one million people, most of which fully depend on its natural resources. With approximately 25 inhabitants per km^2, the population density of the Inner Delta is much higher than in its dry surroundings.

The major characteristic of the Inner Delta is the large variation in natural conditions between seasons and between years. This is due to changes in flood level and the large seasonal and annual variation in rainfall. As a consequence of variable rainfall and flood level, the productivity of resources also varies from year to year. Many people living in the Delta, such as herders and fishermen, move with the flood to make optimal use of the variation in productivity in different ecological zones. Herders have to migrate with their cattle while fishermen follow the shifting waterfront.

Chapter 2 and 3 provided many details about the annual variation in rainfall and flood level. The annual production of natural resources (fish, livestock and cereals) is described in Chapter 5, 7 and 8. The present Chapter deals with the human population and pays special attention to the change in population during the last 30 years, based on three National Censuses in Mali, i.e. in 1976, 1987 and 1998 (Ministère du Plan, Direction Nationale de la Statistique et de l'Informatique 1976, 1987; Ministère de l'Economie et des Finances, Direction National de la Statistique et de l'Informatique 1998).

This chapter is structured as follows. Section 4.2 explains the transition from the traditional system of natural resource management in the Inner Niger Delta to a more modern form of management. Section 4.3 concentrates on population changes in the Inner Delta by evaluating trends retrieved from the censuses and on the process of depopulation. Section 4.3 also investigates the link between depopulation, climate and flooding in the Delta. This Section pays special attention to the role of temporary lakes in the process of depopulation. Conclusions are drawn in Section 4.4.

4.2 Change in traditional system

Exploitation of natural resources

For centuries, the natural resources of the Inner Delta were neatly divided among the people. The Fulani herders came with their cattle to graze on the floodplains in the dry period, where the Bozo and Somono people had been fishing some months earlier. The farmers (Marka, Bambara, Sonrai, etc) planted rice in the rainy season, just before the flood covered the area, to harvest it some months later during receding water. In this traditional system, each ethnic group produced a part of the daily diet while the remaining food was complemented through local trade. According to an estimate for the early 1980s, about 30% of the Delta inhabitants were fishermen, 30% belonged to the agricultural community and the remainder were herders.

The traditional system of exploitation of the natural resources of the Inner Niger Delta encompassed:

- Semi-sedentary farmers, growing rice and millet,
- Semi-nomadic fishermen,
- Semi-nomadic herders, raising cattle, sheep, goats, etc.

The Great Drought in the 1970s and early 1980s forced many rural people in the Inner Delta to abandon their specialisation. Fishermen started to grow rice on the side, while farmers began to fish and raise cattle as well. Some Fulani even began to cultivate rice. Such mixed ways of exploitation have become more prominent in recent years, and in fact have now been transformed into new professions, i.e.:

- agri-pastoralist,
- agri-fishermen.

Natural resource management

The Fulani ruled the Inner Delta from the early 19th century until the arrival of the French in 1893. They imposed a system of resource management, called the Dina, on all major production systems. The Dina divided the area into a number of grazing territories and by doing so, formalised the already existing resource management system. The Dioro, the head of a Fulani clan, ruled each territory. The actual management of the floodplains was done by the "masters of the water" (*maître d'eau*) and the 'masters of the land' (*maître de terre*). The master of the water managed the access to the fishing grounds and the master of the land did the same to the floodplains when dry. In practice, the two masters managed the same area but in different seasons.

Studies of Gallais (1967), Moorehead (1991) and others showed that this socio-economic system was already in crumble half a century ago. Due to population growth, the pressure from outside people increased. Although the rural communities were still the owners of the terrain, the masters no longer had sufficient power to deny right of access to the growing number of outsiders. After independence in 1960, the State started to build its own administration with technical services, such as '*Eaux & Forêts*'. This new control system further weakened the traditional system of community-based resource management. The new policy of decentralisation since 1992 can be considered as an attempt to integrate traditional management into modern society.

4.3 Population changes in the Inner Delta

Census

At present, about one million people live in the Inner Delta. As shown in Table 4.1., the population in the Delta slowly increased with 0.7% per year between 1976 and 1998. For this period, the growth rate in Mali as a whole was much higher. The Malian population increased with 2.43% per year from 6.4 million in 1976 to 9.8 million in 1998. As a result, the fraction of the Malian population living in the Inner Delta declined from 15.4% in 1976 to 13.4% in 1987. In 1998, the fraction of the population living in the Delta had further declined to 11.3%.

Within the Delta, population trends differ for each cercle. The population in the region of Mopti increased from 197,000 to 263,000 people between 1976 and 1998. On the other hand, in Gourma-Rharous the population decreased from 96,000 to 68,000 in the same period. In the 1960s, more than 100,000 people lived in Gourma, so the decrease of the population had started even earlier (Hiernaux 1993).

The relative decline of the population has been larger in the northern part of the Inner Delta than in the southern part. In 1976, 7.6% of the Malian population lived in the region of Tombouctou. This decreased to 5.8% and 4.9% in 1987 and 1998, respectively. For the region of Mopti these figures are: 17.7, 16.7 and 15.1%. This is also a decline, but not as large as in the region of Tombouctou.

The population of the Inner Delta can be classified as urban or rural. People living in towns and villages with more than 10,000 people are considered urban. All other people are labelled rural. According to this criterion, the urban population lives in the following 17 settlements: Diafarabé, Diré, Echell, Gossi,

Table 4.1. Number of people living in the nine *"cercles"* covering the Inner Niger Delta and immediate surroundings. The five northern *cercles* form the region of Tombouctou, the four southern *cercles* the region of Mopti. The annual population change is provided for 1976 – 1987, 1987 – 1998 and 1976 – 1998 relative to the year 1976, 1997 and 1976, respectively. Source: Ministère du Plan, Direction Nationale de la Statistique et de l'Informatique (1976, 1987); Ministère de l'Economie et des Finances, Direction National de la Statistique et de l'Informatique (1998).

	population size			population change (%/year)		
	1976	1987	1998	76-87	87-98	76-98
Région de Tombouctou	489,489	459,368	475,858	-0.56	0.33	-0.13
Cercle de Tombouctou	68,996	65,982	70,177	-0.40	0.58	0.08
Cercle de Diré	82,806	80,717	84,393	-0.23	0.41	0.09
Cercle de Goundam	108,730	115,020	130,583	0.53	1.23	0.91
Cercle de Gourma-Rharous	96,021	87,414	67,717	-0.81	-2.05	-1.34
Cercle de Niafunké	132,936	110,235	122,988	-1.55	1.05	-0.34
Région de Mopti	493,031	570,783	631,933	1.43	0.97	1.28
Cercle de Mopti	196,885	248,484	263,719	2.38	0.56	1.54
Cercle de Djenné	118,580	128,641	155,551	0.77	1.90	1.42
Cercle de Ténenkou	96,161	118,189	127,237	2.08	0.70	1.47
Cercle de Youvarou	81,405	75,469	85,426	-0.66	1.20	0.22
Inner Niger Delta	982,520	1,030,151	1,107,791	0.44	0.69	0.58
Mali	6,394,918	7,696,348	9,810,911	1.85	2.50	2.43

Goundam, Gourma-Rharous, Konna, Korientze, Leré, Mopti/Sévaré, Niafunké, Sofara, Ténenkou, Tombouctou, Tonka and Youvarou. Table 4.2 shows the change in the rural and the urban population. It is obvious the rural people partly moved to the towns. In 1976 not more than 13.4% of the population in the Inner delta lived in towns. This proportion had increased to 17.8% in 1987 and to 18.6% in 1998. Fig. 4.1 clearly shows the rural depopulation in the northern Inner Delta.

Depopulation, climate and flooding

Depopulation and climate change are possibly linked. The harsh climatic conditions in the semi-arid, northern part of the Inner Delta render it difficult to make a living. Over the years, the decline in rainfall in the northernmost areas impedes cattle grazing and rice growing (e.g. Hiernaux 1993, Togola 2002; see also chapter 7 and 8). Another potential cause for

Table 4.2. Size of rural and urban populations living in the regions of Tombouctou and Mopti. The data are the same as in Table 4.1, but subdivided for people living in the country and in towns with more than 10,000 inhabitants.

	population size			population change (%/year)		
Urban	1976	1987	1998	1976-1987	1987-1998	1976-1998
Region de Tombouctou	50095	77036	92650	4.89	1.84	3.86
Region de Mopti	91744	126677	138297	3.46	0.83	2.31
Inner Niger Delta	141839	203713	230947	3.97	1.22	2.86
Rural						
Region de Tombouctou	439394	382332	383208	-1.18	0.02	-0.58
Region de Mopti	401287	444106	493636	0.97	1.01	1.05
Inner Niger Delta	840681	826438	876844	-0.15	0.55	0.20

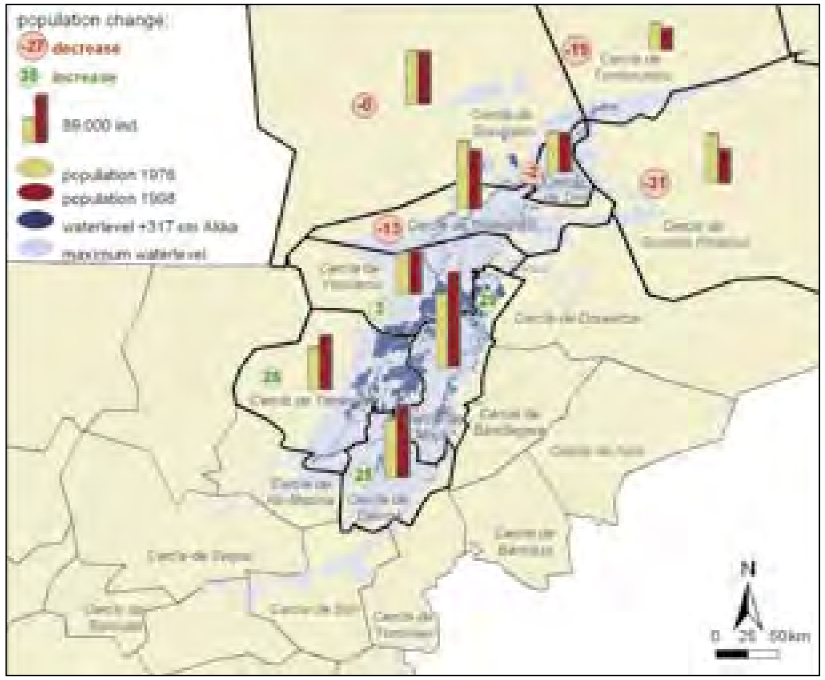


Fig. 4.1. Change in the rural population (%) in nine 'cercles' between 1976 and 1998 in the Inner Delta; data from Table 4.2.

depopulation is the decline in the flow of the Niger since 1973 (Chapter 2.1), effectively reducing the flooded area by 50% (Chapter 3.8). If the reduced flooding is an explanation for the recorded change in population size in the different cercles, it is likely that the population decreased most in regions where flood reduction was most severe. On the other hand, population is expected to remain stable in cercles where the decline in flooding is limited. Fig. 4.2 shows the flooded surface subdivided by cercle. Floodplains are mainly present in three cercles: Mopti (26%), Ténenkou (22%) and Youvarou (21%). Apart from Djenné (12%) and Niafunké (7%), only 12% is left for the four other cercles: Goundam 5%, Diré 4% and 1% for Tombouctou and Gourma. The relative share of the cercles in the floodplain does not vary much. At a water level of 317-343 cm 84% of the floodplain is found in the region of Mopti. This is 80% at a water level of 429 or 511 cm.

This implies that, within the range of the maximal water level during the last 25 years, differences in the relative distribution of the floodplain between the cercles are small.

Because a small part of the floodplain in the NE is not covered by satellite images, Fig. 4.2 underestimates the share of Tombouctou and Gourma in the inundation area. In contrast, the contribution of each cercle to the floodplain at a water level of 625 cm is based on the complete map (Figure 3.1). As the coverage of this latter map is different from the one generated by satellite images, a direct comparison is impossible. Nevertheless, the data of the flood of 625 cm are included in Figure 4.2, because it shows that even at full coverage and at extremely a high water level, the distribution of the flood area remains the same. The part of the floodplain found within the cercles Gourma and Tombouctou increases from 1% at 511 cm (satellite image) to 2% at 625 cm (complete map), from 4 to 5% in Diré, from 5 to 7% in Goundam and from 7 to 11% in Niafunké. This leads to a combined shift in flood coverage in the five northern cercles from 17 to 27%. Therefore, even at extremely high water levels, 70% is still found in the four southern cercles: Mopti and Ténenkou 20%,

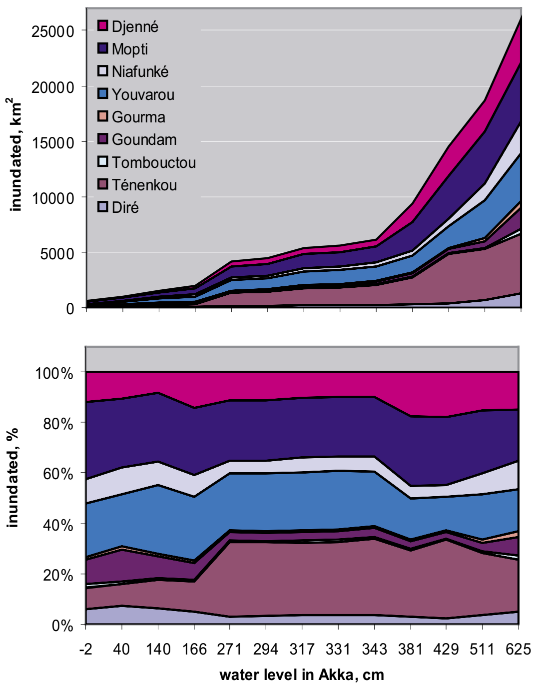


Fig. 4.2. Flooded surface divided by *cercle* (km^2 top and % bottom) at different water levels (Akka, cm), based on the water maps (Figure 3.5; incoming water only). The surface at 625 cm is based on Figure 3.1.

Youvarou 16% and Djenné 14%.

How do the findings of the distribution of the flooded areas between regions compare with changes in the population at the regional level? Within the Inner Delta, the rural population increased in the four southern cercles. Note that the South is the region where always 70% to 80% of the floodplain is to be found. The population in the five northern cercles declined. In this region the floodplain covered 27% at a high flood and 16% in years with a low flood. This suggests a relationship between depopulation and reduced flooding in the Inner Niger Delta.

Temporary lakes and depopulation

The depopulation of the northern Inner Delta is not only related to the flooding, but also to the extent to which temporary lakes are filled by the crue. Apart from the three central lakes (Débo, Walado and Korientzé), all other permanent lakes are found in the northern half of the Inner Delta (Figure 3.1 in chapter 3). Although the lakes are called permanent, most fall dry after floods of 400 cm and less at Akka. In fact, only the three central lakes (Lac Korientzé in the Mopti cercle and Lac Walado-Débo in the cercle de Youvarou) and Lac Horo in the north (cercle de Goundam) have been permanently filled. At high water level of 500 or 600 cm, all permanent lakes are filled and the total surface of permanent water bodies is 2-4 times larger than usual (see Fig. 4.3). The lake surface can grow as much as 10-20 times in Niafunké, Gourma and Goundam. As a result, at a high water level the largest permanent lakes are no longer to be found in the region of Mopti, but in Goundam and Niafunké. To fill these lakes the flood has to surpass a critical level. Therefore, especially for many inhabitants of the regions of Niafunké and Goundam, a difference in the flood level of 10 - 20 cm can be crucial.

This critical threshold is clearly demonstrated by Lac Faguibine. Satellite images and aerial photographs show that this lake was filled with water

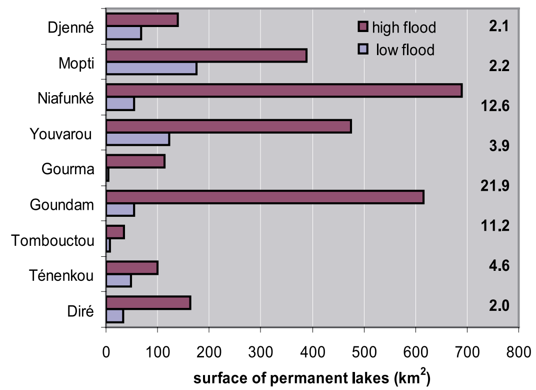


Fig. 4.3. Surface of the permanent water bodies in km^2 at low and high floods for 10 different cercles. The ratio of the surface at high and low floods is shown on the right side of the graph.

in most of the years before 1976. Since then, the lake was completely dry in 21 of the following 28 years. In two years (2000 and 2001), the water level was just high enough to enter the lake. Yet, only a limited portion of the lake was covered with water. The maximal water level in these two years was 465 - 470 cm at Akka. Apparently, this is the critical minimal water level for Lac Faguibine. Indeed, when the water level in Akka rose to 485 - 534 cm in 1994, 1995, 1998, 1999 and 2003, a substantial part of Lac Faguibine was filled with water. In case of the presence of the Fomi dam, Lac Faguibine would have received water only once instead of five times during the last 28 years (Fig. 4.19). Without the Office de Niger and Sélingué, there would have been water in Lac Faguibine for at least seven years.

4.4 Conclusions

Maiga *et al.* (2002) concluded that since the Great Drought the people of the Inner Delta have become more mobile. There is a greater mobility within the Inner Delta, but also from and to the Inner Delta. During the Great Drought many people from the Inner Delta emigrated to neighbouring countries. It is tempting to speculate about the possible effect of Sélingué and Office du Niger on the decision of people in the different cercles to leave and start a new life in a nearby town, elsewhere in Mali or abroad. To answer this question, it is necessary to investigate whether the production of fish, livestock and cereals is related to the flood level and if so, to what degree the reduction in flooding due to Sélingué and Office du Niger has reduced production. This will be the topic of the following chapters.

For the time being, the above evaluation on the relationship between flooding and population growth has led to the following findings:

- The population in Mali has increased with 2.4% per annum during the last 35 years, but there was a decrease in the population in the region of Tombouctou (northern half of the Inner Delta) and an increase of only about 1% in the region of Mopti (southern half of the Inner Delta).
- The rural people in the Inner Delta moved to towns in the Inner Delta. In 1976, 13% of the population was urban. This gradually increased to 19% in 1998. The rural population in the northern Delta decreased in the same 22 years from 439,000 to 383,000 people.
- The Great Drought has been one of the causes of rural depopulation in the Inner Delta. During these years, farming in the semi-arid zone was hardly possible and there was no vegetation for the cattle to graze. Besides the lack of rain, the decrease in the surface of the floodplain was another potential reason for people to leave the Delta.
- The people in the northern Inner Delta suffered more from the reduced flood level than the people in the southern part. Firstly, 70-80% of the floodplain is found in the region of Mopti, independent of flood level. In contrast, 27% of the floodplains are found in the region of Tombouctou at a high flood, but this decreases to 16% at a low flood. Secondly, apart from the three central lakes, permanent lakes are all located in the region of Tombouctou. Most of these lakes remain dry in years with a low flood, but after a high flood, permanent lakes in the region of Tombouctou encompass over 1,600 km^2. Due to low floods, this rarely occurred during the last 25 years. Lac Faguibine was (partly) filled with water during 5 of the last 22 years; without Office de Niger and Sélingué this would have been seven times. If there had been a Fomi dam, the lake would have contained water only once.

5
FISHERIES IN THE INNER NIGER DELTA

Leo Zwarts
Mori Diallo

5.1 Introduction

Old fishermen in the Inner Delta still tell stories about the past when they captured Nile Perches of 1.5 m and longer. This is certainly not a fisherman's yarn. All fishermen in the Inner Delta remember that during the last 30 to 40 years fish have significantly reduced in size. And the fishermen know about the causes of the decline in size. The fish stock in the Delta is almost the same as in the past, but fishing intensified continuously, visible in the increase of fish traps, hook lines and fishing nets. During the décrue, the fish are easy to catch because they become trapped in (temporary) lakes and concentrated in creeks and the riverbed. Nowadays, nearly all fish will be captured long before the next flood arrives. The catch of the following year now mainly depends on the young fish born in the preceding flooding period. Nile Perches in the Inner Delta no longer have the time to reach a size of over 1.5 meters.

A number of studies confirmed the conclusions drawn by the fishermen. Meanwhile, more data have become available. This allows us to extend former research and include additional data, to be used specifically for the purpose of this study. The objective of this chapter is to enhance the current knowledge with regard to the fish production in the Inner Niger Delta and to determine its relationship with fluctuations in the flood level of the Niger River. By determining this production function we will be able to estimate the impact of the management of Office du Niger, Sélingué reservoir and Fomi dam on the fish production in the Inner Niger Delta.

The chapter is structured as follows. Section 5.2 describes previous conducted work on fisheries in the Inner Niger Delta, with a focus on the relationship between flooding and fish catch. Section 5.3 aims to estimate fish production in the Delta by distinguishing between catch and trade of fresh and dried fish. This section also scrutinises existing estimates of the fish consumption in the Inner Niger Delta. The revised estimates of fish production of Inner Delta are compared to those in other African floodplains in Section 5.4. Special attention is paid to the biological upper limit of fish production in the Delta. Section 5.5 applies the production function for fish catch to four scenarios, central in this study. Conclusions are drawn in Section 5.6.

5.2 Literature on fisheries in the Delta

About one third of the 900,000 rural people in the Inner Delta (Table 4.2) depend for their living on fishery. Fish is not a secure food source in the Inner Delta, however. Welcomme (1986) compared the annual fish catch in the Inner Delta for the years 1967 – 1975 and found that in years with a high flood the catches were three times higher than in years with a low flood. Laë (1992a, b) analysed a longer time series (1966 – 1989) and concluded the same. He linked the annual catches with Niger discharge at Koulikoro of the previous year, as well as with maximally inundated area in the Inner Niger Delta.[1]

Since 1967, fish catches in the Inner Niger Delta have been registered by l'Opération Pêche de Mopti (OPM). Our analysis is based upon the same statistics. Fig. 5.1 shows the annual fish catch for the period 1966-2003 according to OPM. The annual catch is closely related to the maximum flood level. Because most fish is captured during falling water in the first half of the year, the catch in Fig. 5.1 is compared with the maximal flood level in October/November the previous year.

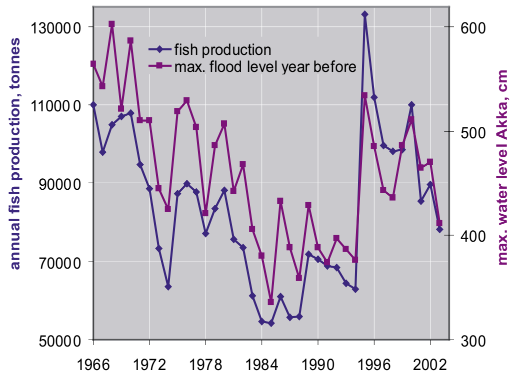


Fig. 5.1. The fluctuation in annual fish catch in the Inner Delta between 1966 and 2003 compared to the fluctuation in the flood level (Akka, cm) in the year before. Source: OPM (fish) and DNH (flood level).

As discussed in chapter 3.7, the annual fluctuation in flooding can be expressed in several ways: maximal flood level, maximal inundated surface and annual or maximal flow of the river entering the floodplains. These variables are highly interrelated, since the river flow determines the maximal flood level as well as the surface of the flooded area. The main question is what lies behind the dependency of fish on the flood volume, the flood level and/or the surface of the flooded area. Clearly, high flood levels allow fish to reproduce and to grow. The flood level is moreover closely related to the duration of the flooding period and thereby on the length of the period during which the fish can grow. In a year with a high peak flood level in the Inner Delta, the flood lasts four months longer than in a year with a low flood: the wave comes one month earlier and continues for an extra three months (Fig. 3.17).

In order to survive, fish have to leave the floodplains during falling water. During the dry period, they are concentrated in the riverbeds and small lakes, where the living conditions for fish are poor. The growth comes to a halt and fish may even lose body weight (Dansoko *et al.* 1976). Therefore, the duration of the flooding period determines the growth of the fish and hence the biological production in a given year. In the central Inner Delta, a surface area at a flood level of 300 cm relative to the gauge of Akka is covered by water for 41% of the year. Yet, due to variations in flood level the coverage by water varies between 15% and 65% of the year (Fig. 3.18). Fig. 3.18 shows that duration of flooding is closely correlated with the maximal water level, i.e. the reason to compare the annual fish catch and fish trade with the maximally inundated area.

[1] The surface of the inundated area was derived from the water loss between inflow and outflow of the Inner Delta (Olivry 1995; see also chapter 3).

After the pioneering work of Daget (1954), a large number of excellent studies have been conducted on fish and fisheries. Quensière (1994) summarised this research. Ten years later, his conclusions and recommendations are still valid. Laë was the first to quantify the effect of Sélingué and Office de Niger on the flooding and fish production of the Inner Delta (Laë1992a, 1992b, 1994, Laë *et al.* 1994, Laë & Levêque 1999, Laë & Mahé 2002).

In this chapter we produce a new estimate of the impact of Sélingué, Office du Niger and Fomi on the annual fish trade. First, however, we analyse and evaluate fish production and then discuss monitoring, production and consumption of fish in the Inner Delta.

5.3 Estimation of fish production and consumption

Since 1967, Operation Pêche Mopti (OPM) monitors the landing, export and price of fish brought from the Inner Niger Delta to the harbour of Mopti. A summary of these data is published in the annual reports of OPM. The original data, from the beginning carefully registered in hand-written books, were recently digitalised by OPM, with the aid of Wetlands International and RIZA. OPM also calculates the annual production of fish and forwards these data to the FAO.

Fish production can be studied from a biological and an economic perspective. In a biological context, annual fish production can be interpreted as the total biomass produced by fish populations, such as determined by natality, mortality and growth rate of different year classes. OPM and FAO use the word fish production in an economical sense: harvested biomass (i.e. the total amount of fish taken each year by fishermen). The economic estimate of the fish production depends on a large number of variables, which are applied as fixed multipliers by OPM. This section evaluates the annual production and examines the validity of some of the multipliers used. The amount of fish sold on the market of Mopti, either as dry fish (“*poissson transformé,*” i.e smoked or dried) or as fresh fish (“*poisson frais*”), is recorded daily. The total fish production is evaluated separately for dry fish and fresh fish.

Dry fish according to OPM

OPM registers the trade in Mopti harbour but makes three corrections to arrive at the amount of dry fish actually traded in the Inner Delta. First, it is assumed that a certain proportion of the trade (i.e. 15% before 1985 and 20% after 1985) occurs outside the harbour of Mopti. Second, OPM assumes that not all trade is registered. OPM estimates that the total trade is 12% higher than the registered trade. Third, OPM estimates that 3% of the traded fish is lost due to packing and another 15% during storage. The loss during storage was 30% before 1985 and 20% in 1986. After these three corrections, the total amount of captured fish to be sold as dry fish is estimated to be 59% higher than the recorded trade in Mopti since 1986.

To estimate the consumption of dry fish by fishermen and local people in the Inner Delta, OPM uses the following variables:

- An estimate is made of the population of active fishermen (x), non-active fishermen (y) and non-fishermen (z); (see below);
- During 360 days a year, each fisherman and each member of its family daily consume on average 20 grams of dry fish;
- During 360 days a year, the other people in the Inner Niger Delta and its surroundings, who get fish directly from the fishermen, consume a daily ration of 15 grams of dry fish.

The sum of trade, auto-consumption and local consumption by non-fishing people gives the total production of dry fish. The calculation of the total production of dry fish is shown in Table 5.1.

Ten parameters are included in the calculation of the total production of dry fish. Only the registered trade in Mopti varies each year. The number of fisher-

Table 5.1. Calculation by OPM of the production of dry fish (kg) in 1987.

Dry fish variables	Multipliers	1987
Registered trade in Mopti	a	2,431,169
Registered trade outside Mopti	20% of a	486,234
Registered trade	c=a+b = 1.2*a	2,917,403
Non-registered trade in Mopti	10% of c	291,170
Non-registered trade outside Mopti	20% of c	58,348
Total trade	d=1.12*c = 1.344*a	3,267,491
Loss at packing	3% of d	98,025
Loss during the trade period	15% of d	490,124
Total production to be traded	e=1.18*d = 1.586*a	3,855,640
Auto-consumption by fishermen (225,000)	f=20*360*(x+y)	1,620,000
Local consumption by non-fishermen (540,000)	g=15*360*z	2,916,000
Total production	h=e+f+g	8,391,640
Total trade as % of total production	e as % of h	46.0%

Note: x+y = number of fishermen (x) + number of their family members (y); z = number of non-fishermen.

Table 5.2. Calculation by OPM of the production of fresh fish (kg) for 1987.

Fresh fish variables	Multipliers	1987
Registered trade in Mopti	i	219.986
Local consumption by active fishermen (62,000)	j=150*360*x	3348.000
Local consumption by non-active fishermen (163,000)	k=50*360*y	2934.000
Local consumption by non-fishermen (540,000)	l=40*360*z	7776.000
Total production	m=i+j+k+l	14277.986
Total trade as % of total production	i as % of m	1.5%

Note: x= number of active fishermen, y family of active fishermen, z = number of non-fishermen.

men and the number of non-fishermen increase at a constant rate. Seven parameters are multipliers relative either to the registered trade (registered trade outside Mopti, non-registered trade in Mopti, non-registered trade outside Mopti, loss at packing, loss during trade) or to population size (daily consumption by fishermen, daily consumption by non-fishermen).

Fresh fish according to OPM

Compared to dry fish, the estimated production of fresh fish is straightforward for trade, but slightly more complex for local consumption. OPM assumes that all registered fish trade takes place in Mopti. The trade in fresh fish was small in the past, so although this figure was known since 1967, was not taken into account in the calculation of the fish production until 1995.

To estimate the consumption of fresh fish by fishermen and local people in the Inner Delta, OPM uses the following variables:

- An estimate is made of the population of active fishermen (x), non-active fishermen (y) and non-fishermen (z);

- During 360 days a year each active fisherman daily consumes on average 150 grams of fresh fish.
- During 360 days a year, the non-active members of fisherman's family daily consume on average 50 grams of fresh fish.
- During 360 days a year, the other people in the Inner Niger Delta are assumed to eat a daily ration of 39 grams (before 1994) or 40 grams of fresh fish (1995 and later).

The sum of trade, auto-consumption and consumption by other people in the Inner Niger Delta who get the fish directly from the fishermen, gives the total production of fresh fish. Table 5.2 illustrates how the production of fresh fish is calculated.

Eight parameters are included in the calculation of the total production. The registered trade in Mopti varies each year. The number of fishermen and the number of non-fishermen increase at a constant rate. Four parameters are multipliers (non-registered trade, daily consumption by active fishermen, daily consumption by non-active fishermen and daily consumption by non-fishermen).

Total production according to OPM

To calculate the total production of dry and fresh fish, the amount of dry fish has to be converted into total amount of fresh fish. During the years 1977-1997, dry fish consisted of smoked fish (75%) and dried fish (25%). Since 1998 the ratio is 83% smoked fish and 17% dried fish. Fresh fish loses 2/3 of its weight after smoking and 3/4 ditto after drying. To express dry fish production in terms of fresh weight equivalents, the following multipliers are used:

(0.75 * 3 + 0.25 * 4) = 3.25 for 1977-1997, and

(0.83 * 3 + 0.17 * 4) = 3.17 for 1998 onwards.

Number of fish consumers in the Inner Niger Delta according to OPM

Most yearbooks of OPM present tables such as our Table 5.1 and Table 5.2.The various multipliers are extracted from these yearbooks. Total fish production is not very sensitive to the assumptions regarding unregistered trade. The use of different estimates of the population size, however, has a dominant effect on calculations of the total production. Throughout the years, various estimates of the population size have been applied by OPM:

- OPM estimated that there were 54,112 active and 26,246 non-active fishermen from 1980 to 1987.
- These numbers changed in 1988 to 196,952 and 84,408, respectively. As a result of this sudden increase, the total production increased by 21% from one year to the next. These numbers remained then the same from 1988 to 1994.
- The OPM-annuals did not report the number of fishermen between 1995 and 2000.
- In 2001 and 2002 the number of active fishermen was 84,255 and 85,928, respectively and the number of non-active fishermen 187,534 and 191,304. This implies an increase of 2.01%. An annual increase of 2.01% is found in several documents and originates from Nadio (1984) who estimated that this was the rate of increase of fishermen in the 1970s and early 1980s (see also Weigel & Stomal 1994).

According to the OPM-annuals, the number of non-fishermen buying fish directly from the fishermen was assumed to be 1.2 million from 1981 to 1988 and about the same (1,166,582) in the period 1989-1994. No data were found in the OPM-annuals for 1995 - 2000, but in 2001 and 2002 the number of non-fishing people was estimated to be 1,496,265 and 1,530,529, respectively.The increase was 2.29%. This figure was first mentioned by the Ministère du Plan (1987) and based upon a comparison of the National Census of 1976 and 1987.

Comparison of the National Census of 1976, 1987 and 1998

A comparison of the National Census of 1976, 1987, and 1998 shows that the population living in and around the Inner Niger Delta increased by only 0.7% per year between 1986 and 1998 (Table 3.1). Since part of the population within the area moved to the cities, the rural population even slightly decreased. This decrease is due to depopulation of the northern delta. The rural population in the southern part of

the Delta has increased with 1% (Table 3.2). These findings imply that the population growth rates as applied by OPM lead to an overestimation of the group of fish consumers in the Inner Delta.

Herry (1994) analysed the census of 1976 and 1987. He used additional data from 1987 to divide the population for all 'arrondissements' within the Inner Delta into fishermen, farmers and cattle breeders. He found that hardly any fishermen lived in the northern Delta in 1987. The area had been dry for several years and most fishermen had moved to the south. The comparison of population change per arrondissement led to similar conclusions. The population increased in the central part of the Delta, where more than 25% of the population are fishermen. Comparable data are not available for the 1998 census. Most fishermen live within the region of Mopti, where the population increase has been 1% per year.

Several independent researchers provided estimates of the number of fishermen in the Inner Delta. Gallais (1967) estimated their number at 70,000. This number increased to over 80,000 in 1975 and 225,000 in 1987 (Morand *et al.* 1991). Nadio (1984) and Laë *et al.* (1994) concluded that the increase of fishermen was 2.01% per year between 1966 and 1976 and 1.5% between 1976 and 1989. The increase of the non-fishing people in the Inner Niger Delta was estimated at 2.29% between 1966 and 1976 and 1% between 1976 and 1989.

Laë *et al.* (1994) and Weigel & Stomal (1994) used these figures to recalculate the total fish production.

They used the results of the National Census of 1987 and the work of Morand *et al.* (1991) to arrive for 1987 at an estimate of 62,000 active and 163,000 non-active fishermen and 540,000 non-fishermen living in the Inner Niger Delta. Now that the results of the National Census of 1998 are available, we can conclude that their estimate of the population increase has been too high.

In our calculation we assume that the population increase of the rural people in the Inner Niger Delta, fishing or non-fishing, has been 1% per year between 1977 and 2003. On the basis of this assumption, the number of active, non-active fishermen and non-fishermen has increased from 56,128, 147,562 and 488,855 in 1977 to 72,700, 191,130 and 633,192 in 2003, respectively. Because these estimates of the population size differ from the estimate applied by OPM, our estimation of total fish production also deviates from the one reported in the OPM-annuals and therefore also by FAO.

The annual fish production in the Inner Niger Delta

By combining the OPM statistics and multipliers on registered trade of dry and of fresh fish in Mopti and our findings on population size in the Inner Delta, new estimates of fish production in the Inner Niger Delta have been made (see Fig. 5.2 and Fig. 5.3). The underlying data are reported in Appendix 6.

Fig. 5.2 shows the annual production (tonnes) of dry and fresh fish, sub-divided into the amount consumed by fishermen, by non-fishermen in the Inner Delta, and the amount sold on the market. Total production is expressed as fresh weight, using a multiplier of 3.25 (or 3.17 in recent years) to convert the weight of dry (= dried + smoked) fish into fresh weight.

Fig. 5.2 clearly shows that at present about half of the dry fish is brought to the Mopti harbour to be traded. Yet, only a small proportion of the fresh fish is marketed. For both fresh and dry fish, these proportions have not been stable over time. In the 1970s 75% of production of dry fish was sold, then decreased to 50-60% in recent years. The relative significance of

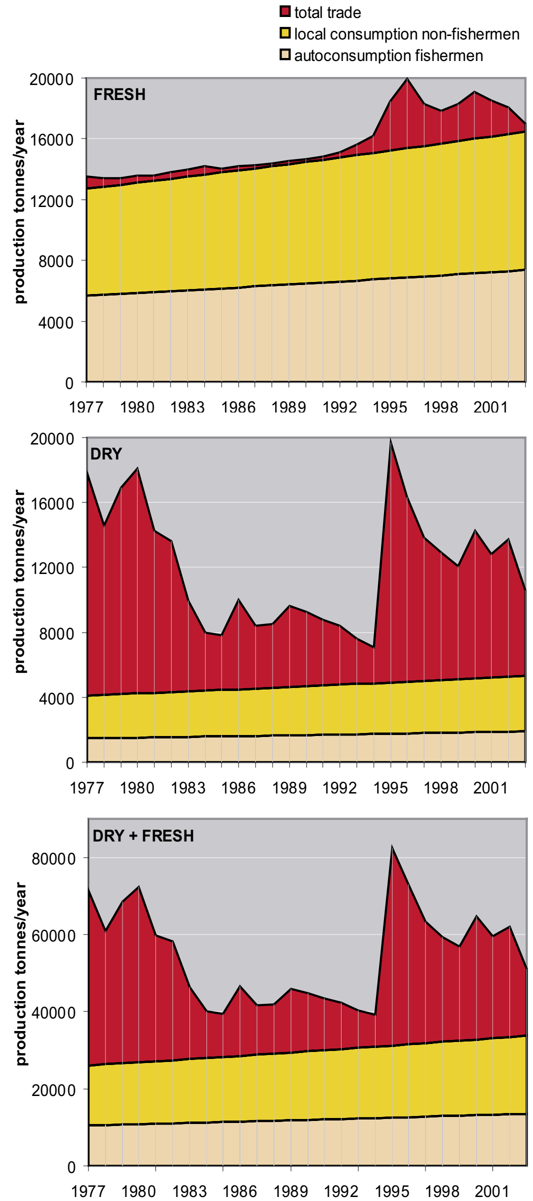


Fig. 5.2. Annual fish production for the Inner Delta, split for trade, informal trade within the Inner Delta and auto-consumption by fishermen.

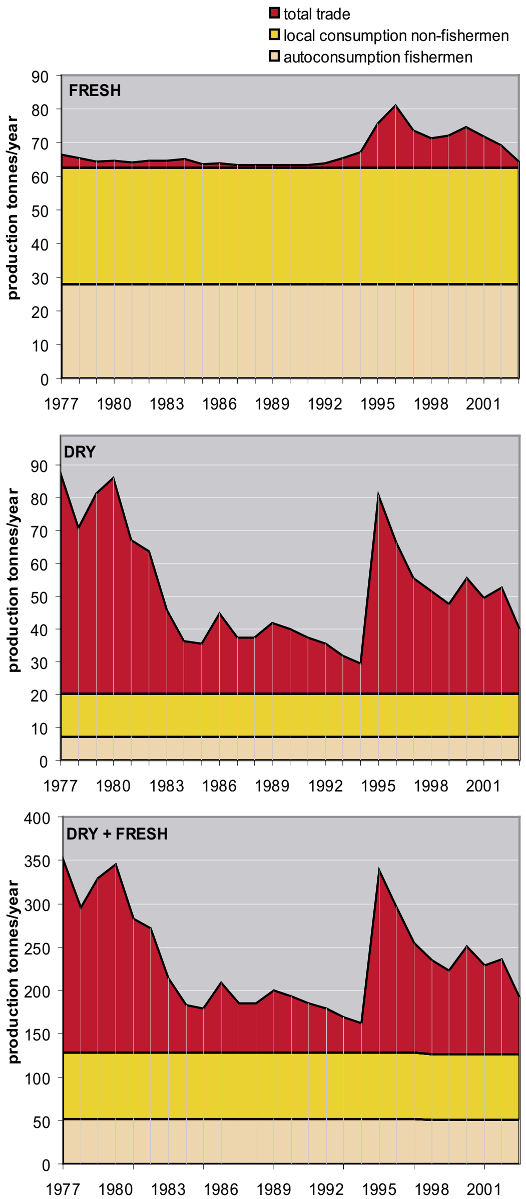


Fig. 5.3. Annual fish production per fisherman in the Inner Delta, split for trade, informal trade within the Inner Delta and auto-consumption.

trade of fresh fish was less than 5% until 1993. Fresh fish trade increased to 10-25% of the total catch between 1995 and 2002. The main reason for this shift might be the presence of an ice factory in Mopti from 1974 until 1984, again from 1986 until 1988 and finally since 2000. It is remarkable, however, that the absolute peak in trade of fresh fish was reached in 1995 when there was no ice factory.

Fig. 5.3 shows the total average annual production per fisherman (either active or non-active) of dry and fresh fish. The total production is the sum of the amount sold on the market, auto-consumption and local trade. The auto-consumption of dry fish is estimated at 7.20 kg/year/fisherman and local trade at 12.96 kg/year/fisherman. Auto-consumption of fresh fish is estimated at 27.92 kg/year and local trade at 34.56 kg/year/fisherman. The estimates are obtained by dividing the total production by the adjusted number of fishermen. To convert the data to production per active fisherman or per family, all production estimates have to be multiplied by 3.57 or by 10.

5.4 Revised estimates

According to the statistics obtained by OPM, total fish production in the Inner Niger Delta during the last 34 years has varied between 54,000 and 133,000 tonnes. More than half of the total production is consumed in the Inner Delta (auto-consumption plus local trade). After adjusting the OPM data for the smaller population increase that we found in the National Census in the Inner Delta (see chapter 4), total fish production is also smaller. Based on a smaller population, our estimate of fish production in 1977 is 17% smaller than provided by OPM; this discrepancy increased over the years to 35% in 2003 (see Fig. 5.4). Note that the data published in the annuals of OPM are also reported by the FAO-site.

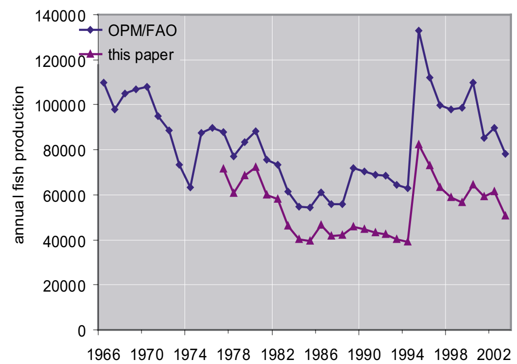
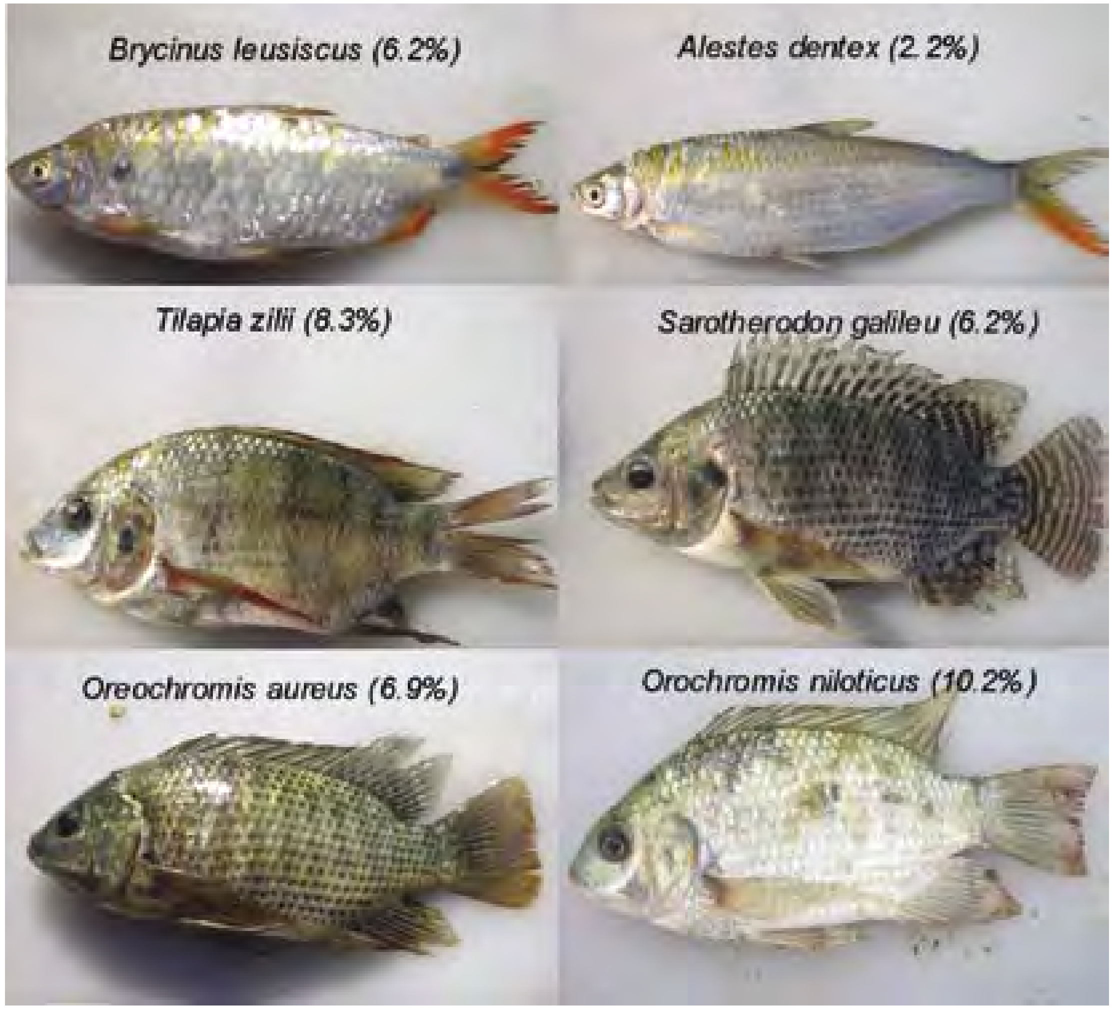


Fig. 5.4. Annual fish production equivalents in the Inner Niger Delta in tonnes fresh weight according to OPM and our estimate that assumes a smaller population growth.

Fish production in the Inner Niger Delta and other African floodplains

That annual fish catches in a floodplain vary in accordance with the intensity of flooding is generally recognised in the literature. Before Welcomme published his paper about the annual catches in the Inner Delta, he had already described a similar relationship between annual catch and flood level in the Kafue River (Zambia) (Welcomme 1979). A similar effect of flood level on fish catch has been found in the rivers Amur, Cross, Danube and Nile (Laë 1992a, Laë & Levêque 1999) and also in Lake Tchad (Durand & Levêque 1978). Laë & Levêque (1999) combined the various case studies to draw a more general picture of the relationship between annual fish catches and variations in the size of floodplain. Their findings are shown in Fig. 5.5.

From an ecological perspective it is obvious that the catches depend predominantly on the size of the inundation area. Welcomme (1986a, b) concludes that fish production of African floodplains amounts to 3.83 tonnes per km^2 floodplain, or 38.3 kg/ha. Fig. 5.5 shows that the relation between fish production and floodplain area is exponential, the exponent of this relationship being 0.63. Note that, if fish catch and floodplain area are independent, the exponent is equal to 1. The exponent is lower than 1 because the catch per hectare declines with floodplain area. For the large floodplains, the catch per hectare varies between 6.5 kg/ha for the Yaérés floodplain in the Logone River (Cameroon) and 40 - 50 kg/ha for the Inner Niger Delta. Two estimates are given for the Inner Delta: 40,000 tonnes at an inundation of 8,000 km^2 and 80,000 ton at an inundation of 20,000 km^2. The only area that is more productive than the Inner Niger Delta is the Sénégal floodplain with a catch of 56 kg/ha. Yet, this estimate refers to the situation before dams and dikes delimited this inundation area. The catches in the Sudd floodplains, southern Soudan (8.8 kg/ha), and the Cross floodplains, southeast Nigeria (25 kg/ha) are much smaller than the Inner Delta.



Economically most important fish species in the Inner Niger Delta. Proportional share of total catches is indicated between brackets. Source: Laë *et al.* (1994).

Production function for fish catch in the Inner Delta

The available data on traded fish and the variation in inundation zone over time allow for the estimation of a production function for fish catch. The main variable that determines the variation in fish trade and catch is the biological production of fish, which in turn is determined by the maximum water level, reached the preceding year in Akka. This relationship has already been described for the total production and over a shorter period: Welcomme (1986a) for 1967 – 1975 and Laë (1992a) for 1966 - 1989. An updated analysis is shown in Fig. 5.6.

The earlier work by Welcomme and Laë concluded that the fish production not only depends on the flood level in the previous year but also on the flood level

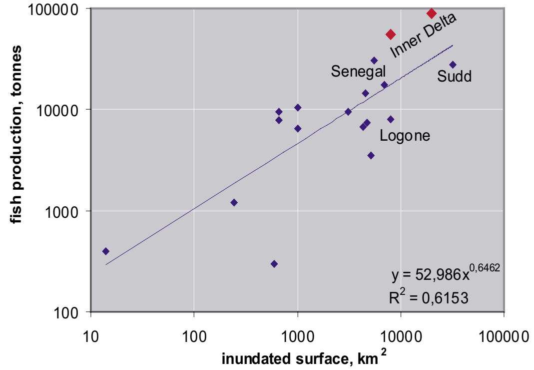


Fig. 5.5. The relationship between annual fish production in different African floodplains and the maximum surface of the inundation zone. Both scales are logarithmic. Source: Laë & Levêque (1999). Two revised estimates are given for the Inner Delta: one for a low and one for a high flood.

two years earlier. To analyse the effect of the flood two years before, the deviation between observed trade and predicted trade, given by the curvilinear regression in Fig.5.6, was plotted against the water level in Akka two years earlier. Although, a curvilinear relationship was again found, the level of correlation was weak ($R^2 = 0.17$) and not significant. The explanation for this weak relationship is that fisheries have intensified so much in recent years that the share of mature fish in the overall fish catches (i.e. fish that is older than one year) declined substantially. More than 30 years ago, the catch of fish in the Inner Delta still comprised several year classes. Since fish catches in the last one or two decades increasingly consists of immature fish (i.e. fish being less than half a year old), there is no reason to expect that the water level of two years ago determine fish catches today (in accordance with the regression analysis).

Since the number of fishermen has increased with 1% per year, one would expect that the trade would have increased over the years at the same rate. In fact, there was, on average, no increase at all. Fig. 5.6 shows the trade separately for two periods, before and after 1990. The relationship between total trade and maximal water level in the previous year is the same for the two periods, hence one common regression line.

That the trade per individual fishermen has not increased over the past 27 years could already be seen in Fig. 5.3. Data from Fig. 5.3 were used to generate Fig. 5.7, showing traded fish as a proportion of total production in relation to the maximally inundated area in the foregoing year. Similar to Fig. 5.6, the data are separately analysed for the period before and after 1990. The positive slope of both curves indicates that higher flood levels lead to more fish trade. Yet, the relative proportion of traded fish is structurally higher in the period before 1990 than after 1990. Therefore, if the flood level is taken into account, each fisherman sold more fish in the past than in more recent years. This may be the first sign of a depletion of fish stocks.

Upper limit of fish production is reached

If it were true that a larger population of fishermen is not able to bring more fish to the market, this suggests that fish production is constrained by an absolute ceiling level in the biological production. This far-reaching conclusion is supported by the work of Amaga Kodio and co-authors (Kodio *et al.* 2002). During a series of years (1994-95 till 1998-99), they measured the daily catch of individual fishermen in the period February - June. There is a substantial fluctuation in the daily individual capture, varying between 1 and 400 kilogram. Poor catches mostly occurred in June while nearly all large catches took place in February and March. On average, there was a decrease in the daily catch from 35 kg/day in early February to 7 kg/day end of June. Kodio *et al.* (2002) concluded that this decrease must be due to depletion of available fish stock and that nearly all fish had been captured by the end of the fish campaign.

Fish older than one year has become increasingly scarce in the Inner Niger Delta (Laë 1994). The only way for a species to survive is to reproduce as early as possible. The reproduction for most species is restricted to the high water period (Bénech & Dansoko 1994). Therefore, the fish stock of a year depends

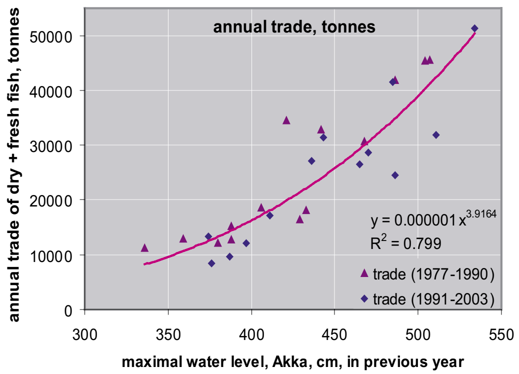


Fig. 5.6. Annual trade (ton fresh fish equivalents) of dry and fresh fish in the Inner Niger Delta as a function of the maximal inundation in the previous year.

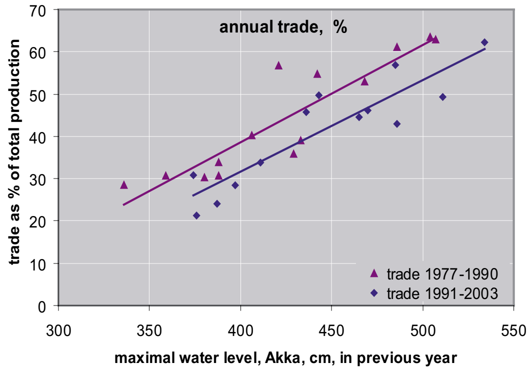


Fig. 5.7. Annual trade as percentage of the total production (dry and fresh fish combined) as a function of the maximal inundation in the foregoing year.

on the spawn and fry produced by the few fish still alive at the end of their first year and the very few fish older than one year. Bénech & Dansoko (1994) found that the fish species in the Inner Niger Delta have adapted to this extreme predation pressure by advancing their age of reproduction.

The depletion of fish stock in the Inner Niger Delta is mainly caused by the introduction of nylon nets in the 1960s. Since then, the exploitation system has changed significantly. In parallel to the continuous decline of the size of captured fish, mesh sizes of the nylon nets have decreased simultaneously. Mesh sizes were less than 50 mm before 1975, 41-50 mm between 1976 and 1983 and 33-41 mm between 1984 and 1989 (Laë *et al.* 1994). By using nets with smaller mesh width, only very small fish can escape. At the same time, since the average fish gets smaller, nets with a wide mesh width become increasingly useless. As described by Laë *et al.* (1994) fishermen have consequently adapted their fishing technique.

The conclusion that the amount of fish being captured has reached a ceiling casts doubts on the earlier conclusions drawn in this section. For example, it would mean that the data on the total production as presented in Fig. 5.2 increasingly overestimated in recent years. If the fishermen are not able to catch more fish than they do now, one may doubt whether the daily consumption by the local population is still at the same level as 20 or 30 years ago. The estimation of the total production is based upon the assumption that fishing people consume daily 30 grams dry fish and the other people in the Inner Niger Delta 15 grams.

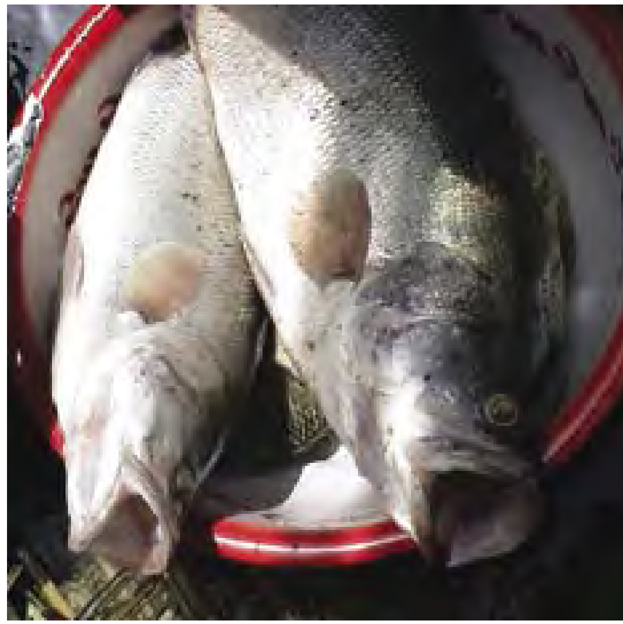
Is auto-consumption and local trade constant over the years?

Two studies are available on the average daily fish consumption by a fisherman's family (10 persons, on average). The daily consumption was 1,183 grams in 1961 and 1,365 grams in 1989 (Laë 1994). It is remarkable that these estimates do not differ more from each other, since the flood in the foregoing year was high in 1960 (580 cm at a maximum in Akka) and low in 1988 (439 cm at a maximum in 1980). Apparently, low food supply does not immediately affect daily rations of fish eaten by fishermen themselves.

There are also two estimates of the daily ration of fish by non-fishermen in the Inner Niger Delta: one from a period when the flood levels were extremely high (1957-58) and one from a year with a very low flood (1991) (Weigel & Stomal 1994). Again, the estimates of the daily rations do not deviate much from each other. It is clear from the study of Weigel & Stomal that it is difficult to estimate the daily fish ration. It is too simple to make a distinction between fishermen and non-fishermen. An average migrant fisherman consumes more fish than a sedentary fisherman and much more than an agro-fisherman. In 1991, 19% of the fishermen were migrants, 48% sedentary and 33% combined fishing with agriculture. It is likely that the latter category has increased in the last few years. As a consequence, the overall auto-consumption would have decreased over the years.

Although the study of Weigel & Stomal (1994) found no difference between the individual fish consumption by local people, it remains unlikely that this ration would not vary between years. Each fisherman has to decide which part of its capture would be sold locally and which part on the market. Fig. 5.6 shows that the annual trade in Mopti varies between 10,000 and 50,000 tonnes. It is likely that the local, informal trade would vary more or less simultaneously with the annual trade in Mopti. In any case, it seems very unlikely that the local trade in a year with a low flood would be the same as in a year with a good flood.

The estimate of the total production changes significantly if the local trade for local consumption varies simultaneously with the trade in Mopti. First, the total production would be much lower in years with a low flood, since the amount of traded fish is low in those years. Second, the total production would be lower in recent years, since the contribution of the local consumption to the total production has increased due to the increase of the population size. Hence, the recalculated production data as presented in Fig. 5.6 would be even lower if one assumes that the local trade varies in accordance with trade in Mopti. Because the evidence for the suggested decrease in the local, informal trade and auto-consumption is missing, the statistics presented in Appendix 6 are applied instead. Still, one should keep in mind that the shown decrease in fish catch per fisherman during the last 30 years is possibly even larger than indicated.



5.5 Production function for fish catch under the four scenarios

The annual fish production presented in Fig. 5.1 and Fig. 5.5 as well as the trade Fig. 5.6 reveal a strong correlation with the flood level. Therefore, a production function for fish trade and fish production in relation to the flood level can be estimated on the basis of fish trade data for the period 1976 – 2003. For reasons of comparison, the functions presenting the relationship between trade and production versus flood level are estimated. Both production functions are presented below:

Fish trade

$$Ht = 0.00003x^{2.1728} \quad \textbf{5.1}$$

($R^2 = 0.801$)

Fish production

$$HP = 7.404x^{0.9459} \quad \textbf{5.2}$$

($R^2 = 0.847$)

where:

T = total fish trade (in tons)

P = total fish catch or production (in tons)

x = maximal flooding surface in the previous year (in km^2)

Next, equations (5.1) and (5.2) are used to evaluate the impact of the irrigation by Office du Niger and the withheld water in the Sélingué and planned Fomi reservoirs. The subsequent variation in flooded area for these scenarios has been substantiated in chapter 3 and Appendix 6. As mentioned, fish trade is known for the period 1976 – 2003. Still, we run the scenarios for the years since 1982 because this is the period for which the effect of irrigation and reservoirs is manifest.

Fig. 5.8 shows the four scenarios for the period 1982-2003 on the basis of the production functions estimated in equations (5.1) and (5.2) for both fish trade (left) and fish production (right). The yellow regression line represents the calibrated present situation (scenario 2). The derived regression functions also simulate the fish catch and production under conditions for higher (scenario 1 and 2) and lower flood levels (scenario 3). The top of Fig. 5.8 shows the difference between scenario 0, 1 and 3 with the baseline scenario (i.e. present situation). By adding these curves to the present situation curve, the absolute levels of fish trade and production are generated (see bottom half of Fig. 5.8).

Compared to the present situation, fish trade would have been 630–2200 tonnes higher without Office de Niger, which is on average 6% of the total fish trade. In a situation in which neither Office de Niger nor Sélingué operates, fish trade would have increased to 1150-7200 tonnes (i.e. approximately 12%). With the reduced river flow due to the planned Fomi dam, the fish trade will decline further with 34%.

According to the above calculations, the relative effect of irrigation and reservoirs is smaller for production than for fish trade. Compared to the present situation, fish production will be, on average 2,7 tonnes higher without Sélingué, which is on average 5% of the total fish production. In a situation with neither Sélingué nor Office de Niger, fish production would increase to 4,100 tonnes (i.e. 8%). The Fomi dam will reduce fish production by 8,500 tonnes per year (16%) compared to the present situation.

Our estimate does not differ much from the previous estimates. Laë (1994) concludes that without Office de Niger and Sélingué the total fish production would have been 4,500 to 5,000 tonnes higher or 9 - 10% of the total production. Two further remarks need to be made with regard to our analysis. First, we assume that auto-consumption and local trade within the Inner Delta are constant and is thus not related to flood level. The main reason for this assumption is the fact that daily fish consumption per family is supposed to remain constant over time. The validity of the implicit assumption is uncertain. It is quite plausible that the daily consumption by local people varies in relation to the total annual

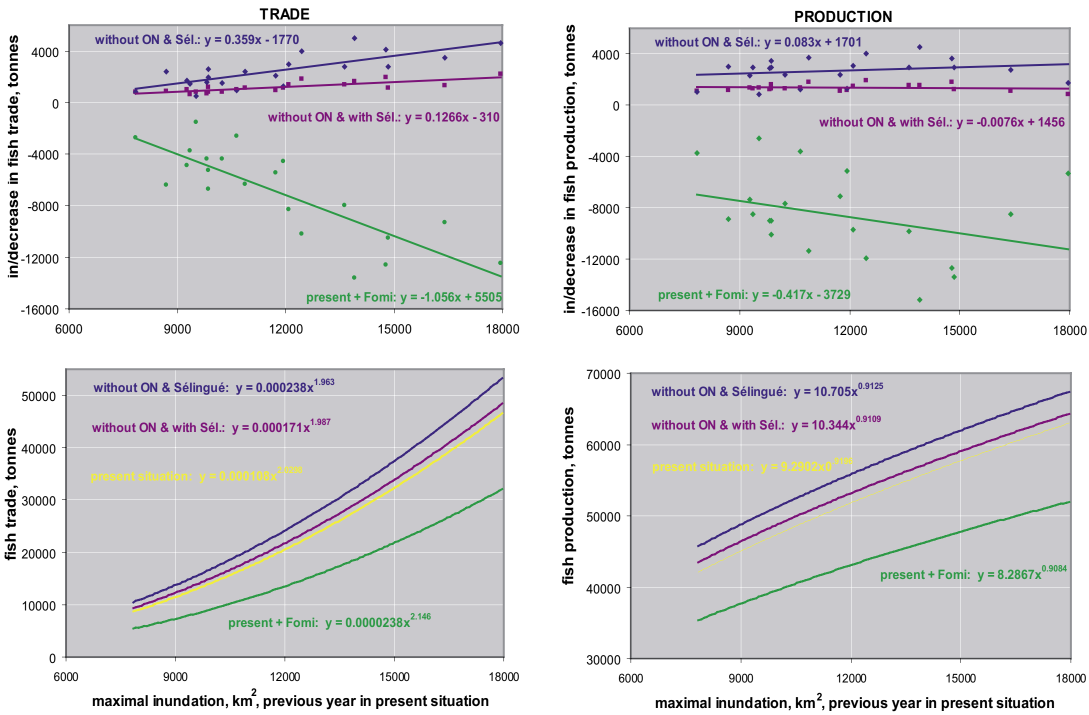


Fig. 5.8 The absolute (bottom) and change in (top) annual fish trade (left) and production catch (right) in ton in the Inner Delta in the present situation compared to three scenarios (0) without Office de Niger & Sélingué, (1) without Office de Niger & with Sélingué, and (3) present plus Fomi.

catch and thus to the flood level. Unfortunately, no evidence of such relationship is available. Second, our as well as Laë's estimate contain an element of underestimation because both analyses ignored the fact that, in the first three years of its existence, the effect of the Sélingué reservoir on fish trade was less extensive (i.e. reduction of 500-1,200 ton). The explanation for this exception is that, in the beginning, Sélingué withheld less water because the reservoir was not completely drained in the dry period and not fully filled during the crue (see Fig. 2.10 and Appendix 2).

5.6 Conclusions

Dams and reservoirs have a significant impact on fisheries in the Inner Niger Delta. Various more specific lessons can be drawn from the above analysis:

- The annual fish production in the Inner Niger Delta, recorded since 1966, highly depends on the flood of the preceding year.
- To estimate the annual fish production, the auto-consumption and the informal, local trade are added to the registered trade in Mopti. The estimate of total auto-consumption by the 300,000 fishermen and the 555,000 non-fishermen in the Inner Niger Delta is based on the measured daily fish consumption per family, assumed to be constant over time. The validity of this implicit assumption is uncertain, because it is plausible that the daily consumption by local people likely varies in relation to the total annual catch and thus to the flood level.
- The annual increase of the rural population in the Inner Delta is not the assumed 2% but instead limited to 1% (Ministère du Plan 1997). Consequently, the auto-consumption and local trade have been overestimated for recent years. An adjusted fish production is provided based on this new information.
- Despite the gradual increase of the population of fishermen in the Delta, the adjusted estimates reveal that fish production did not increase over the last 27 years. This suggests that the biological limit of fish production is reached. Kodio *et al.* (2002) conclude the same as they found that at the end of the fish campaign the daily catch of the fishermen is only a fraction of the daily catch some earlier months. Other studies confirmed that a few fish survive the fish campaign in the dry period. Fish older than one year have become increasingly scarce in the Inner Delta.
- The close relationship between annual fish trade in Mopti and flood level in the preceding year allows for the estimation of the average impact of Office du Niger and Sélingué on fish trade. Fish trade would have been 6% higher without Office du Niger and an additional 13% higher without Sélingué reservoir. The analysis predicts that fish trade would be reduced by another 37% in case of the construction of the Fomi Dam.

6 VEGETATION OF THE LOWER INUNDATION ZONE OF THE INNER DELTA

Leo Zwarts
Ion Grigoras
Jenica Hanganu

6.1 Introduction

At a first glance, the floodplains of the Inner Delta seem to be an undisturbed natural ecosystem. The river takes its own course and flooding of the inundation zone is hardly hampered by dams, dikes and sluices. The extensive fields of floating grass ("bourgou") in Lac Debo give the impression of 'unadulterated nature'. Also cultivated rice fields in the Inner Delta seem to be totally natural. In reality, however, the human impact in the floodplains is significant. The bourgou fields in Lac Debo are planted by local people. Moreover, the vegetation is hugely affected by the two million cattle and four million sheep and goat that graze on the floodplains after the flood has passed. Also, forests have become scarce in the Delta. At present, the Inner Delta is an open landscape with low vegetation of grass, rice and bourgou. Older people, however, still recall the days that extensive forests occupied the higher grounds and several forests were found in the lower floodplains. All in all, the current Inner Delta is a semi-natural habitat of which the natural resources are heavily exploited by the local population. Nevertheless, as shown in Chapter 9, the Inner Delta still attracts millions of waterbirds and has a substantial ecological value.

The aim of this chapter is to describe the present vegetation in the Inner Niger Delta and give a short description of seasonal variation in green biomass. The chapter is based on data from the period 1999-2003. We are particularly interested in the link between vegetation and flooding in the Inner Delta. Therefore, vegetation data will be compared with the digital flooding model (Chapter 3). The vegetation map presented in this chapter will be applied in impact analysis for livestock (Chapter 7) and for agriculture (Chapter 8) and in the description of the ecological values (Chapter 9). Note that two main vegetation types in the Inner Delta (i.e. bourgou and rice) are only partly covered in this chapter. More detailed descriptions of these vegetation types are provided in chapter 7 and 8.

The structure of Chapter 6 is as follows. In Section 6.2 efforts are made to determine vegetation patterns. Available sets of information and images are carefully analysed and complications are solved through data manipulation. Section 6.3 describes the main outcome of the analysis and proposes methods to solve current problems in the analysis. Conclusions on vegetation patterns in the Inner Niger Delta are drawn in section 6.4.

6.2 Quantification of vegetation

Data

The scientific community has elaborately described the vegetation in the Inner Niger Delta, in which Hiernaux played a pioneering role (e.g. Hiernaux 1982, Hiernaux 1983, Hiernaux *et al.* 1983, Hiernaux & Diarra 1983). More recently, Marie (2000, 2002) summarises a substantial amount of work on the vegetation of the Inner Delta. Most of the covered information is published in (internal) reports with a limited distribution. Marie also entered all data in a GIS-system, allowing a quantitative analysis (Marie 2000, 2002), including an atlas with detailed maps. His study does not cover the Delta north of Lac Débo (L'Erg Niafunké / Delta lacustre).

Marie (2000, 2002) distinguished 27 vegetation types, which can be categorized into nine types. As shown in Table 6.1, four of these nine main types cover 80% of the southern and middle Inner Delta, which together measure an area of 16,280 km^2.

The different vegetation types show a clear zoning. The occurrence of the various plant and tree species is determined by the flooding duration and the water depth when the flood reaches its peak. Flood level in the Inner Delta varies enormously, having been extremely low in the early 1980s and higher in recent years, but still far from the level normally reached before 1970. As a consequence, the zoning of vegetation varies over time. Marie (2002) found that the distribution area of cultivated rice has changed between 1952, 1975 and 1989 (see also chapter 8). Similar findings confirm the zone shift of *Echinochloa stagnina*, locally known as bourgou (Zwarts & Diallo 2002).

Table 6.1. The surface area (km^2) covered by four dominant vegetation types in the southern and middle part of the Inner Delta, i.e. the area around and south of the central lakes. Source: Marie (2000, 2002).

Vegetation type	Surface (km^2)	%
Vétiveraire (long grass)	6,399	38.91
Orizaie (rice)	3,424	21.03
Eragrostaie (low grass)	1,902	11.68
Bourgoutière (floating grass)	1,613	9.91

Analysis

Various sources are used as input for the vegetation analysis. Firstly, eleven topographical maps (1:200,000) of the Inner Delta have been scanned and entered into a GIS-system. Although the maps are nearly 50 years old, they were still extremely useful. Secondly, the vegetation work at this stage made use of 44 satellite images (see Table 3.1 and 3.2 for more details). The true colour composites were printed (scale 1:30,000) and used in the field. Thirdly, as soon as the digital flooding model was available, an elevation map was printed and also taken into the field. The fieldwork was performed in January-March 1999-2003 during five periods of 2 to 4 weeks. A GPS was used to pinpoint "training sites", i.e. areas with homogenous vegetation types (see Fig. 6.1). Finally, especially to improve our understanding of historical patterns, local people were asked to outline changes in homogenous vegetation types on the topographical maps. For example, local communities appeared to be perfectly able to explain when and where inundated forests had been removed and transformed into rice fields.

The following vegetation types have been distinguished:

- *Cyperus articulatus* – meadows with short vegetation
- bourgou – *Echinochloa stagnina*, floating grass forming large submerged meadows
- Grass – *Andropogon pseudapricus, Cynodon dactylon, Eragrostis barteri, Panicum subalbidum*
- Dideré – *Vossia cuspidata*, floating grass, often mixed with bourgou
- Bourgoutière – mixture of bourgou and dideré
- Nénuphar - white or purple water lily, often mixed with bourgou or wild rice
- Inundated forest – *Acacia kirkii* and *Ziziphus mauritiana*
- *Mimosa pigra* – low scrub often found on levees along the river
- Wild rice – *Oryza longistaminata*
- Cultivated rice – *Oryza globerrima*

Fig. 6.1. Visited areas with more or less homogeneous vegetations in the Inner Delta. The many hundreds of small areas are indicated with triangles. Pora in the south and Walado-Debo in the centre were frequently visited. The used underground shows the extremely dry Inner Delta on 8 July 1985.

Data manipulation

One image (i.e. 8 February 2003; water level 86 cm) was selected for image processing. The water map of 511 cm shown in Fig 3.5 was used to mask all areas outside the inundation zone. The vegetation classes we intended to distinguish appeared to have a different spectral signature. For instance, rice looks completely different when green, either harvested or burned. Since all these stages can be simultaneously found within the Inner Delta, it is difficult to use a supervised classification. Hence, an unsupervised classification was used, which associates these class

variations to specific vegetation classes. An unsupervised classification with 60 or 100 classes appeared to lack precision. The classification of 150 classes worked out well.

In order to make the classification as quantitative as possible, we calculated for each unsupervised category, the relative occurrence of the different vegetation types. Some classes came out very clear while other categories were less precise. For instance, aggregated over all training sites, 96% of class 20 was found in bourgou sites. Thus, we are certain that class 20 can be classified as bourgou. The area labelled class 20 covers 1,172 km^2. For class 19, however, a more confusing picture appeared. In the 559 km^2 which is labelled as class 19, we found that 75% was bourgou and 16% vetivère. After close examination of the map, however, we concluded that class 19 is bourgou as well. In other cases, it was impossible to assign one vegetation type to a certain class. For instance, class 16 (175 km^2) and class 17 (372 km^2) were dominated by bourgou, 23% and 26%, and nénuphar, 30% and 24%, respectively. Therefore, after studying the distribution of class 16 and 17, we decided to classify both classes as a mixture of bourgou and nénuphar. In this way, the 150 colour classes were merged into to seven vegetation classes:

- Bourgoutière (bourgou and dideré)
- Bourgoutière and water lily
- Grass
- Wild rice
- Rice and water lily
- Cultivated rice
- Vetivère.

The identification of certain types of vegetation was problematic. For instance, Mimosa scrubs were dominant in some of the 150 classes. Yet, when linking up these classes as Mimosa, several sites where scrubs would never occur were indicated as Mimosa scrubs. Similar problems applied to flood forests. They could be distinguished, but when the classes were joined the existing flood forest, such as Akkagoun, Dentaka and Pora, were correctly indicated, but also spots where forest was absent. In fact, we had continuously to weigh one error against another and decided not to use Mimosa and flood forest as separate classes.

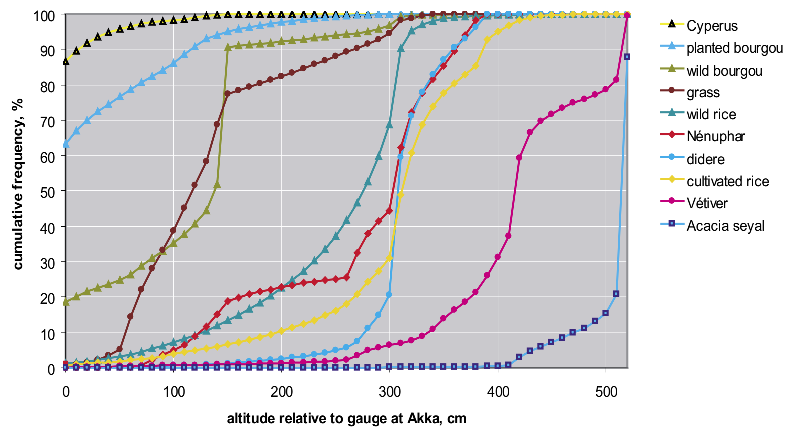


Fig. 6.2 Cumulative frequency distribution (%) of nine vegetation types as a function of the elevation. Bourgou planted by local people has been separated from wild bourgou. Elevation is defined relative to the water-level gauge of Akka. The maximal water level during the last years amounted to 470 cm, on average. Thus, cultivated rice (average altitude 320 cm) is covered by 150 cm at a maximum, wild rice (average elevation 270 cm) by 200 cm and wild bourgou (average altitude 140 cm) by 330 cm.

In the future we intend to improve the vegetation map by careful stepwise analysis of successive satellite images taken throughout the season. For the moment, we attempted to reduce the number of errors by (1) joining vegetation types in the Inner Delta and by (2) using the digital elevation model to correct for evident errors. For that reason, dideré and bourgou have been merged as 'bourgoutière'. Two mixed vegetation types have been separately distinguished: Nénuphar with bourgoutière and Nénuphar with wild rice. Second, we use the digital elevation model to correct for evident errors.

The training sites were combined per vegetation type and the frequency distribution of the elevation was determined for each vegetation type using the inclusive model (chapter 3.4). The vegetation of Cyperus articulatus is only found low in the inundation zone, while Vetiveria nigritans and forests of Acacia are found high in the zone. Dideré, wild rice, nénuphar and cultivated rice are mostly distributed in between (Fig. 6.2).

On average, the maximal water level at Akka during the last 5 years has been 470 cm. Because planted bourgou is mostly found at a water level of 0 cm at the gauge of Akka, these plants grow at a maximum in a water column of 470 cm. Only 20% of wild bourgou is found that low. In fact, most bourgou grows at 140 – 170 cm at the gauge of Akka and thus at a depth of 300 – 330 cm deep. Dideré grows as deep as wild rice, at a level of about 300 cm at the gauge of Akka and thus at a depth of 1.5 to 2 meter. Plots with a mixture of bourgou and dideré are not shown in Fig. 4.2, but they are found between wild bourgou and dideré. Thus, bourgoutière (being bourgou and/or dideré) can be found in a wide range from 0 to 300 cm.

The frequency distribution (Fig. 6.2) was used to correct for errors made in the classification described above. Take for example class 19, classified as bourgou, although it was partly vétivere. This error can be remedied by classifying class 19 as vétivere if the site is found at 350 cm and higher and as bourgou at lower elevations. Other corrections included, for example, wild rice found at 170 cm and lower was considered as grass and grass at 270 cm and higher was changed into vétivere. The vegetation map (Fig. 6.3 right panel), based on the image of February 2003, includes all afore-mentioned corrections.

6.3 Results and discussion

The right-side of Fig. 6.3 shows the vegetation map that was generated on the basis of the image of February 2003, shown on left-side of Fig. 6.3. The vegetation map is based on an image taken during low water (86 cm in Akka), but at that moment the lowest flood plains in Lac Débo were still water-covered. These areas are later in the season covered by the perennial Cyperus esculentus and form extensive green fields. Because the map is based on an image of February 2003, the cultivated rice has been harvested and many stubble fields have been burned. Bourgou in Lac Débo and Walado is still present as a floating vegetation. In other areas, however, especially more to the south, nearly all bourgou has been harvested and heavily grazed. At the latter sites, grass has started to grow.

These examples show that a single vegetation type may look completely different: vivid green, stubble or even burned. A vegetation map based on a spectral analysis of a single satellite image is only reflecting a part of the reality. By using successive images from the same growing season, it should be possible to make a more reliable map.

An analysis of the NDVI-values can serve as an additional source of information. The NDVI is a much used, multispectral index to measure green biomass, and is given by the ratio: (near infrared – red)/(near infrared + red). The NDVI-values of the different vegetation types do not differ much from each other, but the seasonal variation appears to differ. For instance, de NDVI-values of dideré remains constant, while the NDVI of bourgou declines during receding water. Indeed, dideré remains green and bourgou becomes yellow. We did not yet use this information to improve the vegetation map,

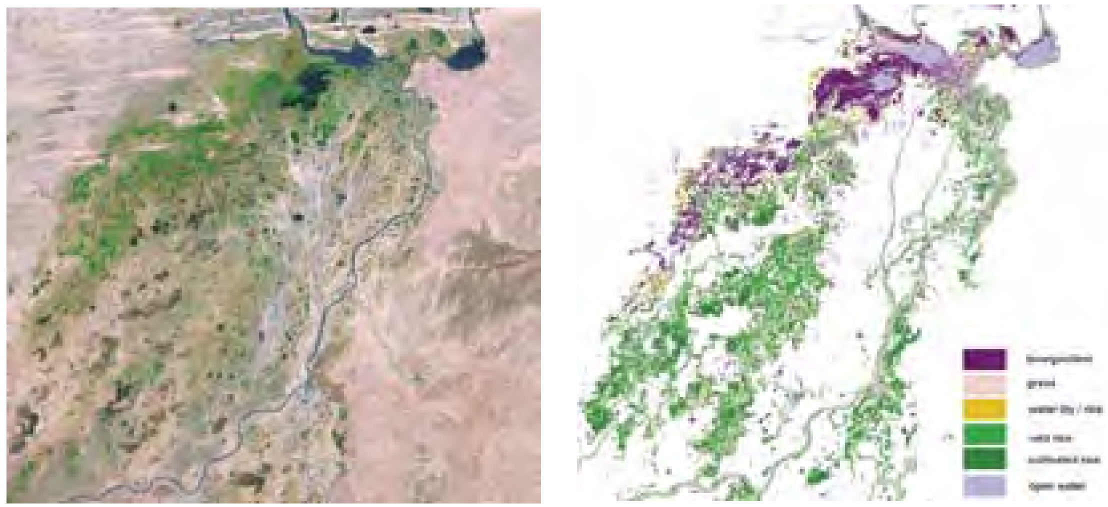
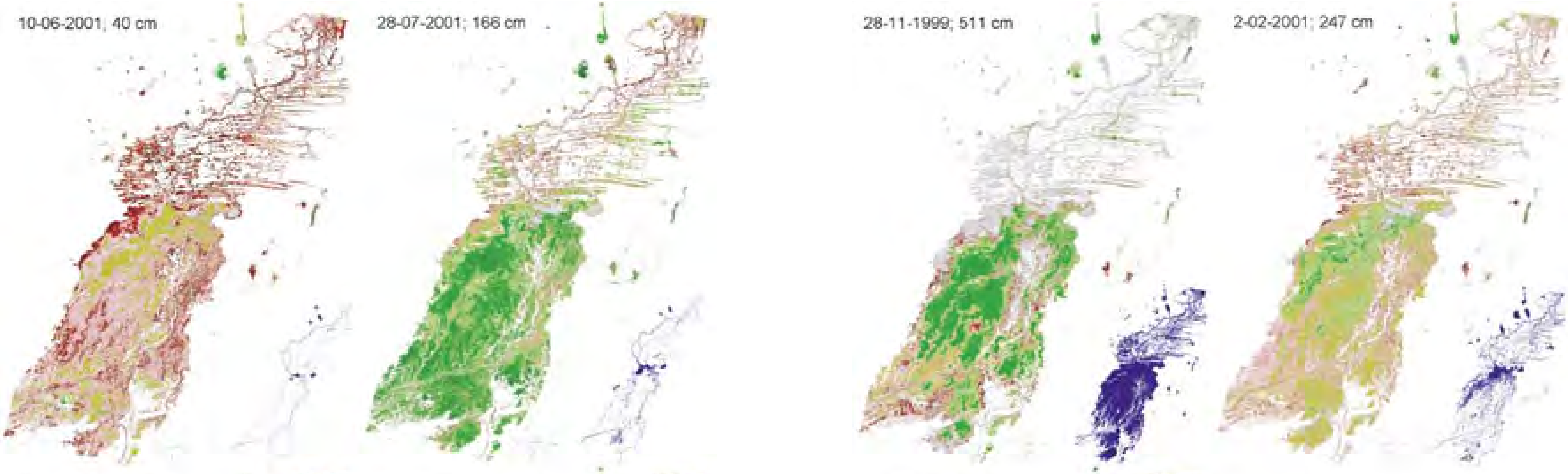


Fig. 6.3. True Colour Composite (left) of southern half of Inner Niger Delta (131 x 139 km) on 2 February 2002 and the derived vegetation map (right). The left image clearly shows the different green tints for vétivere, rice and bourgou. The dark spots in the SE quarter of the scene refer to burned rice fields. Note that the area is still covered by water at water level of 360 cm in Akka.



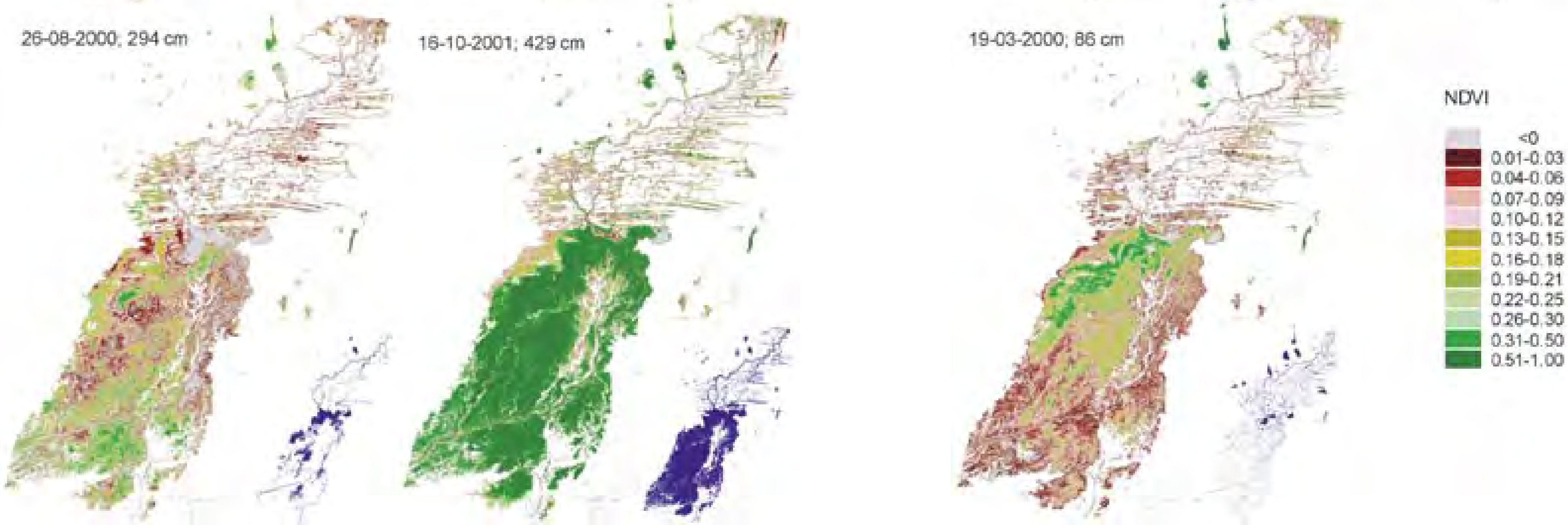


Fig. 6.4. Seasonal variation in the green biomass on the floodplains of the Inner Delta during the crue (left) and décrue (right) measured by the NDVI-index, which is a ratio of different spectral bands. The inset figures show the inundated areas on the same seven days (see Fig 3.5).

but intend to do this in the future.

The NDVI is an excellent tool to describe the global, seasonal and annual variation in green biomass. As a first result, Fig. 6.4 shows for the inundation area the seasonal variation in green biomass during the crue (4 left images) and décrue (3 right images), using images between November 1999 and July 2001. One problem in the interpretation is that biomass below the water surface is not visible and ignored in the determination of the NDVI. Therefore, the area covered by water for all seven images is provided as a small inset figure (see Fig 3.5).

Fig. 6.4 shows how the floodplain in the dry season is bare before the rains (July 2001) and turns into a green meadow after the first rains (July 2000 and August 2001; 85 mm in the fortnight before (Table 3.1)). The inundated floodplain is covered by a dense carpet of floating grasses (October 2000, November 1999). The green vegetation declines as soon as the floodplain is uncovered (February 2001 and March 2000). Fig. 6.4 shows how the variation in biomass is much larger in the northern Delta (with the exception of Lac Horo and Lac Télé) than in the southern Delta. A comparison of the seven pictures also shows that the area southwest of Lac Walado, the Plaine de Seri, is always green, even in the dry period of 2000 and 2001. Only during the Great Drought this area changed colour. All terrain on the True Colour Composite of July 1985 (Fig. 6.1) is red, indicating a bare ground without any vegetation.

The vegetation map shown in Fig.6.3 is considered to be reliable for bourgou. Errors mainly occur in the distribution of grass and of wild and cultivated rice. Nevertheless, the distribution of cultivated rice does not deviate much from the 1987-map developed by Marie (2000, 2002) and reproduced in this report as Fig 8.7. The change in the distribution pattern of cultivated rice during the 50 years is discussed in Chapter 8.

As shown in Table 6.1, Marie (2000) originally calculated the area covered by the different vegetation types. The vegetation areas generated by our approach are presented in Table 6.2. The estimates show that rice covers 2,473 km^2, bourgoutière 1,543 km^2 and grass 1,105 km^2. When we compare our estimates with those of Marie (2000), it can be seen that both estimates do not deviate much, especially taking into account that our data concern the entire Delta and his data the southern half. Moreover, our estimates shown in Table 6.2 do not include the inundation zone higher than 360 cm.

Table 6.2 The total surface (km^2) of the different vegetation types in the lower inundation zone (< 360 cm; see Fig 3.5) in February 2003. Note that the surface not only refers to the area shown in Fig 4.3 but to the entire Inner Delta.

Vegetation type	Surface (km^2)
Cultivated rice	1,040
Wild rice	1,260
Wild rice & water lily	173
Bourgou & dideré	1,039
Bourgou & dideré & water lily	504
Grass	1,105

6.4 Conclusions

Despite the uncertainties attached to the vegetation analysis and the fact that a number of additional steps can be made to improve our knowledge on changes in vegetation in the Inner Niger Delta, a number of conclusions can be drawn already.

- There is a large seasonal variation in green biomass, related to rainfall and flooding; this can reliably be described with the selection of two spectral bands of the satellite images (red and near infrared).

- A vegetation map of the lower Inner Delta, on basis of the satellite image of February 2003, clearly shows the distribution of bourgou (mainly central part of the Inner Delta) and cultivated rice and wild rice (mainly southwestern part of the Inner Delta).
- The main vegetation types reveal a definite zoning in relation to water depth. Bourgou occurs where water depth exceeds 3 m. Dideré, wild rice and cultivated rice grow in about 2 m of water.

7 LIVESTOCK IN THE INNER NIGER DELTA

Hasse Goosen
Bakary Kone

7.1 Introduction

Many millions of cattle graze on the southern fringe of the Sahara. Some 25 years ago a Malian-Dutch research team working on the "Production primaire au Sahel (PPS)" confirmed what the herders already knew for ages. They discovered that in the sub-arid zone grass cover is not luxuriant, but grass-stalks are lush. The scientists reported that grass is of a good quality due to high protein content and low presence of crude fibre. Therefore, digestibility of the grass for cows is high. The scientists also concluded that the herders made optimal use of the temporal and spatial gradients of grass quantity and quality by moving around with their cattle. After the first rains, it takes some time for the grass to germinate. Initially the young green grass has a very high quality, after which biomass further increases and quality declines. Recent research revealed that the inverse relationship between quantity and quality differs for sandy and clayish soils. Herders exploit this spatial variation by matching grazing patterns.

The main objective of this Section is to analyse how pastoralists, who always seem to be in a fragile equilibrium, depend on the flooding of the Inner Niger Delta. We investigate how the herds grow when the floods are good, and we will demonstrate the expected impacts of changes in water availability on livestock. This Chapter analyses the annual variation in the number of cattle, and shows whether this is related to variable flooding of the Inner Delta. Before the analysis is performed, it is necessary to investigate if there is a relationship between flooding and productivity of cattle. The key factor is the annual flood-related variation in the food supply of cattle in the Inner Delta.

This Chapter is structured as follows. Section 7.2 describes the current situation regarding livestock in the Inner Delta in terms of data availability and the herd size. Section 7.3 covers the explanatory factors of changes in the livestock of the Inner Niger delta. Various aspects are discussed, such as impact of rain, availability of food for livestock, and overgrazing of vegetation. In Section 7.4 the link between livestock and flooding during the Great Drought is analysed using a multiple regression between livestock and its main explanatory variables. From this latter analysis, production functions for the Mopti and Tombouctou regions are derived. The changes in livestock are simulated for four scenarios in Section 7.5. Conclusions are drawn in Section 7.6.

7.2 Livestock in the Inner Niger Delta

Data availability

A wide range of livestock data of the Inner Niger Delta is available, partly on cercle level (annual reports of the Direction Générale de l'Elevage since 1980) and partly on regional level (annual reports of the DGRC and OMBEVI). We focus on the regions of Mopti and Tombouctou, because these regions are located within the Inner Niger Delta. The two main sources of data are: (1) annual data of the Direction Générale de l'Elevage, and (2) annual reports of 1984-1999 of DGRC/OMBEVI. Although both sources differ slightly in the absolute figures of livestock, they are strongly correlated. For example, the number of bovines in the Mopti region for 1984-1999 as given by the two data sources generate a fit of $R^2 = 0.91$.

Missing data occur in time series and livestock type. For Tombouctou the sources are: Rapports annuels de la Direction Générale de l'Elevage, de la Direction Régionale de l'Appui au Monde Rural de Tombouctou and de la Cellule de Planification et de Statistique du Ministère du Développement Rural.

The most complete data is available for cattle, sheep and goats, hence our focus on these categories. For Mopti there is good information on cattle and total livestock. Cattle is a good indicator for total livestock, as evident from the high correlation between both ($R^2 = 0.973$).

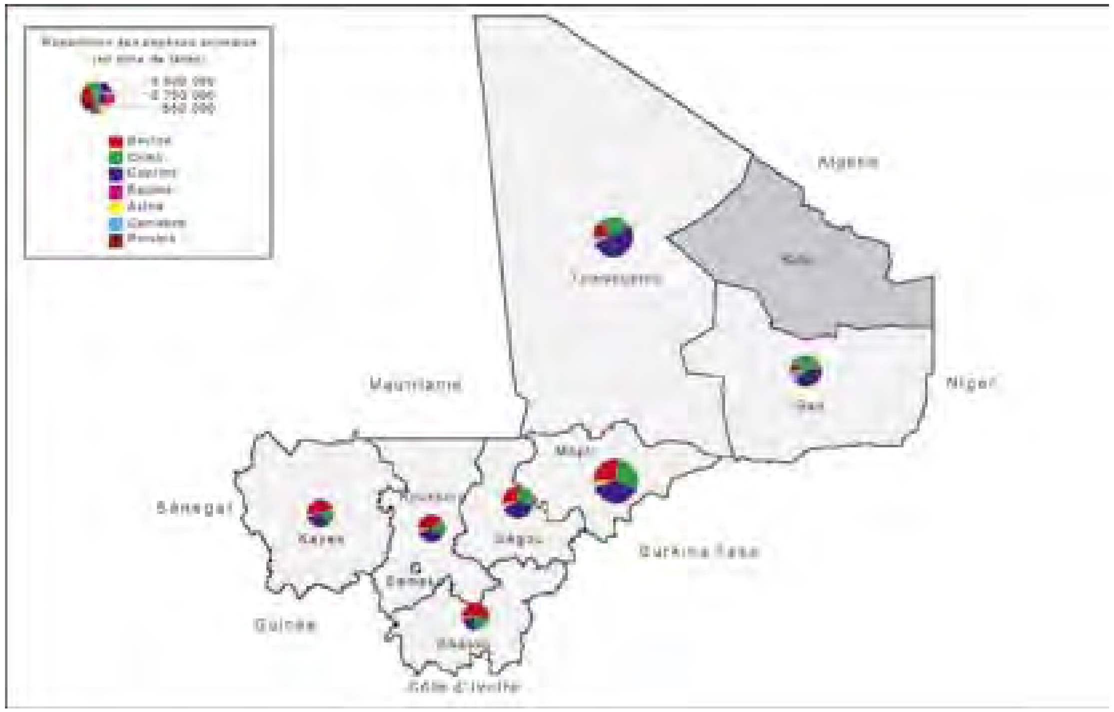


Fig. 7.1. Composition and relative importance of livestock in different regions of Mali, 1999. Source: Cellule de Planification et de Statistique du Ministère du Développement rural, Mali.

Total stock

Fig. 7.1 shows the proportion and number of livestock for different regions in Mali. Total livestock mainly consists of cattle (*bovines*), sheep (*ovins*) and goats (*caprins*). Fig. 7.1 also illustrates the relative importance of the regions of Mopti, Ségou and Tombouctou for livestock farming in Mali. Clearly, the three regions are the main centres of livestock in Mali. Fig. 7.2 shows the development of the total stock in two regions over 1982-2002. Although some data are missing, Fig. 7.2 shows the decrease of the stock after the severe drought of the early 1980s.

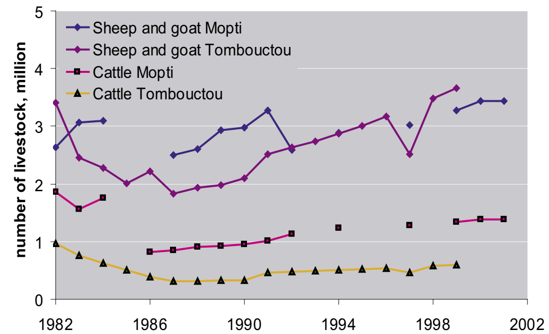


Fig. 7.2. Total stock of cattle in three regions in 1977 - 2001.

7.3 Explanatory factors of livestock changes

Rain and pastoralism in West Africa

Pastoralists obtain most of their sustenance from domestic animals, either as flesh, milk, blood or the sale of animal products. They mostly inhabit savanna and desert zones, which necessitates seasonal migrations in search of water and pastures (Deshmukh 1986). Pastoral nomads master a complex and harsh environment with marginal and floating resources. Pastoralists have become masters in insurance. Many tribes mix different types of livestock. If the rains or flood are good, cattle and sheep will do well. In times when flood and rain are poor, the hardier goats and camels will survive (Harrison 1987). To spread the risk over a larger area, herds are usually split between relatives or loaned to other families. To survive a period of drought, there is a tendency to maximize herd size (Harrison 1987). Periods of severe drought can wipe out large proportions of the stock. The bigger the herd, the higher are the chances of ending up with a viable population when times get better. Periods of drought take a heavy toll on livestock and pastoralists. The pastures and ponds dry up, distances between water sources increase and longer distances have to be crossed. Diminishing milk production leads to a shortage of food for the calves, and consequently calve mortality can increase to 36% in dry years (Harrison 1987).

The average rainfall in the semi-arid zone north of the Inner Niger Delta is 100 mm. Yet, the amount of rain is rather unpredictable. There is a chance of approximately 10% that the annual rainfall is less than half of this average. Further south, where the average annual rainfall is 750 mm, the probability that rainfall is less than half of the average is only 1%. Each year, herders in the Delta have to decide how far

north they will move at the beginning of the rainy season. After the short rainy season, the grass withers and the herders move south again. If they return not too early, their cows can graze in the agri-cultural zone. Cattle outside the Inner Delta survive the dry period feeding on stubble of rice, millet or sorghum, or on the savanna vegetation. Cattle in the vicinity of the Inner Delta, on the other hand, can feed on the dried-up floodplain. This also explains why of 60% of the five million cows in Mali are concentrated in the regions of Mopti and Tombouctou where the floodplain of the Inner Delta is located (see also Fig. 7.2).

Food availability for livestock in the Inner Delta

The major part of the floodplain of the Inner Delta is covered by a floating aquatic grass species: wild rice *Oryza longistaminata*, floating rice planted for consumption (*Oryza glaberrima*) and two plant species locally known as didéré *Vossia cuspidata* and bourgou *Echinichloa stagnina*. The floodplain is covered by several meters of water and thus are inaccessible to cows during inundation. Due to the rain, however, the cattle has a good alternative, i.e. temporary grasslands in the surroundings. Between December and March, when the water begins to recede with 3 to 5 cm a day, a rich food supply gradually becomes available.

Because there are also many farmers in the Inner Delta, the herders are not allowed to enter the Inner Delta when the rice is not yet harvested (see Box 7.1). As water levels fall, grass and *Cyprus* start to grow abundantly. These green meadows are an attractive, temporary grazing ground from late January until early May. The bourgou is harvested and fed to the cows later in the season. When the crue in July-September submerses the floodplain, the herders gradually retreat to higher grounds where, due to rainfall, cattle can graze again on young grass.

De Leeuw & Milligan (1983) were the first to perform aerial counts of cows in the Inner Delta, i.e. between February 1980 and March 1981, covering the entire southern half of the Inner Delta. As shown in Fig. 7.3, which is based on the work of De Leeuw & Milligan (1983), during the *décrue* 1.2 million of cows penetrate into the southern Inner Delta at high water from the 'waiting zones' along the flooded area. At low water levels, most of the cattle concentrates south of Lac Debo-Walado. Their counts confirmed what Gallais (1967) had already described: about 500,000 cows enter the southern Inner Delta from the south and the northeast while another 650,000 cows flow into the Delta from the north and west.

Depending on flood level, cows only graze in certain zones of the floodplain. De Leeuw & Milligan (1983) discovered that cattle grazes with a density of 100 animals per km^2 and higher. According to their counts, about 400,000 sheep and goats migrate into the southern Inner Delta during the *décrue*. They move at a low pace and therefore lag behind the cows. Ultimately, they catch up with the cows and then graze in the same lower zone with a density of 30 animals per km^2 or more. As zebu-cows weigh 250 kg, and goats and sheep about 20 kg, the total grazing pressure is equivalent to 26 tonnes/km2. This is high compared to an average grazing pressure of 2-4 tonnes/km^2 on grassland in the western Sahel (Penning de Vries & Djitèye 1982).

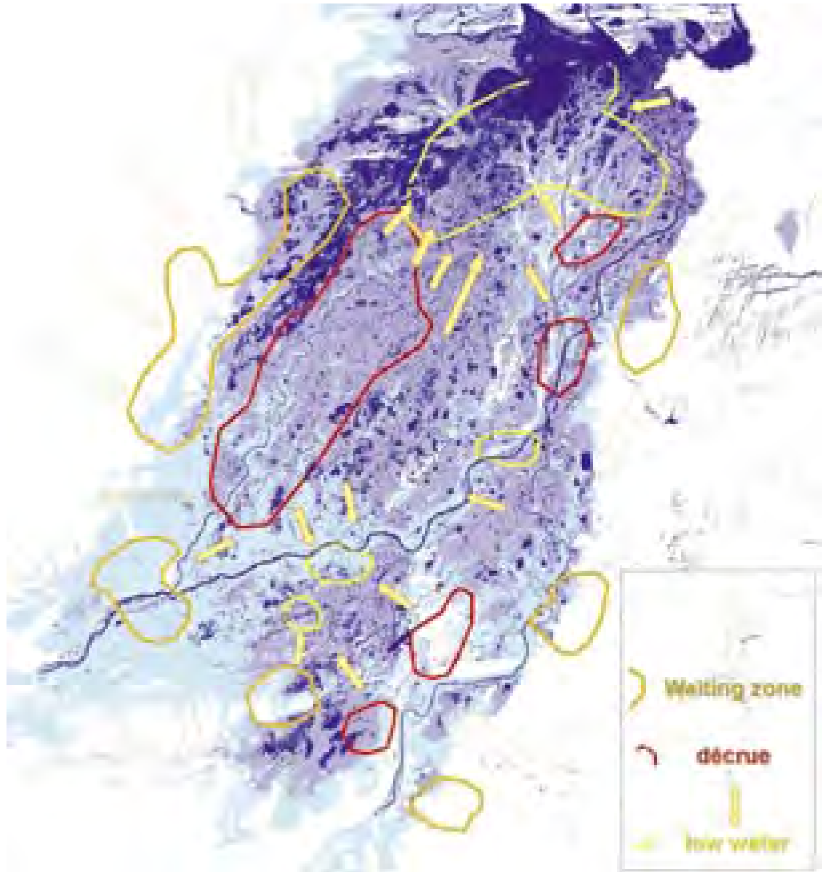


Fig. 7.3. The movements of more than one million cows in the southern half of the Inner Delta during the décrue. Source: De Leeuw & Milligan (1983).

The transhumance in the Sahel has been studied extensively. Also, many papers have been written on food supply for cattle on the floodplain of the Inner Delta. Hiernaux & Diarra (1983, 1986) and François *et al.* (1989) measured the seasonal variation in biomass bourgou. The biomass increases during the *crue* to reach a level of 20-30 tonnes dry mass/ha during the flood, of which around 5 ton consist of leaves and stems above the water table and 15- 25 ton/ha of stems growing below the water surface. The contribution of the underwater stems of bourgou is substantial. Bourgou grows 3-4 cm a day during at least four months. Driven by the rising water level, it can form stems of 3-6 meter.

Because of its high productivity and nutritional value, local people plant bourgou. Yet, the digestibility varies during the season (François *et al.* 1989). Young sprouts that shoot in the dry period after the plants have been cut have a high quality. The productivity of these sprouts is estimated at 3-5 tonnes/ha of which 85 - 90% is eaten by cows (Hierraux & Diarra 1986). During this period, the cattle ignores old stems of rice due to its poor digestibility. By burning the rice stems regrowth is stimulated. Still, due to the poor quality of rice stems, only 5-10% is consumed by cattle (Hierraux & Diarra 1986).

Planted bourgou grows at least 1 meter deeper than wild bourgou. By planting bourgou deep,

Box 7.1

Prevention of conflicts between herders and farmers in the Inner Delta

When the floodplains during the décrue become accessible to livestock, the farmers still have to harvest their rice. Yet, herders have an interest in arriving as soon as possible on the immersed floodplain because the quality of aquatic plants decreases within weeks as the heat scorches the vegetation. Obviously, farmers do not accept cows entering their rice fields and eating the rice crop before harvest. The Dina, the law introduced by the Peuls (see Chapter 4.1) in the 19th century, offered a compromise in these conflicting interests. Although the Dina lost its importance during colonial time, it was decided at a meeting in 1966 to re-establish the Dina with regard to grazing of cattle in the Inner Delta. In the modern version it is not the Dioro but the High Commissioner of the Mopti region who coordinates the different parties.

The annual meeting of stakeholders seeks to determine when cattle is allowed to enter the different zones in the Inner Delta. This meeting takes place before the start of the décrue, so that the 'calendrier de déplacement', also known as 'calendrier de traversées' or 'calendrier de la campagne des bourgoutières' can be ascertained based on the expected date that the floodplain becomes available, taking into account the effect of local rainfall.

The herders and their cows need to cross the river. There are 32 frequently-used crossings. The river-crossing is celebrated each year. Popular festivities are, for instance, 'Jaaral jafaradji' at Diafarabé and 'Deggal diali' at Dialloubé. The date at which cows are allowed to cross the river differs for the various official crossing-points. For example, Sendegué is usually a week or a fortnight later than Kontza. Because the floodplain in the southeast becomes available in advance of the floodplain in the central Inner Delta, access is already permitted in November in Diafarabé. Between 90 to 110 days later, the area near Lac Walado-Debo is opened for grazing. When the rain starts, the cattle leaves the Inner Delta to graze on the grasslands. Normally the cattle is present in the Inner Delta until the end of June, but in dry years it stays longer.

The entry dates also vary between years. After the low flood of 1984, cows were allowed to enter the floodplain around four weeks earlier compared to the high flood of 1994. By comparing the dates of access since 1980 and the flood levels, it is clear that the entry date is not determined by the flood level alone. Each year, the stakeholders negotiate fanatically about the calendar.

Source : Nouhoun Diakité (pers. comm.), Moseley *et al.* (2002).

local people artificially increase productivity. The annual variation in productivity of bourgou has not yet been quantified. For several reasons it is likely that the flood level has a positive impact on the average productivity of bourgou. Firstly, as mentioned earlier, stems grow longer at a higher water level. Secondly, high water levels extend the duration of the flooding period, and hence increase the period of growth of the bourgou with several months (see Section 3.7).

Diarra & Hiernaux (1986) compared the productivity of the major vegetation types in the Inner Delta for two years, 1982 and 1984. The flood in 1982 was rather low with a maximum of 406 cm at Akka. The 1984-flood was even lower with a maximum of 336 cm at Akka. The difference in vegetation was dramatic. The productivity of bourgou was reduced by 85% while rice production declined by as much as 90%.

Despite the limited information on the relationship between plant productivity and flooding, it is still possible to make an approximation. The zoning of bourgou and other aquatic plants is not fixed. Using satellite images, Zwarts & Diallo (2002) showed that Lac Walodo was colonized by bourgou in 1985 and 1986. During this period, the flood level had been low for number years. Apparently, it took at least one or two years for the bourgou to occupy its new depth zone. After a series of high floods in the early 1990s, bourgou disappeared from Lac Walodo because the lake became too deep for bourgou to survive. In the same period that bourgou settled in the lowest zone of the Inner Delta, elsewhere in the Delta much larger bourgou fields were replaced by *didéré*, a plant species growing in more shallow waters. These observations showed that the area of bourgou declines considerably with a sudden change in flood level. It takes one or two years before bourgou occupies its novel optimal depth zone.

By assuming that bourgou colonizes the optimal depth zone, the loss of bourgou habitat with a reduction of water level can be estimated. Most bourgou is planted at around 0 cm relative to the gauge in Akka. Given the average water level of 450 cm during the last 30 years, the optimal water depth for bourgou is between 4-5 m. Most wild bourgou is found one meter shallower at a water depth of 3-4 m. Although bourgou can survive 5-6 m below the water surface, this depth is suboptimal as many bourgou plants drown.

Using the digital elevation model developed in Section 3.5, the surface area of the optimal zone and the zone of shallow and deep bourgou can be calculated for each water depth. Fig. 7.4 clearly shows that the surface of suitable habitat for bourgou increases with flood level. The zone with the optimal depth starts to decline beyond a water level of 510 cm. Moreover, if the water depth is less than 420 cm the surface of habitat of optimal bourgou habitat is 100-200 km^2 smaller per 10 cm reduction of the water level. At a water level of 340 cm nearly all bourgou habitat is too shallow to be optimal. This explains why, during the Great Drought, when the maximal flood level decreased to a level of 336 cm, bourgou lost its entire optimal habitat in the Inner Delta.

The relation between surface of optimal bourgou habitat and maximal water depth at Akka for the range 320-530 cm is given with the equation:

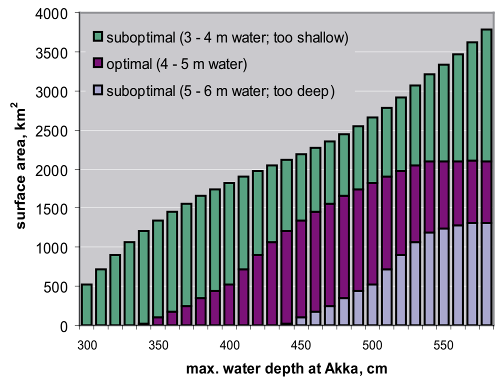


Fig. 7.4. The surface (km^2) of the floodplain of the inner Delta where the water depth is 3-4, 4-5 or 5-6 m deep as a function of the water level in Akka. Bourgou occurs in all three depth classes, but the zone with 4-5 m water is considered as optimal.

$$y = -0.0007x^3 + 0.8506x^2 - 331.27x + 41863 \quad (7.1)$$

$(R^2 = 0.993)$

where:

y = surface of optimal bourgou habitat (in km^2)

x = maximal water depth at Akka (in cm)

Overgrazing

The decline of bourgou during the Great Drought was not only due to the flood-related loss of habitat. Bourgou fields also disappear when there is too much grazing on the sprouts that start to grow in the dry season after the plants have been cut. By comparing satellite images from recent years, we reconstruct the relocation of bourgou fields in Lac Debo. When verifying the images with statement of local people, all vanished bourgou fields appeared to have been heavily grazed in the stage when the bourgou started to sprout. Local people are convinced that overgrazing is one of the main reasons of the disappearance of the bourgou fields from large parts of the lower Inner Delta during the Great Drought. If indeed overgrazing is a dominant factor in the growth of bourgou, the availability of bourgou is not only related to the current flood level, but also to the degree of overgrazing in the preceding year. A complicating factor in this hypothesis is the fact that bourgou is regularly (re)planted by the people since the early 1980s.

It is clear that the ascertained decline of bourgou with 85% during the Great Drought is partly due to the low floods itself, by which bourgou lost most of its optimal habitat, and partly due to overgrazing. Consequently there was a huge reduction in the carrying capacity of floodplain for livestock.

Link between rain and floods

One other difficulty arises when estimating the link between size of the herd and flood level in the Inner Niger Delta. From July to November, cattle depend on grasslands near the Inner Delta. When local rains are very poor, the physical condition of the cows is negatively affected. However, years with little rainfall coincide with low floods in the Inner Delta (Fig. 2.5 and Fig. 2.6). Hence, it is difficult to split the effects of rain and flooding. There are two ways to unravel this problem. Firstly, the precise role of flooding can be verified in more detail by comparing the decline in cows during the Great Drought at the cercle level. Secondly, the relative impact of rain and flooding on the number of cows can be quantified by conducting a multiple regression analysis. Both approaches are explained in the next Section.

7.4 Analysis livestock and flood

Decline of livestock during the Great Drought

Since 1980, counts of livestock per cercle are published in annual reports of the Direction Générale de l'Elevage. Livestock is counted between October and February when livestock is compulsory vaccinated against pneumonia and plague. Table 7.1 compares the average number of cows in 1980-1982 to herd size in 1986 in the region of Ségou and Mopti and to the 1987-numbers in the region of Tombouctou. Note that the 1986-count was not available for the Tombouctou region. Fig. 7.5 shows the spatial distribution of the information provided in Table 7.1.

In 17 out of 19 cercles a large decrease in the population was recorded. Similar counts for other regions in Mali showed that herders had moved their cattle further south. The highest number of cattle in southern Mali (i.e. Sikasso) was counted in 1985 and following years. In those years, herders moved even further south into northern Ivory Coast. This implies that the decline shown in Table 7.1 is partly due to a temporary shift of the transhumance towards the south. The main reason for the decline in cattle during the Great Drought, however, remains mass mortality of livestock.

A number of additional observations can be made from Table 7.1 and Fig. 7.5.

- Because the irrigation by Office du Niger made the cattle in Niono less susceptible to drought, the number of cows increased in Niono.
- The average decline in sub-arid cercles was much larger than in cercles with more rainfall. In Tombouctou, for example, the decline was 62.5% (i.e. from 1.1 million to 0.4 million cows). In Ségou, the decrease was 20.4% only (i.e. from 0.7 to 0.55 million). Mopti was in between these two cercles with a decline of 51.9% (i.e. from 1.5 to 0.7 million).
- Compared to its surroundings, the Inner Delta experienced a smaller average decline. The decline of cows in four cercles in the region of Mopti outside the Inner Delta (Bandiagara, Bankass, Douentza and Koro) was 67.3% (i.e. from 0.83 to 0.27 million cows) against 32.6% for the cercle inside the Delta (i.e. from 0.66 to 0.45 million in Djenné, Mopti, Ténenkou and Youvarou).
- The decline was much larger in the northern part of the Inner Delta than in the southern part. As mentioned in Chapter 4, low flood levels affected the northern cercles within the Inner Delta more than the southern ones, not only because the shrinkage of flooded areas in the north was larger than in the south, but especially because the flood was insufficient to fill the permanent lakes. Before

Table 7.1. Number of cows in 19 cercles of the regions Tombouctou, Mopti and Ségou in 1980-1982 (average of three years) compared to the population in 1986 (Mopti, Ségou) or 1987 (Tombouctou). Source: Annual reports of the Direction Générale de l'Elevage.

Cercle	1980-82	1986	% change
Diré	73,667	45,000	-38.9
Gourma Rharous	461,667	110,000	-76.2
Goundam	196,000	124,000	-36.7
Niafunké	273,000	109,200	-60.0
Tombouctou	73,333	16,000	-78.2
Bandiagara	155,500	46,000	-70.4
Bankass	270,000	94,200	-65.1
Djenné	95,000	80,000	-15.8
Douentza	236,000	51,304	-78.3
Koro	167,500	79,563	-52.5
Mopti	222,500	134,933	-39.4
Ténenkou	204,500	125,995	-38.4
Youvarou	141,030	105,773	-25.0
Barouéli	94,000	85,000	-9.6
Bla	97,000	98,000	+1.0
Macina	130,667	84,000	-35.7
Niono	74,333	99,000	+33.2
San	63,667	53,000	-16.8
Segou	147,000	85,000	-42.2
Tominian	89,333	50,000	-44.0

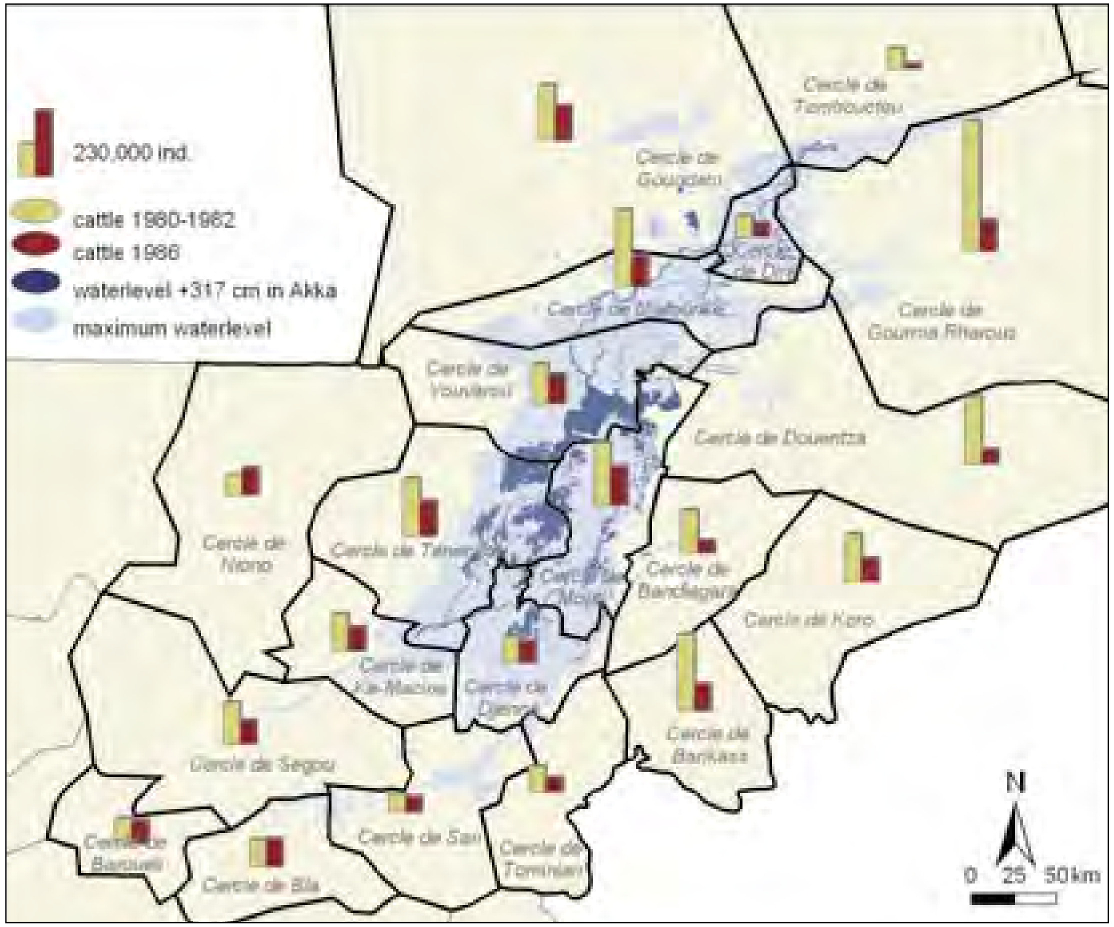


Fig. 7.5. The % change in cattle population per cercle during the Great Drought; original data provided in Table 7.1.

the Great Drought, the largest number of cows was found in the cercle of Gourma. Of these 0.5 million cows, only 0.1 million remained immediately after the Great Drought.

- The large decline of livestock outside the Inner Delta shows that poor rains during the Great Drought seriously impacted livestock. As herd size in the remaining floodplains of the Inner Delta declined much less, the importance of the inundation zone as a buffer against poor rainfall is clearly illustrated.

Regression analysis

To determine the dependence of cattle on the availability of water, numbers of cattle have been correlated with several hydrological parameters. As most pastoral livestock in African regions depend on precipitation, rainfall is a plausible parameter to test for. However, the situation in the Inner Niger Delta is atypical in the sense that it has an exceptionally large inundation area. Nomadic pastoralists move into the delta when the flood arrives. Strong correlations between livestock numbers and river height and size of the inundation area are therefore even more likely

Table 7.2 Correlations of livestock with five parameters in two regions.

	Mopti		Tombouctou		Average
	Cattle	Sheep and goat	Cattle	Sheep and goat	
R^2 flood duration	0.79	0.51	0.51	0.74	0.64
R^2 bourgou	0.69	0.43	0.44	0.51	0.52
R^2 water level	0.59	0.23	0.47	0.53	0.46
R^2 inundation area	0.55	0.19	0.45	0.52	0.43
R^2 rainfall	0.19	0.04	0.14	0.19	0.14

Table 7.3. Production functions for number of livestock and area of optimal bourgou habitat.

	Mopti	R^2	Tombouctou	R^2
Cattle	y = 393x + 797.389	0.69	y = 149x+ 332.511	0.44
Sheep & goat	y = 506x + 2.572.123	0.43	y = 947x + 160.717	0.51

to be found as between livestock and precipitation.

This hypothesis is tested in time-series regression between the number of livestock in the Inner Niger Delta and four hydrological parameters (i.e. rainfall, maximum water level at Akka, maximum inundation area, and duration of the flood based on river heights at Mopti), and with bourgou habitat. In running the regression for the five parameters, a distinction is made between the drought in the 1980s and the period of recovery after the Great drought, as the behaviour of the herds showed a completely different trend before and after 1987 (sees Fig. 7.2).

The duration of the flood explains most of the variance in livestock populations (see Table 7.2). The longer the flood lasts, the higher the number of cattle, sheep and goats in the region. Next best in explaining the variance is the maximum water level measured at Akka.

Because duration of the flood best explains changes in livestock numbers, this would also be the most appropriate variable to use in the simulation of the four scenarios. However, it seems a nearly impossible task to generate predictions based on hydrology with a temporal resolution of days. Therefore, we focus on the 'next-best' option by using the habitat suitable for bourgou as the explaining variable for estimating changes in livestock populations in the four scenarios.

Production functions in the two regions

Production functions have been estimated for the two regions of Mopti and Tombouctou, which capture the relationship between numbers of livestock (cattle and sheep/goat) and the surface area of optimal habitat for bourgou. Because the data make no distinction between sheep and goat, both are analysed under the same heading. Patterns were very irregular during the collapse in the early 1980s, all regression analyses are conducted for the 'recovery-period' after the drought of the 1980s. The production functions for the three regions are presented in Fig. 7.6. The plots of the subsequent productions are presented in Annex 7.

7.5 Livestock farming under four scenarios

The above production functions in combination with the estimated surface area of optimal habitat for bourgou, as described in Section 3.7, have been used to analyse the impact on livestock for the four scenarios. The analysis was repeated for two other variables, i.e. the maximum water level at Akka and the estimated inundated area, to check whether this would lead to different outcomes.

Mopti

The results for the region of Mopti are summarised in Table 7.4 to Table 7.6. If we compare a change from the present situation (Scenario 2) to a future where there is no more water taken from the Niger by the Office du Niger (Scenario 1), we find a minor increase of livestock in the region of Mopti (i.e. around 1% increase). Given the uncertainties caused by the imperfect correlation for these hydrological variables, this effect is negligible. When we move from the present situation to a scenario where both Office du Niger and Sélingué are absent (Scenario 0), an average increase of 5% in the cattle population is calculated. This increase represents the average increase in numbers of cattle, in 1987-2001. The increase is less significant for goats and sheep (i.e. less than 2%). Finally, if we move from the present situation to a situation with the Fomi dam (scenario 3), a negative impact on livestock numbers of almost 5% are simulated, for cattle as well as goats and sheep.

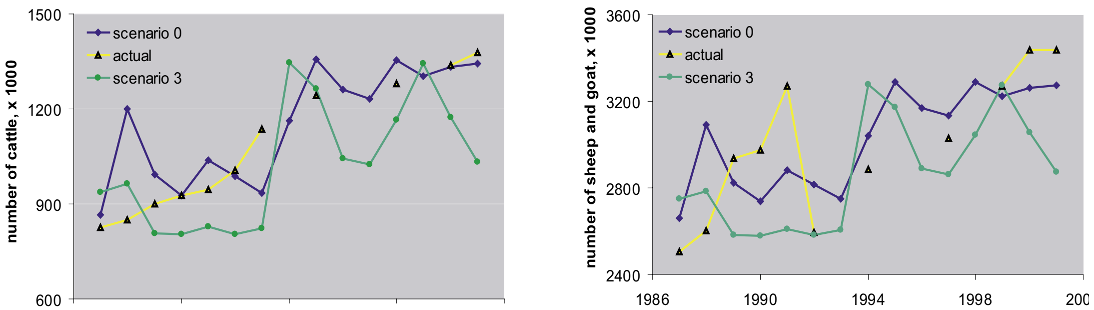


Fig. 7.6. Trends in cattle (left) and sheep and goats (right) populations in the Mopti region as calculated from estimated production functions and calculated impacts of the scenarios on the total area of bourgou.

Table 7.4. Expected impacts of the scenarios on livestock in Mopti on the basis of changes in the area of bourgou.

Mopti	Scenario 2 -> Scenario 1		Scenario 2 -> Scenario 0		Scenario 2 -> Scenario 3	
	Cattle	% change	Cattle	% change	Cattle	% change
average	16,403	1.7	41,850	4.5	-128,922	-3.7
Stdev	26,740	2.5	89,621	8.4	131,677	3.8
	Sheep & goat	% change	Sheep & goat	% change	Sheep & goat	% change
average	21,116	0.7	53,875	2.0	-165,965	-5.4
Stdev	34,423	1.2	115,372	3.9	169,512	5.5

Table 7.5. Expected impacts of the scenarios on livestock in Mopti on the basis of the maximum water level at Akka.

Mopti	Scenario 2 -> Scenario 1		Scenario 2 -> Scenario 0		Scenario 2 -> Scenario 3	
	Cattle	% change	Cattle	% change	Cattle	% change
Average	18292	1,67	56281	5,1	-148839	-4,69
Stdev	3345	0,48	10208	1,49	37153	1,30
	Sheep & goat	% change	Sheep & goat	% change	Sheep & goat	% change
Average	18334	0,57	56410	1,78	-149180	-4,70
Stdev	3352	0,13	10232	0,39	37238	1,30

Table 7.6.Expected impacts of the scenarios on livestock in Mopti on the basis of the inundation area.

Mopti	Scenario 2 -> Scenario 1		Scenario 2 -> Scenario 0		Scenario 2 -> Scenario 3	
	Cattle	% change	Cattle	% change	Cattle	% change
average	15,673	1.4	49,689	4.4	-115,127	-4.4
Stdev	1,178	0.16	6,766	0.62	25,337	0.91
	Sheep & goat	% change	Sheep & goat	% change	Sheep & goat	% change
average	15,046	0.6	47,702	1.8	-110,522	-4.3
Stdev	1,131	0.04	6,495	0.23	24,324	0.87

Tombouctou

In Tombouctou the effects are more profound. Table 7.7 to Table 7.9 summarise the main results of the four scenarios for the three variables that were tested: area of bourgou, maximum water level at Akka and inundation area.

Fig. 7.7 shows the calculated developments of the livestock populations over time for the different scenarios in Tombouctou. The actual number of livestock (from our data) is also indicated in the figures.

It appears that scenario 3 will have considerable impacts on sheep and goats in Tombouctou (10 to 15%, Table 7.10). Although impacts on cattle are slightly higher in Mopti (a decline of about 4%) than in Tombouctou (about 2% decline), the overall effect seems small. However, during the Great Drought cattle numbers declined steeply (Table 7.1, Fig. 7.2). And although it may seem that scenario 3

Table 7.7. Expected impacts of the scenarios on livestock in Tombouctou on the basis of changes in the area of bourgou.

Tombouctou	Scenario 2 -> Scenario 1		Scenario 2 -> Scenario 0		Scenario 2 -> Scenario 3	
	Cattle	% change	Cattle	% change	Cattle	% change
average	6,237	1.6	15,913	4.1	-49,020	-1.7
stdev	10,167	2.4	34,077	7.8	50,067	1.7
	Sheep & goat	% change	Sheep & goat	% change	Sheep & goat	% change
average	39,546	1.6	100,898	4.6	-310,819	-11.2
stdev	64,467	2.6	216,069	8.6	317,461	11.6

Table 7.8. Expected impacts of the scenarios on livestock in Tombouctou on the basis of the maximum water level at Akka.

Tombouctou	Scenario 2 -> Scenario 1		Scenario 2 -> Scenario 0		Scenario 2 -> Scenario 3	
	Cattle	% change	Cattle	% change	Cattle	% change
Average	7,910	1.78	24,338	5.5	-64,363	-2.50
stdev	1,446	0.53	4,414	1.63	16,066	0.89
	Sheep & goat	% change	Sheep & goat	% change	Sheep & goat	% change
Average	49,771	1.90	153,136	5.94	-404,974	-15.72
stdev	9,100	0.59	27,776	1.84	101,090	5.58

Table 7.9. Expected impacts of the scenarios on livestock in Timbouctou on the basis of the inundated area.

Tombouctou	Scenario 2 -> Scenario 1		Scenario 2 -> Scenario 0		Scenario 2 -> Scenario 3	
	Cattle	% change	Cattle	% change	Cattle	% change
average	6,942	1.51	22,008	4.8	-50,990	-1.92
stdev	522	0.19	2,997	0.71	11,222	0.40
	Sheep & goat	% change	Sheep & goat	% change	Sheep & goat	% change
average	43,794	1.63	138,843	5.25	-321,691	-12.13
stdev	3,292	0.22	18,906	0.80	70,798	2.53

Table 7.10. Summary of expected impacts of the scenarios on livestock in Mopti and Tombouctou on the basis of three variables.

Method used	Scenario 2 -> Scenario 3 Mopti (% change)		Scenario 2 -> Scenario 3 Tombouctou (% change)	
	cattle	Sheep & goat	Cattle	Sheep & goat
Bourgou	-3,7	-4,7	-1,7	-10,7
Max. water level	-4,6	-4,7	-2,5	-15,7
Inundation area	-4,4	-4,3	-1,9	-12,1

has a minor effect on the maximum size of the herds, it may well have implications for the viability of the remaining population after droughts. Secondly, the decrease of the flood may also have an impact on the frequency of droughts.

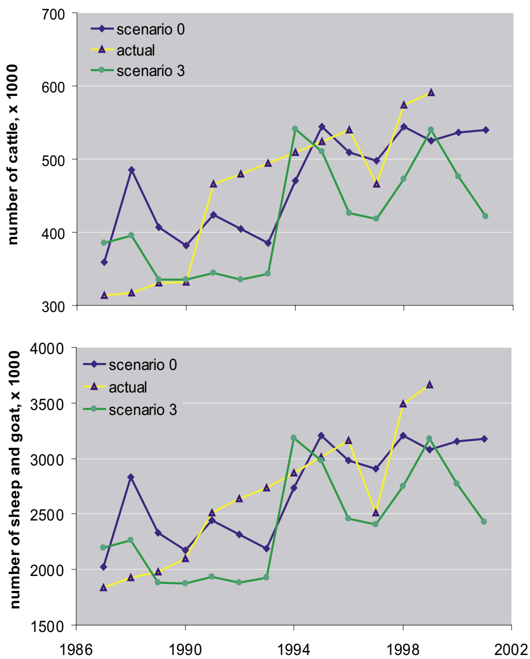


Fig. 7.7. Trends in cattle (top) and sheep and goats (bottom) populations in the Tombouctou region as calculated from estimated production functions and calculated impacts of the scenarios on the total area of bourgou.

7.6 Conclusions

The above analysis shows again how sensitive the local economy in the Inner Niger Delta is to changes in the flooding regime. Although livestock is mobile and can one way or another mitigate damage from reduced water availability, livestock migration is unable to avoid significant losses during droughts. Despite statistical uncertainties, several conclusions can be drawn.

- The number of livestock increases with river height in the Inner Niger Delta. Nomadic pastoralists increase the size of their herds when water is available. This implies that the maximum sustainable population of livestock is limited by the availability of bourgou in the Inner Delta and thus by the flow of Niger and Bani Rivers into the Inner Delta.
- The maximum number of livestock will be negatively affected by the Fomi dam (Scenario 3). The most severe impact is expected on sheep and goats in Tombouctou, where the calculated decrease in average number of animals ranges between 10 to 15%. Negative impacts on cattle range between 2 to 4%.
- In the absence of Office du Niger and Sélingué, the number of cattle, sheep and goats in the regions of Mopti and Tombouctou are expected to increase on average with roughly 4 to 5% per year.

8 RICE PRODUCTION IN THE INNER NIGER DELTA

Leo Zwarts
Bakary Kone

8.1 Introduction

Trucks filled with rice arrived in Sévaré and Mopti in August 2002 to fill the repositories with a new emergency food supply. Had a food shortage already been foreseen due to the low rains in the weeks before? Or was it already known in August that the forthcoming flood would be limited? With current technology, it is indeed possible to predict the inundation of the Inner Delta two or even three months beforehand. Weather satellites continuously register the clouds all over the world and these data are used to estimate daily rainfall. This information has been entered into early warning systems to forecast food shortage in semi-arid areas (Global Information and Early Warning System, www.fao.org/giews). So, the food aid agencies may have been informed that the rainfall in the catchment area of the Upper Niger was limited in August 2002 and hence the peak river flow would be reduced in September and also the maximal flooding of the Inner Delta in October - November. FAO-experts in Rome may know earlier than the farmers in the Inner Delta that a food shortage is to be expected.

This Chapter will show the effect of flooding on the annual rice production. If this effect can be demonstrated, it allows quantification of the impact on rice production in the Inner Delta resulting from the water usage by Sélingué and the Office de Niger irrigation zone. To do this, it is necessary to separate the effect of local rain on the rice production from the effect of flooding itself. As shown in Chapter 2.1, flooding and local rainfall in the Inner Delta coincide. That is why we will investigate the relationship between rice production and flooding separately for years with different levels of local rainfall.

This Chapter is organised as follows. Chapter 8.2 will show the dependence of the rural economy in Mali on rainfall. Chapter 8.3 will give some background information on cultivating rice in the floodplain area. Chapter 8.4 will deal with rice production in the floodplains and will show that in the Inner Delta the effect of rainfall is limited but that flooding has a significant impact on the rice production. Chapter 8.5 will conclude that the Sélingué reservoir and the irrigation by Office de Niger have a substantial effect on the rice production in the Inner Delta and that the envisaged Fomi dam would have a very large impact.

8.2 Annual cereal production and rainfall

As in other Sahel countries, the rural production of Mali varies from year to year depending on the fluctuating rainfall. The *Cellule de Planification et de Statistique* (CPS), a service within the *Ministère du Developpement Rural* (MDR), published in 2001 a document summarizing many rural statistics (CPS-MDR 2001). The data were extracted from the annual reports of DNAMR (*Direction National de l'appui au monde rural*) and DNSI (*Direction Nationale de la Statistique et de l'Informatique*). The text of this Section is based on the data given by CPS-MDR (2001).

The total cereal production in Mali varies between one and three million tons (Fig. 8.1). Millet and sorghum form the bulk, but the production of rice and maize has increased in recent years. When the total cereal production is plotted against annual rainfall, the relationship appears to be curvilinear (Fig. 8.2).

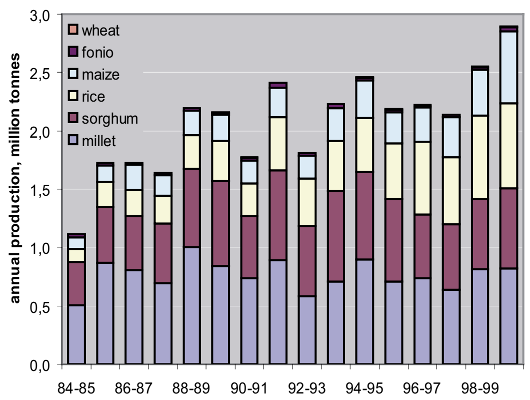


Fig. 8.1. The production of cereals in Mali. Source: CPS-MDR (2001).

The production increases by about 60% if the rainfall goes up from 300 to 450 mm, but if the rainfall increases by another 150 mm there is hardly any additional effect on the total production. The cereal production is not simply a curvilinear function of rainfall, however, because there are several other qualifying factors. Five intervening variables can be mentioned:

- A part of the rice and wheat is grown in irrigated areas, so for these two cereals the effect of rainfall would be less pronounced than for the other crops.
- A part of the rice is grown on the floodplain and, as will be shown in this Chapter, this production is, independent of rainfall, highly dependent on the flood level.
- The total cereal production has gradually increased over the years. Fig. 8.2 shows the production separately for the years before and after 1992. The effect of rainfall is evident in both periods, but the production has been raised to a higher level in more recent years. This increase is partly due to the extension and improvement of irrigation areas (Chapter 10 and 11) and partly due to the extension of the agricultural land. Within 16 years, the area on which rice is grown has almost doubled and the surface area for maize has even quadrupled.
- The general relationship shown in Fig. 8.2. for Mali as a whole differs per climate zone. The rainfall in the northern regions of Tombouctou or Gao is only a quarter of the rainfall in a southern region such as Sikasso (Fig. 2.4). Moreover, the lower the average rainfall, the larger the annual variation. Thus, the cereal production in the southern half of Mali fluctuates less than in the semi-arid half of Mali.

CPS-MDR (2001) gives the annual cereal production separately per region and this offers the opportunity to analyse whether the variable climate has a larger impact on the cereal production in the semi-arid regions than in the southern Sahel zone. Fig. 8.3 compares the effect of rainfall on the production for the region of Tombouctou, Mopti and Ségou. The

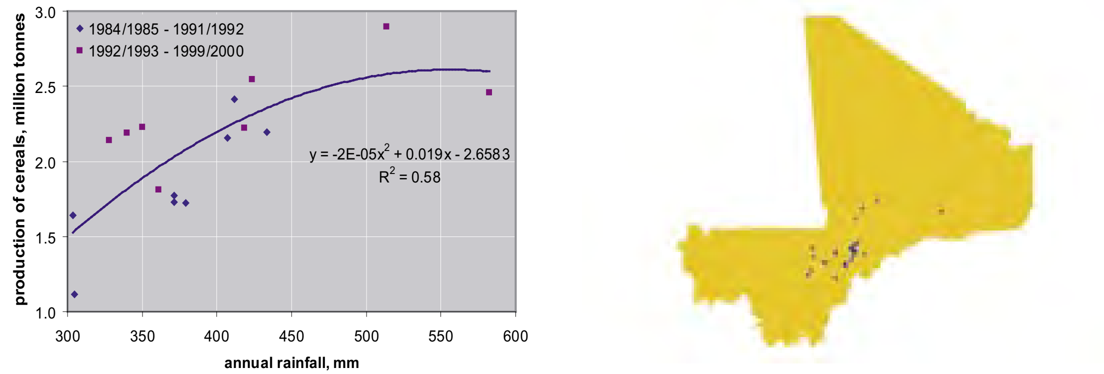


Fig. 8.2. Total annual cereal production in Mali (same data as Fig. 8.1) as a function of the annual rainfall. Source: CPS-MDR (2001). The inset figure shows the 28 meteorological stations that were used for the calculation of the annual rainfall. Sources: IER, ORS, ORM, etc.

average production is low in the dry Tombouctou region and high in the relatively humid region of Ségou. In all three regions rain has a large effect on the production. If rainfall is low, the production in Ségou goes down from 0.8 to 0.4 million ton and also in Mopti it halves from 0.4 to 0.2 million. The effect is most pronounced in Tombouctou where the production decreases from 0.1 million to nearly zero. The production in the three regions is not fully determined by the rainfall. There are irrigated areas in the region of Tombouctou (box 3.1) and a large part of the cereals produced in Ségou comes from the 740 km^2 of irrigated land in the Delta Mort (Chapter 11). The farmers in the Inner Delta may have a high production, even with less rainfall, as long as their land has been well flooded.

DRAMR (Direction régionale de l'appui au monde rural) distinguishes for the region of Tombouctou the production of millet and sorghum grown on floodplains during the décrue and in areas outside the floodplains. During the last five years, the production of millet on the floodplains (*mil de décrue*) varied between 7,100 and 9,500 tons. In the same years the production on the areas outside the floodplains (*mil pluvial*) was 11,400 – 32,800 tons. Growing millet in the décrue zone gives more security (yield: 297 – 529 kg/ha) than outside the

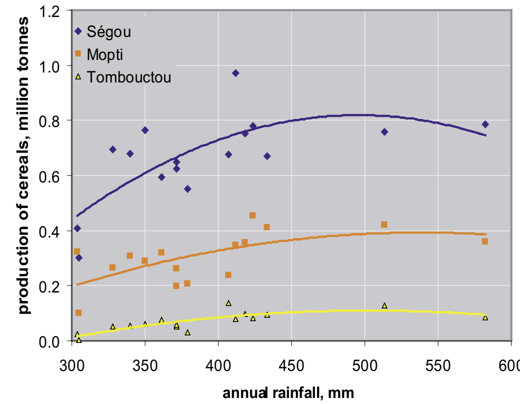


Fig. 8.3. The total annual cereal production in the regions of Ségou, Mopti and Tombouctou as a function of the annual rainfall in the Sahel zone (same data as Fig. 8.2). Source: CPS-MDR (2001).

floodplain (107 – 436 kg/ha). The annual production of 4,500 tons of millet in the décrue zone shrinks into insignificance, however, beside the total average production of 220,000 tons of millet in the regions of Tombouctou and Mopti. Of the 258,000 tons of sorghum produced in 2001/02 in the region of Mopti, 177,000 tons came from the cercles of Bandiagara, Bankass, Douentza and Koro, thus from outside the Inner Delta and this was the same for sorghum: 21,000 of the 32,000.

The main conclusion from this Section is that rainfall has a large impact on the rural economy of Mali and that is still nowadays the case, despite the fact that an increasing part of the cereals are produced in irrigated areas. The next Sections will focus on the agricultural production of the floodplains. A part of millet and sorghum is grown during the *décrue* on the exposed floodplains, but since most of these crops are from outside the actual floodplains, we will restrict our analysis to the rice production.

8.3 Constraints in rice production

Farming is not easy in the Inner Delta and that is certainly true for rice farming. Experience is required to make it a success. This was clearly shown by Maïga et al. (2002) who found that within a same area, the traditional riziculteurs, the rice farmers being Rimaïbe, Chérif or Marka, always achieved a higher rice production per ha than the agro-fishermen (Bozo and Somono) and a much higher yield than the agro-pastoralists (Peul).

The farmers on the floodplain grow a West-African rice variety *Oryza glaberrima*, known as *riz flottant* or floating rice, which is well adapted to grow upwards with the rising water during the *crue*. However, ideally the seed should have been germinated before the flood arrives. That means that the farmers have to sow the rice grains before the first rainfall, in the hope that the rain comes before the flood and the rice has sprouted

Riz flottant

Riz sauvage

before the flood arrives. With the flood the depth of the water column increases by several cm a day. Rice plants are able to grow 3-4 cm a day following the *crue*. The stems may be as long as 5 metres, but usually they are about 2 metres long. After a flooding period of about 3 months, the rice can be harvested during the *décrue*. A lot can go wrong in such a system:

- If there is no rain before the flood covers the floodplains, the seed has had no time to germinate before the area is covered by water.
- If there has been sufficient rain to sprout, the rice still needs water. That is why the flood must arrive not later than a fortnight after the last rains.
- If the timing and the amount of rain has been good, but the flood is low, the rice plant will grow, but the yield will be low due to the short growing season. A minimal flooding of 3 months is required.
- If there has been enough rain, but the flood is higher than expected, the production is lowered too. The optimal water depth is about 2 metres.
- Even if the growing of rice has been successful, the ripening grains must be protected later on against seed-eating birds, known -with reason- as '*mange-mille*'.

The annual peak flood level varies in the Inner Delta by about 230 cm on the gauge of Akka (Fig. 8.4). During the Great Drought the average peak level was 360 cm, while it was 580 cm during the long series of humid years before 1967. Given an optimal water depth of 2 m, rice should have been planted ideally at a level of 160 cm during the Great Drought and at 380 cm in the 1950s. Maybe more important than the depth of the water column is the duration of flooding. For each year, we calculated the water level at which an area is immersed for 3 months. As shown in Fig. 8.4, this level also varies annually, depending on the maximum water level. The level at an immersion of three months, x_{3month}, is a function of the maximum water level, y_{max} (both in cm Akka):

$$x^3_{month} = 1.0625\, y_{max} - 108 \qquad \textbf{8.1}$$

$$R^2 = 0.9225$$

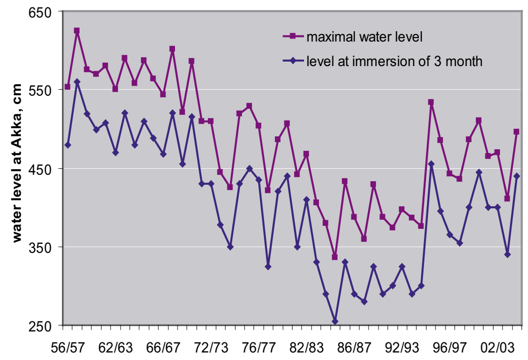


Fig. 8.4. The maximum water level in Akka and the water level at which the area is covered by water for 3 months (25% of the year).

Equation 8.1 reveals that the minimal immersion time of rice is achieved if the water column is 85 cm deep at a peak water depth of 360 cm, decreasing to 71 cm at a peak level of 580 cm. That means that if farmers plant the rice in a zone being flooded by 1 - 2 m water, the flooding period is always long enough.

The farmers have to decide where they should plant their rice. Of course, they prefer to plant their rice on their own land being cultivated already for years. Nevertheless many farmers decided during the Great Drought to give up their traditional rice area and start to reclaim new ricefields lower down in the inundation zone. The people of Pora could indicate in the field precisely how, between 1973 and 1987, they successively removed nearly all flooded forests south of Kouakarou in an attempt to adapt themselves to the lower flood level. When the floods were higher again from 1994 onwards, they gradually moved back to the traditional ricefields. We heard the same stories from farmers elsewhere in the Inner Delta. Gallais (1967) already noted that the rice farmers are forced to be semi-nomadic due to the variation in flood levels. Of course the farmers cannot predict the flood level when they have to sow their rice. On the other hand, the flood level of the Inner Delta has shown over the last 80 years a long term fluctuation

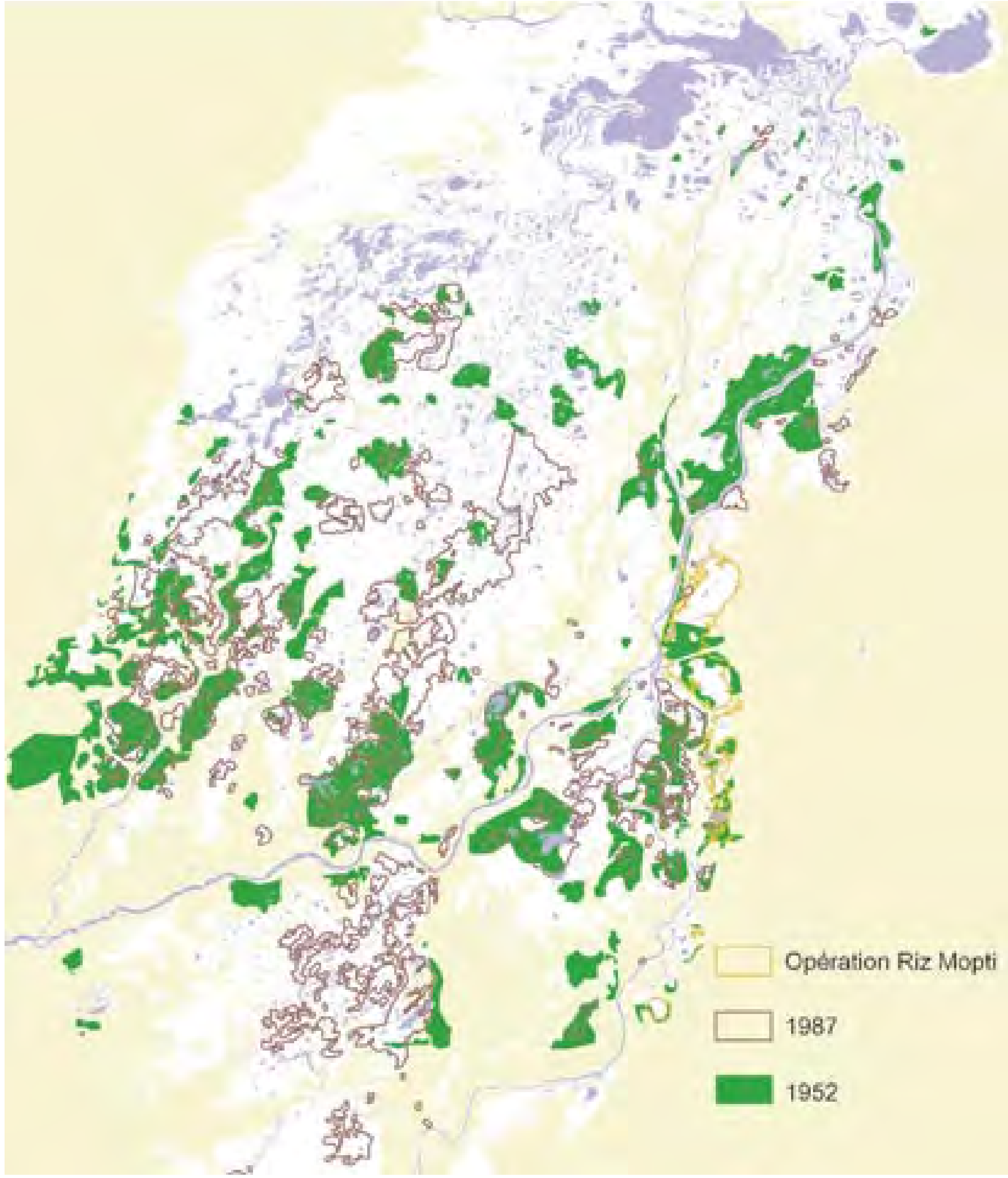


Fig. 8.5. The area with cultivated rice in 1952 and in 1987. The 'casiers' of Opération Riz Ségou (ORS) and Opération Riz Mopti (ORM) are indicated. Sources: topographical maps IGN for rice in 1952 and Marie(2000) for rice in 1987.

(Fig. 2.5, Fig. 8.4), so the flood levels during the previous 5 or 10 years may therefore serve as a guideline in their decision where to cultivate their rice. The digital flooding model (Chapter 3) gives the opportunity to quantify this afterwards.

Fig. 6.3 shows the distribution of cultivated rice across the Inner Delta. In combination with the digital flooding model, it was possible to indicate that in the season 2002/03 the ricefields were found at a level between 200 and 400 cm relative to the gauge of Akka. The average maximum water depth was 470 cm in the previous five years and since the ricefields in that period were situated in the same areas, we conclude that in the late 1990s, the average water depth in the rice fields was 178 cm when the flood was at its maximum level.

The distribution of ricefields is also known for 1952, when aerial photos were taken on which the topographical maps of IGN were based. The ricefields, such as indicated on topographical maps, were digitized and combined with the digital flooding model. The same was done with the data of Marie (2002) who gives a map of the ricefields in 1987. The ricefields in 1952 and 1987 are shown in Fig. 8.5. It is clear that the ricefields in 1952 were more on the fringe of the southern Delta and those of 1987 further inside. The elevation of the ricefields, relative to the gauge of Akka, is given in Fig. 8.6. Most of the rice fields in 1952 were cultivated at a level of 230 – 360 cm and in 1987 at 310 – 410 cm. So, while the flood level was 220 cm lower, the farmers moved down about 80 cm. As a consequence, the rice was covered with much less water in 1986 than in 1952. Fig. 8.7 converts the data from fig. 8.6 to show the water depth on the ricefields. In 1987 the rice grew in 47 cm of water and the flood did not cover a quarter of the ricefields at all. In 1952 and 2003 rice was covered by 178 and 149 cm (median values).

After a series of five low floods why did the farmers not grow their rice in the 1980s further down in the inundation zone? Several answers can be given:

- The farmers remained optimistic and hoped that the flood would be better next year.

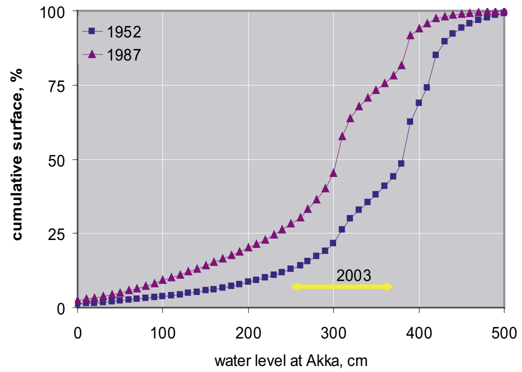


Fig. 8.6. The altitude (level relative to the gauge of Akka) at which rice has been cultivated in three different years, given as cumulative frequency distribution (1952 and 1987) or as range (2003). The frequency distribution of the depth is determined for the ricefields (Fig. 8.4 for 1952 and 1987 and Fig. 6.3 for 2003) using the digital flooding model (Chapter 3).

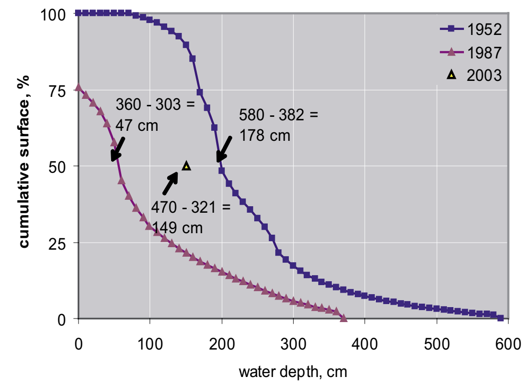


Fig. 8.7. The cumulative frequency distribution of the water depth in the ricefields in 1952 or 1987 (Fig.8.4), such as derived from Fig. 8.5, taking into account the water level, being 580 cm in the early 1950s, 360 cm in the mid 1980s and 470 cm in the years before 2003 (Fig. 8.6). The median water depth is indicated also for 2003 (Fig. 6.2).

- Although many farmers cultivated new ricefields, most remained to live in the same village (Marie 2000, Maïga *et al.* 2002). Their new fields were further from their village than the old ones, so the distance may have been a practical limitation in the choice of where to cultivate rice in a period of low floods.
- There was not enough suitable ground to be cultivated at a low flood. The digital flooding model (Chapter 3) was used to check whether this was indeed the case (Fig. 8.8).

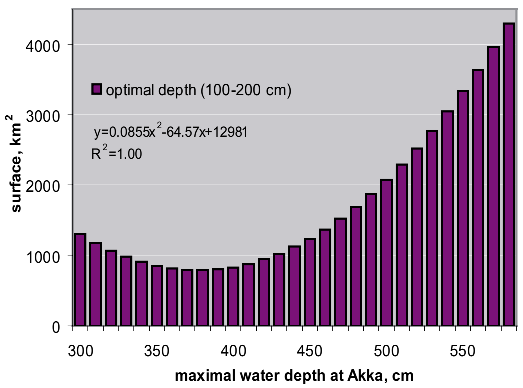


Fig. 8.8. The potential maximal surface area of cultivated rice zone, given a water depth of 100 to 200 cm, as a function of the maximal water depth in Akka. The calculation is based on the digital flooding model (Chapter 3).

Fig. 8.8 shows the surface area of the zone with a water depth of 100 to 200 cm as a function of the peak water level in Akka. At a water level of 580 cm, 4300 km^2 would be suitable for rice cultivations regarding the water depth. This decreases by 80% to 800 km^2 at a flood level of 360 cm. Marie (2002) already did the same kind of calculations and also concluded that there was a reduction in the potential rice habitat at a lower flood level. Marie (2002) also compared the total surface area of actual ricefields to the calculated surface area of the zone with an optimal water depth. His conclusion was that not all the habitat having an appropriate water depth is suitable for growing rice. Rice does not grow well, for instance, in sandy bottoms, being less fertile than clayish substrate. It is not without reason that the cultivated rice area is concentrated in the southern part of the Delta (Fig. 8.4), where the clay content of the substrate is rather high. Farmers in the Inner Delta do not use artificial fertilizers, so they depend on ground with a natural fertility. The digital flooding model should therefore be integrated with scattered information about soil (e.g. Makaske 1998) and nutrients (e.g. Orange 2002b) to show the absolute limitations to a further extension of the cultivated rice area given different flood levels.

The surface area of rice cultivation has increased during the last 80 years (Table 8.1). The figures in Table 8.1 are not fully comparable. The estimated surface area for 2003 is relatively low, since all bare areas within ricefields or areas being covered with grass, are not reckoned as ricefields. In contrast, these areas are included by Marie and on the IGN map. This presumably also explains why the estimate of Gallais (1967) for the same year is much lower. The trend is clear, however: the surface area of the ricefields has increased during the last 80 years. This increase may be explained by the increase of the human population (Marie 2002). In 1957, there were 78,000 rice farmers and, including women and children, 170,000 people depended on rice cultivation for a living. In 1987, the population had doubled to 340,000 and also the cultivated area was twice as large (Table 8.1). Hence, the area per person had remained the same at about a half ha per person. Since, on average, the yield has also remained constant during the last 50 years at about 1000 kg/ha (Gallais 1967; annual reports of DRAMR), the rice production per person, although varying from year to year, has also remained at a similar level.

Table 8.1. Six estimates of the surface area of land being cultivated for rice in the Inner Delta.

Year	Surface, km²	Source	Method
1920	160	Gallais 1967	Field visit
1935	645	Gallais 1967	Field visit
1952	790	Gallais 1967	Field visit
1952	<1648	IGN	Aerial photos
1987	1590	Marie 2002	Remote sensing
2003	>1040	This study	Remote sensing

Marie (2000, 2002) gives three other estimates for the cultivated rice area in the southwestern part of the Inner Delta: 596, 986 and 770 km^2 in 1952, 1975 and 1989 respectively. This suggests that during the Great Drought the increase in the surface area of rice cultivation has come to an end, or that there was even a temporary decrease.

Taking all information together, it is obvious that the rice farmers in the Inner Delta increasingly compete for good areas to grow rice. The lower flood levels in recent times only aggravate the situation. Marie (2002) and Moseley *et al.* (2002) both point to an important implication. If farmers start to grow rice lower in the inundation zone, they have to remove existing bourgou fields. Bourgou grows in deeper water than rice, so the rice farmers will remove the most shallow bourgou fields. As discussed in Chapter 7, bourgou is a highly productive plant, being essential for the survival of very large numbers of cows. This implies that farmers growing rice and farmers raising cattle are in competition with each other and that this competition increases with a reduction of the flood level.

8.4 Annual rice production

Rice farmers in the Inner Delta produce on average 86,000 tons of rice, but there is a large variation from year to year (Fig. 8.9). The farmers themselves consume almost all the rice and only a small part is sold. Kuper & Maïga (2002), who did an extensive and excellent study on the trade of rice within the Inner Delta, concluded that in good years no more than 10% is traded and that this reduces to almost nothing in poor years. The study of Kuper & Maïga (2002) was partly based on the annual statistics obtained by the DRAMR in Mopti. Our analysis is also based upon the annual reports of DRAMR-Mopti since 1987, but also on the reports of DRAMR in Tombouctou. The analysis could be extended over a longer period because the Operation Riz Ségou (ORS) has published annual reports since 1970, in which all their essential rural statistics have been recorded. The annual reports of Operation Riz Mopti (ORM) appear since 1981.

Fig. 8.9 shows the annual variation in the production of rice in non-irrigated fields in three areas: the area managed by ORS and by ORM and the floodplains in the region of Mopti. DRAMR distinguishes areas where rice is grown in different ways (Table 8.2). Fig. 8.9 shows the annual variation for three of the eight categories given in Table 8.2; the three are printed in bold. Irrigated rice fields are excluded from the figure, since we are interested in the variation in rice production in relation to rainfall and flood level and both factors have hardly any or no effect on the rice production in actively irrigated fields. There are a few large irrigated areas in the region of Tombouctou, in total about 110 km^2. The production is substantial: 36,000 – 45,000 tonnes and also the yield is high with about 4000 kg/ha. In the region of Mopti, there are several small, irrigated areas near villages. The total surface area is altogether 16-27 km² with a total production of 6,000-16,000 tonnes and a yield of 5700 – 6000 kg/ha.

Unfortunately we do not have the complete data set of the rice cultivation on the floodplains of the region Tombouctou, so they are not included in Fig. 8.9 or in the further analysis. *Riz de bas fonds* is cultivated in the region of Tombouctou on 37 – 40 km²; production 900 – 1900 tonnes, giving a yield of 380 – 560 kg/ha. *Riz de décrue* is cultivated in the northern lakes on 85 –106 km²; production 7,600 – 13,000 tonnes and the yield is: 1300 – 1500 kg/ha.

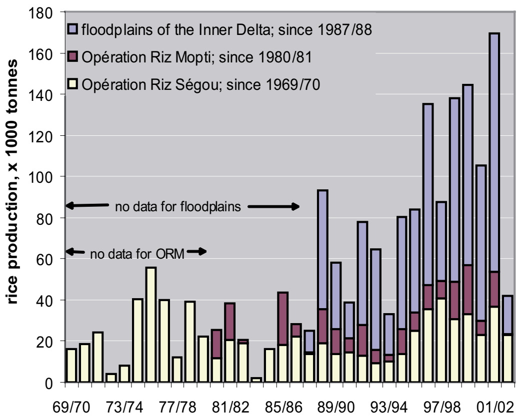


Fig. 8.9 The annual production of rice in the areas of ORS and ORM and on the floodplains (*'riz à submersion libre'*) in the region of Mopti. Sources: ORS, ORM, DRAMR.

The total production of non-irrigated ricefields in the Inner Delta fluctuates between 40,000 and 200,000 tons but, as could be expected, the production of the irrigated fields does not vary much and amounts to 40,000 to 60,000 tonnes. In the next three Sections, we analyse the rice production by ORS, ORM and the production of *riz à submersion libre* in the region of Mopti in relation to local rainfall and flood level.

Rice production by Opération Riz Ségou (ORS)

ORS manages three areas: Markala 53 km², Dioro 150 km² and Tamani 152 km², in total 354 km². It is situated along the Niger River east of the town of Ségou, in the cercles of Ségou and Baruéli (Fig. 8.5). There are over 200 villages in the area of ORS with 200,000 people. There is no active irrigation. There are dikes and sluices to delay the flooding, if necessary, and to manage the water level during the décrue. Hence it is a polder, a '*casier*', but the water management is passive. If the flood does not rise high enough, the area remains dry. That means that the agricultural production will only depend on local rain and the flood of the river.

The local rain is well registered. ORS measures the rainfall in 14 stations. We calculated the average of 6 stations with (almost) complete series since 1982; unfortunately no rainfall data are available for the years before. For flood level, we take the peak flood level of Mopti. Of course, Mopti is downstream of the ORS area, but given the close relationships between the peak flood levels measured at different places, the measurements of Mopti can be used as a good indicator of the annual flood level.

Table 8.2. The rice production (x 1000 tons) in three regions and in five types of ricefields. The given range refers to the minimum and maximum production during four seasons (1999/2000 – 2002/2003). Fig. 8.9 shows the annual production for three categories (bold printed). Source: DRAMR-Mopti and DRAMR-Tombouctou.

Region	Ségou	Mopti	Tombouctou
Irrigué, irrigated ricefields		6-16	36-45
Submersion controllée, polders of ORS and ORM	**23-37**	**1-24**	
Submersion libre, rice grown on the floodplains		**19-116**	5-10
riz de bas fonds, rice grown in depressions			1-2
riz de décrue, rice grown in immersed area (lakes)			8-13

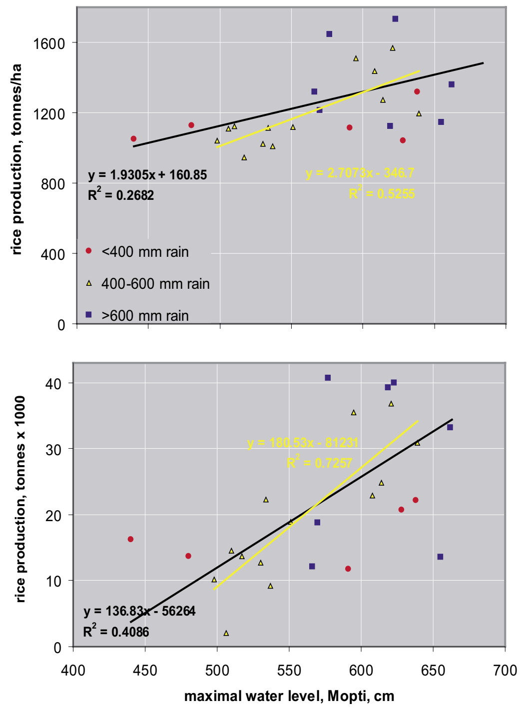


Fig. 8.10. The rice production in the area of ORS as a function of the flood level. Symbols with different colours indicate years with low, average and much rain. The function is given for all data (1974 – 2001) and for years with 400 – 600 mm of rain (data for 1982-2001). Source: ORS.

The total annual production during the last 35 years varied between 2,086 tonnes in 1984/85 and 55,718 tonnes in 1976/77 and amounted to an average 22,022 tonnes. Of the 350 km² available, on average 240 km² is annually cultivated for rice growing, of which 171 km² produces, on average, enough rice to be harvested. That means that, on average, the annual production in the cultivated rice area is 932 kg/ha (see Table 8.2).

The ORS-annual reports clearly show that the huge variation in production is caused by a highly variable part of the area with crop failure and also to a large variation in the yield of the area being harvested. The surface area being cultivated without any harvest varied between 5 and 82%. The average yield in the harvested area also varied per year, but less, between 945 kg/ha to 1750 kg/ha.

The variation in productivity is related to the flood level (Fig. 8.10). The black regression line shows the calculated relationship: the production increases by 137 tons if the peak water level goes up one cm. This function is based on all the data. When the data are split up for years with low rain (<400 mm) and much rain (>600 mm) and average conditions in between, it is clear that the production is always low if the rain is limited (see the purple dots in Fig. 8.10). All years with exceptionally high production have much rain, but there are also rainy years with a low production. When the years with low rain (<400 mm) and much rain (>600 mm) are taken apart, the flood levels still have a dominant effect on the production (see yellow line and yellow printed function).

There is still variation around the yellow regression line shown in Fig. 8.10, so there are, apart from flood level and rainfall, still other factors, such as the timing of the rainfall and the timing of the flooding that may influence the annual rice production. Another possible factor might be the variable amount of artificial fertilizer used. Until 1988 no or hardly any fertilizer was used in the area of ORS but since then there has been an exponential increase to 2145 tonnes in 2004. When the amount of fertilizer annually used is plotted against the deviation from the regression line, we found no relationship. Moreover, the average yield has not increased during the last 20 years. We conclude from this that rain explains a part of the observed huge variation in annual rice production in the ORS area, but that flooding is the major factor.

Table 8.3. Average surface area, yield and number of farmers in the rice areas managed by Opération Riz Ségou(ORS; 1973-2002) and Opération Riz Mopti (ORM; 1981-2002).

	ORS	ORM
Total surface, km^2	350	330
Cultivated area, km^2	240	183
Harvested area, km^2	171	85
Total production, tonnes	22,022	10,593
Yield cultivated area, kg/ha	921	616
Yield harvested area, kg/ha	1290	1079
Number of farmers	12,546	11,133

Rice production by Opération Riz Mopti (ORM)

The area managed by ORM has the same kind of infrastructure as the ORS. The farmers also depend on the peak level of the flood and the local rain. The *casiers* of ORM are in total about as large as those of ORS, but the cultivated rice area is smaller and the area with yield is even smaller still (Table 8.2). The annual variation in rainfall in the area has been measured since 1981 at 17 places. The average rainfall in the area can therefore be described precisely. Since the southern part of the ORM areas is situated along the Bani before it flows together with the Niger, we take as a measure of flooding the maximal water level of Sofara, along the Bani just upstream of the ORM.

In Fig. 8.11 the rice production in the ORM area is plotted against the flood level in Sofara. Again there is a very good fit. The data are split into two groups: years with less or with more than 400 mm annual rainfall. In all cases where rainfall has been more than average, the production was high with about 1200 tonnes. In all these years, however, the flood level was also high. When rainfall was less than average, the flood level has a very dominant effect on the production, varying between 0 and 1400 tonnes. The data from ORM thus confirm the conclusion drawn

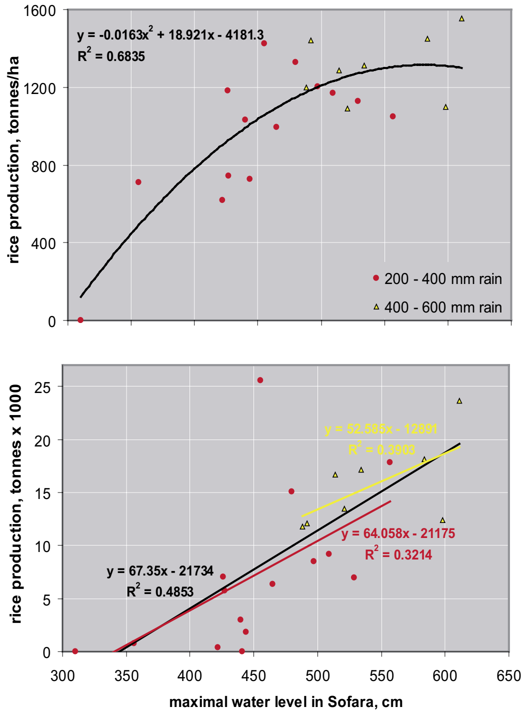


Fig. 8.11. The rice production in the area of ORM as a function of the flood level. The yellow and purple symbols and regression lines refer to years with more or less than 400 mm of rain since 1981. The function of all data (the black regression) is given for all data (1974 – 2001). Source: ORM.

for ORS that flooding is the major factor determining the rice production in the flooded *casiers*.

Rice production on the floodplains of the Inner Delta

The data of ORS and ORM concern the rice production within a limited area of 680 km^2. If the flood level is not sufficient to flow into this area, the rice harvest is very limited. One may argue that the farmers in the Inner Delta might do better, since they have more opportunities to move down to the lower inundation zone in years with reduced flood levels. According to the annual reports of DRAMR the area

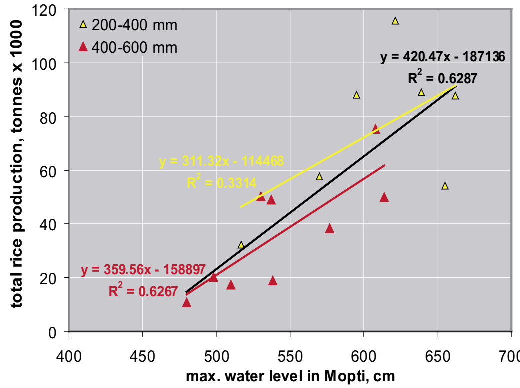
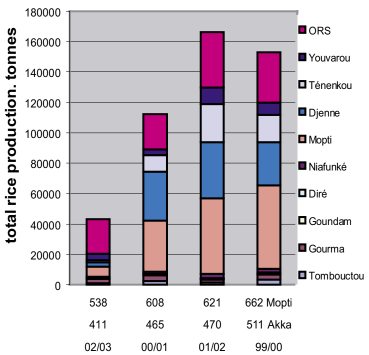


Fig. 8.12. The total rice production in the region of Mopti (excluding the area of ORM) as a function of the peak flood level in Mopti. Symbols with different colours indicate years with rain above and below the average. The function is given for all data (1985 – 2001), as well as for the two levels of rainfall. Source: DRAMR.

cultivated by rice farmers in the region of Mopti has gradually increased from 1000 km^2 to 1200 km^2 in recent years. The yield is highly variable and also in a good year not higher than about 1000 kg/ha. Fig. 8.12 shows the relationship between the total production with the flood level in Mopti. The data are split up for more or less than 400 mm rain, using the same data set as we already used for ORM. The picture is similar to Fig. 8.12. If there is less rain, the production decreases with 10-20,000 tonnes, but the impact of the flood level is much more pronounced. During a low flood the production is only 20,000 tonnes, but this increases to 60-120,000 tonnes at a high flood.

Rice production per cercle

It is obvious that the rice production decreases at lower flood levels. One may expect that this negative effect is maximal for ricefields found higher in the inundation zone. Since the ricefields in the cercles of Ténenkou, Djenné and Mopti are found at a higher level than the ricefields in Youvarou, the impact of



	HIGH	LOW	CHANGE
ORS	30958	22951	-26%
Youvarou	7625	4475	-41%
Ténenkou	18115	1175	-94%
Djenne	32444	3088	-90%
Mopti	46093	6312	-86%
Niafunké	2230	878	-61%
Diré	747	621	-17%
Goundam	189	45	-76%
Gourma	3160	3060	-3%
Tombouctou	2320	720	-69%

Fig. 8.13. The total rice production in four recent years with a different peak flood level in Mopti and Akka in the 9 cercles of the Inner Delta and in the ORS area. The table beside the figure compares the production of 2002/2003 (low flood) with the three foregoing years (high flood).

lower floods should also be different when cercles are compared. Fig. 8.13 shows the total production for ORS and the nine cercles of the Inner Delta during three years with a relatively high flood level and one with a low level. The rice production in the three years with a high flood did not differ much and also the share over the cercles and the ORS-area was about the same. When the flood is high, most rice in recent years is grown in the cercle of Mopti (inclusive the ORM-area), in Djenné and the ORS area. During the low flood of 2002-2003, the rice production was 70% lower than in the three years before, but the decrease was about 90% in Ténenkou, Djenné and Mopti. The farmers in Youvarou were, as expected, less affected.

8.5 Scenarios

The impact of flood level on the rice production in the area of ORS, ORM and on the floodplains is evident (Fig. 8.10 - 8.12). Hence the impact of the reduced flood levels due to Sélingué, Office de Niger and Fomi on the rice production may be quantified. The peak water level at Sofara or Mopti was used as a measure of the flood level in Fig. 8.10 - 8.12 , but we use the flood level in Akka as an indicator of the flood level in our scenarios. That is why the impact of the dams on the entire rice production in the Inner Delta (including ORM and ORS) has been related to Akka water level (Fig. 8.14). Due to a lack of data the figure only shows the rice production for the seasons 1987/88 tot 2002/03. Within those years the total annual

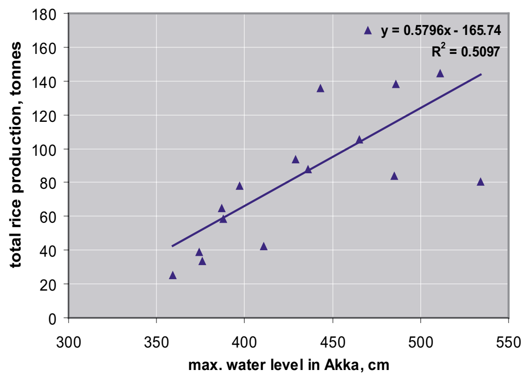


Fig. 8.14. The total rice production of ORS and the region de Mopti (including ORM) as a function of the peak flood level in Akka. Symbols with different colours indicate years with rain above and below the average. The function is given for all data combined as well as for the two levels of rainfall. Source: DRAMR, ORM and ORS.

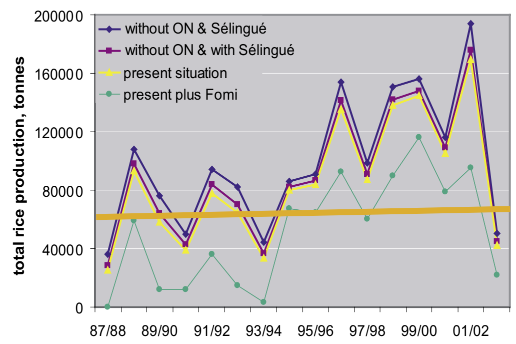


Fig. 8.15. The annual variation in the total rice production by ORS and in the region of Mopti (including ORM) in the present situation and in three other scenarios. The straight line shows the amount of rice needed to feed an increasing population of 750,000 persons in 1987 to 850,000 people in 2002 with 80 kg rice per person per year.

production varied between 10,600 and 115,700 tons. Fig8.14 gives the production of ORS, ORM and floodplains of Inner Delta combined

A multiple regression analysis was performed to see whether we could obtain one function in which the combined effect of rainfall and flood level could be shown. Rainfall was not significant. Also the relationships shown in Fig. 8.10 to 8.12 showed a (highly) significant effect of the flood level, but that rainfall had no significant effect.

Using the combined regression function of rice production against peak flood level in Akka (shown in black in Fig. 8.14), the effect of Sélingué, Office de Niger and Fomi can be indicated (Fig. 8.15). On average, the lower flood due to Sélingué causes a reduction in the rice production of 8900 tonnes or 10.4%. The impact of Office du Niger is larger: 4300 tonnes or 4.9%. Fomi would reduce the rice production with 34,500 tonnes or 40.1%. The effect differs depending on the total production. The following three equations for the three scenarios give the effect relative to the present situation.

scenario 2 > 0 (effect Sélingué +ON) +8788 + 0.051x **8.2**

scenario 2 > 1 (effect Sélingué) +3396 + 0.010x **8.3**

scenario 2 > 3 (effect Fomi) -18610 – 0.185x **8.4**

Chapter 13 will integrate the evident negative effect of the upstream infrastructures on the rice production on the floodplains. Two remarks can already be made. First, the 200,000 tonnes of rice produced since 1987 with irrigated river water in the area of Office de Niger, is only possible at the expense of a reduced flood level in the Inner Delta, by which the farmers face an annual loss of 4300 tons. This loss in the Inner Delta was equivalent to 5% of rice production of Office de Niger in the late 80ties. The rice production at Office de Niger has increased (Chapter 11), while the amount of water taken has remained at the same level (Chapter 2). That is why the loss of rice production in the Inner Delta due to Office de Niger has decreased to 1.8% relative to the recent production of Office de Niger. This changes the cost-benefit analysis, but this does not matter to the farmers in the Inner Delta.

The second remark is that the rice production in the Inner Delta is regularly insufficient to feed the local people. According to Randalph (1995) the people in Mali eat per person and per year 30 kg of rice and 120 to 150 kg of millet and sorghum. The people in the Inner Delta consume 80 kg rice and less millet and sorghum. The population in region of Mopti has increased between 1987 and 1998 from 570,000 to 630,000 people (Table 6.1). The ORS area is cultivated by 15,000 to 17,000 farmers, thus including their families, the rice they grow must be sufficient to feed 60,000 to 70,000 people. In total 200,000 people live in the ORS-area. Given an auto-consumption of 80 kg of rice for 760,000 - 840,000 people, this would result in an annual consumption of 61,000 to 67,000 tonnes. Since 1987, the actual production has been below this level in 4 out of the 16 years. This would have been 10 out of the 16 years, if the Fomi dam had reduced the flood level and hence the rice production.

8.6 Conclusions

- As in other Sahel countries, the annual rainfall has a dominant effect on the rural economy of Mali, especially in the drier part of the country. The production of millet, sorghum and rice decreases sharply if the annual rainfall in the Sahel zone decreases to below the 400 mm.
- The rice farmers in the Inner Delta are also dependent on rain in the weeks before the flood covers their ricefields, but the production is mainly determined by the flooding. The rice variety being used on the floodplains grows with the rising water and needs coverage by water for 3 months. Most rice is cultivated in areas being inundated by 1 – 2 metres.
- During the Great Drought, the flood level decreases by 2.2 metres. Farmers started to grow rice further down in the inundated area. On average, they moved down 80 cm, by which the inundation of rice decreased by, again on average, 140 cm. This is the main reason why the rice production falls during the periods of low floods.
- At low flood levels the farmers in the Delta did not move lower down in the inundation zone, because there was not sufficient area suitable for rice cultivation at such low water levels.

- The rice production in the area of Opération Riz Ségou, Opération Riz Mopti and on the floodplains of the Inner Delta varied from year to year. This variation could be attributed to flood level and to a lesser degree to rainfall. In total, the average production amounted to 83,000 tonnes, but at a low flood this reduced to 10,000 and if the flood is high to 80,000 to 120,000 tonnes.
- Since the rice production on the floodplain and in the flooded polders is strongly related to the peak flood level, the impact of the reduction of the water level due to the dams or irrigation can be reasonably well indicated. Due to Sélingué, the farmers produce, on average, 8900 tonnes,

or 10,4%, less. The irrigation of Office du Niger, lowers the rice production in the Inner Delta by 4300 tonnes, or 4.9%. The Fomi dam would have a very large impact: minus 34,500 tonnes or 40% of the present average production in the Inner Delta.

9 ECOLOGICAL VALUES OF THE INNER NIGER DELTA

Jan van der Kamp
Bouba Fofana
Eddy Wymenga

9.1 Introduction

Since time immemorial livestock dominates the floodplain of the Inner Niger Delta. Wild grazers like antelopes have virtually disappeared together with lions and elephants. The intensive human exploitation through fishing, grazing and the use of other natural resources leaves no room for these wild animals, though some hippos and manatees are still dwelling in the deeper parts of the Niger. Notwithstanding this loss of African wildlife and transformation of a natural floodplain, the Inner Niger Delta still can be considered as a hotspot of biodiversity in the Sahel. Its large concentrations of waterbirds and breeding colonies of herons and cormorants have been one of the main reasons for the Malian government to assign the entire Inner Niger Delta as International Important Wetland under the Ramsar Convention (on February 1st, 2004). With 4,1 million ha it is by now one of the largest Ramsar Sites in the world (www.ramsar.org).

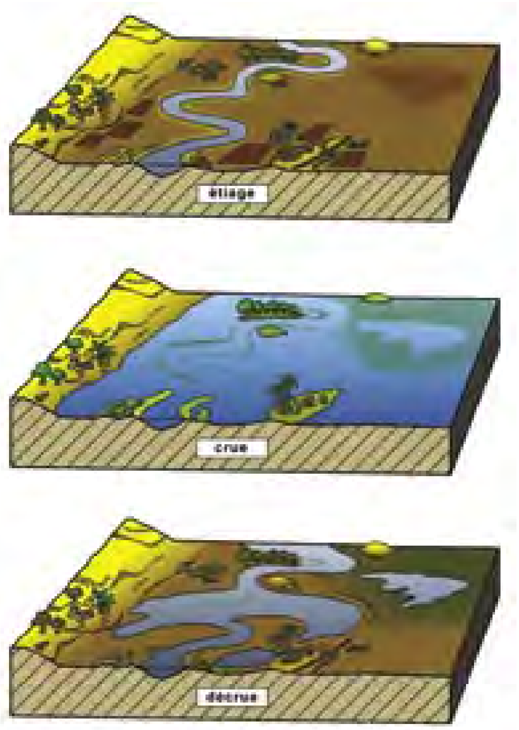
The few floodplains in the Sahel (Fig. 2.1) are renowned for their ecological values. These values are strongly related to the hydrological regime (Welcomme 1986, this study) and between floodplains show many similarities. In short we can recognise a flood-driven annual cycle of aquatic vegetations with species such as *Nymphaea* and *Utricularia ssp.* and floating 'meadows' with *Echinochloa stagnina, Vossia cuspidata* and *Oryza spp.*, a high fish biodiversity, dwindling populations of ungulates, reptiles and other fauna and, last but not least, a rich birdlife (cf. Lot 2004, Peeters 2003, Carmouze *et al.* 1983, Wymenga *et al.* 2002). It is remarkable also that since long flood forests have almost disappeared in Sahelian floodplains (Drijver & Marchand 1985).

In this Chapter we evaluate the ecological values of the Inner Niger Delta, focusing on the ornithological importance of the area (Section 9.2). In Section 9.3 we investigate if and how this value, in particular the size of water bird populations, is influenced by the flooding cycle and water levels. The poorly developed fauna (vertebrates other than avifauna) is dealt with in Section 9.4. Invertebrates are not taken into consideration: apart from a study on the benthic fauna in Lac Debo (Zwarts *et al.* 1999) the knowledge of other groups of organisms is limited (but see Dumont 1986 for zooplankton). Conclusions are drawn in Section 9.5. As background we first give a short view on the ecological aspects of a floodplain.

Floodplains as ecological environment

Sahelian floodplains form a rather extreme environment. In the Inner Delta the annual variation in water level amounts to 4-5 m and permanent water bodies are scarce. From June to November the Inner Delta changes from a near-desert environment during low water (étiage) into a vast wetland with few dry places at the height of the flood (crue) (Fig. 9.1). These extremes demand intricate adaptations of plants and animals or, alternatively, migration during periods of environmental stress. Flooding imposes significant environmental constraints to plants (non-motile!) and barely motile animals such as molluscs. During flooding this concerns in particular the hypoxic soil conditions and the low rate of dissolved oxygen in the water. Aquatic plants, helophytes and many fish species are highly adapted to these constraints (Keddy 2002). Especially in the Sahelian floodplains the hot dry season is another stress factor requiring survival strategies.

Adaptations to life in a floodplain are conspicuous in the Inner Niger Delta. Floating grasses like Bourgou *Echinochloa stagnina* and Wild Rice *Oryza longistaminata* start growing at the onset of the flood and have a growth rate of 3-5 cm a day, enough to keep up with the rising water level. Each plant community has an optimal position in the inundation zone, related to the duration of flooding (Chapter 6). The benthic



- Retreat of fish and other aquatic organism to the river bed
- Decomposition and mineralisation of manure and remaining biomass
- Concentration of Afrotropical waterbirds near remaining water bodies

- Flooding, annual variation in maximum
- Planting bourgou, also rice at limited scale
- Growth of bourgou and wild rice
- Spawning of fish and growth of fry on floodplain
- Colonisation of lower banks by molluscs
- Breeding of herons and other waterbirds
- Limited harvest of bourgou through cutting

- Fishing as soon as décrue sets in; at the end of the décrue fish concentrations heavily fished in remaining water bodies
- Grazing of bourgou pastures
- Concentration of birds, Palearctic birds migrate to northern breeding grounds

Fig. 9.1. Three stages in the flood cycle, respectively rise and peak of the flood (*crue*: July-November), retreat during December-April (*décrue*) and lowest water level in May-June (*étiage*) before the onset of the rainy season. In the box on the right an indication is given of major human activities and important ecological processes. Altered after Drijver & van Wetten (1994).

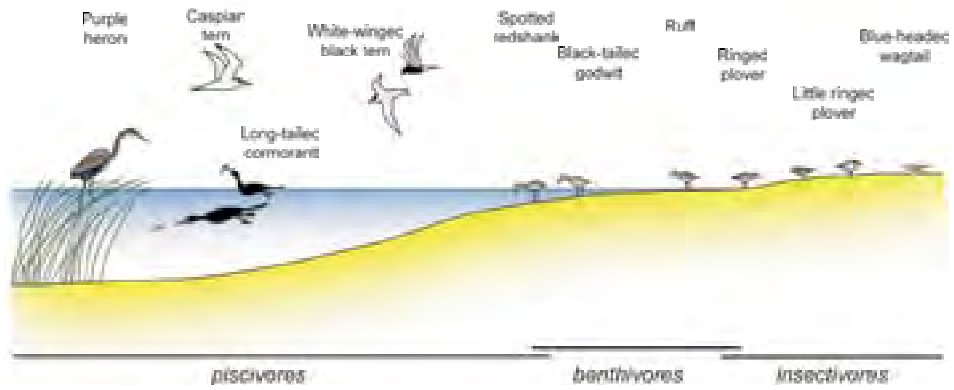


Fig. 9.2. Foraging habitat for birds in the central part of the Inner Delta (source: Wymenga *et al.* 2002).

fauna on the lowest banks of the floodplain mainly consists of three species of molluscs with a high biomass. They constitute an essential food resource for many waterbirds during the décrue. Despite the fact that nearly all molluscs are consumed by fish and birds, or die when the banks are exposed, their reproductive system enables them to recolonise the banks each year during flooding (Zwarts *et al.* 1999, van der Kamp *et al.* 2002a). Several fish species in the Niger river system are specifically adapted to the low rate of dissolved oxygen, in some cases through lung-like branchia or the ability to swallow oxygen on the surface. Their reproduction depends on the flood cycle: spawning occurs as soon as the delta is flooded (Welcomme 1986, Lévêque & Paugy 1999).

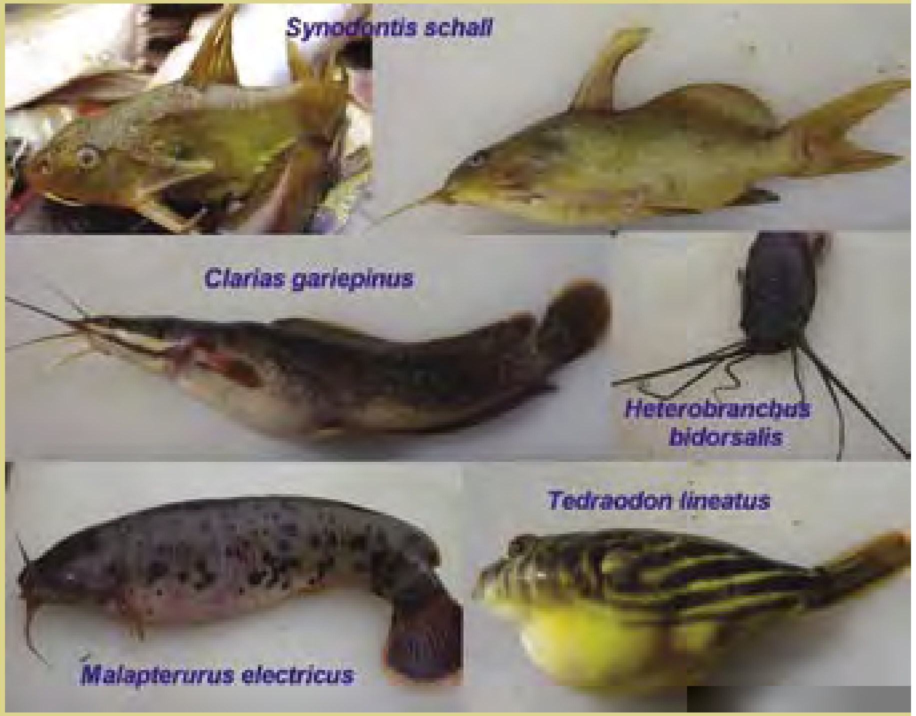
Flooding in the Inner Niger Delta is hardly hampered by dikes or other infrastructures, this in contrast to the Senegal Delta and the Logone floodplain (*cf.* Lot 2004, Scholte *et al.* 1996, Peeters 2003). The Inner Delta, however, can not be considered as a natural, unaffected ecosystem, as during the décrue the entire floodplain is intensively exploited through fishing and livestock grazing. Following the receding water the Inner Delta is invaded by herds of a few million domestic animals which graze on the exposed pastures. In Chapter 7 the total grazing pressure is calculated at 26 ton/km^2. The manure of these herds, which equals up to 12 kg N/ha (1 Live Standard Unit = 250 kg, which produces 912.5 kg dry matter with 1.28% N, from Masson *et al.* 2002) forms an important nutrient source in the system. This concerns the primary production (Arfi 2002a) as well as the floating meadows – *bourgoutières* – which are a key habitat in the floodplain-ecosystem. The habitat plays a basic role in the (nutrient) cycle of growth and grazing but also functions as a nursery for fish fry and as feeding habitat for piscivorous birds (Bacalbasa-Dobovrici 1971 cited in Welcomme 1986). This essential ecological role in the production of the floodplain makes clear that also the economical significance of bourgou should not be underestimated.

Another habitat - flood forests of *Acacia kirkii* – was once an important natural habitat in the Inner Delta (e.g. Guichard 1947) but since long has nearly vanished and been replaced by rice- or bourgou-fields. The few remaining forests are of paramount importance as roosting and breeding habitats for birds. Other important bird habitats are the low banks in the central Delta (Debo complex) with high densities of molluscs (Fig 9.2). Except for birds and fish, biodiversity in the Inner Delta is relatively modest as a consequence of the extreme environmental conditions, (over-)exploitation and - for large mammals

Box 9.1

Adapted to live in a floodplain environment

Many fish species in the Inner Niger Delta are adapted to live in a riverine floodplain environment with often low-oxygen and turbid water. One species – Protopterus annectens - can even survive a period of drought by retracting in a self made cocoon in the mud. Important morphological adaptations concern the way of oxygen intake (e.g. breathing from the surface), the development of small tentacles and electric organs (sensors) facilitating feeding and localisation. Electric organs also may be used for defence. For more information see: Quensière et al. (1994) and Lévêque & Paugy (1999).



- also exploitation in the past. Once a rich mammal fauna existed in the Inner Delta with gazelles and other ungulates. Today most of these species are on the verge of extinction (Kingdon 1997, Section 9.4). Therefore, this Chapter on ecological values concentrates mainly on birdlife.

9.2 Bird species, numbers and distribution

As a consequence of the available habitats the avifauna of the Inner Delta primarily consists of wetland species. In total 111 species of waterbirds (wetland-related species excluded) have been recorded by Van der Kamp *et al.* (2002b, 2005), of which 43 occur in small to large numbers and 68 have been observed rarely or irregularly during 1998-2004. The avifauna comprises species which are piscivorous (herons, cormorants, terns), benthivorous and omnivorous (waders, ibises) and insectivorous (some plover species, wagtails), besides a few seed-eating species (mainly ducks). This means, that waterbirds are involved in most links of the food web in the floodplain.

In this Section we show the huge international ornithological importance of the Inner Delta and the way the flooding cycle determines the availability of habitats and numbers of birds. The information is based on the monitoring of waterbirds during this study (van der Kamp *et al.* 2005) and the data gathered during 1998-2002 by Van der Kamp *et al.* (2002a-c). The regular monitoring concerns roost counts of colonial waterbirds and terrestrial counts of the concentrations of waterbirds in the central part of the Inner Delta. This census area – the Debo complex – covers 460 km^2 and comprises Lac Debo, Walado Debo and Lac Korientzé. This area was chosen because waterbirds from a large area tend to concentrate in this low-lying area during the décrue. Information from this area may act as a barometer for an important part of the Inner Delta.

This approach, however, does not cover the entire Delta and is in particular reliable for birds which are gregarious and do not conceal themselves in densely-vegetated habitats. Non-gregarious and diffusely distributed birds are easily underestimated. Therefore, from 2002 onwards additional density counts of birds were performed (Appendix 8; van der Kamp *et al.* 2005). An assessment of bird densities per vegetation type – by which units of homogeneous vegetation types are counted – gives the opportunity to determine the significance of different vegetation types and make an estimation of the total bird population in the Inner Delta. Although this method does not cover all birds or meets all constraints mentioned above, it is a systematic way to link these data to habitat availability.

9.2.1 Breeding waterbirds

Colonial waterbirds

Breeding colonies of large wading birds in the Inner Delta are situated in flood forests of *Acacia kirkii*, of which the impenetrable crowns and large needles provide excellent protection against predators, especially in combination with water underneath. In the last decades 13-17 species of large wading birds were found breeding in flood forest colonies (Table 9.1). In addition three other colonial species of waterbirds occur: Whiskered Tern *Chlidonias hybridus*, considered a non-breeding bird in West-Africa by Borrow & Demey (2001), is found breeding in the Debo area since 1991 in scattered colonies (200-250 pairs). Also a small colony of Little Tern *Sterna albifrons* is present (van der Kamp *et al.* 2002c). Finally, Abdim's Stork *Ciconia abdimii* is breeding in small colonies in trees in some villages around the Inner Delta.

Table 9.1. shows estimates of the number of breeding pairs of large wading birds in the Inner Delta. They breed in two large colonies which are located in the flood forests of Akkagoun and Dentaka, in the central part of the Inner Delta around Lac Debo (Fig 9.3; van der Kamp *et al.* 2002c). On initiative of the IUCN the colonies are being protected since 1987 in collaboration with the local people (IUCN 1989, Beintema *et al.* 2002). Despite this protection, frequent disturbance or exploitation takes place, in par-

Table 9.1. Estimated number of breeding pairs of colonial waterbirds in the Inner Niger Delta during four episodes in the last decades. The estimate of 1986-87 is based on Skinner et al. (1987). The figures for 1994/96 only cover Dentaka; this forest however represents the major part of the population in the Inner Delta. Source: van der Kamp et al. (2002c) complemented with recent provisional estimates. + = present but numbers unknown, ? = insufficient data for a reliable estimate.

Species		1986/1987	1994-96	1999/2001	2004/2005
Cattle Egret	*Bubulcus ibis*	63000 – 65000	65000 – 90000	50000 – 60000	50000
Long-tailed Cormorant	*Phalacrocorax africanus*	17000 – 17500	16000 – 17000	18000 – 20000	19000
Great Egret	*Egretta alba*	2800 – 3100	500 – 1000	1500 – 1800	700
Little Egret - white morph	*Egretta garzetta*	900 – 1000	500 – 1000	500-1000	1500
Little Egret - black morph	*Egretta garzetta*	80 – 110	+	80	50
Intermediate Egret	*Egretta intermedia*	800 – 875	>200	1700	200-300?
Squacco Heron	*Ardeola ralloides*	550 – 650	+	500	500
Black Heron	*Egretta ardesiaca*	200 – 250	150	130	<50
Black-crowned Night heron	*Nycticorax nycticorax*	1 – 10	100 – 300	1 – 10	<10
Grey Heron	*Ardea cinerea*	10 – 15	30 – 50	0	0
Black-headed Heron	*Ardea melanocephala*	10	1 – 5	2	<5
Purple Heron	*Ardea purpurea*	0	2 – 10	0	0
African Darter	*Anhinga rufa*	40 – 45	15 – 30	250 – 300	150
Sacred Ibis	*Threskiornis aethiopica*	30 – 40	50	200 – 250	<50?
Glossy Ibis	*Plegadis falcinellus*	0	150	0	0
African Spoonbill	*Platalea alba*	300 – 350	50	100 – 150	100-150
African Openbill	*Anastomus lamelligerus*	30 – 40	0 – 1	0	0

ticular in Akagoun. Besides Akkagoun and Dentaka only a few scattered fragments of forests are present (Fig. 9.3.), whilst formerly (1940-1950) more than 20 forest with breeding colonies existed (Skinner *et al.* 1987). These fragments now serve as essential roost sites for non-breeding and immature wading birds, which enables them to exploit the entire Inner Delta as a whole. Also, these sites are very important as favourable locations for potential forest regeneration (Beintema *et al.* 2002).

Large breeding colonies of Afrotropical waterbirds are very scarce in West-Africa. The colonies in the Inner Niger Delta are amongst the largest in the region. The colony in the forest of Dentaka is probably by far the largest in West-Africa if not the largest in Africa (*cf.* Turner 2000). According to Hafner (2002) exceptionally large-sized colonies seem to indicate a shortage of nesting possibilities, which in the case of the Inner Niger Delta is supported by the demise of forests (Fig. 9.3) and slightly declining numbers (Table 9.1).

To assess the ornithological significance of an area for waterbirds the criteria of the Ramsar Convention on International Important Wetlands can be used. When an area regularly holds >1% of a well-defined

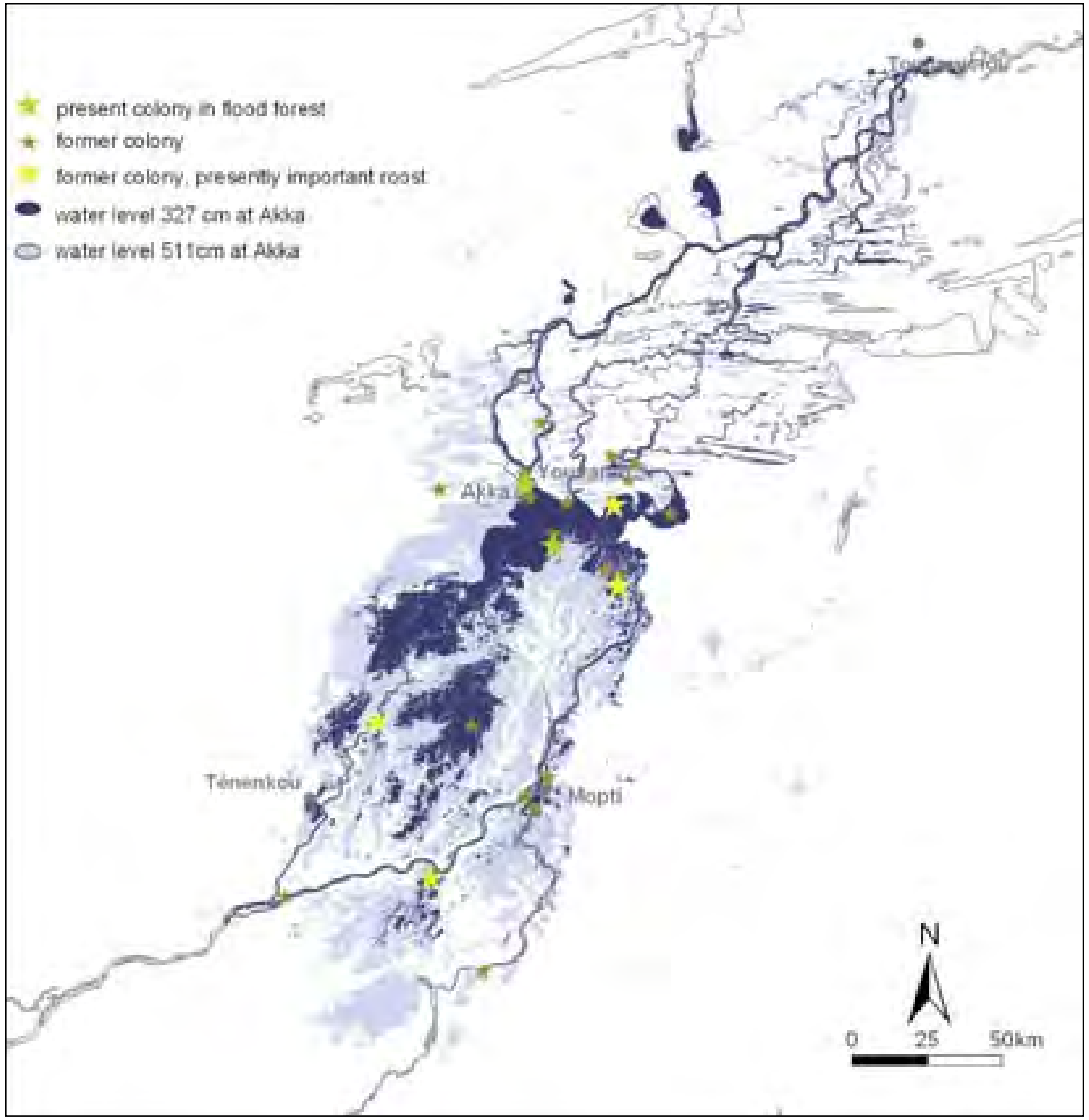


Fig. 9.3. Location of flood forests and breeding colonies in the Inner Delta in 2000-2004. At present two large breeding colonies exists in the (protected) flood forests of Akkagoun and Dentaka, whilst the other (fragments) of flood forests (resp. Pora, Niasso, Gourao, Bouna) are important roost sites for cormorants, herons and ibises (non-breeding adults, juveniles). Also former colony sites are shown (after Skinner et al. 1987).

flyway population of a species, this area is considered as internationally important (www.ramsar.org). Comparison with the 1%-criteria for total populations (Table 9.2) shows, that Cattle Egret, Long-tailed Cormorant *Phalacrocorax africanus*, Great Egret *Casmerodius alba*, Intermediate Egret *Egretta intermedia* and Little Egret *Egretta garzetta* easily exceed the 1%-criteria. For the Long-tailed Cormorant and the Cattle Egret the breeding numbers in the Inner Delta represent a large part of the breeding numbers in Sahelian floodplains. The colonies in the Inner Niger Delta therefore are of paramount international importance. The fact that only two large flood forests in the Inner Delta remain urges forest regeneration. Today this challenge is undertaken as a joint effort by Wetlands International and IUCN.

Other important breeding waterbirds

Within the Inner Delta a wide array of other Afrotropical waterbirds is breeding of which we only mention the most important species; for a full account we refer to Lamarche (1981) and additionally Wymenga *et al.* (2002). For a lot of waterbirds, other than colonial waterbirds, information on breeding is very scarce. For example, species like White-faced Whistling Duck *Dendrocygna viduata*, Spur-winged Goose *Plectropterus gambensis* and African Pygmy Goose *Nettapus auritus* are thought to reproduce in the Inner Delta, but hard data are lacking. During the dry season relatively high numbers of these birds concentrate in the Debo complex, but undoubtedly also breeding birds from a wider part of the Sahel are involved. At least for the Spur-winged Goose the Inner Delta seems a very important area, exceeding 9 times the 1%-criterium during the *étiage* in June (see Table 9.3).

Other groups of waterbirds with several species breeding in the Inner Delta are gallinules and jacanas (for example Lesser Moorhen *Gallinula angulata*, Allen's Gallinule *Porphyrio alleni*, Purple Swamphen *Porphyrio porphyrio*, African Jacana *Actophilornis africana*), Lesser Jacana *Microparra capensis* and waders (for example Senegal Thick-knee *Burhinus senegalensis*, Egyptian Plover *Pluvianus aegyptius*, Spur-winged Lapwing *Vanellus spinosus* and Kittlitz's Plover *Charadrius pecuarius*). The relative importance of these populations in the Inner Delta is unknown. The near-threatened Black-crowned Crane *Balearica pavonina* still breeds in the region of Toguéré-Koumbé. It concerns a small population of c. 25 pairs at maximum. Also in the Inner Delta this species suffers persecution as juveniles are collected and sold for keeping at home (Kone & Fofana 2001).

Black-crowned Crane

Besides waterbirds *sensu stricto* several typical African wetland species can be encountered such as some raptors (African Fish Eagle *Haliaeetus vocifer*, Black-shouldered Kite *Elanus caeruleus*), Marsh Owl *Asio capensis* and Pied Kingfisher *Ceryle rudis*. Passerines worth mentioning are Yellow-crowned Bishop *Euplectes afer* (frequent, typical wetland bird) and the Red-shouldered Widowbird *Euplectes axillaris*.

9.2.2. Staging and migrating waterbirds

Being one of the major floodplains in the Sahel, the Inner Niger Delta serves as a key staging and foraging area for Afrotropical waterbirds and Palearctic migrants throughout the year, the latter visiting the area during the non-breeding season. This function extends to all parts of the Inner Delta with (shallow) water and otherwise wet conditions. Quantitative information on the dynamics of staging waterbirds is available for the central part of the Inner Delta. In this Section we want to clarify the function of this key area and show how waterbird numbers depend on water level. Using density counts we also want to show the relative significance of various main habitats in the Inner Delta. The combined results are used to explain the international significance of the Inner Niger Delta.

Dynamics of waterbirds in the Debo area

The change of waterbird numbers in the central lake area, the Debo complex, reveals a cyclic pattern, for Afrotropical and Palearctic waterbirds, although these patterns are not synchronous (Fig. 9.4). The Palearctic waterbirds show a distinct peak just before the departure to the breeding grounds in the north. After the boreal breeding season there is a small peak in August but during the peak of the flood there are, compared to the maxima in February and March, hardly any Palearctic birds in the central part of the Inner Delta. The latter also applies to Afrotropical waterbirds, of which the pattern in the central part of the Inner Delta is complementary to the flood cycle.

Obviously these patterns are linked to the flood cycle as shown when the number of staging waterbirds is plotted as a function of the inundated surface (Fig. 9.5). At high water levels the low presence of staging waterbirds is simply a result of deep water (up to 4-5 m), unsuitable for feeding and resting. Caspian Terns *Sterna caspia* for example, enter the Debo complex as soon as the water level at Akka drops below 300 cm, i.e. when the first sand banks emerge

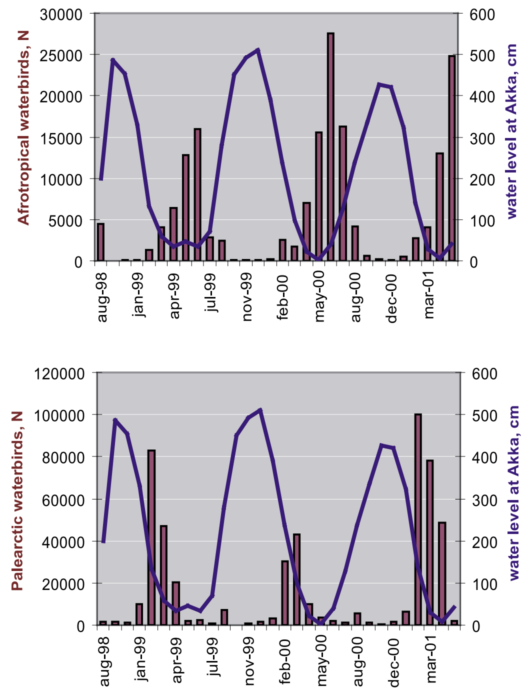


Fig. 9.4. Number of strict Palearctic and Afrotropical waterbirds in the central part of the Inner Delta (Lac Debo, Walado Debo, Lac Korientzé) from August 1998 to May 2001 (van der Kamp et al. 2002b). In both diagrams also the flood cycle is shown. Data from waterbirds of mixed population are not included (see Table 9.3).

on which they can rest when they not feeding.

The relationship between waterbird numbers and flood level explains also why waterbirds from a larger area concentrate in the Debo complex during the décrue. This contraction is caused by the limited surface of wet habitats in the Inner Delta at low water levels. Although the Debo complex comprises about 2% of the entire floodplain area, 70% of all water in the Inner Delta is found within this area at a water level of 0 cm, and it still covers about 20% as long as the water level is less than 300 cm (Fig. 9.6). Its low-lying position within the Inner Delta also explains why most waterbirds are found in the central lakes

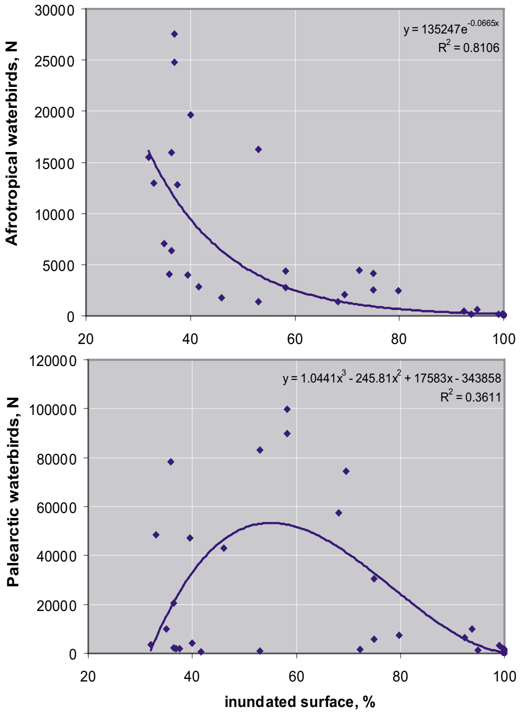


Fig. 9.5. Number of staging waterbirds in the central part of the Inner Delta (see Appendix 8 for delineation) as a function of the percentage of the area which is inundated. The area attracts massively waterbirds beneath a water level at Akka of 200 cm; the highest number of Afrotropical waterbirds is present during the '*étiage*' when the rest of the Inner Delta is nearly dry. Most Palearctic waterbirds have by then migrated to the breeding grounds.

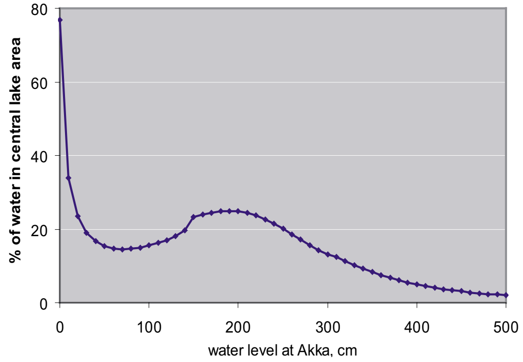


Fig. 9.6. Proportion (%) of the inundated surface area of the Inner Niger Delta found in the central part of the Inner Delta as a function of the water level at Akka. See Appendix 8 for delineation of the area.

when there is hardly any water remaining: when there is not much water left in the central lakes, there is *no* water elsewhere in the Inner Delta, beside the stagnant water in some permanent lakes (cf. Fig. 3.5). Since bird numbers are more or less stable at water levels below 200 cm (Akka gauge), this suggests that all waterbirds from the southern and central Delta concentrate in this area.

The availability of water, however, does not seem to be the only reason why the Debo complex attracts so many birds. While the presence of Afrotropical waterbirds fits nicely to the change in inundated surface (Fig. 9.5A), Palearctic waterbirds show a different pattern. They already tend to concentrate in this area – mostly at water levels from < 200 cm – when Afrotropical waterbirds are still at other wet places in the Inner Delta (or even a wider region) (Fig. 9.6).

A logical explanation would be, that feeding conditions in the area are above-average, as the presence of waterbirds in wetlands usually shows a strong relationship with available and exploitable food resources (e.g. Zwarts 1996, van Eerden 1997). If this were also true for the central lakes, it can only be tested when information is available on the relative distribution of food resources within the Inner Delta and the exploitability of these resources for birds. Unfortunately, this information is not available.

From the work of Zwarts *et al.* (2002), however, it can be deduced that the Debo complex is rich in food, in particular benthic fauna. This fauna consists mostly of two bivalves - *Corbicula fluminalis*, *Caelatura aegyptica* – and one snail *Cleopatra bulinoides*. Zwarts *et al.* showed, that the biomass of these bivalves is strongly related to the duration of flooding and the highest biomass is found below a height of 200 cm relative to the Akka-gauge. The benthic fauna is a principal food resource for waders, ibises and other waterbirds (Zwarts *et al.* 2002). As soon as the low banks around the lakes become exposed bivalves and snails are massively consumed, or die when flood recedes. This means that a vital population of benthic fauna only can survive when a part of the population survives the décrue and étiage in *permanent* water bodies, and the duration of flooding suffices to recolonise low banks after flooding. From the water maps in Fig. 3.5 it is clear, that within the Inner Delta the low-lying Debo complex is the only area of some scale where this is the case.

From the other principal food resource - fish - we have less information. During the décrue fish retreats from the floodplain to the river bed (Bénech *et al.* 1994). This evidently leads to high fish densities in the remaining water bodies, which are then heavily exploited by fishermen (Chapter 5) and also attract large concentrations of birds. In the next Section we show that also the presence of shallow bourgou – as a key foraging habitat for birds –contributes significantly to the function of the Debo complex.

Densities of waterbirds in different vegetation types

The preceding analysis gives an insight into the role of the Debo complex within the Inner Delta. It does not throw any light yet on the rest of the Inner Delta nor on the presence of dispersed species which occupy well-vegetated habitats. Hence, from 2002 onwards density-counts have been instigated, i.e. counts of all (water)birds in small sampling plots of known size. Up to 2004 613 plots have been sampled; the plots were not selected randomly but stratified according to habitat presence. In Appendix 8 technical details and results per species are presented (see also Van der Kamp *et al.* 2005). In this Section we use the data to analyse the relative significance and utilisation of main habitat types for waterbirds.

Waterbirds are not evenly distributed over the Inner Delta. We already showed that the Debo complex attracts a lot of birds, but also within other parts of the Inner Delta one type of habitat is much more favoured by birds than another. Though the explanatory factors probably are related to feeding conditions, in this study we only quantify the differences as a first step in analysing bird distribution. Using the results of Chapter 6, the vegetation types were lumped into 14 categories in which bird densities were assessed, which afterwards were joined to 6 habitat types.

Fig. 9.7 shows the mean density for four groups of waterbirds. It appears that overall density is very high in habitats with stagnant water (present in some northern lakes) whilst the density in wild rice is very low. Overall, waders and passerines reach the highest densities. For passerines, in particular the Palearctic Yellow Wagtail *Motacilla flava* and Sedge Warbler *Acrocephalus schoenabaenus* contribute to these high densities (Appendix 8). The mean density per habitat, however, is not very illuminating since the variation in bird densities is large and mainly explained by water depth in the plots.

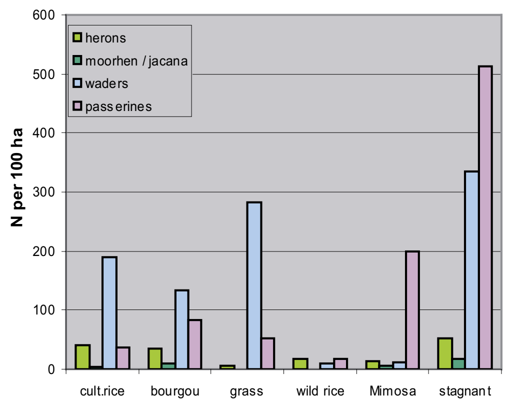


Fig. 9.7. Mean density (n per 100 ha) of groups of waterbirds in main vegetation types in the Inner Niger Delta. See Appendix 8 for details.

The water depth in each of the plots was routinely measured and with these data the mean bird densities can be calculated per water depth interval for each habitat type (Appendix 8). As an example, in Fig. 9.8 these data are presented for cultivated rice and bourgou fields respectively. It is obvious that dry and deep water habitat types are the least attractive, while habitats with humid and shallow conditions hold the highest densities. Also, there is a marked difference between cultivated rice and bourgou fields. In cultivated rice humid conditions have a high density, which is largely explained by foraging Cattle Egret *Bubulcus ibis* and Ruff *Philomachus pugnax*. In bourgou fields the shallows are more attractive. In particular bourgou with 40-80 cm of water is frequented by herons. Herons can forage in these habitats because they can walk on the floating stems. The buoyancy of bourgou is larger than, for instance, of wild rice, but feeding opportunities also depend on the compactness of the vegetation and the weight of the species involved. For instance, Squacco Herons *Ardeola ralloides* already start to feed in bourgou fields with a depth of 80 cm, while the heavier Great Egrets *Egretta alba* arrive when the water is less deep.

With the aid of the flooding model in Chapter 3 we can investigate the distribution of favourable combinations of habitats and water depths at different flood levels. In Appendix 8 the distribution of water depth–intervals per habitat type has been calculated for five different flood levels. Because cultivated rice can be found relatively high in the inundation zone, at a flood level of 250 cm (Akka), the rice stands dry already and thus is not attractive to waterbirds. At the same time, still a significant proportion of bourgou fields and wild rice is humid or has a shallow water depth. From Fig. 9.7 we know that wild rice has only very low bird densities. So at low flood levels (< 250 cm) the optimal foraging habitats for waterbirds are being represented by shallow bourgou fields and humid and shallow grasslands (cf. Table A8.2). This undoubtedly is related to favourable feeding conditions: the abundant benthic fauna in grasslands and probably a high fish density in shallow bourgou fields. If we keep in mind that at low flood levels

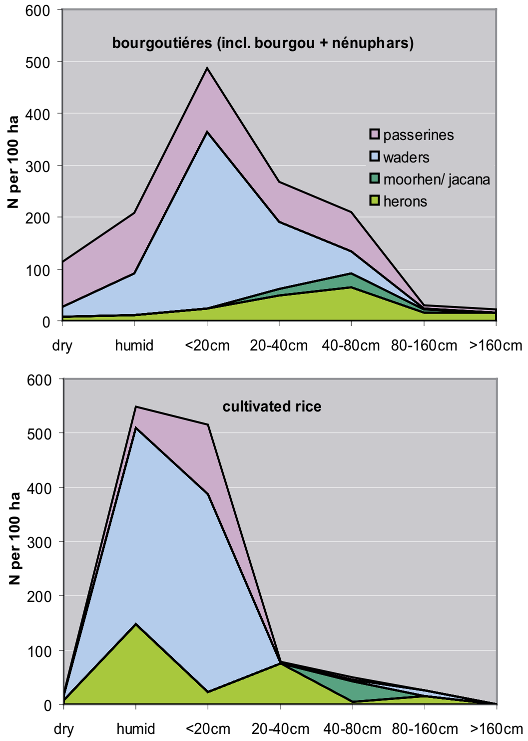


Fig. 9.8. Mean density (N per 100 ha) of groups of waterbirds in six different intervals of water depth in bourgou fields and cultivated rice in the Inner Niger Delta. See Appendix 8 for details.

(< 200 cm) extensive shallow bourgou and grasslands are only found around the central lakes (Chapter 6) and that vegetation types of stagnant water are confined to some northern lakes, it is all the more clear that the Debo complex plays a key role for waterbirds in the Inner Niger Delta.

An important question is how the birds react on the decreasing availability of suitable (=wet) habitats during the *décrue*. One would expect an increase in bird densities provided that no significant numbers of birds leave the area. Unfortunately, sample size up to now is too small. As an alternative to see whether densities increase, in Appendix 8 a comparison is made between the counted bird numbers in the

Table 9.2. Number of herons and waders counted in Lac Debo, Walado Debo and Lac Korientzé between November and March averaged over four years (460 km^2, 1998-1999 until 2001-2002) and split for five flood levels (Akka, cm). Numbers counted are compared to estimates derived from sampling plots. The two lower lines give the ratio between the number counted and the number derived from the samples. Summarised data from Table A8.4.

Flood level (cm)	**50**	**150**	**250**	**350**	**450**	**Average**
Herons						
Counted	22177	19673	13136	6858	1821	12733
Based on sampling	24749	41673	28574	42619	17054	30934
Waders						
Counted	56803	47757	24092	6265	192	27022
Based on sampling	97831	285366	49312	38579	2433	94704
Herons: ratio	0.90	0.47	0.46	0.16	0.11	0.41
Waders: ratio	0.58	0.17	0.49	0.16	0.08	0.29

Debo census area (460 km^2) and the estimates on the basis of plot counts. Table 9.2 summarises the figures for waders and herons. It is clear that there are (many) more birds in the area at lower flood levels, both in the actual counts and in figures based on sampling plots. As we used in the estimates the same densities for all flood levels, one may conclude that bird densities increase indeed as the available wetland habitats decrease. The variation in the ratio actual counts: estimates in Table 9.2 reveals, that there is still a large gap between both and more data are needed to arrive at sound estimates.

International ornithological importance of the Inner Delta

Through monthly counts during the period 1998-2001 and additional monitoring during vital moments in the year we obtained a good impression of the ornithological significance of the central lakes in the Inner Delta. We also know now that waterbirds congregated here during low water represent the major part of all waterbirds of the southern and central Delta.

In Table 9.3 the maximum number of a selection of waterbirds in the Inner Niger Delta is presented and compared to the 1%-criteria for International Important Wetlands (Ramsar Convention; Delaney & Scott 2002). No less than 28 species exceed this criterion while for 10 species more than 10% of the population can be present in this area. For species like Long-tailed Cormorant *Phalacrocorax africanus*, Glossy Ibis *Plegadis falcinellus*, Kittlitz's Plover *Charadrius pecuarius*, Gull-billed Tern *Sterna nilotica* and Caspian Tern *Sterna caspia* this part of the delta serves as a key area for a substantial part of the population. Also Purple Heron *Ardea purpurea* and Collared Pratincole *Glareola pratincola* concentrate in large numbers here, but it is not quite clear which criterion should be applied; probably for these species a mixed population of Palearctic and African origin is present. From Table 9.3 it can be concluded, that the Debo complex is of prime international importance for many waterbird populations.

To get an idea of the total population of wetland-related bird species present in the Inner Niger Delta in Appendix 8 mean bird densities are calculated in combination with the flooding model (Chapter 3) and the vegetation map (Chapter 6). Though a sound estimation on species level is still hampered by the small sample size (Table A8.3, details in Appendix 8), it is likely, that the Inner Delta harbours 3 to 4 million waterbirds including a number of wetland-related passerines. Despite shortcomings, the analysis shows that the Inner Delta is of huge importance to some species which are grossly underestimated in the regular monitoring activities. This applies

Table 9.3. Maxima of a selection of waterbirds in Lac Debo, Walado Debo and Lac Korientzé in the central part of the Inner Niger Delta in 1998-2004. Maximum numbers of Long-tailed Cormorant and African Darters are based on roost counts. Source: van der Kamp et al. (2002b, 2005). The figures are compared to the 1%-criterium as presented by Delany & Scott (2002; for Egretta alba/intermedia and Philomachus pugnax: Fishpool & Evans 2001, Circus aeruginosus: Hagemeijer & Blair 1997). The last column denotes the biogeographical population on which these criteria are based: Af = Africa, Subsah = Africa south of the Sahara, Eur = Europe, MerN = Black Sea, Med= Mediterranean; n north, e east, s south, o west, c central. In case of doubt two populations and criteria are mentioned.

Species	1%-criterion	Max. 1998-2004	x1% criterion	Refers to
Pelecanus onocrotalus	600	4300	7,2	Af-o
Phalacrocorax africanus	1.000	55867	55,9	Af-o/c
Anhinga rufa	250	641	2,6	Af-o/c
Ardea cinerea	2.200 - 2.700	5663	2,6 - 2,1	Eur – Méd-e/MerN
Ardea purpurea	(120) - 2.200	4171	(34,8) - 1,9	(Eur) – Méd-e/MerN
Egretta alba	3.000	5534	1,8	Subsah
Egretta alba / intermedia	1.500	6178	4,1	Subsah
Egretta ardesiaca	1.000	390	0,4	Subsah
Egretta intermedia	1.000	1501	1,5	Subsah
Egretta garzetta	3.500	10915	3,1	Subsah
Ardeola ralloides	3.000	1663	0,6	Subsah
Nycticorax nycticorax	1.200	4620	3,9	Eur-e/Méd-e/MerN
Mycteria ibis	750	210	0,3	Subsah
Leptoptilos crumeniferus	2.000	380	0,2	Subsah
Threskiornis aethiopica	3.300	1037	0,3	Subsah
Plegadis falcinellus	530	10651	20,1	MerN/Eur-so
Platalea alba	1.000	893	0,9	Subsah
Plectropterus gambensis	1.000	11457	11,5	Af-o
Alopochen aegyptiacus	180	590	3,3	Af-o
Nettapus auritus	100	101	1,0	Af-o
Balearica pavonina	150	32	0,2	Af-o
Porphyrio porphyrio	1.000	673	0,7	Subsah
Himantopus himantopus	770	2998	3,9	Eur-o/so
Pluvianus aegyptius	350	753	2,2	Af-o
Glareola pratincola	190 - 240	18310	96,4 - 76,3	Eur-so/Af-n - Eur-se/MerN
Glareola cinerea	100	11	0,1	Upper Niger, Mali
Vanellus spinosus	4.000	5732	1,4	Subsah
Charadrius hiaticula	2.100	4696	2,2	Eur-ne/Russia
Charadrius pecuarius	350	13676	39,1	Af-o
Charadrius marginatus	130	791	6,1	Af-o
Limosa limosa	1.700	26852	15,8	Eur-o
Tringa erythropus	1.000	4557	4,6	Siberia-o
Tringa nebularia	3.100	2513	0,8	Eur-n
*Gallinago media**	350	135	0,4	Scandinavia
Calidris minuta	2.000	31802	15,9	Eur-n/Russia-no
Calidris ferruginea	7.400	3754	0,5	Siberia-o
Philomachus pugnax	10.000	47281	4,7	Af-o
Chlidonias hybridus	260	3600	13,8	Eur-o/Méd-o/Af-no
Chlidonias leucopterus	20000	4009	0,2	Eur-c/e
Gelochelidon nilotica	130 - 270	3759	28,9 - 13,9	Eur-o/Af-o - Eur-e/MerN
Sterna caspia	65	3334	51,3	Eur
Sterna albifrons	340	345	1,0	Eur-o/Af-no
Circus aeruginosus	450	231	0,5	Eur

especially to widely dispersed species like Wood Sandpiper *Tringa glareola*, Yellow Wagtail *Motacilla flava* and Sedge Warbler *Acrocephalus schoenobaenus*.

When considering the ornithological importance of the Inner Delta, in addition to the above mentioned values the following remarks should be kept in mind:

- Beyond the Debo complex the Inner Delta has several other areas with large concentrations of birds (Girard & Thal 1999-2001, van der Kamp *et al.* 2002b). Basically these areas hold water at low water levels, in particular Plaine de Séri and the lakes in the north. However, the areas in the south can also hold large concentrations of birds, especially at the peak of the crue. For instance, van der Kamp *et al.* (2002c) counted 10,500 roosting Black-crowned Night Herons at the forest remnants of Pora and Koumbé-Niasso. In particular the northern lakes are important for waterbirds at the end of the décrue, because of the retention of water (Lac Horo and Lac Télé). Although we only carried out some terrestrial counts, Table 9.4 makes clear that this area holds internationally important waterbird numbers. This concerns species which are less numerous in the southern and central part of the Inner Delta: White-faced Whistling Duck *Dendrocygna viduata*, European Shoveler *Anas clypeata*, Ferruginous Duck *Aythya nyroca* and Common Moorhen *Gallinula chloropus*. The latter – an Afrotropical population – profits from the abundant aquatic vegetation developed in the wake of water retention. The northern lakes in the Inner Delta are a prime staging area for the endangered Ferruginous Duck, with a maximum of >14,000 individuals in 2001 (Trolliet 2003).
- The aerial surveys of Girard & Thal (1999-2001), which covered the entire Delta, are reliable for relatively large and easy recognisable birds. Their counts revealed huge numbers of Garganey *Anas querquedula*, White-faced Whistling Duck and Ruff *Philomachus pugnax*. This concerns hundreds of thousands of birds which apparently disperse over the Inner Delta. In particular during low floods the Inner Delta serves as a refuge for a large part of the waterbirds which frequent the Sahel. For instance in 1987 - a year with a low flood maximum - aerial surveys of the IUCN (1989) yielded almost 900,000 Garganeys and 180,000 Ruffs.
- The Delta is an important staging site for several rare species. For a full account we refer to Van der Kamp *et al.* (2002b). Worth mentioning are Black-crowned Crane *Balearica pavonina*, Ferruginous Duck, Pallid Harrier *Circus macrourus* and Great Snipe *Gallinago media*, all of which are near-threatened or vulnerable species according to the list of Threatened Birds of the World (Birdlife International 2000). At least the population of Ferruginous Duck may be of overriding importance for the preservation of these species (Trolliet 2003).

Table 9.4. Maximum number of a selection of waterbirds in Lac Télé, Fati and Horo in early March 2003. These data are compared with the 1%-criterium; further explanation see Table 9.3. Note the number of Ferruginous ducks *Aythya nyroca* which is a near-threatened species according to the list of Threatened birds of the World (Birdlife International 2000).

Species	1%-criterion	N March 2003	x1%-criterion	refers to
Nycticorax nycticorax	1.200	600	0,5	Eur-e/Méd-e/MerN
Plegadis falcinellus	530	750	1,4	MerN/Eur-so
Dendrocygna viduata	3800	4000	1,1	Af-o/c
Plectropterus gambensis	1.000	1300	1,3	Af-o
Anas querquedula	20000	8500	0,4	(Eur) - Méd-e/MerN
Aythya nyroca	530	1600	3,0	Subsah
Gallinula chloropus	10000	2265	0,2	Subsah
Chlidonias leucopterus	20000	2760	0,1	Eur-c/e

9.3 Explanatory factors on population level

The size of a population in general is determined by mortality and natality. Both key factors are determined by different environmental circumstances. Mortality of adult birds is a key factor in the population size of many waterbirds, as has been shown for instance by Hitchcock & Gratto-Trevor (1997). Hence, the environmental conditions in the Inner Niger Delta may play a role in determining the population size of waterbirds, depending largely on this area (e.g. Table 9.3). In this Section we show this relationship by linking variation in population sizes to maximum flood levels, the latter used as an overall indicator of feeding conditions. First we approach this question from the side of recruitment (some examples of Afrotropical birds), then from the side of mortality (examples of Palearctic birds).

Recruitment in relation to flood maxima

The reproductive success of a species depends partly on the availability of nesting sites (a key requirement in colonial waterbirds) but especially on the quality of the surrounding feeding habitats. Therefore it seems plausible that the breeding success of birds nesting in the Inner Delta is influenced by the inundated surface. These wet conditions not only refer to the maximum crue level, but also to the amount of rainfall, as in years with a high crue there is higher precipitation and vice versa (Fig. 2.6). The data of some Afrotropical species can be used to look for the suggested relationship. One of these is the Spur-winged Goose, of which the change in numbers in the Débo complex in June indeed are related with the inundated surface area during the preceding crue (Fig. 9.9). This, however, is an indirect relationship and we do not have information on reproductive success or on the extent of immigration from a wider region. On the other hand, a direct relationship can be shown for the Kittlitz's Plover. Fig. 9.10 shows the annual reproduction of this species as a function of the inundated surface area in the preceding breeding period. At least for this species natality is evidently determined by preceding flood performance and rainfall.

It is plausible that similar relationships exist for colonial waterbirds (cf. Hafner & Fasola 1992). Unfortunately, the data in table 9.1 are not suitable for such an analysis. However, we can use roost counts of African Darters performed in several years in January-February, directly following the breeding season and thus revealing the breeding performance for that particular year. The annual change of the population size of Darters indeed shows a relationship with the extent of the inundated area (Fig. 9.11). The year 2004 forms an outlier, probably because of considerable disturbance in the breeding colony resulting in a poor production and a drop in numbers. Disturbance or exploitation frequently occurs in the breeding colonies in the Inner Niger Delta. Scholte (in prep.) shows how colony protection was crucial in the recovery of the Black-headed Heron *Ardea melanocephala* in the partly rehabilitated Waza Logone floodplain. In the Inner Niger Delta the limited number of breeding sites in combination with the disturbance at these sites may have a significant impact on the population size of colonial waterbirds, and may therefore obscure a direct relation with flood performance (feeding conditions).

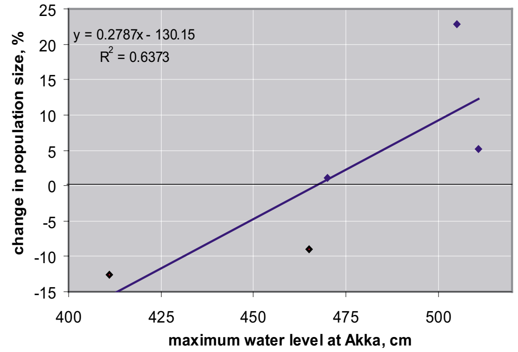


Fig. 9.9. Number of Spur-winged geese *Plectropterus gambensis* in June in the central part of the Inner Niger Delta in relation to crue maxium during the preceding flood. Data from 1998-2004.

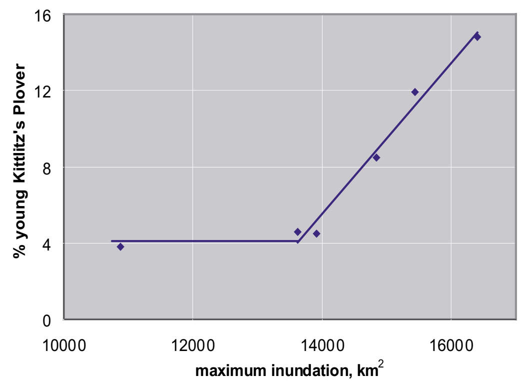


Fig. 9.10. Percentage of juvenile birds in June-concentrations of Kittlitz's Plover *Charadrius pecuarius* in the Debo complex, in relation to the flood maximum in the preceding breeding period. Data from 1999-2004.

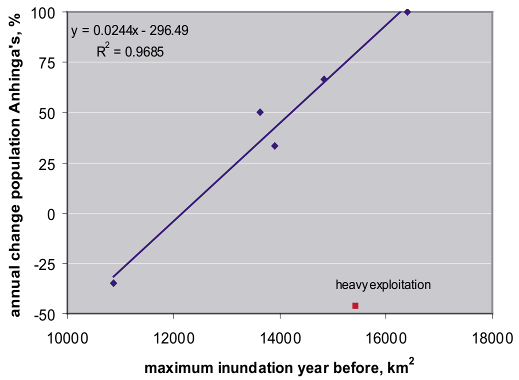


Fig. 9.11. Annual change of the size of the total population of the piscivorous African Darter *Anhinga rufa* in the central part of the Inner Niger Delta as a function of the maximal inundated area during the flood involved. Data from the floods of 1986-87, 1994-95, 1998-99 to 2003-04

Mortality in relation to flood maximum

Under natural circumstances mortality in a population predominantly occurs outside the breeding season, viz. in the Sahel in the dry and hot season. Actual mortality depends on various factors, but in general feeding conditions – availability and exploitability of food – play a major role. Additionally, in some cases, direct mortality also plays a part through heavy exploitation.

Assuming that feeding conditions in the Sahel are related to the amount of rainfall and the (maximum) flood level, it can be expected that Sahelian droughts cause a high mortality. Indeed, for a number of Palearctic migrant species a relationship between Sahelian rainfall, flood levels and population trends in the European breeding quarters have been recorded. Examples are Purple Heron (den Held 1981, Cavé 1983), Sand Martin *Riparia riparia* (Szép 1995) and several passerines (e.g. Wammes *et al.* 1993). In particular the Sahelian droughts of the 1970s and 1980s have caused serious declines in the population size of some migrant European birds species, although recuperation has occurred since (cf. Peach

et al. 1991 for *Acrocephalus schoenobaenus*, Marchant 1992 for trans-Saharan migrants, Baillie & Peach 1992 for *Sylvia communis*).

In the framework of a study in progress on the relationship between Sahelian rainfall, river discharge and population trends of migrating birds the data of the Sahelian floodplains will be analysed thoroughly. In the present report we confine ourselves to data gathered in the Inner Niger Delta, of which only for a few species long-term data are available. One of the migratory species which is present in relatively large numbers in the Inner Niger Delta (>50% of the known population, Table 9.3) is the Caspian Tern. It largely concerns the North-European breeding population, as evident from recoveries of ringed birds (Staav 2001, Wymenga *et al.* 2002). In Fig. 9.12 the annual change of the wintering population in the Debo complex is plotted against the maximum flood level. A relationship is indicated but for the lower range of flood levels we have limited data. However, it may signify higher mortality at low floods.

Apart from feeding conditions this higher mortality may also be partly explained by a higher exploitation, thus direct mortality through catches. At low floods the area with shallow water is limited and such locations are heavily exploited by local fishermen. Also, the birds are forced to concentrate in these spots, being the only sites where they can still feed. This results in higher densities and sometimes big concentrations, as shown in the previous Section. By tradition birds are caught with hook lines and nets (Kone *et al.* 2002), especially Caspian Terns with hook lines. Captured birds are either used for

auto-consumption or sold on the market. During three décrue seasons in 1998-2004 the commercial supply was monitored. When these figures are plotted against the maximum flood in the same year it seems that low flood levels correspond to higher levels of exploitation (Fig. 9.13). This is in line with the experience of local fishermen and observations on the Mopti market in years that exploitation was not quantified (pers. comment B. Kone, Wetlands International). The conclusion must be, that low flood levels force the waterbirds to concentrate in the few remaining spots in the Inner Delta. There they are confronted with heavy human competition for the same food resources (particularly fish) and increased risks of being caught. Lower flood levels therefore make waterbirds more vulnerable to human exploitation.

A last example of how low flood levels can cause higher mortality because of poor feeding conditions is presented in Fig. 9.14. It concerns Ruffs preparing for migration to the northern breeding grounds in February-March. Normally their weight increases strongly in the period January-March because of the storage of fat. In March 1985, one of the years of severe drought, more than 10.000 Ruffs were seen on the dry floodplains and even in villages, trying to get some food (Altenburg *et al.* 1986). A number of females was caught and Fig. 9.14 shows that their

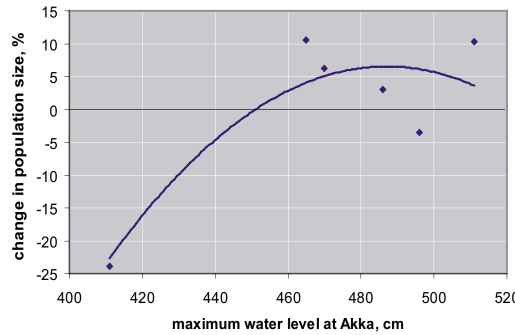


Fig. 9.12. Annual change in population size of the piscivorous Caspian Tern *Sterna caspia* in the Debo complex as a function of the maximal flood level during the flood peak. Data from the crues of 1986-87, 1994-95, 1998-99 to 2003-04.

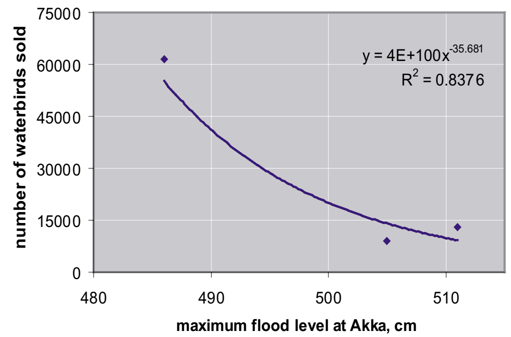


Fig. 9.13. Number of waterbirds sold at the main markets in the central Inner Niger Delta in three décrue-seasons (1998-1999, 1999-2000, 2003-2004) plotted against the maximum flood level. Note that the figure for the flood of 505 cm (2003-2004) is too low because of the limited number of markets which could be visited.

weight was far below the lean weight (lean weight = basic weight without fat). For these birds migration must have been out of the question and probably most of these birds died under these extreme conditions. It also suggests, that at very low floods the timing of migration of Palearctic waterbirds in relation to pre-migratory fattening and departure may fall out of line with the short time during which food resources are available in the Debo area. This makes them and probably other Paleactic migrants under similar stress vulnerable to lowering of flood levels.

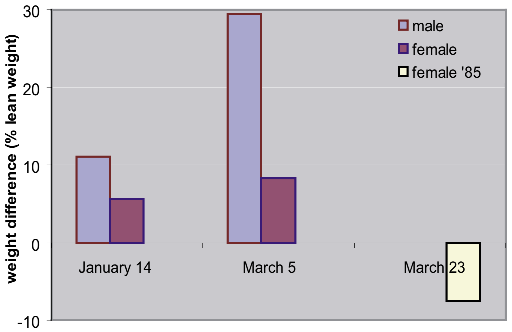


Fig. 9.14. Weights of Ruff *Philomachus pugnax* in the Inner Niger Delta, January 1989, March 2001 and March 1985, a record drought year. Weights expressed as the proportional difference compared with the corresponding lean weight, by which the percentage is an indication for fat storage (cf. Zwarts et al. 1990).

9.4 Other important ecological values

Apart from the rich birdlife in the Inner Niger Delta the floodplain also accommodates other important ecological values. In general, it must be stressed that the presence of natural floodplain habitats such as the *bourgoutières*, *oryzaies* and flood forests is of great ecological value. Though dominant plant species are not under threat, their habitats are under pressure in other Sahelian floodplains due to hydrological barriers such as dams and dikes. For instance in the Senegal Delta natural habitats are largely replaced by unnatural habitats and overgrown by invasive species like *Pistia stratiotes* and *Typha australis* (e.g. Peeters 2003).

Daget (1954), Lowe-McConnell (1985), Laë (1992, 2003) and Quensière (1994) already elaborated on the fish fauna in the Upper Niger Basin. In the entire Upper Basin 130 different species were found, but relatively few species are endemic because the Niger River in former times was linked to the Chad and Nile systems at various times (Lowe-McConnell 1985). Some of the known endemic fish species are *Syndodontis gobroni* and a cichlid, *Gobiocichla wonderi*.

Reptiles

The vast floodplain and river basin provide habitat for Nile Crocodile *Crocodylus niloticus*, Nile Monitor lizard *Varanus niloticus* and African Rock Python *Python sebae*. In the Inner Niger Delta the Nile Crocodile is on the edge of extinction. Nile Monitor lizard and python are facing heavy human pressure (Wymenga *et al.* 2002). Compared with protected areas in the Senegal Delta the density of Nile Monitors lizards in the Inner Delta is low (own observations, cf. Peeters 2003).

Mammals

A mixture of Sahelian species is present in the Inner Delta are (Kingdon 1997): Warthogs *Phacochoerus africanus*, Libyan Striped Weasel *Ictonyx libyca*, Side-striped Jackal *Canis adustus*, Patas Monkey *Erythrocebus patas*, Sand Fox *Vulpes pallida* and African Wild Cat *Felis silvestris* (AMD 1999, Happold 1987, Wymenga *et al.* 2002). Several species, still indicated by Kingdon (1997) for this region, seem to have vanished, but accurate information on the status of Clawless Otter *Aonyx capensis*, Spotted-neck Otter *Lutra maculicollis*, African Civet *Civetticutus civetta*, Caracal *Felis caracal*, Serval *Felis serval*, Striped Hyena *Hyaena hyaena* and Spotted Hyena *Crocuta crocuta* is not available. During intensive (terrestrial) field work from 1998-2004 none of these species was recorded. A small population of African Elephants *Loxodonta africana* still lives east of the Inner Delta; the animals migrate between Burkina Faso and south-eastern Mali (Shumway 1999).

Other mammal species are closely linked to wet habitats in the Inner Delta. Hippos *Hippopotamus amphibius* are present in the central and southern delta with an estimated population of 40-60 individuals (Wymenga *et al.* 2002). West African Manatees *Trichechus senegalensis* are still present but in very low numbers. Antelope populations have been seriously reduced by droughts in the past, bushmeat trade and competition with grazing livestock. Once Buffon's Kob *Kobus kob kob* was abundant in the Inner Delta, but is no longer present. This also seems the case for Roan Antelope *Hippotragus equinus*, Dorcas Gazelle *Gazella dorcas* and Dama Gazelle *Gazella dama*. Small populations of the Red-fronted Gazelle *Gazella rufifrons* are believed to be still present, though little information is available (Wymenga *et al.* 2002, Kingdon 1997).

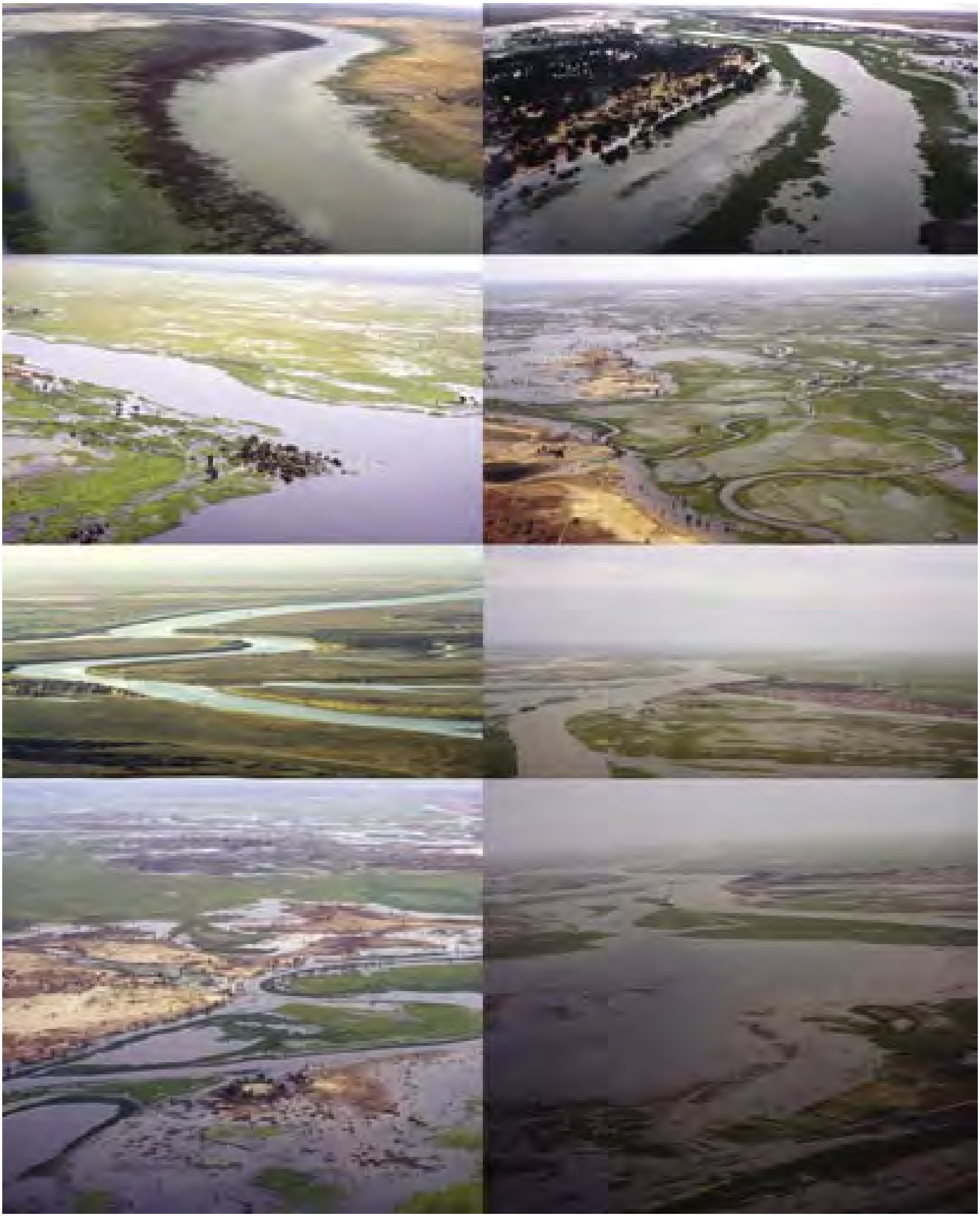
In general, it can be concluded that the populations of all larger mammal and reptile species have been greatly reduced by human population pressure, and the remaining populations are under threat. Low floods force wetland-related mammals and reptiles into the few remaining wet spots to survive. This makes them – and especially species like the West-African Manatee - very vulnerable to exploitation.

9.5 Conclusions

The evaluation of the ecological values of the Inner Niger Delta and the analysis of the impact of varying flood levels on these values can be summarised as follows:

- The Inner Niger Delta is a hotspot of biodiversity, with a rich fish- and birdlife, and modest populations of other species groups. Apart from fish and birds intensive human exploitation leaves little room for large African mammals and other terrestrial and aquatic wildlife
- The Delta accommodates two of the largest known breeding colonies of herons and cormorants in Africa and very large concentrations of staging Palearctic and Afrotropical waterbirds. According to density counts of waterbirds in various habitats the Inner Delta harbours 3 to 4 million waterbirds. For several waterbird species the Inner Delta serves as a key area for a substantial part of the population. The environmental conditions in the Inner Delta play a major role in determining population size of these waterbirds
- The central lakes in the Inner Delta – the Debo complex – play a key role in the ornithological value of the Inner Delta. This low-lying area not only offers humid and shallow habitats during low floods when nearly the entire Delta is dry, but also has good feeding conditions for waterbirds in the form of shallow bourgou fields and grasslands with a high biomass of benthic fauna
- The (maximum) flood level in the Inner Niger Delta is one of the qualifying factors which determines recruitment and mortality in Afrotropical and Palearctic waterbird population
- At lower flood levels waterbirds, and other species groups like aquatic living mammals and reptiles, are forced to concentrate at the few remaining wet spots in the Inner Delta, which leads to high feeding densities, large concentrations and competition with local people. Under such circumstances waterbirds and other fauna are susceptible to human exploitation. It can be concluded that in the present situation, especially during low floods, the ecological values of the Inner Delta are at stake.

African Fish Eagle



10
SÉLINGUÉ RESERVOIR

Jan van der Kamp
Leo Zwarts
Bakary Kone

10.1 Introduction

The construction of the Sélingué reservoir must have had a huge impact on the local people, just as everywhere else in the world where artificial lakes have been constructed. Due to the Sélingué dam, 13,500 people from 30 villages lost their houses, their traditional grazing grounds, orchards and land on which many generations have grown their millet or sorghum. Everything was covered by several metres of water, including the graves of their ancestors. Even if the government provides financial compensation, does that make up for these losses? On the other hand, a reservoir often creates new possibilities to make a living. The people from the Sankarani valley being affected directly by the Sélingué reservoir were compensated, for instance, by the construction of an irrigation system.

In this Chapter we will try to give a concise profile of the Sélingué reservoir, its environment and people. The area and its management is described in Section 10.2, fisheries and agriculture in Section 10.3 and ecological values in Section 10.4. The conclusion in Section 10.5 summarises the documentation.

10.2 The area

Situation and setting

The Sélingué reservoir is situated in the Sankarani valley, 150 km south of Bamako, within the *cercle of Yanfolila*, in the region of Sikasso (Fig. 10.1). The reservoir has the shape of a fork, since the dam has been constructed downstream at the place where the Wassoulou-Balé flows into the Sankarani River. The average water depth is 5.3 metres. However, the water level in the reservoir varies seasonally each year up to 3 m above and below this average (Fig. 2.10 in Chapter 2). Due to the seasonal fluctuation in water level, the surface area also varies. At the highest water level, the reservoir is 80 km long and 3 to 8 kms wide. Satellite images clearly show the continuous change in the shape of the lake (Fig. 10.1).

After its creation the Sélingué-reservoir, also known as Lac Sélinkegny, was managed by the Autorité du Barrage de Sélingué, and later by the Office d'Exploitation des Ressources Hydrauliques du Haut Niger (OERHN). In 1989, the production of hydropower was transferred to the Direction Nationale de l'Energie du Mali (EDM), but for the rest OERHN remained responsible. In 1994 OERHN was changed into *Office de Développement Rural de Sélingué* (ODRS), a department of the Ministère du Développement Rural. The annual reports of ODRS contain a lot of detailed information about fisheries, agriculture, etc. This Chapter is largely based on this source of information and on Haidara (2003) and PAPIM/ODRS (2003).

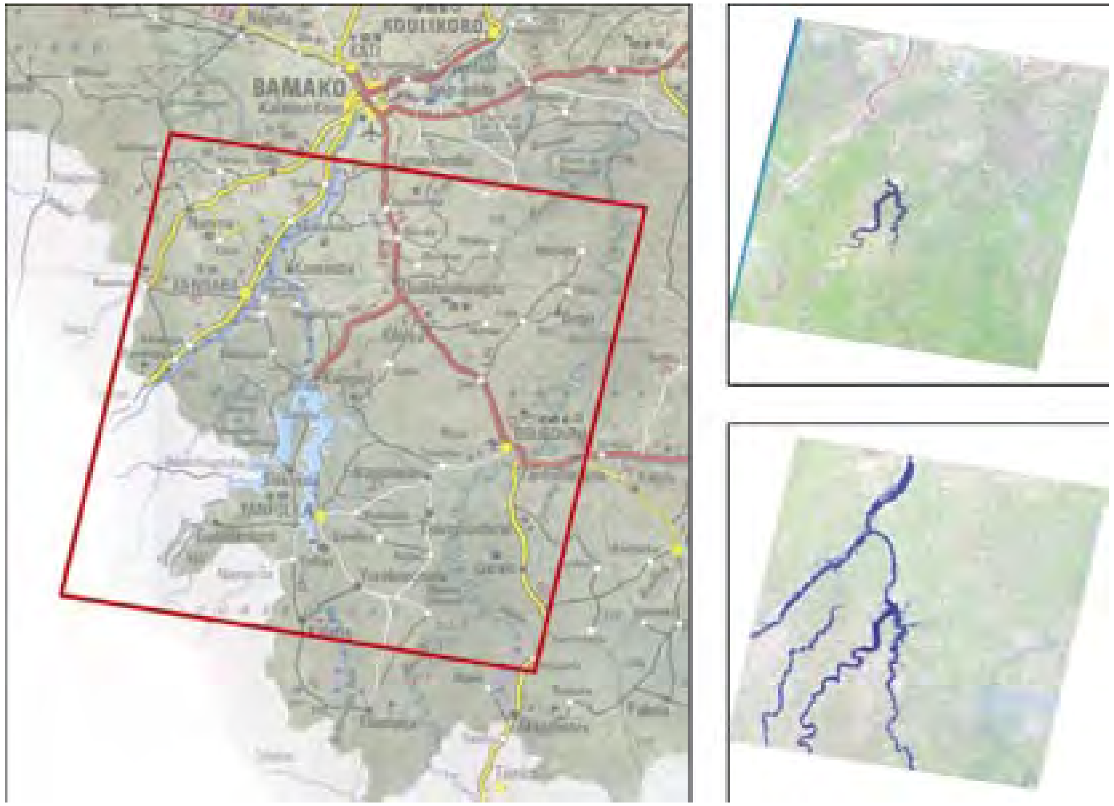


Fig. 10.1. The shape of Lac Sélinkegny at a water level of 343 m (above: the satellite image of 5 June 2000) and 349 m (below; image of 12 September 2001). The area covered by the image (180 x 180 km) is indicated on the map (left).

People

The Sélingué zone is an agricultural and fisheries region since it is situated in the Guinean climate belt, with abundant rainfall (1100-1200 mm) and several water courses in the area. Since the construction of the Sélingué dam, creating *Lac Sélingué*, the resident Wassoulou population consisting of Peul people has increased considerably, with fishermen and new rice-farmers settling in the area. Even fishermen from the Inner Niger Delta region moved to the lake. However, the new reservoir affected the fruit cultivation, one of the main economic activities, by the inundation of mango, guava and orange orchards. The ODRS co-ordinates the agricultural activities of 15 villages in some 1600 parcels, and of fisheries executed by over 1000 families of fishermen (8900 persons) spread over 72 settlements.

The three National Censuses show that the population in the *Cercle de Yanfolila* has increased from 96,925 to 123,535 people between 1976 and 1987, thus by 2.5% per year. This increase was even larger in the following 11 years, since in 1998 there lived 163,798 people in this cercle, an annual increase of 2.96% since 1987. This rate of increase is slightly higher than the population increase of 2.43% for Mali as a whole. However, since the rural population of Bamako grows with 5% per year, the average increase of the rural population is less than 2.43%. The relatively high population increase in Yanfolila may be explained by immigration.

Landscape and habitats

The Sélingué dam became operational in 1980. The landscape had changed dramatically by then, from a wooded savanna to a large lake. Before the reservoir was filled with water, many trees were cut down. Altogether 268,800 m^3 of wood was taken from the forests. The remaining trees were submerged and after 25 years still many dead trees can be seen emerging from the shallow parts of the lake.

The lake habitat is characterised by a falling water level in the period from January to June, and the shores of the lake become exposed. From July to September the lake is filled again. Various grassy habitats develop on the clayey, sandy, and even stony grounds between woodland and the waterline when the water in the lake falls. There are no marshy habitats. Downstream from the dam, some 1300 ha of mainly rice crop area - out of the 55,000 ha planned - have been reclaimed as compensation for the loss of arable land and dwelling grounds of 30 villages and hamlets. Together with the lake, and the Niger river itself, the irrigated rice fields constitute important wetland habitats in the region.

10.3 Production

Fish production

Everywhere in the world reservoir fisheries are an important source of income for local people, so much that in many reservoirs fisheries are pushed to a level of over-exploitation (Crul & Roest 1995). The annual fish catches in Lac Sélingué have also increased since its origin, from 1000 – 2000 tonnes to over 4000 tonnes in recent years (Fig. 10.2; Laë & Weigel 1995). We can put this figure into perspective as Laë & Lêveque (1999) compared the total fish production in different lakes and man-made reservoirs in Africa to their surface area and volume. They found, as expected, that the fish production increases with water surface area and water volume. The fish catches in the Sélingué reservoir (4000 tonnes in a lake of 400 km^2) fits within the observed trend.

The fishermen themselves consume about 30% of the captured fish, 70% is traded. In contrast to the Inner Delta, not many fish are dried in the sun or smoked. Nearly all traded fish is transported daily along a perfect road to Bamako, where freshly caught fish can be sold on the market the same day. The fishermen in Lac Sélingué come originally from the Inner Delta. They took with them their skills but also their traditional fishing techniques. Most fish in Lac Sélingué is caught with nylon nets, hook lines and fish cages. The increase in the number of fishermen in Lac Sélingué leads to more problems about the use of the fishing grounds. A committee was formed some time ago by local fishermen and authorities, to solve these problems.

Altogether 86 fish species have been found in Lac Sélingué (Laë & Weigel 1995; annuals of ODRS). Most belong to the following families: Bagridae (*Bagrus bayad*, *Chrysichthys nigrodigitati*, *Auchenoglanis occidentalis*), Cichlidae (*Oreochromis niloticus*, *O. aureus*, *Tilapia zilli* and others), Ciprinidae (*Labeo senegalensis*), Shibeidae (*Eutropius niloticus*), Mochokidae (*Synodontis* spec.), Citharinidae (Citharinus), Characidae (*Brycinus leusiscus*, *Alestes dentex*), Centropomidae (*Gymnarchus niloticus*) and Osteoglossidae (*Heterotis niloticus*). *Micralestes acutidens*, locally known as Miri, is a small but a very abundant fish in the lake. The fishermen capture mainly Taka *Tilapia spec.* (30%) and Korokoto *Auchenoglanis occidentalis* (15%). Most species are found everywhere in the Niger River and also in the Inner Delta, although their relative occurrence differs.

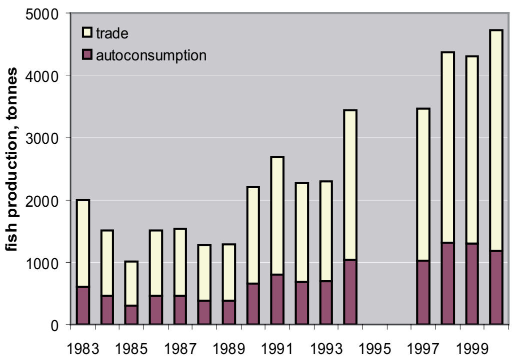


Fig. 10.2. Annual fish production in Lac Sélingué, split up for the amount consumed by the fishermen and the amount being traded. Source: Annual reports of ODRS.

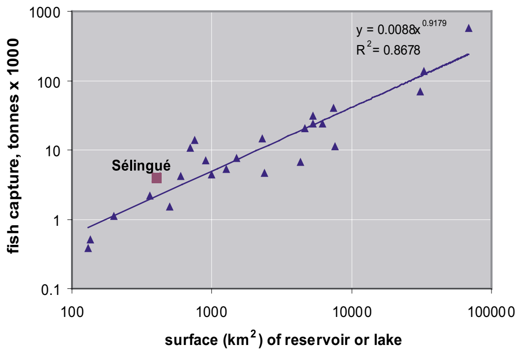


Fig. 10.3. Fish catch as a function of the surface area of the lakes and man-made reservoirs in Africa. Source: Laë & Lêveque (1999).

Most striking difference between Lac Sélingué and the Inner Delta is the size of the fish being caught. Nearly all fish in the Inner Delta are nowadays less than 10-20 cm and fish of 30 cm or longer have become rare. In Lac Sélingué, most captured examples of *Lates niloticu* (in bambara: Saalé), *Gymnarchus niloticus* (So dyege), *Heterotis niloticus* (Fana) and *Citharinus citharus* (Tala) are still longer than 30 cm, just like in the Inner Delta more than 25 years ago. As described in Chapter 5, the increased fishing intensity in the Inner Delta reduces the survival time of fish, so that the majority of the fish caught are less than one year old.

There is a remarkably large seasonal variation in the catches, being low in November – February and high in May – July (Fig. 10.4). The most likely explanation is that the fish are easier to catch in May - July because the fish are more concentrated due to the lower water level. However, this is only true if (a part of the) fish are withheld by the dam and do not leave the reservoir together with the outflow. When the reservoir is completely filled at the end of the *crue*, its water volume is 2.1 km^3, but some months later the surface area is reduced by 70% and the volume even by 90% (Table 2.4; Appendix 2). The water volume was extremely low in 1999. One might expect that in such a case, the fish could be very easily caught, but as shown in Fig. 10.4 this was not the case. On the contrary, the peak catches were lower than in other years. Possibly, the total amount of fish still present in the reservoir greatly decreased when the reservoir was emptied.

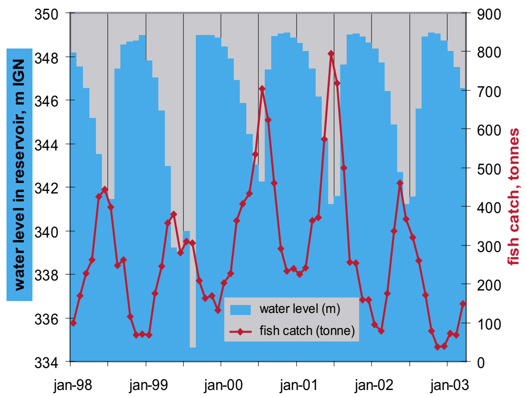


Fig. 10.4. Lac Sélingué. The monthly variation in fish catches between January 1998 and March 2003 compared to the variation in water level (m IGN). Source: annual reports of ODRS.

Cattle

According to the annual reports of ODRS 73,000 cattle and 54,000 sheep and goats are counted annually in the *cercle de Yanfolila*. During the Great Drought zebu cows came from the region of Ségou, Koulikoro and the *cercle de Bougouni* to the surroundings of Lac Sélingué. This caused overgrazing but also had another long-term negative effect. The local cows are a breed which are tolerant against N'Dama, or trypanosomiasis (sleeping sickness), but the zebu are not. During the Great Drought a subspecies (*le méré*) came into existence being less resistant to the sleeping sickness.

Due to the construction of the reservoir, the cows lost a part of their grazing grounds. The newly created irrigated land downstream from the dam gives no solace, since the farmers there have two crops per year and do not allow cows on their land. The immersed area that re-appears at a low water level in the reservoir is grazed by livestock, but this probably does not compensate for the loss of grazing grounds since the creation of the reservoir. Hence, the Sélingué reservoir has brought no nett advantages to the cattle breeders.

Rice

It would be possible to irrigate 55,000 ha along the Sankarani river up and downstream from Sélingué dam. So far 1350 ha has been realised of which annually 900 ha is cultivated. The area is used for growing rice. The farmers have two crops a year, one

in January – June planted in the off-season (contre-saison) and one in July – December, planted in the rainy season (hivernage). In recent years, the production amounts to 4.67 – 5.82 tonnes per ha in the *contre-saison* and to 2.46 – 4.48 tonnes per ha after the *hivernage*. That gives a total annual production of 6000 - 7500 tonnes rice. The yields are of the same order of magnitude as those of the Office du Niger irrigation zone (Chapter 11).

There are about 1600 farmers who each rent 0.5 ha. In the past, the parcels were 1 ha but due to the individualisation, it became more convenient to farm out the land in smaller parcels.

10.4 Ecological values

When Lac Sélingué came into existence, an estimated 1.8 million trees drowned. Large dead trees still rise above the surface of the water and now function as a perch for a large variety of bird species, such as Long-tailed Cormorant *Phalacrocorax africanus*, Cattle Egret *Bubulcus ibis*, White-faced Whistling Duck *Dendrocygna viduata*, African Fish Eagle and Osprey *Pandion haliaetus*. Whereas before the construction of the dam wetland habitat was confined to the river bed, now both the lake and the irrigated rice polder make up two important wetland habitats. Both have a distinct ecological function.

Breeding waterbirds

Breeding habitat for waterbirds are found to be very limited in the rice fields. Breeding colonies were not found during the field work in 2002-2004, but fishermen claimed breeding 'herons' further upstream on the lake. In June 2004, bush cover along the Sankarani just downstream from the dam hosted several white heron species (100-200 birds in total) and <10 Black-crowned Night Herons *Nycticorax nycticorax* were roosting, whereas Squacco Herons *Ardeola ralloides* in full summer plumage are assumed breeders in this area.

Staging waterbirds

Information on the lake is available for December and February (van der Kamp *et al.* 2005). Waterbird numbers on the lake were mainly made up by White-faced Whistling Duck: 80-95% of the total concerns this species. The numbers counted increased between December 2002 and February 2003 from 4500 to 15000 birds. Another frequent bird on the lake is the Osprey (Fig. 10.5). Their number doubled from

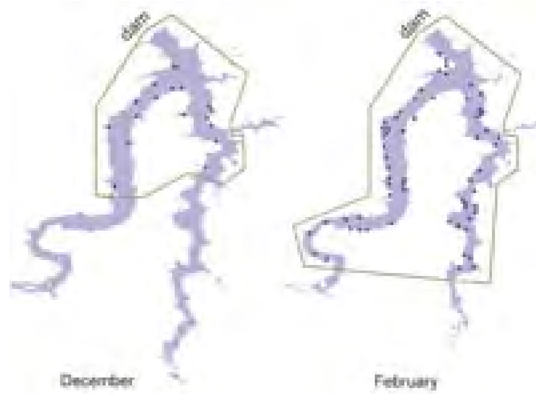


Fig. 10.5 Distribution of Osprey on Lac Sélingué at high water (December 2003) and low water (February 2004). The green line limits the counted area.

December to February, which may partly be triggered by receding water levels, or first pre-migratory movements of birds from elsewhere. Shore counts in June-July revealed very modest waterbird numbers, with Spur-winged Plover *Vanellus spinosus*, Egyptian Plover *Pluvianus aegyptius* and Kittlitz's Plover *Charadrius pecuarius* among the more common species. Locally rare and endangered species, although seen yearly, were White-headed Lapwing *Vanellus albiceps* and Grey Pratincole *Glareola cinerea*. Dead trees at the lakeside served as a night roost for Long-tailed Cormorant *Phalacrocorax africanus* (several hundred), Cattle Egret (1500-2000) and Black Kite *Milvus migrans* (>500).

Data on bird densities were obtained from the rice polder downstream from the dam (Table 10.1). Overall densities are somewhat higher than in the irrigation zone of Office du Niger (Chapter 11.4). In July, African Jacana *Actophilornis africana* was by far the most common species together with Spur-winged Plover. The second common wader species in July was the Afrotropical Greater Painted-snipe *Rostratula benghalensis*. The Sélingué irrigation zone serves as a staging area during the dry season for species such as Cattle Egret *Bubulcus ibis* and African Wattled Lapwing *Vanellus senegallus*. Wood Sandpiper *Tringa glareola*, Cattle Egret and Yellow Wagtail *Motacilla flava* were the most numerous species in February and contribute most to the total density (Table 10.1).

With regard to its international importance the White-faced Whistling Duck and the African

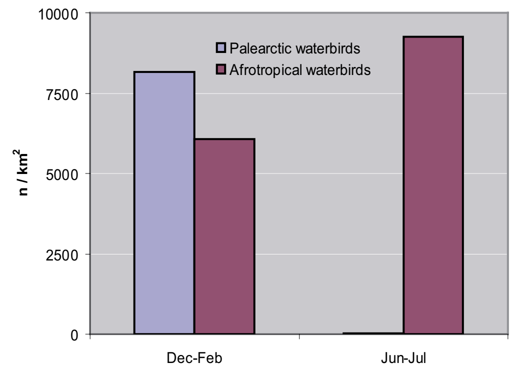


Fig. 10.6. Total density (n/km^2) of Palearctic and Afrotropical waterbirds and wetland-related species in the irrigated rice fields near Sélingué (data 2002-2004). In total 431 plots are counted. Note the absence of Palearctic waterbirds in the rainy season (June-July). For details and methods see van der Kamp *et al.* (2005).

Wattled Lapwing at least meet the 1% criteria (see also Chapter 9) when the rice area and the lake are combined. The lake is also an important wintering area for Osprey *Pandion haliaetus* (estimation of 50-100 birds). Also the presence of the vulnerable Great snipe must be taken into account when considering the international value.

Other fauna groups

Information of other fauna groups than birds is almost completely lacking, but according to local people there is rich wildlife around, among which are Crested Porcupine *Hystrix cristata*, monkeys and several antelope species. This qualification may be biased as the Wassoulou region, in which Sélingué is situated, has a hunting tradition. Many species of bats *Chiroptera* are found in the area (see Kingdon, 1997). In July 2003 the occurrence of Hippopotamus *Hippopotamus amphibius* was confirmed by traces on the west bank of the lake near the Sélingué dam, and local villagers confirmed the incidental occurrence of two hippos in this area. The status of West African Manatee *Trichechus senegalensis* in the lake is unclear: some people agree on its occurrence, others don't.

Table 10.1. Mean densities per 100 ha and estimated populations of waterbirds and wetland-related species in rice fields in the ODRS-irrigation zone in 2002-2004 (330 counts in December and February and 101 counts in June and July). For details and methods see van der Kamp *et al.* (2005) and Appendix 8 in this report. Common species with low densities are omitted. 1% crit = 1% criterion of Ramsar Convention (see Table 9.2), Exc.= exceeding 1% crit., n = no criteria available.

English name	Latin name	n per 100 ha		Estimated total		1% crit	Exc.
		Dec-Feb	Jun-Jul	Dec-Feb	Jun-Jul		
Long-tailed Cormorant	*Phalacrocorax africanus*	0	17.3	0	225	1000	
Purple Heron	*Ardea purpurea*	0	1.6	0	21	120	
Intermediate Egret	*Mesophyx intermedia*	28.2	2.8	367	36	1000	
Cattle Egret	*Bubulcus ibis*	295.0	0	3835	0	n	
Squacco Heron	*Ardeola ralloides*	16.5	69.2	215	900	3000	
Green-backed Heron	*Butorides striatus*	0	54.4	0	707	10000	
Hamerkop	*Scopus umbretta*	10.9	0	142	0	10000	
Lesser Moorhen	*Gallinula angulata*	0	12.7	0	165	n	
African Jacana	*Actophilornis africana*	30.2	615.6	393	8003	n	
Lesser Jacana	*Microparra capensis*	0.6	29.4	8	382	1000	
Collared Pratincole	*Glareola pratincola*	9.2	0	120	0	240	
Greater Painted Snipe	*Rostratula benghalensis*	0.7	69.7	9	906	n	
Spur-winged Plover	*Vanellus spinosus*	87.1	42.6	1132	554	4000	
African Wattled Lapwing	*Vanellus senegallus*	119.1	16.0	1548	208	450	3.4
White-headed Lapwing	*Vanellus albiceps*	0	4.0	0	52	500	
Little Ringed Plover	*Charadrius dubius*	15.2	0	198	0	1000	
Forbes's Plover	*Charadrius forbesi*	8.7	0	113	0	1000	
Wood Sandpiper	*Tringa glareola*	397.1	0	5162	0	10400	
Great Snipe	*Gallinago media*	14.2	0	185	0	350	
Ruff	*Philomachus pugnax*	29.9	0	389	0	10000	
Yellow Wagtail	*Motacilla flava ssp*	353.6	0	4597	0	n	
Northern Red Bishop	*Euplectes franciscanus*	0	1.7	0	22	n	
Yellow-crowned Bishop	*Euplectes afer*	0	3.9	0	51	n	
Overall total (incl. omitted species)		1477	962	19,297	12,512		

10.5 Conclusions

The construction of the Sélingué reservoir and the associated hydropower plant results in a stable production of electricity, amounting to 12.93 Gwh monthly (annual mean); more details can be found in Chapter 2 and Appendix 2. Sélingué provides a substantial part of the present national demand.

The conclusions from this Chapter can be summarised as follows:

- The creation of the storage lake, covering 34 km^2, led to the disappearance of grazing grounds for cattle and the inundation of fruit orchards, one of the main economic activities in the region. However, the lake nowadays provides other means of subsistence. This apparently attracted people from elsewhere, like fishermen from the Inner Niger Delta who are now fishing in the lake. Indeed, the rural population has increased in the surroundings of Lac Sélingué due to immigration.
- The present total annual fish production amounts to 4000 tonnes, of which the larger part is sold as fresh fish in Bamako. The production is about the same as the calculated reduction in the fish production in the Inner Niger Delta due to the lower flood levels caused by Lac Sélingué. About 100 families and 8900 people are involved in the fishing activities. The construction of the dam also made it possible to construct an irrigation scheme downstream. Actually with 1350 ha the irrigated perimeter is rather small. The production of rice is 6000-7500 tonnes annually (<1 % of the national production) based on double-crop cultivation.
- Whereas before the construction of the dam wetland habitat was confined to the riverbed, now both the lake and the irrigated rice polder make up two important wetland habitats. Both have a distinct ecological function. The lake area is of international importance due to Osprey and White-faced Whistling Duck. Though small in surface area, the irrigated rice area is internationally important for the African Wattled Lapwing (3 times 1% criterion) and the vulnerable Great Snipe. Total numbers are close to another Ramsar-criterion match: regularly holding 20,000 birds.

- The significance to other fauna is not well known. The occurrence of Hippopotamus in the lake was confirmed during the fieldwork, but no other large mammals or reptiles were observed. The status of West African Manatee remains unclear.

11 THE IRRIGATION ZONE OF OFFICE DU NIGER

Eddy Wymenga
Jan van der Kamp
Bouba Fofona

11.1 Introduction

'Rice is life' is the slogan used by the FAO for the International Year of Rice 2004 (www.fao.org/rice2004). This motto applies literally for the population in Mali as, besides millet and sorghum, rice is their staple food. The vital importance of rice, however, was not the principal motivation for founding the Office du Niger. The present irrigation scheme, developed in the 1930s, was initially meant to produce cotton in order to support the colonial French textile industry. As these plans proved to be ill-omened the changeover to rice cultivation was a successful way out. Following initial difficulties and stagnation in production as well as expansion, the Office du Niger has now grown into the largest irrigation scheme in West-Africa. Covering 17% of the total area of rice cultivation in Mali it contributes 40% to the national production of rice. Very appropriately Bonneval et al. (2002) call the Office du Niger the rice granary of Mali.

Today the Office du Niger irrigation zone covers ca. 74,000 ha with an annual production of ca. 320,000 tonnes of rice (data 1999-2000) and in addition other products such as sugar cane and vegetables. Irrigation takes place under gravitation and is made possible by the Markala dam. The irrigation zone is the largest consumers of water in the Upper Niger Basin (Chapter 2). Recently Bonneval *et al.* (2002) published a solid historical, environmental and socio-economic essay on the Office du Niger zone. This Chapter therefore is confined to a concise overview of the most important developments in the area, which are connected to the themes in this book. It shows the success story of the irrigation zone and the high, nowadays more or less secured production, which is independent of rainfall and flood performance. However, there are limits: special attention therefore is paid to the envisaged expansion of the irrigation zone and the constraints, which are related to this (see also Keita *et al.* 2002). Since its foundation the Office du Niger records essential data on the development of the zone, and for this study these statistics were generously put at our disposal.

11.2 The area

Situation and setting

The Office du Niger area is situated about 40 km north-east of Ségou, lying on the north bank of the Niger, about 20 km upstream from Ké-Macina at the entrance of the Inner Delta (Fig. 11.1). Within the irrigation zone Niono functions as the central town, while other larger villages are Kourouma and Sokolo in the north and Kolongotomo, Boky Wéré and Macina in the east. The actual administrative scale of the Office du Niger zone is much larger than the irrigation zone itself, and extends from Niono in the west into the Inner Niger Delta in the east, taking up over 1.9 million ha. Within this area future expansion is sought, as elaborated on in the regional development plan issued in 1999 (*Schéma directeur de développement*, Sogréah-BCEOM-Betico 1999).

The irrigation zone is located in the Delta Mort,

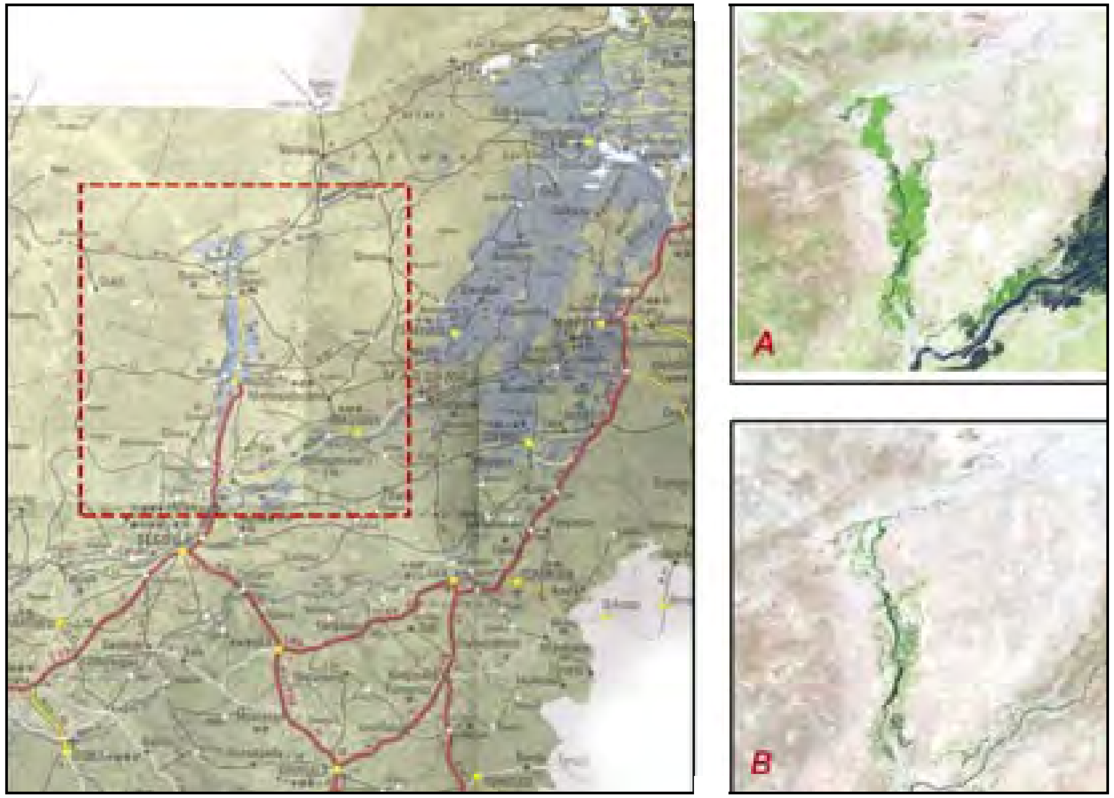


Fig. 11.1. Irrigation zone of Office du Niger with topographical names used in the text. In addition, two satellite images are shown: image A of 7 October2001 representing the rainy season, and B of 16 March 2002 after the harvest of the crops and before the off-season crop.

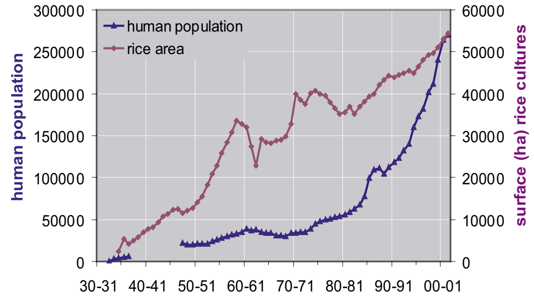


Fig. 11.2. Development of the human population and the surface area of rice cultures (ha), both within the Office du Niger irrigation zone. The total irrigation zone of the Office du Niger covers ca. 74,000 ha. Source: Office du Niger.

an ancient delta of the Niger, stretching eastwards and bordered on the west side by a dune system. The Delta Mort is a rather flat alluvial plain with heterogeneous soil conditions, ranging from sandy elevations and dunes to argillaceous soils in the former basin and silty soils in between (MDRE/ME 1999). It forms a secluded part of the Niger Basin since the construction of the Markala dam in the 1940s. Two old river branches (so-called *Falas*), connected by an irrigation canal system, nowadays act as water suppliers for agriculture in this area: one heading north through the Niono region (*Fala de Molodo*), the other northeast towards the Macina region (*Fala de Boky-Wéré*).

Historical development

The first steps towards creating the largest irrigation scheme in West Africa go back to the beginning of the 20th century (1919-1920) when a French mission, seeking alternative cotton production for the French textile industry, assessed the Delta Mort as a suitable location for a 1 million ha large cotton plantation. As a result Office du Niger was founded in 1932 and directed by French colonial administration. In 1945 an area of about 25,000 ha was used for irrigated cotton and rice cultivation. The Markala dam, being operational from 1947 onwards, greatly improved the possibilities for irrigation and a firm growth set in (1948-59: average 10.3% per year, Fig. 11.2). In the sixties however, during nationalisation, Office du Niger went trough a deep crisis. At the same time, with Chinese help, the first sugar cane plantations were developed. Between 1965 and 1970 the growing of cotton was abandoned and since then the rice area has increased (changeover to rice, see Fig. 11.2).

In 1978 the production of rice reached a temporary peak of 101,000 tonnes, dropping to an average of 60,000 tonnes in the years that followed. This regression was, amongst other factors, due to negligence in maintaining the irrigation system and soil depletion. In the early 1980s Office du Niger again faced a difficult period. From then on intensive support by foreign donors and the liberalisation of the rice market resulted in a positive impulse. Between 1983 and 2001 the area of cultivated rice increased on average by 2.3 % annually. Schreyger (1984, 2002) reports extensively on the historical development of the Office du Niger zone, the high price, which was paid and the socio-economical difficulties which ensued from this.

After a further gradual development the devaluation of the Franc CfA (1994), which made national rice much more competitive to imported rice, and an intensive program to restructure the irrigation zone, Office du Niger is now in full swing. In 2000 an estimated 74,000 ha of irrigated land north of the Niger River received water from Markala. This total surface area is roughly composed of the following sectors (Keita *et al.* 2002):

- 55,500 ha of rice polders within the Office du Niger;
- 1580 ha new rice polders at Ké-Macina and Bewani;
- 5800 ha of sugar cane area;
- 3000 ha of rice managed by the Opération Riz Ségou;
- 8000 ha of cultivations outside the regular ON-embankments (*hors-casiers*).

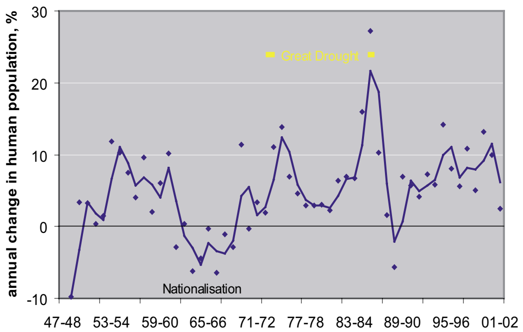


Fig. 11.3. Annual change in the population of the Office du Niger irrigation zone. The line represents the two-year running mean. During nationalisation the population shrank while during the drought periods a strong migration towards the area occurred. Source: Office du Niger.

People

The success of the Office du Niger irrigation zone, providing food and labour, logically attracts many people. Brondeau (2002) calls it an "Isle of prosperity" and in a Sahelian context with food insecurity as a rule, this is significant. Indeed, as shown in Fig. 11.1, the population of the Office du Niger increased enormously, from 21,700 in the late 1940s to 270,289 in 2002. This attractiveness has not always been the case: at the start of the project 2000 labourers were recruited by force to construct the irrigation works. In the early 1940's new colonists were bound by incentive-like credits (Schreyger 2002).

Thanks to the database of the Office du Niger a lot is known about the development of the zone. In Fig. 11.3 these data were used to calculate the annual change in the population which shows, despite the obvious increase over the years, large fluctuations. There are several causes to this pattern (cf. Bonneval *et al.* 2002), but especially the dip during nationalisation (1960's) and the two drought periods (early 1970's and 1984-1985) stand out. The drought periods temporarily caused a strong migration to Office du Niger. After the last drought period the annual growth varied between 5-10%. Between 1978 and 1998 the number of villages grew from 136 to 208. The next Section shows that the number of families that are involved in the exploitation increased synchronously while the exploited area per family decreased strongly.

Landscape and habitats

The landscape of the Delta Mort can be characterised as a bare to sparsely wooded savanna locally with thorn shrub. Important tree species are *Guiera senegalensis* (N'Goudjé), *Ptiliostigma reticulatum* and *Combretum micranthum* (N'Golobé). Directly to the west the Delta is bordered by a higher dune complex (PIRL 1990) cited by Bonneval *et al.* 2002). In this Section we are interested in particular in the wet zone of the Office du Niger consisting of the depressions of the former river branches, the Falas, and the rice fields in the irrigation zone. Forested habitat also occurs in the Delta Mort, but the growing rural population has an impact on its sustained existence because of firewood demands (Nouvellet & Sanogo 2002). In areas where drainage water from the irrigated polders is discharged (into the Fala area) substantial forests including *Acacia nilotica* have developed. These have an important ecological function (Section 11.4).

Falas

The Fala area must have followed the Niger flood regime before the construction of the Markala dam and its related hydraulic infrastructure, into the surrounding floodable areas. The characteristic dynamic water levels, within as well as between years, in the river's annual cycle, including the dry conditions during low water, are nowadays eliminated. The marshy area has become a permanent wetland situated in a former dry savanna transformed into a huge rice cultivation area. The wetland habitats now have stagnant instead of dynamic water conditions, which is a major ecological change.

The Falas and their adjoining forelands have turned into permanent wetlands, whereas the primary irrigation canals also contain permanent water. Open water and abundant aquatic vegetation with interspersed agricultural plots give a natural-looking

marsh appearance. The main vegetation comprises *Typha australis* (Cat tail) and *Nymphea micranthum* fields, whereas Water hyacinth *Eichhornia crassipes* also occurs. The latter is an invasive species occurring in the Niger river since the early 1990s and causing problems at sluices and inlets, e.g. at the Sotuba hydro-electric power station inlet in Bamako. The ongoing growth of extensive *Typha* vegetations in the water bodies of the Falas is a result of the stagnant water conditions in combination with eutrophication (cf. Keddy 2002). Similar growths, but then on a much larger scale, occur in the Senegal delta as a consequence of the Diama dam (e.g. Peeters 2003). In the irrigation zone the *Typha* vegetations are considered a pest causing problems in small irrigation canals. In the current wetlands this may, however, be an important habitat for water birds and other aquatic fauna (Section 11.4).

Rice fields

In the irrigation zone, the rice fields constitute a major wetland habitat, where several varieties of rice are being grown. Especially the parcels with a thin vegetation and the ones which have been harvested are very attractive to waterbirds. The wet season cultivation ('*hivernage*') in the irrigation zone starts at the end of May and the harvest takes place in October-November (Fig. 11.4). Farmers with a double-crop ('*hivernage*' and '*contre-saison*') tend to use short-cycle rice rather than long-cycle, as they would have little time between crops to remove weeds from bordering rice field dikes and to plough the land. At present rice planting ('*repiquage*') is generally practised in order to maximise yields. The period of December-May shows an arid post-harvest landscape except for the parcels occupied with dry season crops; these crops basically cover the mid-January-May period.

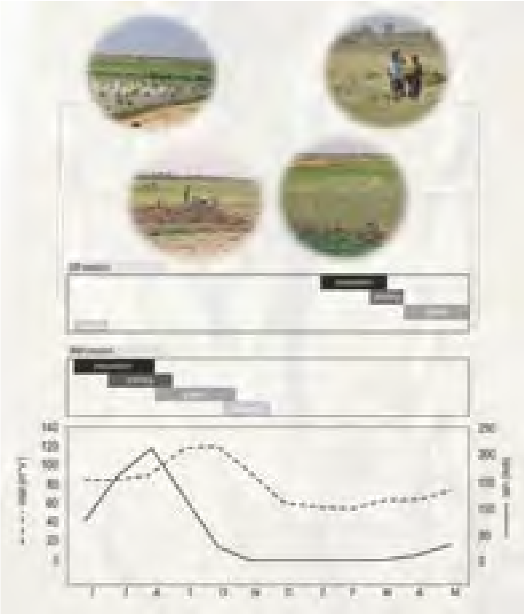


Fig. 11.4. Global annual cycle of wet season and off-season rice cultivations in the Office du Niger. Also the monthly rainfall and intake of water is indicated. Partly based on N'Diaye (1998).

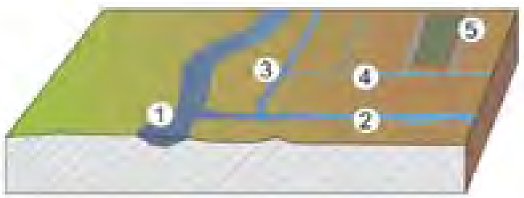


Fig. 11.6. Schematic view of the irrigation system: 1 *distibuteur*, 2 *partiteur*, 3 *arroseurs*, 4 *rigoles*, 5 *division des persels en bassins.*

Irrigation system

In order to supply the rice fields and sugar cane plantations with water, the river discharge at Markala is dammed to 5.5 m above the lowest water level. This enables the use of a hierarchical hydrological system with dropping water levels, feeding larger and smaller canals. The intake of water at Markala fluctuates from 58 (January-mean 1989-2004) to 131 m^3/s (October id.). This water is directed through a large canal (*canal adducteur*, capacity 200 m^3/s) towards point A, from which it is divided between three larger canals (Fig 11.5):

- *Canal du Sahel* (100 m^3/s) discharging into Fala de Molodo, leading to the irrigated areas north of Niono (Molodo, Sokolo and the surrounding area);
- *Canal Costes-Ongoïba* (13 m^3/s) supplying the sugar cane plantation of Siribala;
- *Canal du Macina* (50 m^3/s) leading into Fala de Boky-Wéré, which in its turn runs in an easterly direction towards the polders of Macina.

From each of the falas, water is let into distribution canals (*distributeurs*), acting as a primary supply system for Sections of 3000-9000 ha, which in their turn feed a secondary supply system of *partiteurs*. These smaller canals cover secondary Sections of 200-600 ha, which approximately correspond to the irrigated area which can be managed by one settlement or village. Figure 11.6 shows the hydrological system in more detail up to the level of irrigated parcels. Complementary to the supply system there is a drainage system (*collecteurs*).

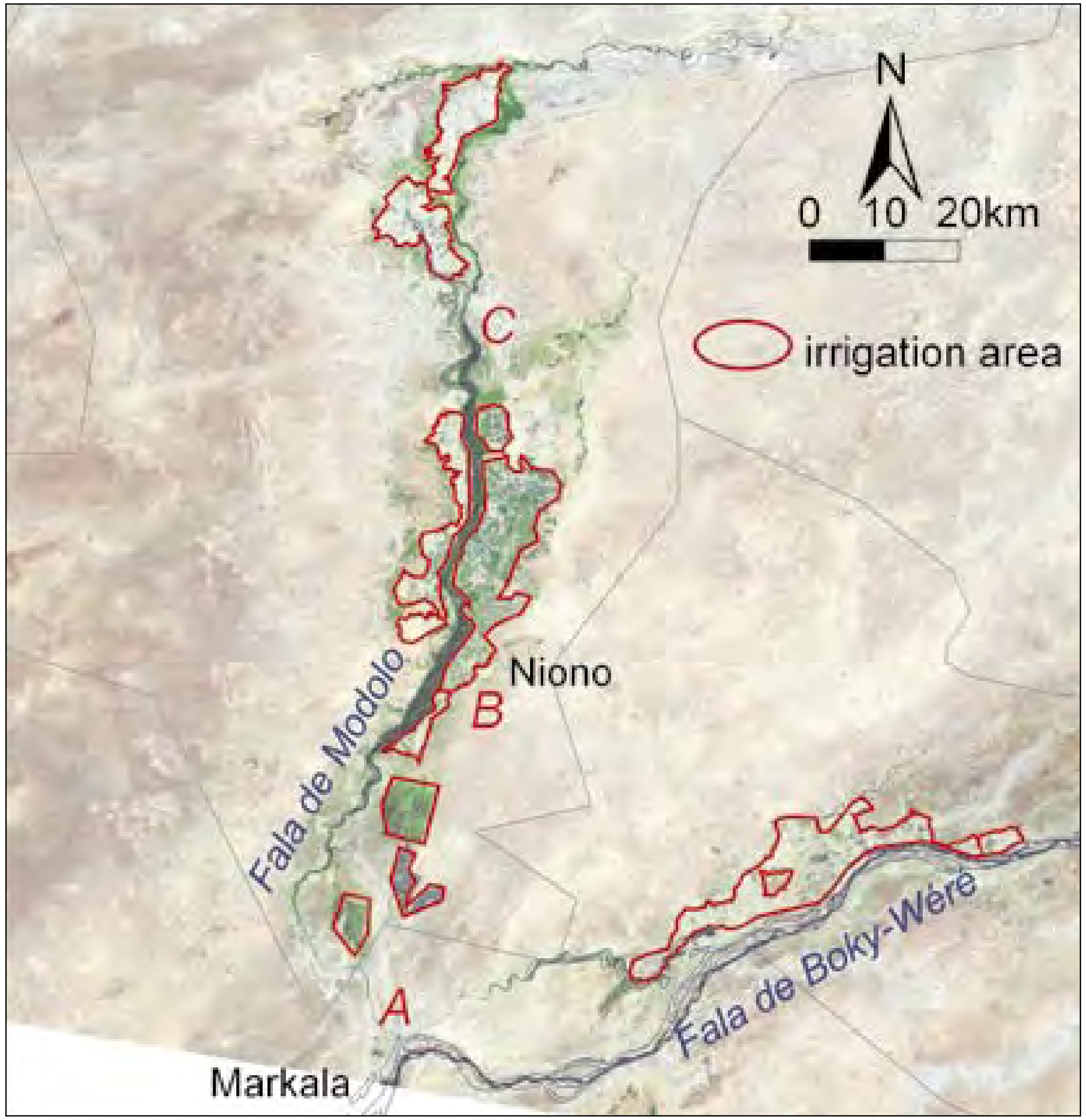


Fig. 11.5. The irrigation zone of the Office du Niger with water distribution system and irrigated perimeters (Source: Bonneval et al. 2002, Keita et al. 2002) drawn on true colour composite of a satellite image of 16 March 2002.The area shown measures 160 x 125 km.

11.3 Production

Rice production

In traditional rice farming systems, rain fed or flood-dependent, one family with on average 3.5 active members exploits about 5-6 ha, yielding ca. 1-2 tonnes/ha depending on flood conditions and other constraints such as rainfall (Chapter 8). In fact the initial yields in Office du Niger were in the same order of magnitude: e.g. 1.56 tonnes/ha in 1943. In the course of time, the farmers in the irrigation zone managed to attain better results. The statistics of the Office du Niger show that the production of rice increased enormously from 4129 tonnes in 1935 to 333,078 tonnes in 2001 and in this Section we explore how this increase was achieved.

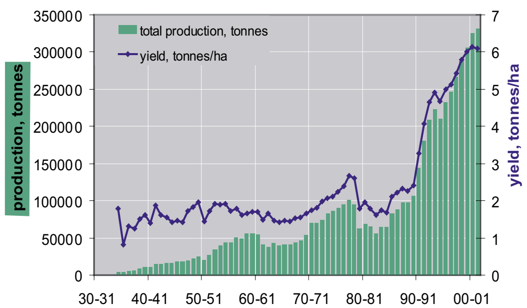


Fig. 11.7. Total production (tonnes) and yield (tonnes/ha) in the irrigation zone of the Office du Niger. No data for the period 1930-1934. Production and yields of off-season rice are not included. Source: Office du Niger.

The initial growth of the total production in Office du Niger was simply a result of a growing surface area of rice (Fig. 11.3). The trend in yield per ha in Fig. 11.7, however, clearly demonstrates, that from the early 1990s onwards there is a leap in the total production, which coincides strongly with improved yields per ha. Several factors have contributed to this huge improvement.

As remarked under "historical development", Office du Niger was in trouble during the early eighties and production strongly lagged behind expectations. With the help of foreign donors, an intensive campaign started, aimed at increasing the production and restructuring the irrigation zone. The relevant projects and measures are described in detail by Bonneval *et al.* (2002). Cornerstones were the stimulation of off-season cultivation, restructuring the irrigation zone (with back repair of the irrigation system), stimulation of the planting of rice instead of sowing, a more efficient water use and finally lowering the exploited surface area per operating family. Together with the liberation of the rice market (effective at the end of the eighties) and devaluation of the FCFA (1994), both crucial stimuli according to Chohin-Kuper *et al.* (2002a) , this resulted in a boost in production and yields (Fig. 11.7).

The separate significance of the factors mentioned above is hard to indicate. All of the envisaged measures were carried out. The surface area of the restructured area within the irrigation zone (*riz d´hivernage sur casiers réhabilité*) grew from 450 ha in 1982 to 29,740 ha in 2001. Up till now this is 54% of the total area of rice cultivations. Also the planting of rice was taken up: while in 1983 rice was planted on only 5 ha this method is now practised on 98% of the total area. In addition to these measures, the fertilisation (inorganic and organic by cattle) went up and farmers got improved skills through agricultural instruction. Surprisingly, over the period 1987-2001 we found no relation between total production and total use of inorganic (DAP and Ureum) fertilisation (R^2 0.0096). The improved production methods demanded more labour. With a growing population of operating families this was achieved by a strong decrease of the mean surface area exploited per family (Fig 11.8). This also is related to land demand and individualisation: young family members increasingly want their own exploitations.

Double-cropping was initiated during the 1980s and is nowadays still developing but in terms of cultivated area represents only 10 to 20% (1994 to 2001) of the wet season area. This is far less (although it involves more ha) than in Sélingué where cultivated surface areas during wet and dry season are more or less equal. The yields per ha of the off-season rice, which demands more skills and labour, lag behind the wet season cultivation, ranging from 2.2 tonnes/ha in 1994 to 4.0 tonnes/ha in 2001. According to Chohin-Kuper *et al.* (2002b) farmers choose alternative crops such as eschalot and maize because of the higher return.

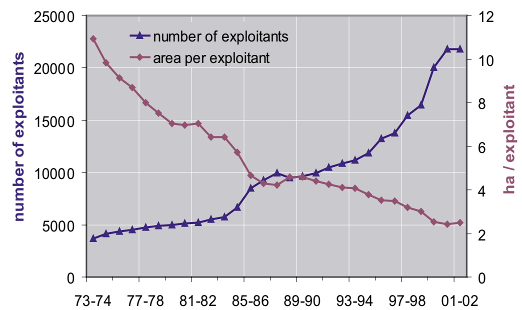


Fig. 11.8. Number of operating families (*exploitants*) and the mean surface area per family in the irrigation zone of the Office du Niger. A substantial decrease in parcel-size per family has been part of the strategy to intensify rice cultivation. Source: Office du Niger.

Other products

Since the early 1990s, a growing area for other cultivations such as eschalot and maize is being operated outside the wet season. This diversification is stimulated by Office du Niger since it offers the farmers a substantial complementary income (Chohin-Kuper *et al.* 2002b). Alternative cultivations are still developing: maize increased from 140 ha in 1994 to 600 ha in 2001, while vegetables take up 2500-3500 ha (1994-2001). Eschalot is the most important crop and in addition tomatoes, garlic and cabbage are grown.

Water use

An important question in the framework of this study is; if the increasing production and expansion in the course of time also led to an increasing water demand? As put forward in Chapter 2, the water intake at Markala does not show a clear trend during the last 15 years. For the period 1989-2003, being the period in which the production greatly increased, we didn't find any relationship between the water intake on the one hand and the total production and the total surface area of rice on the other (for both $R^2 < 0.001$), nor did we find a link between rainfall and production ($R^2 < 0.01$). Water intake seemed to be a little higher in relatively dry years, but the relationship is weak.

An important conclusion is, that the recent expansion and enormous leap in production were realised independently of the rainfall and without using additional water. In other words, nowadays water is used much more efficiently than in the past, which is shown in Fig. 11.9. The water use per kg of rice has reduced to 8000 l/kg of rice at present. Ouvry *et al.* (2002) report an efficiency of water use in the irrigation zone of *ca.* 35% at parcel level, which is still lower than the international norm for gravity irrigation (50-60%). A part of the reported loss however is explained by infiltration, and water use for other functions than agriculture and application outside the irrigated polders. Yet, it suggests that even a higher efficiency is possible. This is exactly part of the plans of the Office du Niger, who wants to use a norm of 2 l/s/ha for future expansion instead of the current norm of 2.4 l/s/ha (Keita *et al.* 2002).

The reverse of the water use, namely the downstream effects in the Inner Niger Delta, are elaborated in Chapters 5-8 and 12 of this book. The water intake for the benefit of the irrigation zone leads to a reduction in flood area in the short term and consequently in fish and rice production and the grazing possibilities for livestock. For instance the reduction in rice production in the Inner Delta amounts to 20,000 tonnes annually. At the same time the reduced flooding deteriorates the conditions for the survival and recruitment of the (avi)fauna in the Inner Delta.

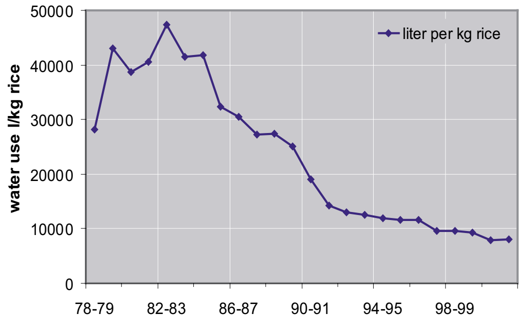


Fig. 11.9. Total annual water intake expressed as intake per kg of rice (total annual rice production). From the early 1980s onwards, it has been a deliberate policy of Office du Niger to increase the efficiency of water use, for example, by a better maintenance of the irrigation system and restructuring of the irrigation zone. Source: Office du Niger.

11.4 Ecological values

Although the ecological values of the irrigation zone of the Office du Niger have been recognised earlier, for instance in an environmental study by MDRE/ME (1999), documentation is very scarce. Up till now, attention was paid in particular to crop-damage caused by grain-eating birds like sparrows and weavers. According to the above mentioned study, crop-damage by birds amounts to 4-6% of the total damage (loss). Between 1994 and 1997 in total 315 million FCFA (€ 480,000) has been spent on the chemical destruction of these birds, mostly at their roosting sites in the Fala's. No information is available on the environmental and ecological impact of the use of these chemicals in the Office du Niger zone.

As mentioned in Section 11.2, important wetland habitats in the irrigation zone of the Office du Niger are the irrigated rice polders and the stagnant marshes of the Falas. That is why fieldwork activities in 2002-2004 mainly focussed on these habitats. Information on birds were gathered systematically, but given the time available it was not possible to cover the whole of the irrigation zone during each visit. That is why counts of densities of birds were performed, because these are particularly interesting in the artificially created rice polders. Bird censuses were performed in December, February and June-July (for details and methods see van der Kamp *et al.* 2005 and Appendix 8). The latter period is chosen because in the dry season the irrigated fields are one of the few wet spots in the Sahelian belt. Additional to the bird counts, non-systematic observations were gathered of other fauna groups (mammals, reptiles). Focussing on waterbirds, we document in this Section the high ecological values of the wetland habitats in the Office du Niger irrigation zone.

Breeding waterbirds

Breeding habitat for waterbirds can be found in the extensive marshy Fala areas, in the few existing adjacent wet forests and, to a very limited degree, in the rice fields. There are no forests of any size in the Office du Niger zone but adjacent to the Fala area one can find small-sized forests, in particular in the northern part. These serve, at least partly, as breeding grounds for herons and egrets. In early July 2003, a breeding colony of Cattle egret and Squacco heron was found in an *Acacia nilotica* forest near Diabaly. These heron species were also found breeding in a small patch of *A. seyal* (Kokry; June-July 2002, 2003). All substantial forests in Office du Niger provide a very important potential for breeding colonies of herons, egrets and other large wading birds (storks), since in the direct vicinity these birds find extensive feeding habitats in the rice fields. Since these birds consume mainly insects (locusts!), fish and small animals (mice, rats) they are also important to farmers and serve as biological "pest controllers". Unfortunately, these breeding sites are under serious stress due to reclamation programs and other human disturbance and exploitation.

The extensive *Typha*-habitats (with loose *Typha*-vegetations and other aquatic plants) in the Falas provide breeding possibilities to a number of other waterbirds. In the period 2002-2004 the breeding of the following species, at least, has been observed or suspected: Black-crowned Night Heron *Nycticorax nycticorax* in the Boky Wéré fala, Little Bittern *Ixobrychus minutus ssp. payesi*, Cattle Egret *Bubulcus ibis*, Squacco Heron *Ardeola ralloides*, Green-backed Heron *Butorides striatus* and possibly other *Ardeidae*, Purple Swamphen *Porphyrio porphyrio*, Allen's Gallinule *Porphyrio alleni*, Black Crake *Amaurornis flavirostra* and other *Rallidae*. Marsh Owl *Asio capensis*, generally described as an uncommon to rare breeding species in West Africa (Borrow & Demey 2001), is a fairly common breeding species, with main breeding numbers probably in the Fala sectors and to a lesser extent in the rice paddies.

Staging waterbirds

To understand the function of the irrigation zone for staging waterbirds, it is necessary to know their constraints, related to the crop season and the conditions of the area (van der Kamp *et al.* 2005). In general a lot of water birds, (e.g. ducks, herons, egrets), exploit the inundation zone by using the Fala area and adjacent forests as a roosting and resting place while they feed at day time in the surrounding rice fields. The falas are long but their width is limited, allowing favourable hunting conditions and other disturbances by people who have their (often unofficial) crops in the Fala's forelands. An important constraint therefore seems to be the lack of sufficient large-scale resting areas.

A second constraint is posed by feeding conditions. Feeding areas (rice fields) deteriorate under post-crop, arid conditions from December to January (cf. Fig. 11.4). The rice fields are most attractive just after the harvest or when they are inundated. In particular for Palearctic waterbirds, for which December-February is the key staging period (Chapter 9), this is a limitation. The relatively recent development to grow off-season crops, turning arid post-harvest polders into favourable wetlands, have high potential for waders and may attract other species under these more constant wetland conditions. However, for Palearctic waterbirds the December-January post-crop period may remain a bottleneck.

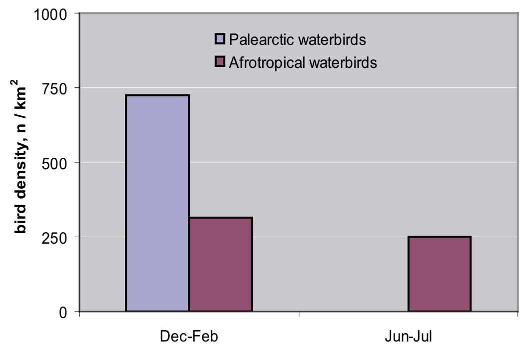


Fig. 11.10. Density (n/km^2) of Palearctic and (mainly) Afrotropical waterbirds in rice fields of the Office du Niger irrigation zone (data 2002-2004). In total 716 plots were counted (78.2 km^2). Note the absence of Palearctic waterbirds at the end of the Sahelian dry season. For details and methods see van der Kamp et al. (2005).

Related to the above mentioned constraints, during December and February very few ducks and geese were observed in the irrigation zone and limited numbers of waders, with the exception of Wood Sandpipers in the off-season crops. In all general counts, Cattle Egret and Spur-winged Lapwing *Vanellus spinosus* are the most common waterbird species in the rice fields, both resident breeders with a known tolerance for drier habitats. Despite the post-crop conditions, the density of waterbirds in the rice fields in December-February is distinctly higher than in June-July, which can be completely attributed to the absence of Palearctic birds in the dry season, i.e. the boreal summer season (Fig. 11.10).

Squacco heron showed an increase in the rice fields in June-July and then turned out to breed in the Fala and *Acacia* habitats. Other *Ardeidae*, except Cattle Egret and Yellow-billed Egret *Egretta intermedia*, also seem to mainly visit in June-July (Table 11.1). Waders are relatively rare in the rice fields, with a marked absence of Black-tailed Godwit *Limosa limosa* and Ruff *Philomachus pugnax*. Palearctic migrants such as Yellow Wagtail *Motacilla flava*, and Western Turtle Dove *Streptopelia turtur* - among several other Afrotropical dove species - exploit the rice fields as feeding zone whilst roosting in the Fala area. Total roost numbers of the Western Turtle Dove may exceed 100,000 individuals, which are severely hunted (van der Kamp *et al.* 2005), despite their function as removers of waste rice grains, which would otherwise attract pest animals like mice and rats.

The Fala zone is important to a wide range of Afrotropical waterbirds and acts as a boreal-winter quarter for Palearctic migrants, i.e. Purple Heron *Ardea purpurea*, Sand Martin *Riparia riparia*, Sedge Warbler *Acrocephalus schoenobaenus* and other *Acrocephalus* species. Afrotropical prinia's and cisticola's are widespread. At the start of the wet season in particular the Fala area is frequented by Afrotropical species, amongst which are larger numbers of White-faced whistling ducks *Dendrocygna viduata*.

A valuation of the (inter)national ornithological significance of the irrigation zone is complicated by the fact that complete and frequent censuses of

Table 11.1. Mean densities per 100 ha and estimated numbers* of water birds and wetland-related species in rice fields in the irrigation zone of Office du Niger in 2002-2004 (716 plots counted, 78.2 km^2). See Fig. 11.11 for the area where the counts were performed. For details and methods see van der Kamp et al. 2005, and Appendix 8. Common species with low densities are omitted. 1% crit. = 1% criterion of Ramsar Convention (see Table 9.2), Exc. = exceeding 1% crit,. N = no criteria available.

English name	Latin name	n per 100 ha		Estimated total		1% crit.	Exc.
		Dec-Feb	Jun-Jul	Dec-Feb	Jun-Jul		
Grey heron	*Ardea cinerea*	1.0	0.0	550	0	2450	
Great egret*	*Egretta alba*	0.0	18.4	0	10120	3000	3.4
Intermediate egret	*Mesophyx intermedia*	8.5	2.8	4675	1540	1000	4.7
Little egret	*Egretta garzetta*	3.0	0.0	1650	0	3500	
Cattle egret	*Bubulcus ibis*	124.0	27.7	68200	15235	N	
Squacco heron	*Ardeola ralloides*	7.2	38.1	3960	20955	3000	7.0
Little Bittern	*Ixobrychus minutus*	0.0	1.1	0	605	1000	
Green-backed heron	*Butorides striatus*	0.0	2.5	0	1375	10000	
Hamerkop	*Scopus umbretta*	0.2	1.9	110	1045	10000	
African Jacana	*Actophilornis africana*	0.0	29.3	0	16115	N	
Black-winged Stilt*	*Himantopus himantopus*	17.9	0.0	9845	0	770	12.0
Collared Pratincole	*Glareola pratincola*	10.5	0.0	5775	0	240	24.1
Greater Painted Snipe	*Rostratula benghalensis*	0.0	9.7	0	5335	N	
Spur-winged Plover	*Vanellus spinosus*	128.4	88.9	70620	48895	4000	17.7
Wood Sandpiper	*Tringa glareola*	120.7	0.0	66385	0	10400	6.4
Common Sandpiper	*Actitis hypoleucos*	0.0	0.0	0	0	17000	
Common Snipe	*Gallinago gallinago*	3.0	0.0	1650	0	20000	
Great Snipe	*Gallinago media*	2.7	0.0	1485	0	350	4.2
Little Stint	*Calidris minuta*	3.2	0.0	1760	0	2000	
Marsh owl	*Asio capensis*	2.9	14.1	1595	7755	N	
Yellow wagtail	*Motacilla flava ssp*	585.4	0.0	321970	0	N	
Zitting Cisticola	*Cisticola juncidis*	14.6	9.4	8030	5170	N	
Prinia spec	*Prinia ssp.*	4.7	0.0	2585	0	N	
Yellow-crowned Bishop	*Euplectes afer*	1.3	5.9	715	3245	N	
Overall total (including omitted species)		1082	252	595155	138655		

* The estimation of a number of species (e.g. Great Egret, Black-winged Stilt) seems too high, judged from additional field observations. This is related to the method (see Appendix 8).

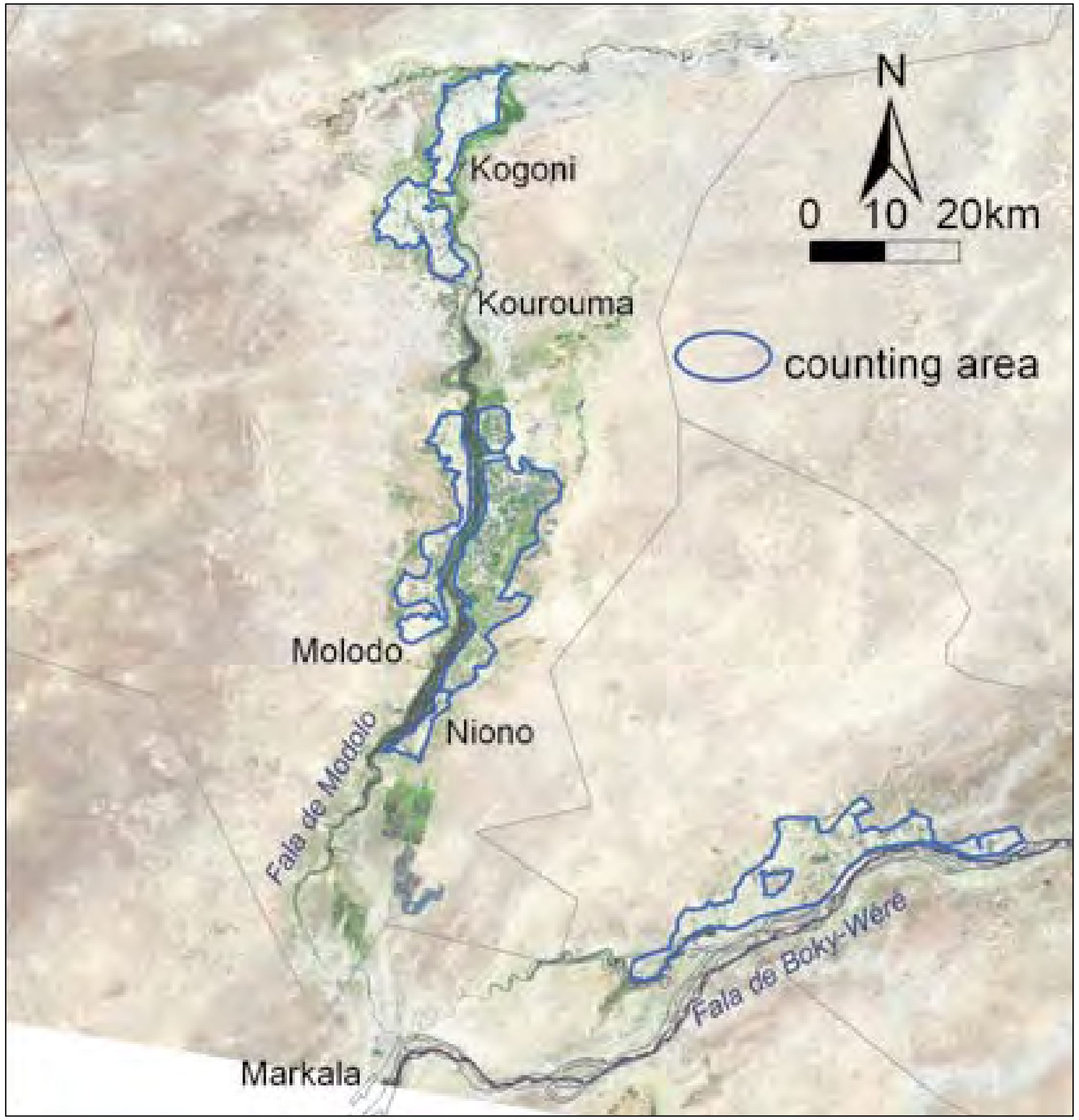


Fig. 11.11. Area within the irrigation zone of Office du Niger where density counts have been performed, and to which the population estimates in Table 11.1 correspond. See also van der Kamp et al. 2005.

the Fala area are lacking. However, using the density counts we can make a rough estimate of present numbers in the 550 km^2 large rice field area. When the 1% criteria (see Chapter 9) are applied, it appears that at least 8 species are present in internationally important numbers. The irrigation zone harbours a relatively large proportion of the populations of Spur-winged Plover *Vanellus spinosus* and Collared Pratincole *Glareola pratincola*. Also noteworthy is the presence of the endangered Great Snipe *Gallinago media*. On the basis of additional observations in the Fala´s we expect that also the Eurasian Marsh Harrier *Circus aeruginosus* and Purple Heron will exceed this criteria. Furthermore, Purple Swamphen *Porphyrio porphyrio* (hundreds), African Pygmy Goose *Nettapus auritus* (some dozens) and African Darter *Anhinga rufa* (>50), all relatively scarce species in West Africa, have been observed in substantial numbers. The African Swallow-tailed Kite *Chelictinia riocourii*, having a seasonal pattern, shows up at the end of the year and disappears in the following months. Some 3000 birds of this insectivorous species were noted at night roosts in December 2003.

Other fauna groups

There is almost no information on other fauna groups than birds. Patas *Cercopithecus patas* and Green monkeys *C. aethiops* occur in wooded areas, while Side-striped Jackal *Canis adustus* has a wider distribution. The rice area holds considerable populations of rats, mice and insects (e.g. grasshoppers, locusts, beetles, etc.) attracting avian predators like Marsh Owl, Black-shouldered Kite *Elanus caeruleus* and African Swallow-tailed Kite (see above).

According to local people Hippopotamus *Hippopotamus amphibius*, West African Manatee *Trichechus senegalensis* and Monitor Lizard *Varanus niloticus* occur on the adjacent Niger River. Fishermen near Molodo claim the incidental occurrence of Hippos, whereas rumours about crocodiles occurring in the Fala area have not been substantiated during further investigations. However, the Fala zone contains apparently suitable habitat: grassy and muddy places, huge stretches of *Typha* beds and open water with submerged vegetation and bushy shores. The permanent water bodies in the Fala areas therefore have a high potential for these species, but on the other hand they are subjected to a heavy human presence.

11.5 Future expansion: perspectives and constraints

The future consolidation and further development of Office du Niger is an important spearhead of Mali. Of the one million ha once allocated as being suitable for potential irrigation only 6% is being exploited at this moment. In 1998 Office du Niger launched a regional development plan (*schéma directeur de développement*) in which different scenario's, both short and long term, for future expansion are elaborated on. Keita *et al.* (2002) give a very useful description of the envisaged expansion and the constraints which may be met in the future. Using their results and additional hydrological information from Chapter 2 in this Section it will be clear that there are limits to the expansion.

The administrative zone of Office du Niger covers eight *'systèmes hydrauliques'*, together taking up ca. 1 million ha, which theoretically are suitable for irrigation. Only a fraction of this area, 74 km^2, is being irrigated at this moment (Fig. 11.12). In the regional development plan a conservative scenario aims at an expansion in the coming decades of 14,000-23,000 ha. With the aid of national and/or foreign investors this may be enlarged to 30,000-40,000 ha in 2020 (Témé & Tonneau 2002, cf. Bélières & Kuper 2002). Several well-wrought studies have drawn attention to the fact that, beside the high financial demands, an expansion of the irrigation zone has its hydrological and environmental limits (for example Bélières & Kuper 2002, N'Diaye 1998, Témé & Tonneau 2002, Keita *et al.* 2002). These constraints are concisely listed below.

Fig. 11.12. *Systèmes hydrauliques* in the zone of Office du Niger covering 1 million ha (from Keita et al. 2002). The study area of the regional development plan (schema directeur de développement) is even greater with 2.8 million ha.

Soil and surface area

When soil types and elevation are taken into account the one million ha of the eight *systèmes hydrauliques* (Fig. 11.12) of the zone of Office du Niger are potentially suitable for irrigation by gravity (Keita *et al.* 2002).

Hydrology

Most studies point to the hydrological constraints of an expansion, especially during the dry season with the lowest river discharge. Kuper *et al.* (2002a) already concluded that expansion is not feasible with Sélingué as a sole reservoir. Presently, the Office du Niger uses 2.4 l/s/ha as the norm for overall water use, but for the expansion 2.0 l/s/ha is taken as a goal. The bottleneck is posed by the river discharge in May-June, during the étiage. In Fig. 11.13, we see that the natural discharge is elevated by the Sélingué reservoir and till now the water intake by Office du Niger can be met (see also Chapter 2). Even in June 1999, when the water management of Sélingué caused a drop down in the river discharge (Kuper *et al.* 2002b), this did not affect the water intake at Markala. It also appears, however, that in a series of rather dry years in May (1989-1995) the natural discharge was insufficient to meet the water intake for the irrigation zone of Office du Niger, and the water intake was fully dependent on Sélingué. When the envisaged norm of 2 l/s/ha would be used an area of 100,000 ha can be irrigated with 200 m^3/s. For 200,000 ha this is 400 m^3/s and for 960,000 ha, the area which was aimed at in 1930, one needs 1900 m^3/s, as calculated by Keita *et al.* (2002). In reality this volume is even more since water must be transported over greater distances, causing a higher evaporation. The mean discharge in May and June over 1989-2003 was 239 m^3/s and 398 m^3/s respectively. This discharge, however, can not completely be used for water intake for irrigation because at least a *minimal ecological flow* is necessary to avoid downstream problems. Though this minimum required flow is not yet studied in detail, we do have some indications for this. We argue in Chapter 12 that the water level in Akka in the central Inner Delta should not fall below -0.40

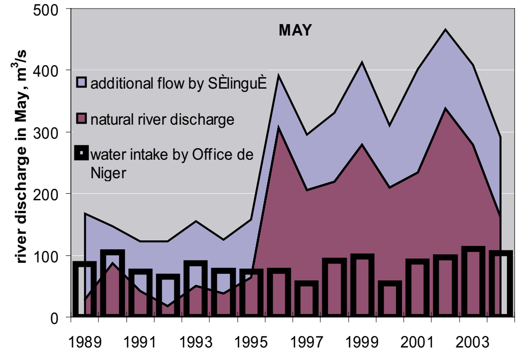


Fig. 11.13. Water intake at Markala in May during 1989-2004 compared to the natural river discharge and the additional flow at Sélingué. Source: Office du Niger.

cm for ecological as well as economical reasons (fish survival). To maintain this level at least a minimum flow of 50 m^3/s at Ké-Macina is needed. With this flow international obligations are also secured. The additional precondition of a minimum flow has consequences for the maximum intake during the *étiage*. The average intake in May (1989 –2004) amounts to 84 m^3/s. When the required minimal flow of 50 m^3/s is added, the flow must be at least 50 + 84 = 134 m^3/s. Including the additional flow of the Sélingué, the river discharge has been regularly below this level (1983, 1985, 1988, 1990, 1991, 1992, 1994, 2003).

The analysis above means that already in the current situation, during a critical part of the year, the maximum of what can be taken from the Niger river's discharge is reached in dry years. Therefore, a substantial future expansion is not possible with Sélingué as a sole reservoir, as already concluded by Kuper *et al.* (2002).

According to Keita *et al.* (2002) expansion without a higher intake in the short term is possible if the water management is improved and an adapted scheme for sowing is used, for the wet season crop as well as for the off-season crop. For the wet season crop these authors arrive at a maximal irrigated area of 108,000 ha and when double crops are used at a

total of 86,000 ha. Though they do not mention a minimum required flow they do stress the need for an integrated water management of the Upper Niger river taking into account interests upstream as well as downstream.

Soil degradation

As in all irrigation systems in the world there is always a serious risk for soil depletion/degradation and processes such as salinisation, alkalinisation and sodification. In the case of the Office du Niger irrigation zone several studies on these problems were carried out (e.g. N'Diaye 1998). Soil degradation is a common phenomenon in the Office du Niger irrigation zone. The extent to which it occurs depends on soil texture and varies a lot between locations. According to the study of N'Diaye (1998) in the zone of N'Debougou 1% of the surface area is affected, while these figures amount to 6.9 and 13% for the zones of Niono and Molodo respectively. In the short term these processes related to irrigation are not expected to raise major concerns but in the long term (> 20 years) they are a potential threat, also for a future expansion (Malet & N'Diaye 2002).

To prevent soil degradation in Office du Niger, drainage and conveyance of irrigation water is important; in the long run the present hydrological system may not be suitable for this. One of the possible solutions which is envisaged in the regional development plan is the construction of a '*Collecteur du Sahel*'. This should be a newly constructed drainage canal with a high capacity, either discharging into the Niger at Ké-Macina (east of Office du Niger, at the entrance of the Inner Niger Delta) or heading north towards Lac Debo in the centre of the Inner Delta. Given the high costs and the large amount of questions of a social, economic and environmental nature it is questionable if such a project is feasible (Bélières & Kuper 2002).

Other socio-economic and environmental constraints

The populations in the zone of Office du Niger are facing severe health problems. This concerns diseases as malaria, bilharzia and semi-epidemic diarrhoea which are strongly related to the omnipresence of shallow stagnant water and the deplorable sanitary conditions (e.g. Niono). It is to be expected that an expansion of the irrigation zone will bring along a further spread of these diseases, as has been the case in the Senegal Delta (*cf.* Peeters 2003). The enormous growth of the population in the irrigation zone (Fig. 11.2) and the presence of large herds of cattle in the dry season cause a severe degradation of vegetation in the surrounding area as well as a large demand for wood. According to Nouvellet & Sanogo (2002) the annual demand for wood has grown analogous to the population growth. They report a mean consumption of wood of 0.53 to 0.57 ton per inhabitant per year. With the actual population of 270.000 people (2001-2002) this means an annual wood consumption of 143.000 ton. The environmental and ecological pressure will grow with a further expanding population. A sustainable management of wood supplies and forests is therefore needed (Nouvellet & Sanogo 2002). The co-existence of irrigated cultivations and cattle grazing after harvesting the paddies in Office du Niger is not without concern. Especially the northern area can attract large herds from Mauritania and northern Mali the transhumance. On the one hand, the organic manure is an important source for fertilisation; on the other hand the large herds cause degradation of soil and vegetation. In particular, with regard to the off-season crops this increasingly leads to conflicts between rice farmers and herders (le Masson *et al.* 2002).

Ecological constraints and changes

Finally there are ecological constraints. The Fala area underwent a major ecological change when the dynamic water table changed into more or less stagnant conditions. As in similar wetlands habitats (e.g. Senegal Delta), this causes a rapid increase of *Typha* vegetations and intruders such as Water Hyacinth and Water Salad. Beside the ecological change, these plants also cause obstruction of the irrigation system. In the long run this can lead to a necessary mechanical clean up of the ditches and canals (assuming that a chemical treatment is not desirable). This process will take place independently of expansion.

In general, it must be stressed that expansion also provides new wetland habitat. The ecological value of the irrigated rice fields largely depends on the presence of large resting areas (water bodies, forests) where birds and animals are not being disturbed or hunted (van der Kamp *et al.* 2005). The ecological values of the irrigation zone have been underexposed up till now, but may constitute a worthwhile theme for incorporation in future developments. As a counterpart to crop damage the important function of several bird species as biological pest controllers should also be appreciated.

11.6 Conclusions

The following conclusions can be drawn from the concise description of the Niger irrigation zone:

- The Office du Niger irrigation zone covers *ca.* 74,000 ha with an annual production of *ca.* 320,000 tonnes of rice. Other crops like maize and vegetables are increasingly grown. At present Office du Niger has grown into the largest irrigation scheme in West Africa and provides a secure food resource independent of rainfall and flood performance. Nowadays the Malian rice production meets 90% of the national demand, of which the Office du Niger zone accounts for 40%. The present rice production in Office du Niger is therefore of paramount national importance.
- The recent expansion and enormous leap in production were realised independently of rainfall and without using additional water. In other words, the water has been used much more efficiently than in the past. At the same time the water intake at Markala results in downstream effects, such as a reduction of 20,000 tonnes of rice in the Inner Niger Delta, in addition to effects on fish production, livestock and biodiversity.
- Important wetland habitats in the Office du Niger irrigation zone are the irrigated rice polders and the stagnant marshes of the Fala area. A valuation of the (inter)national ornithological significance shows that at least 8 water bird species are present in internationally important numbers. All substantial forests in the Office du Niger zone provide an important potential for breeding colonies of herons, egrets and other large wading birds. The permanent water bodies in the Fala areas have a high potential for large aquatic living mammals and reptiles. In general, the current ecological values are under serious stress due to reclamation programs and other human disturbance and exploitation.
- The future development of the Office du Niger zone is an important spearhead of Mali. Several studies have drawn attention to the fact that an expansion of the irrigation zone has its hydrological and environmental limitations.

- The most important constraint is the water intake. The bottleneck is posed by the river discharge during the *étiage* when the water intake for the irrigation zone of Office du Niger is fully dependent on Sélingué.

- When respecting a minimal required flow during the critical *étiage*, necessary to avoid problems downstream, the water intake already reached its maximum during dry years in the current situation. Therefore, a substantial future expansion is not possible with Sélingué as a sole reservoir. As proposed in other studies a further expansion is

still possible, at the current water intake, with better water management and adapted crop schemes.
- Other important constraints are the degradation of soils and vegetation, the growing demand for wood and the increasing conflicts between farmers and cattle herders. Moreover, the populations in the zone of the Office du Niger are facing severe health problems, which are related to the omnipresence of shallow stagnant water and the deplorable sanitary conditions.
- The ecological values of the irrigation zone have been underexposed up till now. Attention has been paid largely to negative aspects such as crop damage and the development of intruding species such as *Typha* and Water Hyacinth. Ecological values may, however, constitute a worthwhile theme for future developments in which the important function of several bird species as biological pest controllers are also appreciated.

12

ECOLOGICAL EVALUATION OF DAMS AND IRRIGATION IN THE UPPER NIGER

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Jan van der Kamp
Bouba Fofana
Leo Zwarts

12.1 Introduction

The ecological effects of hydrological changes in the Upper Niger Basin have a far-reaching scope. The basin serves a number of functions at a regional and national level, most of which directly affect the welfare of people in Mali. Ecological changes in the Inner Delta also have an international aspect. In the Netherlands, for example, several governmental programmes are running to protect breeding waterbirds and endangered marshland birds. These programmes amount to some tens of millions of euros per annum. The species, which are supposed to benefit from these actions, are to a large extent African migrants, which stay the non-breeding season in the Sahel. The above-mentioned efforts are in vain when mortality during the non-breeding season, i.e. on their staging sites and during migration, systematically exceeds recruitment in the breeding season. A successful stay of these waterbirds in the Inner Delta depends on the hydrological and related ecological conditions. There are thus multiple reasons why ecological changes in the Inner Delta deserve international attention.

In this Chapter we look at ecological changes in the Upper Niger Basin, resulting from hydrological interventions. Section 12.2 covers the changes in habitats, including natural and man-made wetlands. In Section 12.3 we examine the impact of reduced flooding in the Inner Delta on the population levels of waterbirds and other fauna. In that Section we also introduce a minimum required flow, representing the minimum river flow during the low water season to avoid extreme low water levels in the central lakes in the Inner Delta. The conclusions of this Chapter are given in Section 12.4.

12.2 Natural versus man-made wetland habitats

The term *habitat* refers to the natural environment of plants and animals and goes beyond the vegetation in a narrow sense. Some species are specifically related to habitats, during their complete life or during a part of their lifecycle. Exemplary in this respect are bourgou fields, which are indispensable for fish fry as a nursery habitat providing protection and food (Bacalbasa-Dobovrici 1971 cited in Welcomme 1986, Paugy & Lévêque 1999), and flood forests being essential as breeding habitat for colonial waterbirds. A first step in this ecological evaluation is a survey of the changes of habitats and their quality. In this Section we demonstrate how floodplain habitats in the Inner Delta are under pressure because of hydrological changes in the basin. We also show that man-made wetland habitats - irrigated ricefields and reservoirs - do not compensate for a loss in natural floodplain habitat, because of differences in natural values.

Changes in surface area

Interventions in the Upper Niger basin, such as water retention by dams or extraction by irrigation, result in a reduced river flow (Chapter 2.5). This leads to a smaller inundated surface area (Chapter 3.6) and a shorter duration of flooding (Chapter 3.7), which particularly affects habitats that require extreme flooding conditions. In the Inner Delta these are - from low to high in the inundation zone - low lying grasslands, floating bourgou fields, Wild rice fields (*oryzaies*) and flood forests of *Acacia kirkii* (Chapter 6.3).

Using the flooding model (Chapter 3.5) and vegetation map (Chapter 6.3), we evaluated surface areas of the main habitat types under different scenarios (Table 12.1). The change in surface area of habitats is not proportionate to the change in the inundated area, as already shown in Chapter 7.3 for bourgou and in Chapter 8.3 for rice. In the baseline scenario (scenario 0) the area of floodplain habitats would have been considerably larger, though this could not be quantified for all main habitats. The impact on flood forests, for instance, is difficult to assess using this approach (Chapter 6). However, we do know that in former years with high floods the forested area was substantially larger (Chapter 9, Wymenga *et al*. 2002). In the southern Inner Delta, for instance, the shifting of rice fields to low-lying places in the inundation zone was realised by removing flood forests (Chapter 8.3). This also might have occurred in an undisturbed situation, but the chances of recovery of flood forests would have been larger under that scenario. As Table 12.1 shows, bourgou is the habitat being mostly affected. Compared to scenario 0 the proposed Fomi dam will even reduce the surface area of optimal bourgou fields with 68.6% (which is 62% relative to the present situation).

The hydrological structures in the Upper Niger also created (or will create) new wetland habitats (Chapters 10 and 11). It concerns reservoir lakes due to the dams at Sélingué and Fomi, the irrigated areas themselves, and the stagnant Fala marshes in the irrigation zone of the Office du Niger. The irrigated area at Fomi, in case the Fomi dam were build, is planned at 300 km^2 (Chapter 2.3). Comparing the total loss of inundated surface area (second row Table 12.1) with the total of man-made habitats (lower rows), we conclude that due to Office de Niger and to Fomi, new wetland habitat is created but that this did not compensate for the loss in wetland habitats downstream.

The habitat changes as a result of dams and water extraction in the Upper Niger Basin is no isolated case. Keddy (2002) shows how hydrology and fertility are two key factors that determine the kind of wetlands that occur in a landscape. He also points to the fact that the natural variety of conditions, including those with high flood levels and low fertility, is disappearing. In many wetlands in the world wetland communities become dominated by *Typha spec*. The construction of dams and the deposition of nutrients are two of the main processes behind this (Keddy 2002). This is also what happened in the Senegal Delta, where the construction of dams, in combination with eutrophication (drainage water of irrigation schemes), has resulted in a change from floodplain habitats to *Typha*-vegetations (see references in Peeters 2003). On a much smaller scale this process occurred in the Fala area in the Office du Niger zone. Under these more or less stagnant and eutrophic conditions other "pest" plants flourish (see Box 12.1). In the Inner Delta *Typha* rarely occurs, although IUCN (1989) reports "*typhaies*" in Lac Horo and in former times in the lakes Aougoundou and Faguibine. The more general phenomenon of reduction in flood dynamics has taken place in all major river systems in the Western Sahel zone. Hydrological structures in the Senegal (Diama and Manantali dam), the Bénoué (Lagdo dam) and the Chari-Logone (Maga dam, SEMRI I, II) have strongly reduced flood dynamics and consecutively the surface area of floodplain habitats in these areas. In all these case other cascading effects have been reported (Loth 2004, Ngounou Ngatcha *et al*. 2002. Peeters 2003, Scholte *et al*. 1996).

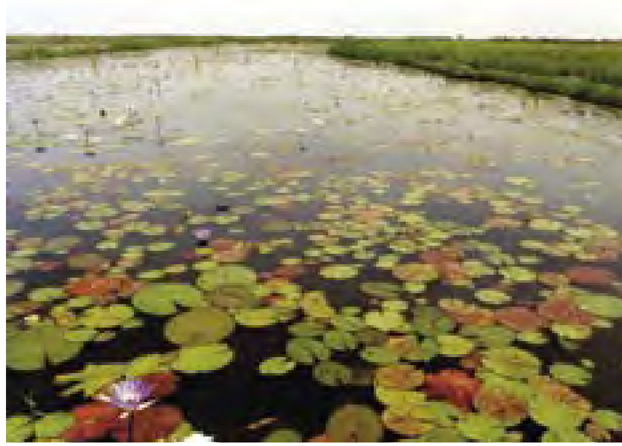
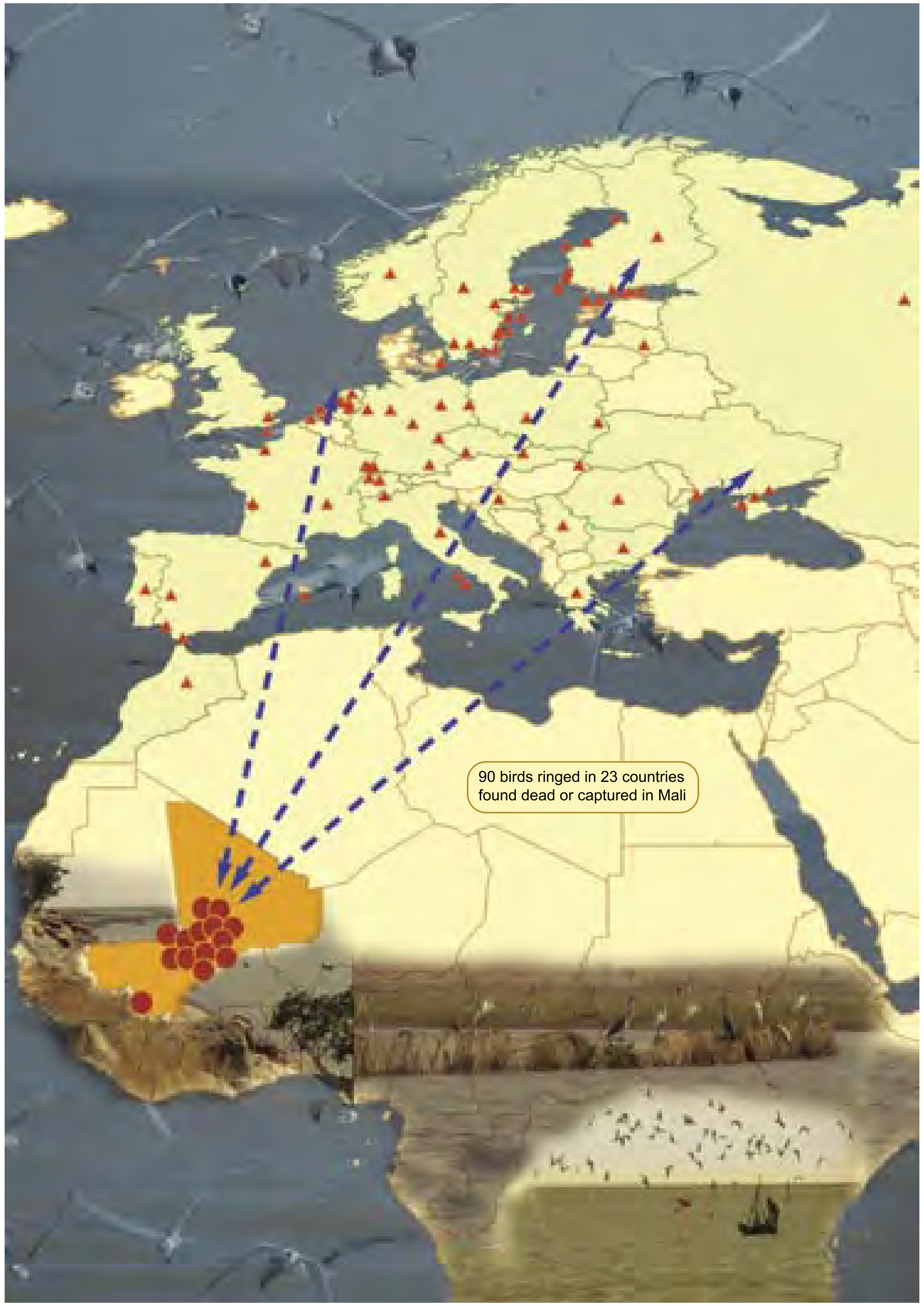


Table 12.1. Average surface area (km^2) of main wetland habitats in the Inner Niger Delta, Sélingué and the Office du Niger irrigation zone in four scenarios. For grasslands and flood forests only a qualitative indication can be given. Between brackets the proportional change is given compared to scenario 0. The surface of optimal habitat for bourgou and rice is derived from data given in Chapters 7.3 and 8.3.

Scenario	0. Without Sélingué & ON	1. With Sél. & without ON	2. Present situation	3. Present + Fomi dam
Inundated surface area	12,765	12,165	11,865	10,765
Loss of inundated surface area (relevant to Sc0)		*600 (-4.7)*	*900 (-7.1)*	*2000 (-15.8)*
Fala area - natural (dynamic) conditions	160	160	0	0
Typical floodplain habitats				
Low lying *Cyperus*-grasslands	+	-	-	- -
Optimal Bourgou-fields incl *Nénuphars*	1212	1078 (*-11.1*)	999 (*-17.6*)	380 (*-68.6*)
Flood forests of *Acacia kirkii*	+ +	-	-	- -
Wild rice fields - *Oryzaies*	+ +	-	-	- -
Optimal cultivated rice in floodplain	1090	1052 (*-3.5*)	999 (*-8.3*)	790 (*-27.5*)
Newly created wetland habitats				
Open water - stagnant lakes	0	280	280	580
Typha-marsh and stagnant open water (Fala area)	0	0	160	160
Irrigated area, most rice fields	0	13	753	1053



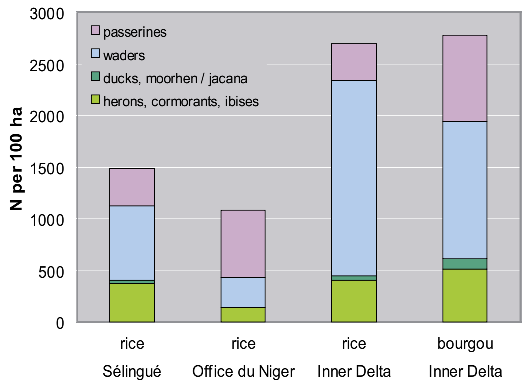


Fig. 12.1. Average density (n/km^2) of waterbirds and wetland related species in irrigated ricefields in Sélingué, the Office du Niger irrigation zone (ON rice) and in rice and *bourgou* fields on the flood plain in the Inner Delta (DIN). All data are from the period December-March 2002-2003 and 2003-2004. Number of plots sampled 330 (Sélingué), 716 (Office du Niger), 64 (rice in the Inner Delta) and 327 (*bourgou* in the Inner Delta).

Obviously, the characteristic floodplain habitats are under pressure in the Western Sahel zone, in favour of irrigated cultivations. Relatively recently, though, one has started with partial restoration of floodplain habitat, by restoring flooding conditions. Restoration projects in the Waza Logone floodplain and the Diawling National Park (lower Senegal delta) are encouraging. The results, however, are variable and dependent on local circumstances and human pressure on the newly restored habitats (Hamerlynck *et al.* 2002, Scholte *et al.* 2000a-b, Loth 2004, Hamerlycnk & Duvail 2003).

Comparing densities of waterbirds

In the framework of this study a series of plots was sampled on densities of waterbirds (Appendix 8; van der Kamp *et al.* 2005). Based on these data we compare irrigated ricefields in Sélingué and Office du Niger, with bourgou and ricefields on the floodplain in the Inner Delta (Fig. 12.1). Bird densities as well as species diversity are (considerably) higher on the floodplain. Most bird species were found in the bourgou field (46). The number of species in ricefields is relatively low and about the same for the three areas: the Inner Delta (27), Sélingué (32) and Office du Niger (23). The overall bird density in ricefields on the floodplain is much higher than that of irrigated ricefields. The higher densities on the floodplain (for other main habitats see Fig. 9.7) particularly concern waders and the group of (mostly piscivorous) cormorants and herons, and ibises. For passerines, to which the Yellow wagtail is contributing most, the differences are less pronounced.

The large difference in bird density between habitats, combined with the habitat change (Table 12.1), means that dams and water extraction result in a considerable loss of suitable waterbird habitat. In order to compare the scenarios with each other, we used a quantitative score, incorporating the international importance of the Inner Delta and the irrigated areas. In Table 12.2 this is illustrated for Grey Heron *Ardea cinerea* and Wood Sandpiper *Tringa glareola*. Using the mean bird densities, an estimation was made of the total numbers present in each scenario, based on the surface area per habitat in Table 12.1. This calculation was done separately for optimal bourgou and rice fields on the floodplain (mean densities in Appendix 8), the irrigated area at Sélingué (Table 10.1), the irrigation zone of the Office du Niger (Table 11.1) and the planned irrigation scheme at the Fomi dam (scenario 3). As bird density for Fomi the mean was taken of Sélingué and the irrigation zone of the Office du Niger.

The resulting figures for both species are given in the Table 12.2 in column "Est. Number". Next, we determined how many times the 1% criterion of the Ramsar Convention was exceeded. This score is also presented as an index in Table 12.2, setting the baseline scenario (0) at 100. The results show the impact of the different scenarios for the floodplain habitats (loss) and the irrigated areas (gain) separately. Mark the difference between the species: Wood Sandpiper profits much more from man-made irrigated rice fields than Grey Heron. This also applies to other abundant species in irrigated areas, such as Yellow Wagtail and Cattle Egret *Bubulcus ibis*.

Box 12.1

Invasive species

Under natural conditions permanent water bodies in the Western Sahel zone are not or hardly found, apart from flowing rivers and connected lakes. With the coming of irrigation works and reservoirs this has changed. These permanent water bodies with a more or less stagnant water table, not drying out during the hot dry season, offer ample opportunities for invasive species. Today, Water Hyacinth *Eichhornia crassipes*, Kabila Weed *Salvinia molesta,* Water Lettuce *Pistia stratiotes* and Red Water Fern *Azolla filliculoides* are wide spread, everywhere where man-made hydrological changes result in permanent and stagnant water conditions. Also Cat's tail *Typha australis* flourishes under these circumstances. As invasive species compete with indigenous species and obstruct waterways and irrigation canals, they are often considered as pest plants. In Sélingué and the irrigation zone of the Office du Niger some of these species are abundantly present. In the Inner Niger Delta, on the contrary, they are rarely found. Water Hyacinths do occur, however, since 2002 on Lac Fati, nowadays having a flood-controlling water inlet (dam). Water Lettuce is present in the flood forest of Dentaka, where it profits from the fertile conditions near the breeding colonies of waterbirds.

Table 12.2. Indicative valuation of scenarios based on waterbird densities. For each scenario, and separately for bourgou & rice fields in the Inner Delta and irrigated areas upstream, the estimated number, number of times the 1%-criterion is exceeded (score) and a corresponding index is given for Grey Heron Ardea cinerea and Wood Sandpiper Tringa glareola. A same calculation was done for all waterbirds for which the overall index is given in the right column. Estimated numbers are calculated from mean bird densities from December-March (Table 10.1, 11.1 and data in Appendix 8) and the surface area of relevant habitats from Table 12.1. As 1% criterion for the Grey Heron the mean is taken of West- and East-European 1% criteria (2,200-2,700 birds; see Table 9.3).

Species		Grey Heron (1% criterion 2450)			**all waterbirds**
Habitat type / scenario		Est. Number	Score	Index	*Overall Index*
Bourgou & rice fields	0. without Sél & ON	38,961	15.9	100.0	***100.0***
	1. with Sél, without ON	35,108	14.3	90.1	***93.4***
	2. present: with Sél & ON	32,667	13.3	83.8	***87.9***
	3. present + Fomi	14,681	6.0	37.7	***55.6***
Irrigated areas	0. without Sél & ON	0	0.0	0.0	***0.0***
	1. with Sél, without ON	0	0.0	0.0	***0.1***
	2. present: with Sél & ON	550	0.2	1.4	***1.4***
	3. present + Fomi	150	0.1	0.4	***1.9***
		Wood sandpiper (1% criterion 10,400)			
Bourgou & rice fields	0. without Sél & ON	492,077	47.3	100.0	
	1. with Sél, without ON	444,637	42.8	90.4	
	2. present: with Sél & ON	414,086	39.8	84.2	
	3. present + Fomi	192,114	18.5	39.0	
Irrigated areas	0. without Sél & ON	0	0.0	0.0	
	1. with Sél, without ON	5162	0.5	1.0	
	2. present: with Sél & ON	66,385	6.4	13.5	
	3. present + Fomi	77,670	7.5	15.8	

A similar calculation was done for all waterbird species. All these different indices were taken together to calculate an overall index (given in right column in Table 12.2). As an indicator of ecological effects this index has many shortcomings, since it is only based on waterbird densities in a limited set of habitats, it does not cover the full array of species and it neglects important underlying biological processes (see Section 9.3). It does, however, provide a tool to compare the scenarios with each other. The results shows, that due to the dam at Sélingué and the irrigation zone of the Office du Niger the index declines to 93.4 and 87.9 respectively. The index downstream is reduced nearly by half if the Fomi dam were build. With respect to the present situation this is a loss of 36%. The quantitative valuation, however, also makes clear that the value of man-made irrigated areas is only a fraction of floodplain habitats and obviously does not compensate for the losses downstream.

12.3 Effects on population level

This study and the work of Orange *et al.* (2002) show that the Inner Niger Delta is a flood-dependent system in all its aspects, adapted to the dynamic "flood pulse" (Arfi 2002b, see also Junk *et al.* 1989). At high flood levels food resources are amply available, which results in high levels of biological production (primary production, fish, livestock, and other fauna), a high recruitment and low mortality. When floods are low the reverse happens. The surface area of inundated floodplains decreases and consequently feeding conditions are getting worse on all levels of the system. In particular during the lowest floods there is growing competition for food resources, concentrated around the last remaining wet spots. The limits to the available food have an impact on recruitment and mortality of many organisms. Under such extreme conditions human exploitation is also concentrated, resulting in overgrazing, depletion of fish stocks and increased exploitation of waterbirds. In this way, flood reduction might lead to lower population levels of, for example, birds. This will be further explained in the next Section.

The depletion of natural resources during periods of low flood levels, by human local populations, is unsustainable. However, they hardly have alternatives for it. As a consequence they are locked in a vicious circle of poverty since overexploitation also reduces the chances of recovery of these resources. Overgrazing for instance, especially grazing the young sprouts, hampers the regrowth of bourgou fields (Chapter 7.3). Forests of *Acacia seyal*, which occupy the higher levels in the inundation zone, also are affected in this respect. Zwarts & Diallo (2002) showed that in the early 1980s still large forested areas where present north of Akka. One would expect these forests to regenerate on lower elevations during periods with low levels of flood, since the higher parts of the inundation zone become unsuitable (too dry). However, heavy grazing prevents such a shift, while at the same time the existing forests are being cut or die. Nowadays the *A. seyal* forests north of Akka have nearly vanished.

Recruitment and mortality in relation to reduced flooding

The variation and distribution in numbers of waterbirds and the occurrence of other fauna in the Inner Delta is largely determined by flood performance (Chapter 9; van der Kamp *et al.* 2002a,b). As illustrated in Chapter 9, recruitment of resident breeders is positively related to the inundated surface area, probably with feeding conditions as underlying factor. Mortality of staging waterbirds shows a similar, but negative dependency. Reduced flooding thus has a negative effect on recruitment and results in a higher mortality. Since recruitment and mortality directly translate into numbers of individuals, reduced flooding leads to lower population levels.

The *average* reduction of the flood peak by Sélingué, the water intake by the Office du Niger and the planned Fomi dam is 15, 7, and 45 cm respectively (Chapter 3.6). Note that these reductions have most effect in years with low floods (Table 3.4). To illustrate the effect of flood reduction, we use the reproduction of the Kittlitz plover, expressed as the proportion of juveniles in the population (Fig. 9.10). The annual proportion of juveniles in recent years varied between 4 and 15%. The reproduction would have been 1.5 to 4% higher without the dam at Sélingué and the water intake by the Office du Niger. In case the Fomi dam were build there is a reduction of 9,2%, on average. In the current situation reproduction reaches critical levels below flood levels of about 440 cm. When the Fomi would be in operation, such low levels will be reached more frequently. Similar calculations can be made for the other relationships found in Chapter 9. The Fomi dam therefore is expected to have a severe impact on population levels of species as Long-tailed cormorant, African darter (Fig 9.9), Kittlitz plover, and a wide range of heron and egret species. This may also put the breeding colonies of cormorants, ibises, herons and egrets at risk.

Timing of pre-migratory fattening

The timing of migration of Palearctic waterbirds needs special attention. Waterbirds in the Inner Niger Delta congregate in the Walado Debo-complex during the 'décrue' to feed on fish and benthic fauna in shallow water (Chapter 9.3). Van der Kamp *et al.* (2002b) showed that the harvestability of the benthic fauna depends on water level. Only a fraction of the total food resources are actually available for birds, because of the fast rate of decreasing water level (ca. 5 cm daily). As soon as the low-lying banks become exposed the benthic fauna – snails, bivalves, etc. – dies in the hot climate, and is not consumed any more. During most years the waterbirds succeed

in profiting from these food resources in February-March and fatten up for their long-distance migration to the northern breeding grounds. However, at very low flood levels the availability of these food resources does not coincide with the period of pre-migratory fattening. Hence, birds may fail to fatten up for migration with extreme mortality as a result (Fig. 9.11, Chapter 9). Responding to a low flood level by advancing the onset of migration is no real option. The timing of migration, and thus the moment of fattening, is fixed since the birds have to arrive at a certain time in their breeding areas.

The significant reduction of flood level by the planned Fomi dam (on average 45 cm) increases to 60 cm in years with low floods (Table 3.4). This enhances the chance that the timing of migration of Palearctic waterbirds will run out of phase with the short period during which food resources are available in the Walado Debo-complex. This may have far-reaching consequences for these migrants. Further research is needed to define the critical limits of this "migration window".

Overexploitation and minimum required flow

A critical period during the year is the '*étiage*', the period with the lowest water levels. This period is roughly extending from mid March to the end of June. During the *étiage*, water bodies in the Inner Delta are very scarce (Fig. 3.5) and consequently food resources are low. A distinct feature of a flood-pulse system is the adjustment to highly dynamic flooding conditions and the ability to recover after drought periods (e.g. Arfi 2002b). Exemplary in this respect are the flood forests of Akkagoun and Dentaka which, when protected from grazing and cutting on the initiative of the IUCN, showed a spectacular recovery since 1987 (Beintema *et al.* 2002). In addition, the restoration project in the Waza Logone floodplain demonstrated the capability of regeneration after (partly) restoring the flooding conditions (Scholte *et al.* 2000a, 2000b, Loth 2004). Extreme drought periods and subsequent recovery are a recurring phenomenon in the Sahel (e.g. during 1910-1914 and the early 1940s). Recovery in our times, however, is heavily impeded by human pressure. This is an enormous difference between the past and the present.

In the present situation there is an extreme fishing pressure in the Walado Debo-complex, when water levels are very low during the *étiage* (own observations, Quensière *et al.* 1994). In short term this provides extra income and food, but in the longer run it is detrimental for fish stocks, and consequently for dependent organisms. Also other food resources are heavily exploited (e.g. by concentration of grazing livestock) and the survival of waterbirds and other organisms is at risk. Therefore, we advocate the necessity of a *minimum required flow* downstream of Markala to avoid excessive and unsustainable depletion of natural resources.

An indication for a minimum required flow can be obtained from the water levels during the étiage. The flood level in the Inner Delta is at its minimum in June. There is a linear relationship between the water level in Akka in June and the combined flow of the Niger at Ké-Macina and the Bani at Douna in May:

Akka = 0.565 x flow +62,

where:

Akka = water level (cm) in June

flow = river discharge of Bani+Niger in May , m^3/s

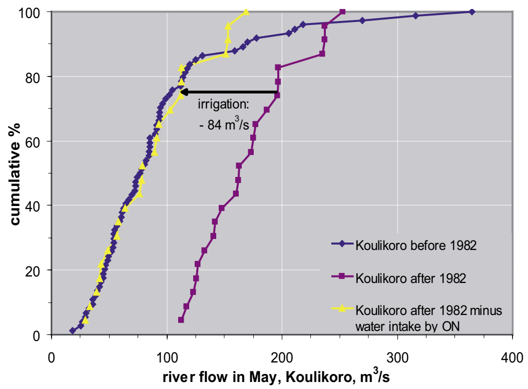


Fig. 12.2. The cumulative frequency distribution of the river flow in May at Koulikoro in two periods: 1907-1981 and 1982-2004. Since Office de Niger takes at Markala in May, on average, 84 m^3/s, the yellow line shows the flow since 1982 downstream of Markala.

According to this function, the water level at Akka is 0 cm at a flow of 110 m^3/s. The water level decreases to –20, –40 and –60 cm at a flow of 75, 39 and 4 m^3/s respectively. In years when the water level decreases to –40 cm (such as occurred in 1984 and 2003), Lac Walado looses its connection with Lac Debo and runs dry. The average river flow of the Bani in May amounts to only 22 m^3/s, on average, which is low compared to the average flow of the Niger in May: 110 m^3/s. Hence the contribution of the Bani to a required minimum flow in dry years is insignificant. To prevent that Lac Walado will fall dry, a minimum required flow of 50 m^3/s is required.

Fig. 12.2 demonstrates that flows below 50 m^3/s were not exceptional before 1982, when the Sélingué reservoir dam became operative: in 18 years of 74 years, the flow in May was below 50 m^3/s. After 1982, with the releases from Sélingué, the river flow at Koulikoro was never lower than 113 m^3/s, thus far above the required minimum. However, the current water intake by Office de Niger in May amounts to, on average, 84 m^3/s (Chapter 11.5). When this water loss is substracted from the river flow at Koulikoro, the river flow in May appeared to have been below 50 m^3/s in 6 of the 23 years since 1982 (Fig. 12.3). Hence, with the current water intake by Office de Niger, years with extremely low flood level in June occur as often as in the past. A further increase of the water intake at Markala in May, would imply a larger risk of unsustainable exploitation of the natural resources in the Inner Delta.

A minimum required flow is not the only way to avoid excessive depletion of fish stock. Additional measures may include the introduction of protected fishing zones. Such zones are successful in the Chari river in Cameroun where they are introduced with support of the local communities (Anonymous 2004).

Longitudinal fish migration

An issue not covered in this study, but important with respect to dams in the Upper Niger Basin, is longitudinal fish migration. This migration enables fish to occupy different habitats during the flood cycle and avoid unfavourable conditions. Daget (1954, 1957) paid specific attention to fish migration in the Upper Niger Basin. Some species move upstream at the beginning of the flood to spawn in upstream riverine floodplains. Daget (1952, cited in Welcomme 1986) mentions dry-season movements of some species, especially of *Brycinus leuciscus* which migrates upstream from the central lakes as the water recedes. Before the Markala dam was built, this species was reported to migrate distances up to 400 km. According to Laë (1995) the dams do not affect the reproduction of many fish species since spawning areas are situated downstream. For a number of species, however, the upward migration is disrupted, and reduction in species is mentioned for *Gymnarchus niloticus*, *Polypterus senegalus* and *Gnathonemus niger*.

It is common knowledge that (longitudinal) fish migration is blocked by dams. The current dams may affect fish production in the floodplain (Chapter 5), but the few available studies do not report that they are detrimental for fish populations in the Upper Niger Basin with respect to migration (Laë 1992a, 1992b, 1995, Quensière 1994). This may change, however, when new dams are built. Specific research related to this subject seems a necessity.

12.4 Conclusions

- The realised and envisaged construction of dams in the Niger river has a significant negative impact on valuable floodplain habitat in the Inner Niger Delta. Construction of the Fomi dam will reduce the surface area of floating bourgou fields in the Inner Delta with approximately 60%. Bourgou fields are a key habitat in the floodplain for people, fish and birds.
- Newly created man-made wetlands upstream, consist of irrigated rice fields, lakes, and swamps with near-stagnant water tables. They do not compensate for the loss of valuable floodplain habitat downstream. The ecological quality of bourgou fields, in terms of species diversity and numbers of waterbirds, is many times larger than that of man-made habitats. Ecological valuation shows that the latter habitats may only compensate a few percent of the value which will be lost by creating the Fomi dam.
- Given the strong relationship between flood levels and reproduction of African waterbirds the construction of dams results in lower reproduction. In case of the Fomi dam this will have a severe impact on the population of species as Long-tailed cormorant, African darter, Kittliz plover, and a wide range of heron and egret species. The largest - and one of the last - breeding colonies of cormorants, ibises, herons and egrets in West Africa will we pushed to the edge of extinction.
- Similarly, the realised and envisaged dams lead to a higher mortality of staging waterbirds. This is particularly critical for several species for which the environmental conditions in the Inner Delta play a crucial role in determining the population size.
- The reduction of flood level by the planned Fomi dam increases the chance that the timing of migration of Palearctic waterbirds will run out of phase with the short period during which food resources are available in the Walado-Debo-complex.
- At very low water levels, human exploitation of the natural resources in the Inner Delta may become excessive. To avoid unsustainable depletion of resources a *minimum required flow* downstream of Markala is advocated. This minimum flow is set at 50 m^3/s.

13 ECONOMICS OF DAMS AND IRRIGATION IN THE UPPER NIGER

Pieter van Beukering
Bakary Kone

13.1 Introduction

The Poverty Reduction Strategy Paper (PRSP) of Mali constitutes the sole framework for Mali's development policies and poverty reduction strategies (GoM 2002). This influential document highlights the need to exploit the country's hydroelectric and hydro-agricultural potential, in the order of 5,000 GWh/annum and 2 million hectares, respectively. A review of the PRSP by the International Development Association (IDA) and the International Monetary Fund (IMF) confirms this, stating that "further development of Mali's untapped hydrological potential is a critical need, as it directly addresses one of Mali's core vulnerabilities, that of the temporal and spatial variability in rainfall, as well as the uncertainty of climatic conditions" (IDA & IMF 2003).

Although Mali's hydroelectric and hydro-agricultural potential has yet to be fully realised, it is widely questioned whether the costs and benefits of such mega-investments are properly estimated. Besides the economic feasibility (i.e. direct costs and benefits) of additional dams, it is still unclear what the indirect effects of hydroelectric and hydro-agricultural schemes are on downstream beneficiaries of rivers.

The overall aim of this Chapter is to support decision making at basin level with regard to management and construction of dams and irrigation schemes in the Upper-Niger in relation to food security and ecological conditions in the downstream Inner Niger Delta. This is achieved by conducting an extended cost benefit analysis (CBA) for the main economic sectors addressed in the previous chapters.

The Chapter is structured as follows. The methodology underlying the cost benefit analysis of dams and irrigation schemes in the Niger River basin is explained in Section 13.2. The valuation of the direct costs and benefits of the Office du Niger, Sélingué and the Fomi dam is conducted in Section 13.3. The indirect costs and benefits of the four scenarios are estimated in Section 13.4. The indirectly affected sectors include agriculture, fisheries, livestock, transport and biodiversity. In Section 13.5, the extended cost benefit analysis is conducted. Conclusions are drawn in Section 13.6.

13.2 Methodology

In estimating the costs and benefits associated with dams in the Niger River basin we are not taking a novel approach. Cost-Benefit Analysis (CBA) is an indispensable economic tool in any large infrastructure project. Dams are no exception. Traditionally, a CBA was performed using a limited set of parameters. In most cases the costs were restricted to the direct capital investment, construction costs and operational costs. Likewise, only direct (measurable) benefits, such as power generation, irrigation benefits and tourism were taken into account. Nowadays, social and environmental effects are increasingly considered in the planning of dams, through the application of an extended CBA. This analysis requires economic valuation of indirect costs and benefits (Aylward *et al.*, 2001).

Several extended CBA studies have been carried out in the past. The World Commission on Dams (WCD 2001) investigated eight projects in detail. Two of these are situated in Africa: (1) the Orange River Development Project in South Africa; and (2) the lake Kariba dam in Zambia and Zimbabwe. A third interesting study in Africa, which was commissioned by IUCN, focussed at the effects the Maga Dam on the Waza-Logone floodplain area in Cameroon (Loth 2004). These studies have been described in more detail in Annex IX.

Cost benefit analysis of dams

Like any other large infrastructure project, dams require large investments in the planning and construction phase. Investments take the form of financial capital as well as technology and human resources. In comparison with initial investment costs, operation and maintenance costs for dams are relatively low. Besides initial investments and operational costs, large dam projects often have significant impacts on society and the natural environment, representing an additional cost to the project. The best example of social impacts caused by large dam projects is the displacement and resettlement of inhabitants of the flooded area. Whereas resettlement used to be overseen in the planning phase in the past, at present resettlement costs are increasingly budgeted in project planning. Environmental impacts associated with dams include reduction in wetland habitat and restricted fish migration. As with social impacts, the costs of mitigating environmental impacts are included in project planning more than in the past.

Estimation of direct costs

Costs for dam construction projects vary significantly as a result of site characteristics. It is therefore difficult to give a general overview on the costs. Based on the World Commission on Dams (WCD, 2001), which conducted a large survey on the costs of dams throughout the world, we attempt to summarize general findings. As indicated above, direct costs for dams can be divided into 4 main categories: (1) construction costs; (2) resettlement costs; (3) environmental mitigation costs; and (4) operation and maintenance costs (O&M).

Table 13.1. Subdivision of Environmental costs according to size of hydropower project. Source: WCD 2001.

Project size	Type of Cost (US$1991)			
(installed capacity)	Capital	Study	O&M	Reporting
<1MW	$134,500	$21,700	$5,124	$5,900
1-10 MW	$233,900	$153,200	$25,420	$11,800
10 - 50 MW	$1,511,300	$452,800	$33,000	$31,200
50 - 100 MW	$1,266,200	$1,084,000	$9,600	$500
>100 MW	$50,569,000	$307,000	$1,439,400	$176,700

Construction costs are the major component of total project costs in most cases. Construction costs refer to the building of the dam itself as well as all related elements, such as turbines, canals, irrigation schemes etc. The base cost estimates are corrected with a 10-15% to cover unforeseen costs and are subsequently corrected for inflation over the construction phase. Costs depend mainly on the physical setting of the project, with considerable variance in costs caused by differing local geology, making it difficult to give a generalization of construction costs. A study by Head (1999) gives a range of US$1,000 to US$3,000 per KW of generated electricity for hydropower projects, while Ljung (2000) provides a range of US$1,500 - US$2,250 per KW.

In the past, the displacement of people and loss in livelihood resulting from reservoir flooding was not considered in project planning. Recently, resettlement and income restoration (jointly called 'resettlement costs') have gained increasing attention in project design. Direct compensation of those affected is also being included in the design. Gutman (1993) found that estimated resettlement costs were typically overrun by 40%. Resettlement costs can amount to between zero and 25% of total project costs, depending on the local demographic situation.

Dams can have large environmental impacts. To counter negative impacts, mitigation measures are often included in dam design. Examples are fish migration systems, habitat restoration and artificial flooding of wetlands. Environmental mitigation costs are subdivided into study costs, capital costs, operation and maintenance costs and reporting costs. Table 13.1 shows an overview of these costs for hydropower projects in the USA.

One of the attractive features of large dam projects is the relatively small share of operational costs once the construction is completed. On average, these costs amount to only 1-3% of the total project costs. For irrigation projects these costs are generally higher due to high maintenance costs of the irrigation network. Oftentimes, the costs are covered by charging user fees for irrigation.

A major issue with dam projects worldwide remains the, at times, enormous cost overruns. For example, a study of 70 World Bank financed hydropower project shows that the average cost overrun is around 27%. Another study into multipurpose dams comes to an average of 39% over budget. A WCD study (2001) into smaller dams reports overruns of as much as 200%. The majority of cost overruns are due to unpredicted geotechnical conditions. Other causes include late delivery of materials, labour unrest, legal challenges as well as changes in dam design and natural disasters. Another major impact on economic performance of a dam is the projected time schedule in comparison to the actual construction time. Schedule slippage amounted to 80% in a survey done by the Asian Development bank in 1995. Cost overruns and schedule slippages have large implications on the performance of dam projects. Around 8 to 10% of the scheduled dams actually become financially unviable after taking into account these unforeseen overruns and slippages (Gutman 1993, OED 1996).

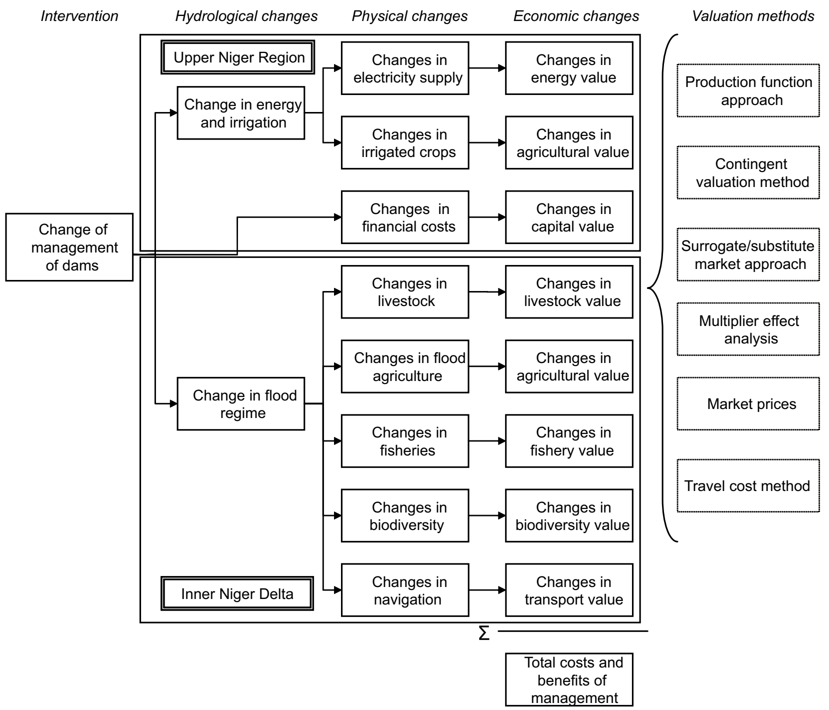


Fig. 13.1. Impact pathway of the economic evaluation procedure of management of the Inner Niger Delta, Mali.

Estimation of indirect costs and benefits

To determine the indirect costs and benefits, a wide range of information is required. A consistent way to organise this information is to pursue the sequence of underlying processes, starting with the cause of an impact, on to the physical impact and ending with the social and economic effects. This so-called "impact pathway approach" is a methodology that proceeds sequentially through the pathway, linking causes to impacts, and valuing these impacts subsequently. The framework of the impact pathway is shown in Fig. 13.1 and represents the physical and socio-economic processes resulting from the management of dams and irrigation schemes in the Niger River. The impact pathway approach proceeds in a series of methodological steps. These include:

(1) Defining the boundaries of the study: The study aims at evaluating different water management scenarios along the Niger River, with a special emphasis on the Inner Niger Delta. These scenarios include: **Scenario 0**: No dam or irrigation scheme; **Scenario 1**: Sélingué dam; **Scenario 2**: Sélingué and Office du Niger; and **Scenario 3**: Séligué, Office du Niger and the Fomi dam. Moreover, the temporal boundary of the project is set at the period 2005 to 2030. This period leaves enough time for the main environmental impacts to come into effect, while it is sufficiently short to make a reliable prediction about future developments.

(2) Identifying significant impacts: Due to practical limitations, the analysis is limited to including the most significant effects only. Inevitably, judgement must be used in deciding what is and is not significant. To judge the magnitude and significance of environmental effects, a range of criteria is identified: (a) The effect on the natural, human, chemical and physical environment depending on their relative sensitivities; (b) The location of the effect, whether within the confines of the site and beyond (local, regional, national and international scale); (c) Timing of the effect (during the construction, operational and post-operational stage); and (d) Whether the effect is reversible or irreversible. Using expert judgment in combination with these criteria, it was decided that the impacts on fishery, agriculture, livestock, transport and biodiversity can be regarded as economic activities in the Inner Niger Delta that are significantly affected.

Effects that are potentially significant, but on which little knowledge is available are the health impacts of dams. On the one hand, dams and irrigation schemes improve human health because of the increased provision of food. On the other hand, they may have a negative effect on health because the expansion of stagnant water boosts the occurrence of malaria and bilharzias. Due to the lack of information on health effects, this effect has not been included in this study.

(3) Physically quantifying the significant impacts: The evaluation of the physical effects of the management of the dams and irrigation schemes is a complex exercise. In the previous chapters, the relationship between the flooding area and the physical production levels of the individual sectors has been estimated, using the production function approach. To assist in predicting the aggregated physical consequences of the various scenarios, a dynamic simulation model has been developed. The model approximates the main effects of each scenario on the various benefit categories and evaluates the changes for the various districts (i.e. upstream and downstream). To calculate these impacts, simplifying assumptions have been adopted, such as for climatic and hydrological conditions, and future economic activities. For example, the assumed population and population growth rates used in this study are presented in Table 13.2 (data from Chapter 4).

Another crucial assumption applied in the economic analysis is the one on climate. Fig. 13.2 shows the trends of rainfall in the Upper Niger region and in the Inner Niger Delta for the period 1926 to 2000 (data from Chapter 2.2). Both series show a clear negative trend. In the simulation model we extrapolate the trend for the study period of 2005 to 2030. The impact of this assumption is tested through a sensitivity analysis.

Another important assumption underlying the model is the annual climate variations. As can be observed from Fig. 13.2, the annual rainfall in the catchment area of the Upper Niger varies between 1,100 and 1,900 mm, with an average amount of 1,500 mm. It is important to simulate these variations in the scenarios because it is generally not the average level that matters but the extremes. For example, in an extremely dry year the impact of dams have a disproportionately large effect on

Table 13.2. Demographic and geographic data at the Cercle level.

Cercle	Population 2004	Growth rate (%)
Tombouctou	70,177	0.08%
Gourma	67,717	-1.34%
Goundam	130,583	0.91%
Diré	84,393	0.09%
Niafunké	122,988	-0.34%
Tenenkou	127,237	1.47%
Mopti	263,719	1.54%
Djenne	155,551	1.42%
Youwarou	85,426	0.22%
Segou	494,609	2.05%
Macina	164,838	1.91%
Niono	198,749	3.28%

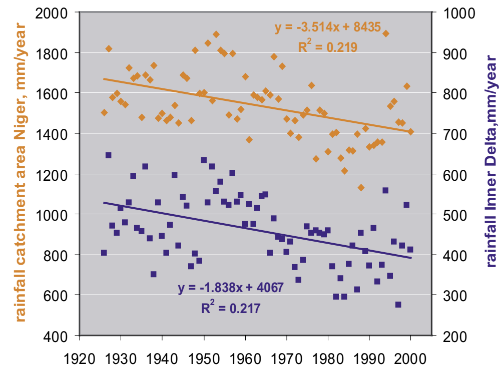


Fig. 13.2. Rainfall trends in the Upper Niger region and the Inner Niger Delta in the period 1926 to 2002.

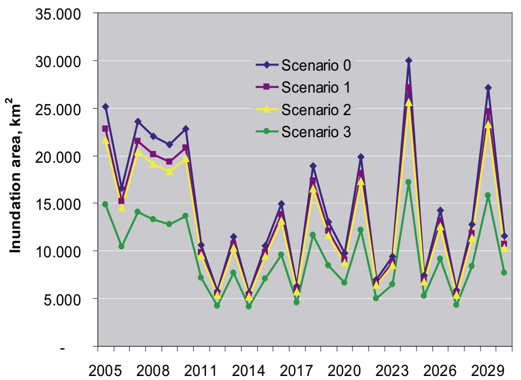


Fig. 13.3. Simulated flooding area for the four scenarios (in km²).

the economic activities in the Inner Niger Delta. Therefore, a random variation in rainfall patterns has been applied in the time series of 2005 to 2030. The maximum variation in rainfall is set at +/-20%. The impact of both short-term yearly variation and the long-term negative trend in climate change on the flooding area has been shown in Fig. 13.3.

(4) Calculating monetary values and conducting a sensitivity analysis: Having established and tabulated the full range and significance of the effects, changes are valued in monetary terms. The main impact pathways that are covered include agriculture (Chapter 8), fisheries (Chapter 5), livestock (Chapter 7), biodiversity (Chapter 12), energy supply (Chapter 2) and transport. As shown on the right-hand side of Fig. 13.1, different valuation techniques are used for these benefits. The most commonly used valuation technique in this study is the net factor income approach which estimates the value of an environmental input in production by subtracting the costs of other inputs from total revenue, and ascribes the remaining surplus as the value of the environmental input. For most of the sectors considered, statistical production functions have been estimated. These were incorporated in the integrated model simulating the four scenarios. The main welfare indicator of the model is the net-benefit of each scenario, which expresses the overall welfare level minus the financial costs of the dams and irrigation schemes. A sensitivity analysis was conducted to test the robustness of the final outcome, in relation to a number of crucial parameters such as climate change, biodiversity and the discount rate. More information on the valuation techniques applied in economic studies on wetlands is provided in Appendix XI.

As shown in Fig. 13.1, another important dimension of the impact pathway approach is the spatial allocation of welfare. Besides having an impact on the absolute level of welfare in Mali and Guinea, establishing dams in the Upper Niger region is likely to generate a transfer of economic benefits from one region to another. The model has therefore been designed at the district level so that a distinction can be made between benefits that occur in the Inner Niger Delta (i.e. livestock, agriculture, fisheries, biodiversity and transport) and those that are generated in the upstream region (i.e. electricity and irrigated crops).

Box 13.1.

Definition of costs and benefits

In the field of CBA often ambiguity may arise with regard to the exact definition of costs and benefits. The main basis for the demarcation of costs and benefits in this study is the stakeholders' perspective. In this study, 'costs' only refer to those direct financial effects that are relevant for the decision-maker who is directly responsible for the financial feasibility of the investment. These values are internal or private to the investment decision. An example of costs in this study is the investments of constructing and maintaining the dams. 'Benefits' are referred to as those effects that arise external to the direct domain of the financial decision-maker. The value of benefits can be both negative (e.g. decline of fisheries in the Delta) and positive (e.g. increase of revenues from irrigation schemes).

13.3 Costs

The cost benefit analysis of the three man-made structures in the Upper Niger is some-what unusual because it compares the Office du Niger irrigation zone and the Sélingué dam, which were established a long time ago, with the Fomi dam, which is yet to be built. To make a fair comparison, we consider a future time period of 2005 to 2030, in which we assume all dams can be active and subsequently generate benefits. However, the cost side of the analysis is more complicated because, as opposed to the investments in the Fomi dam, the initial investments in Office du Niger and the Sélingué dam have already been made. These 'sunk costs' can therefore not be avoided by future decisions.

The presence of sunk costs does not imply that Office du Niger and the Sélingué dam are free of costs. Despite the fact that the initial investments were sometimes made decades ago, the dams still require maintenance and operational expenditures. In addition, the dams consumed capital that could have been spent on alternative economic activities in Mali (i.e. opportunity costs) and therefore need to be valued accordingly.

In valuing the capital costs the following assumptions have been made. First, the capital stock is assumed to depreciate by 0.5% per year. Of the rehabilitation costs made in the past, we assume 25% of it to be additional investments in fixed capital (e.g. roads, canals, turbines). Moreover, in the early stages of operation of the dam and the irrigation scheme, the operational and maintenance (O&M) costs are assumed to be 2% of the value of the capital stock (WCD 2001). Due to increased failure and wearing of the infrastructure, this fraction increases by 1.25% per year. Therefore, the more recently the dams and irrigation schemes have been established, the lower the O&M costs. For example, the present O&M costs of Markala barrage and the Sélingué dam are assumed to be respectively 4.21% and 2.73%.

International funding agencies and national donors covered most of the investments in dams and irrigation schemes in Mali. In the case of Office du Niger, for example, the French Government covered the initial investment costs while the French and the Dutch Ministries of Development Cooperation funded most of the rehabilitation costs. The World Bank also provided substantial funds to rehabilitate the Markala dam and its irrigation area. It is not clear whether, and how much, interest is actually being paid by Office du Niger and the Sélingué dam. Yet, even if the funds have been provided as a grant and organisations of both dams do not actually pay interest for these funds, the capital still represents a scarce good and therefore should be valued accordingly. After all, the same funds could have been invested in other economic activities. Therefore, we assume an opportunity cost of capital of 8% of the actual capital stock.

Sélingué

Limited information is available on the financial costs of the Sélingué dam. As shown in Table 13.3, an initial investment of around €53.4 million was made in the period from 1980 to 1982 for the construction of the Sélingué dam and associated infrastructural works. In 1993 Energie du Mali received a credit of US$ 4.8 million for rehabilitating the hydroelectric scheme. This was followed by the Sélingué Rehabilitation Project, which ran from 1996-2002, requiring funds of the amount of US$ 34.2 million. The goal of the rehabilitation project was to increase the thermal capacity of the system, overall capacity building and the establishment of a long-term institutional framework. This brings the total investment costs to more than € 92 million, assuming an exchange rate of 1 between US$ and the Euro.

Office du Niger

Table 13.4 shows the investments that have been made in the past 80 years. These estimates include the costs of the construction and rehabilitation of the dam itself as well as the development of the irrigation area, which presently measures around 70,000 hectares. As mentioned before, the irrigation area is expected to expand further by another 40,000 ha by 2030. The cost of the expansion of the irrigation area is estimated at €2,300 per hectare. On the basis of projections provided by experts, it is assumed that the irrigation area will grow by approximately 1,500 ha per annum.

Table 13.3. Financial costs of Sélingué dam (in €).

Year	Initial Investment	Rehabilitation by Energie du Mali (funded by IDA)	Rehabilitation by World Bank and European Development Bank	Total costs
1980-1982	53,361,793			
1993		4,800,000		4,800,000
1996-2002			34,210,000	34,210,000
Total	53,361,793	4,800,000	34,210,000	92,371,793

Table 13.4. Financial costs of Office du Niger (in €).

Year	Initial Investment	Rehabilitation by French & Dutch	Rehabilitation by World Bank	Total costs
1919-1920	2,700,000			42,700,000
1945	161,000,000			161,000,000
1979		3,030,000		3,030,000
1979-1983			4,500,000	4,500,000
1985		43,770,000		43,770,000
1988		23,400,000		23,400,000
1989-1992			9,000,000	9,000,000
1989-1997			48,800,000	48,800,000
1993		23,900,000		23,900,000
1995		20,780,000		20,780,000
1996		4,990,000		4,990,000
Total	163,700,000	119,870,000	62,300,000	385,870,000

Source: Schreyger (2002), Slob(2002).

Fomi dam

The construction of the Fomi dam was initially considered several years ago. Therefore, most of the background information originates from the late nineties (Agence Canadienne pour le Développement International 1999). Still, limited financial information is available. The 42 meter high dam is expected to produce 374 GWH per month and is scheduled to provide irrigation to almost 30,000 ha of cultivable land (UNIDO 2004). Similar to the Office du Niger, the costs of the irrigation area are estimated at €2,300 per hectare. It is assumed that the irrigation area will develop over a period of 15 years, gradually expanding by 2,000 ha per year. The construction period of the Fomi dam itself will take 44 months. Table 13.5 shows the limited financial information available.

Table 13.5. Initial investment costs estimated in 1999 (in million 1999 US$).

Cost item	Detailed cost estimate by SNC
hydraulic works	199
transmission infrastructure	62
engineering & management	27
Total costs	288

Source: Agence Canadienne pour le Développement International 1999

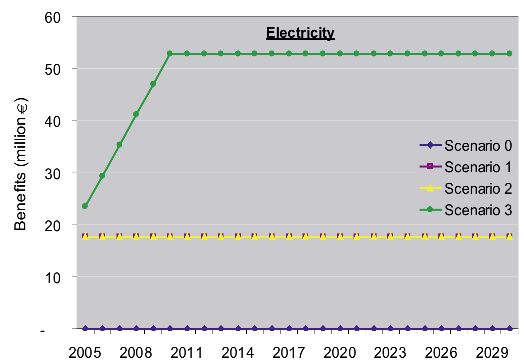


Fig. 13.4. Predicted revenues from electricity production for the four scenarios.

Electricity

Theoretically the installed capacity of the Sélingué hydropower plant is 47.6 MW. This means that the plant could produce 34.8 GWh per month under the condition that all four turbines are available and the reservoir is full. In reality the maximum generated energy was around 25 GWh per month, which is around 70% of the theoretical value. The specified firm energy of 18 MW corresponds to about 13 GWh per month (more details in Appendix II). This is the average estimate that is applied in this CBA. The Sélingué power plant is expected to produce a stable supply of electricity over time. The value added of one kilowatt-hour is FCFA75. The exchange rate applied for the FCFA against the euro is 660. Because the Fomi hydropower plant is scheduled to have a maximum installed capacity of 90 MW at full head, we assume that the power production is twice as big as Sélingué: 26 GWh per month. It will take 6 years for the Fomi power plant to be in full operation. The same value of one kilowatt-hour is assumed. Fig. 13.4 shows the pattern of revenues from electricity supply.

13.4 Benefits

A number of economic activities downstream are heavily affected by management interventions in the dam and irrigation regimes upstream. This Section focuses specifically on these indirect costs and benefits.

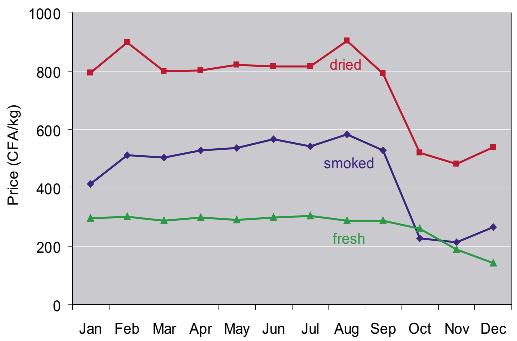


Fig. 13.5. Seasonal fluctuations of fish price for different types on the basis of data from the period 1972 to 2002 (FCFA/kg). Source: OPM-annuals.

Fisheries

The fishery sector is one of the leading economic activities in the Inner Niger Delta (Chapter 5). The economic value of the fishery industry varies due to fluctuations in catch levels as well as variations in the fish price. Fig. 13.5 shows the monthly variation of the price in the different types of fish production based on the average for the period of 1998 to 2002. One possible explanation for the seasonal fluctuation is the level of catch, which is also seasonally dependent. The flooding season causes a significant decline in the overall catch. The catch triples during the dry season. Monthly variations are not taken into account in the simulation model. Therefore, the average value of fish is estimated at FCFA 500 per kg (source: OPM-annuals).

As explained in detail Chapter 5, fisheries are heavily affected by changes in the inundation areas. Fig. 13.6 shows how the fishery sector varies over time. The short-term fluctuations are caused by the standard variation in climate conditions. Clearly, with each additional dam in operation, the fishery industry is reduced further. Therefore, scenario 0 generates the highest benefits. The difference in fish catch is particularly high during wet years.

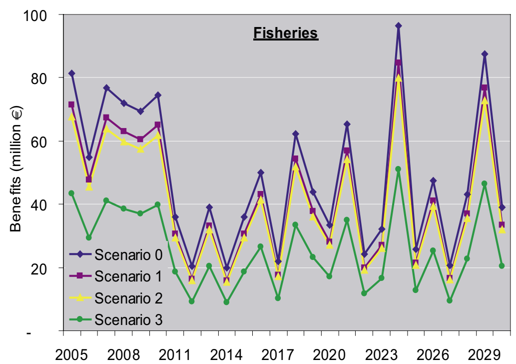


Fig. 13.6. Benefits in the fishery sector over time for the four scenarios (in million €/year).

Livestock

Livestock is valued on the basis of its meat value. It is assumed that on average 2 and 8% of the sheep and goat, and cattle is slaughtered and marketed each year (Annual reports of the Direction Générale de l'Elevage). The weight of the animals varies across the cercle, but the average weight of cattle and sheep is calculated 85 and 9 kg. The average meat price for cattle and sheep in this analysis is 600 and 400 FCFA/kg.

Fig. 13.7 shows the fluctuations of the livestock sector for the four scenarios. Several interesting observations can be made. The scenarios show less sensitivity to short-term climate fluctuations. This is the result of the ability of cattle to move to greener fields. Still, livestock is vulnerable to long-term droughts. This is demonstrated by the collapse in livestock in the period 2010 to 2013 which are modelled as extremely dry years. Another lesson from Fig. 13.7 is that in extremely wet years (i.e. 2005 to 2010) the presence of dams can actually benefit cattle, sheep and goat. This is due to the fact that livestock heavily depends on the availability of bourgou. If the water level is too high, bourgou is negatively affected, and so is the cattle (Chapter 7.3). By tempering the extreme peak flows and thus creating a more optimal

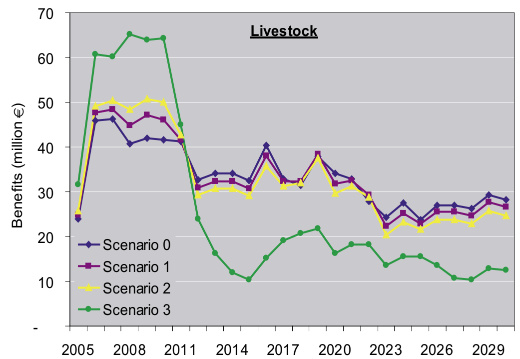


Fig. 13.7. Benefits in the livestock sector over time for the four scenarios (in million €/year).

bourgou habitat in extremely wet years, scenario 3 performs well in periods with abundant rain. By reducing the peak flow far beyond optimal levels in extremely dry years, scenario 3 performs poorly during the years with exceptionally little rain.

Agriculture

The agricultural sector in and around the Inner Delta can be subdivided into irrigated agriculture (Chapter 11) and flood-related agriculture (Chapter 8). The production functions derived in these chapters have been applied in the simulation model. Despite the observed fluctuations in the price of crops, the value added of rice and other crops has been assumed to be FCFA 95,000 and 75,000 per ton, respectively.

Fig. 13.8 shows the simulated scenarios for the agricultural sector. The main contribution to agricultural production in Mali comes from Office du Niger. The present production of Office du Niger is assumed to expand by 1,500 ha per year. The other important source of rice, sorghum, and other crops in the region is expected to be the Fomi dam. Parallel to the implementation of the hydropower capacity, the irrigation fields are developed over a period of 15 years, at 2,000 ha per year.

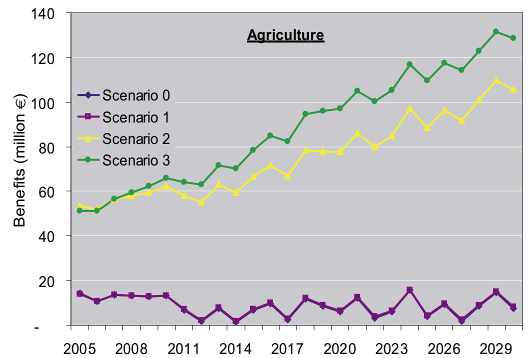


Fig. 13.8. Benefits in the agricultural sector over time for the four scenarios (in million €/year).

Transport

The Niger river plays an important role in the transport of goods and people. Particularly during the wet season, boats are the most popular means of transport in the Delta. Not only does river transport allow people and goods to reach remote places, transport by boat is also relatively inexpensive compared to road transport. As shown in Table 13.6, distances in Mali are significant.

In valuing the transport value of the Niger river,

a distinction is made between the big boats with a maximum capacity of around 400 people and 350 tons of goods and the smaller boat with a capacity of around 10-20 people and 1-5 tons of freight. Big boats need at least 3 to 4 meters of depth, while the smaller boats can still navigate at a depth of 1 meter. Table 13.7 summarises the current capacity and the economic value of the fleet of big boats. Information on the smaller boats is not readily available. Therefore we assume that the fleet of smaller boats has a similar capacity as the larger boats.

Dams and irrigation schemes have an impact on the navigation potential of the Niger River by reducing the water level in the wet season while providing additional flow during the dry season. Reducing the deep-water navigational period, specifically affects larger boats. The additional depth of the Niger in the dry season is particularly useful for smaller boats. The number of navigational days for the four scenarios at various water levels is shown in Fig. 13.9 (based on data given in Chapter 3: Fig. 3.14). Comparing Scenario 0 (no dams) and Scenario 3 (three dams), shows that the latter scenario would lead to an additional 82 days of navigation for the smaller boats while the operational season of the larger boats would be reduced by 20 days.

The results of the model simulation for the transport sector are shown in Fig. 13.10. The scenarios that perform best are the Sélingué dam and Office du Niger. These dams secure sufficient water in the dry season for the smaller boats without causing too much damage in the wet season for the larger boats. Depending on whether the year is relatively wet or

Table 13.6. Transport routes on the Niger River.

Route	Distance (in km)
Koulikoro-Ségou	180
Ségou-Macina	154
Macina-Mopti	170
Mopti-Niafunké	225
Niafunké-Diré	86
Diré-Tombouctou	85
Tombouctou-Gao	408

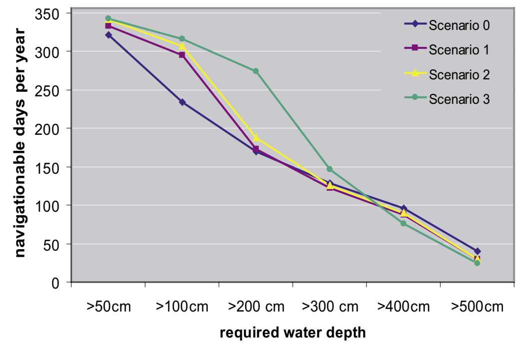


Fig. 13.9. Average seasonal variation of navigational depths at Mopti for the different scenarios based on the simulations for the period 1982-2002 (in number of days in an average year).

Table 13.7. Underlying assumptions of transport analysis for the big boats.

Data	Persons	Unit	Freight	Unit
Maximum capacity	64,613	*Persons*	34,125	*Tons*
Maximum capacity	58	*Million person-km*	31	*Million tonne-km*
Price per unit	13	*CFA/Person/km*	127	*CFA/tonne per km*
Value of transport	727	*Million SFA*	3,890	*Million SFA*

Source: COMANAV

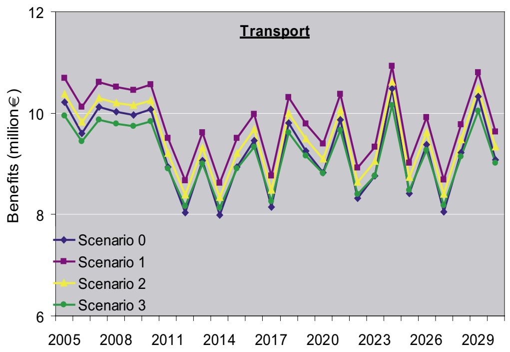


Fig. 13.10. Benefits in the transport value over time for the four scenarios (in million €/year).

not, scenario 0 (no dams) and scenario 3 (Fomi) switch position. In extremely dry years, the Fomi dam performs better in transport terms, while in wet years, the absence of dams is preferred.

Biodiversity

As explained in Chapter 12, biodiversity in the Inner Niger Delta is unique in the world. Therefore, the biodiversity in Mali also represents an economic value. To capture this value, a survey was carried out in the Netherlands in which Dutch citizens were asked about how much financial support they would give for protection of birds in the Netherlands and in sub-Saharan Africa. The results of this survey have been reported in Van Beukering and Sultanian (2005). In summary, the study shows that birds are important for many people in the Netherlands. More than a half of the 800 respondents are willing to pay for protection of bird's habitats. The average willingness to pay is estimated to be around €15 per household per year. If extrapolated across Europe, the fund available for migratory bird protection is more than €2 billion.

Given the importance of Mali as a winter residence for many European migratory birds, we assume that 1% of this amount is available for bird protection in Mali in 2005. The level of these funds is assumed to vary in relationship to the ecological value. As explained in the previous Chapter, the ecological value of birds in the Inner Niger Delta and the irrigation areas is estimated at 7,019 ecological points in scenario 0. Therefore, we fix the price of one ecological point at €3,200 (i.e. 1% of €2 billion divided by 7,019). Because the ecological score varies over time for the four scenarios, a hypothetical economic value for biodiversity can be derived. As opposed to the other sectors, the biodiversity estimate is highly hypothetical and is likely to be significantly higher or lower. However, because we consider excluding this value from the CBA more damaging than including it, we decided for the latter approach. The impact of this assumption on the final result is tested for in the sensitivity analysis (Section 13.5).

The results of the simulation modelling are shown in Fig. 13.11. Birds in the Inner Niger Delta depend heavily on bourgou. As explained in Chapter 7, bourgou does not grow well in extremely deep waters. This is the reason why scenario 2 scores somewhat better than scenario 0 in extremely wet years. However, across the full period, a situation without dams generates the highest biodiversity value. Scenario 3 leads to an extremely low value of biodiversity in the Delta. The reduced flooding surface that results from the Fomi dam forces the water birds to concentrate in limited areas which not only restricts the availability of food but also makes them more vulnerable for human exposure.

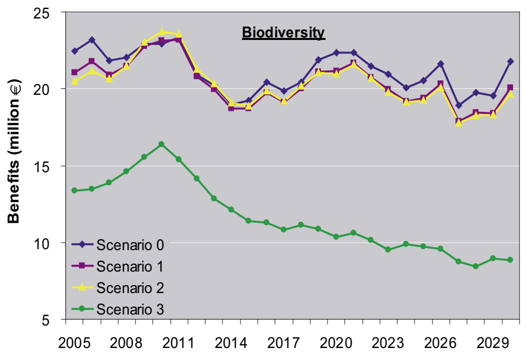


Fig. 13.11. Benefits in the biodiversity value sector over time for the four scenarios (in million €/year).

13.5 Cost benefit analysis

Benefits and costs over time

Fig. 13.12 presents the overall costs and benefits for the four scenarios over the full period of 2005 to 2030. Strictly looking at the benefits, which are shown in the upper part of Fig. 13.12, it is clear that more dams also lead to higher overall benefits. In practically each year, the benefits of scenario 3 (i.e. 3 dams) exceed the benefits of scenario 2 (i.e. 2 dams), which in turn exceeds the benefits in scenario 1 (1 dam). In other words, human intervention can lead to higher revenues for the society at large. Yet, higher benefits do not necessarily imply higher welfare levels. The cost of each scenario should also be taken into account.

The middle part of Fig. 13.12 shows the overall costs over time for the four scenarios. Not surprisingly, a similar ranking pattern arises as in the benefits graph. Obviously, 3 dams cost more than 2 dams, and 2 dams cost more than 1 dam, etc. Yet, the cost differs from the benefits in two ways. First, the difference between the scenarios is much more pronounced in the cost graph. Especially, the combination of three dams (scenario 3) requires significant investments and maintenance costs. This is mainly due to the fact that the Fomi still needs to be built while the Office de Niger and Sélingué dam are already in operation. Second, compared to the benefits, the costs are much more predictable and constant over time as they are independent of climate conditions.

The lower part of Fig. 13.12 resembles the net benefits over time for the four scenarios. Net-benefits are defined as the overall benefits minus the overall costs. The ranking of the scenarios on the basis of net-benefits is changing over time. Due to the high initial investments of the Fomi dam, scenario 3 generates low net-benefits in the first few years but these increase as soon as the Fomi dam gradually go into operation. Typically, the net-benefits of scenario 2 exceed those of scenario 3 throughout the full period. From the fluctuations of the net-benefits in Fig. 13.12, it can also be concluded that dams are particularly beneficial during years of abundant rain. During wet years the foregone benefits downstream are significantly less.

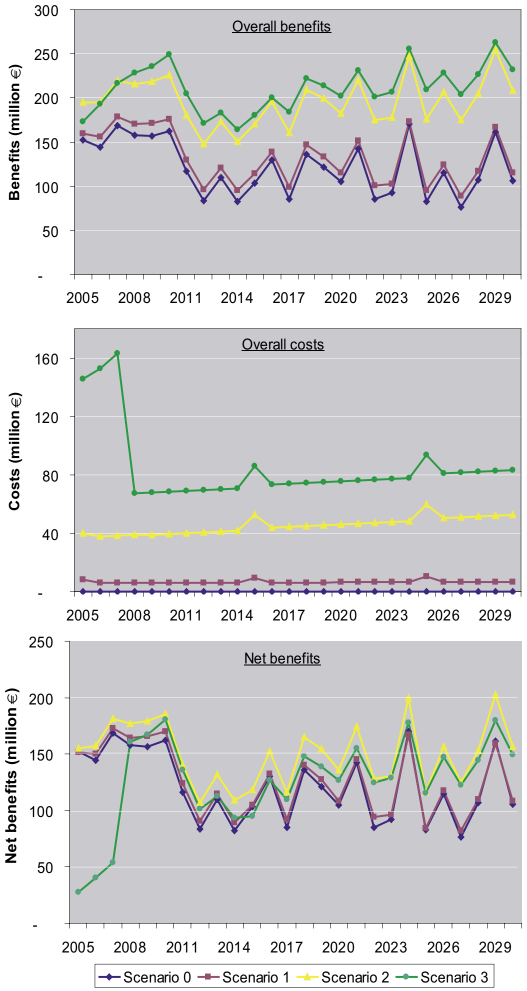


Fig. 13.12. Overall costs and benefits of the four scenarios over time (2005-2030).

Net present value

The next step in analysing the benefits and costs of the four scenarios is to sum up the annual benefits and costs over time. Economists aggregate values over time by converting the annual costs and benefits into present values (PV) by discounting. Discounting is the practice of placing lower values on future benefits and costs as compared to present benefits and costs, reflecting peoples' preferences for the present rather than the future. The discount rate applied in this study is 5%. To demonstrate the impact of this rate, a sensitivity analysis for a range of discount rates is also performed. The calculation of the present value costs and benefits is explained in more detail in Appendix X.

Table 13.8 shows the PV of the *overall* net-benefits of the four scenarios aggregated over the full period (column 2) and as annual values (column 3), respectively. These values represent the total net economic value of each scenario. Both columns show that scenario 2 generates the highest net-benefits while scenario 3 generate the least. This implies that the addition of the Fomi dam has a negative impact on the overall economy.

To analyse the exact individual economic impact of the three combinations of dams, the difference of the dam scenarios with scenario 0 (no dams) is considered. These additional net-benefits of the three dam scenarios are calculated by subtracting the overall net-benefits of scenarios 0 from the net-benefits of scenario 1, 2 and 3. Columns four and five of Table 13.8 show the marginal PV of the aggregated and annual net-benefits of the three dam scenarios, respectively. By looking at the difference between scenario 2 and 3, the additional net-benefit of the Fomi dam to the present situation (Markala and Sélingué) can be determined. By building the Fomi dam, society at large will lose more than €500 million (i.e. €121 + €380 million), which implies an annual loss of €35 million (i.e. €8.5 + €26.4 million). The Sélingué dam generates additional net-benefits of €68.5 until 2030. The Markala dam is the most economically feasible dam of the three by generating aggregated net-benefits of €312 million (i.e. €380 - €69 million), which is equal to almost €22 million per year (i.e. €26.4 - €4.8 million).

Sectoral distribution

The additional net-benefits of the scenarios are comprised of changes in various sectors in the economy. The sectors have been described individually in the previous Section. The configuration of the different sectoral benefits is shown in Fig. 13.13. The negative values represent the accumulative financial costs of

Table 13.8. The net present value (NPV) of the net-benefits of the four dam scenarios calculated by subtracting the overall costs from the overall benefits (net benefits) and comparing the changes of scenarios 1, 2 and 3 relative to scenario 0 (marginal) which resembles the absence of dams.

	Overall		Marginal	
Scenario	PV of net-benefits (*in million €*)	PV of annualised net-benefits (*in million € per year*)	PV of net-benefits (*in million €*)	PV of annualised net-benefits (*in million € per year*)
Scenario 0	1,903	132	-	-
Scenario 1	1,971	137	68.5	4.8
Scenario 2	2,283	159	380.2	26.4
Scenario 3	1,781	124	-121.8	-8.5

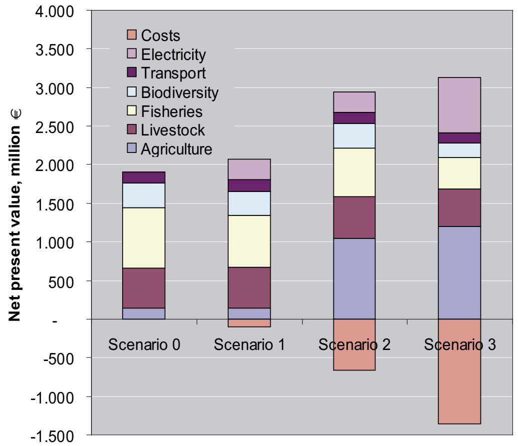


Fig. 13.13. Allocation of the NPV of the related costs and benefits of the four scenarios (26 years, discount rate 5%).

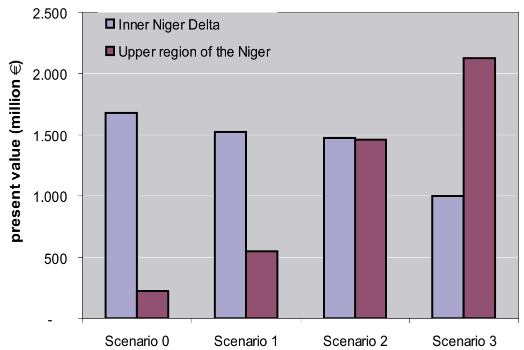


Fig. 13.14. Spatial distribution of the overall benefits divided between the Inner Niger Delta and the Upper Niger region, which includes Mali and Guinea.

each scenario. The costs clearly increase more than proportionally with the addition of the Fomi dam. Although these additional costs are partly compensated for by additional electricity and agricultural benefits, the loss in fisheries, livestock and biodiversity are also substantial. The impact of the Office du Niger and Sélingué are much less pronounced. Fig. 13.13 also shows that a society without dams (scenario 0) mainly generates income through fisheries and livestock. No electricity is produced and agriculture remains rather limited.

Spatial distribution

An important dimension of the study is the spatial distribution of the benefits under the different scenarios. Besides changes in the absolute level of welfare, dams are likely to cause transfers of benefits from one region to the other. Fig. 13.14 shows the allocation of the overall benefits between the Inner Niger Delta and the Upper Niger region. The Upper Niger region includes all those cercle in Mali and Guinea in which dams generate economic activities such as irrigated agriculture and hydropower. In Mali these cercle are Segou, Macina, Niono and Yanfolila. The pattern in Fig. 13.14 clearly shows that with each additional dam, benefits are transferred from the Inner Niger Delta to the Upper Niger region. This transfer is especially large in scenario 3. This implies that the construction of the Fomi dam will substantially benefit Guinea at the expense of the economy in Mali.

Fig. 13.15 shows a more detailed spatial allocation of the overall benefits of the four scenarios across the various cercle. In a situation without dams, Mopti and Ténenkou are the economic centres of the Niger dependent districts. In the present situation, in which both Markala and Sélingué are in full operation, Ségou dominates the river-related economy. Due to the reduced water discharge in the Niger river caused by the Fomi dam, Ségou economic benefits decline, while the Guinean economy increases substantially.

Another way of looking at spatial distribution is to consider the benefits per person in each cercle. Fig. 13.16 shows the different levels of the per

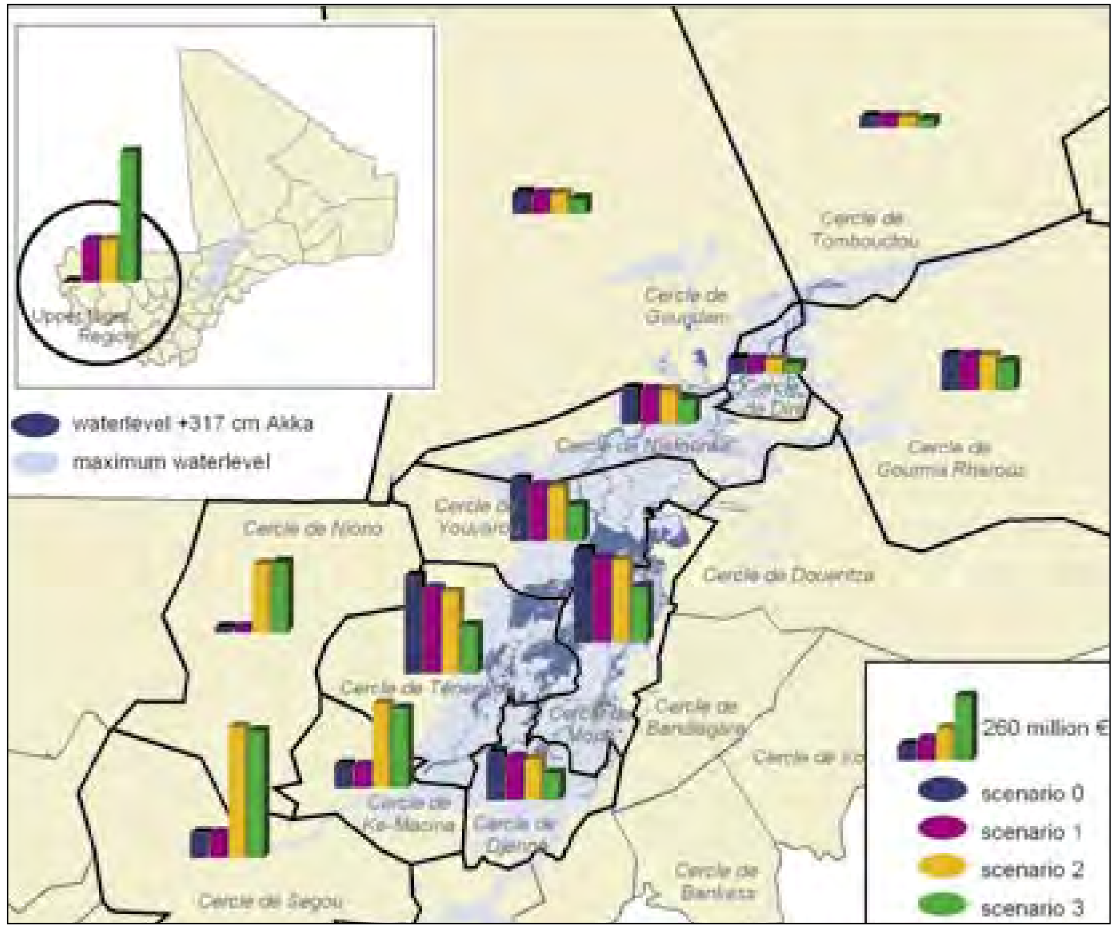


Fig. 13.15. Spatial distribution of the overall benefits across the different cercle for the four scenarios in million € (26 years, discount rate 5%).

capita benefits derived from the Niger river for the four scenarios. Several remarks should be made that explain the outcome presented. First, the current trends in population change have been exogenously extrapolated for the period 2005 to 2030. In reality, these trends are likely to depend on the scenario because more economically successful regions usually attract immigrants from the less prosperous regions. Second, the levels shown in Fig. 13.16 are below the average income levels generally known from the Inner Niger. On the one hand, this may imply that the available statistical data applied in this study underreport the real income generated in the considered economic sectors. On the other hand, it should be realised that the results refer to the river related sectors only. A number of other important economic activities such as road transport, retail and commerce have not been included in the estimates presented in this study. Finally, note that the per capita benefit for the other Upper Niger region in scenario 3 cannot be calculated because the Guinean population benefiting from the Fomi dam is unknown.

Despite these possible methodological caveats, several important lessons can be drawn from the data shown in Fig. 13.16. Clearly, those cercle that are located in the Inner Niger Delta exhibit a significant decline in per capita incomes with an increase of the number of dams. The economic benefits of the Upper Niger cercle obviously show an opposite relationship with the number of dams. Only the establishment of the Fomi dam has a negative impact on the per capita income. For the average Mali citizen, the Markala and Sélingué dam somewhat improved the level of welfare. The average river-related benefit increases with each dam from €44 (scenario 0), to €48 (scenario 1) and €68 (scenario 2). The Fomi dam is expected to reduce the Niger associated welfare of the involved Malinese population from €68 to €52 per capita.

Finally, the spatial distribution can also be presented specifically for the different economic sectors that are active in the cercle. The current allocation of benefits (scenario 2) is presented in Fig. 13.17. In this situation, the region "other Upper Niger" represents the cercle Yanfolila only. The configuration of benefits varies significantly between the different cercle. Gourma depends mostly on livestock benefits while Téenenkou and Mopti are typical fishery disctricts. Ségou, Macina and Niono benefit mostly from revenues derived from irrigated agriculture while Yanfolila benefits predominantly from power generation and some fishery income from the reservoir.

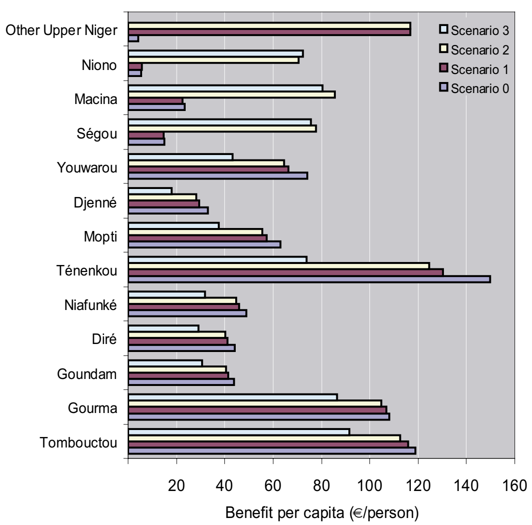


Fig. 13.16. Spatial distribution of the overall per capita benefits generated from the Niger river across the different cercle for the four scenarios in €/person (26 years, discount rate 5%).

Sensitivity analysis

A large number of assumptions have been made to be able to generate the results. This is necessary, given the constraints of data and the time available for this research. These assumptions need not be problematic as long as the results are relatively robust vis-à-vis changes in the assumed parameter values. In this stage, the sensitivity of the outcome is tested for two of the most crucial assumptions: the discount rate, climatic conditions and the valuation of biodiversity.

The standard discount rate used for the economic analysis of the management of the Niger River is 5%. Fig. 13.18 shows the results of this sensitivity analysis for a range of 0 to 15%. Two observations can be made from the graph. First, at a discount rate of zero percent, which implies no discounting occurs, all dam combinations generate a positive NPV of the net-benefits. Second, the curves do not intersect. This means that the ranking of the three scenarios remains the same regardless of the discount rate applied. Therefore, the results are robust as far as the discount rate is concerned.

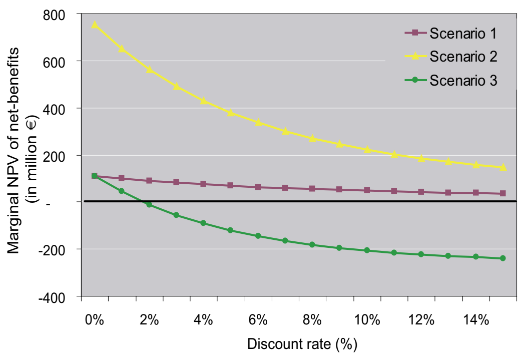


Fig. 13.18. Sensitivity analysis of the impact of the discount rate on the NPV of the net-benefits (in million €).

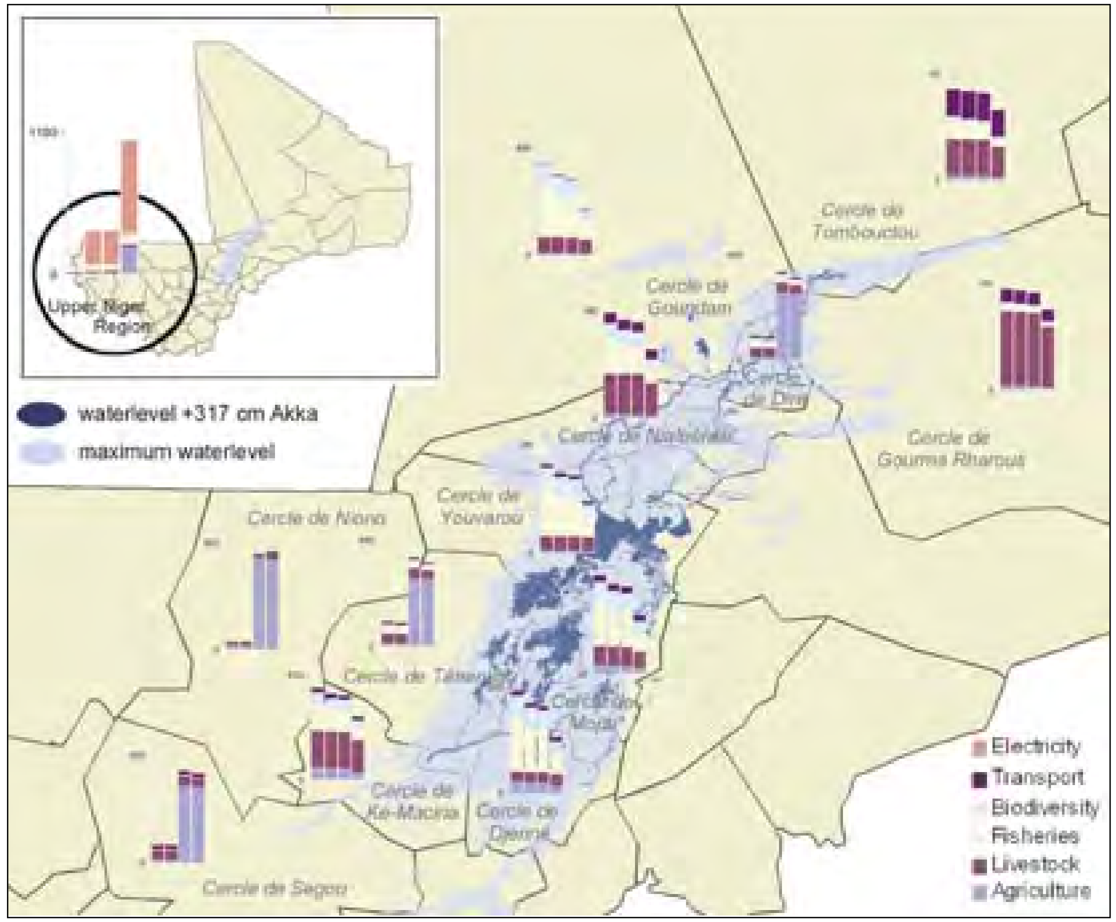


Fig. 13.17. Spatial distribution of the benefits across the different sectors for each cercle for the four scenarios in million € (26 years, discount rate 5%); bars from left to right: scenario 0, 1, 2, 3.

The second crucial assumption in the study concerns the climatic conditions in the Upper Niger region. On the basis of the previous 75 years it was estimated that rainfall declines by 3.5 mm each year. Due to the overall trend of global warming, this rate of decline may well accelerate over the coming decades. To test the impact of an increased trend of climate change, the reduction in rainfall is subsequently increased by 25%, 50%, 100%, and 150% for the different scenarios. The results of this sensitivity analysis are shown in Fig. 13.19, separately for the Inner Niger Delta and the Upper Niger region. Both regions suffer from increased drought conditions, be it to a different degree. For all three scenarios, the Inner Niger

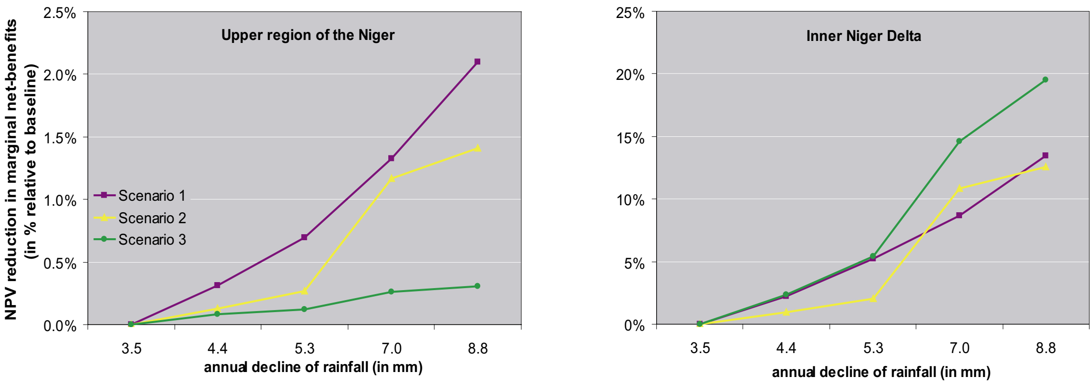


Fig. 13.19. Sensitivity analysis of the impact of more extreme climate conditions on the NPV of the net-benefits (in million €).

Delta is much more vulnerable to drought than the Upper Niger, especially in case of the presence of the Fomi Dam.

The final assumption that is tested is the impact of the biodiversity value on the final outcome. At present, the biodiversity value is mainly an expression of preferences by European citizens. In other words, more biodiversity in the Delta leads to higher welfare in Europe. Only a limited share of this benefit is actually transferred to the communities in the Inner Niger Delta. Because the biodiversity value is a real value measured in Europe and because it is expected that this European biodiversity value is increasingly being used in Mali to protect birds and other types of nature, the estimated value is actually incorporated in the cost benefits analysis in this study. It may be argued, however, that the extent to which the measured biodiversity value will ever benefit the Delta itself is significantly smaller. Therefore we test the sensitivity of the final outcome by assuming that only 10% of the expressed biodiversity value will actually benefit the Malian economy.

The results are shown in Fig. 13.20. The additional net-benefits of the dams have slightly improved as a result of the decline in the biodiversity value. The economic feasibility of the Sélingué and the Markala dam remain intact. The feasibility of the Fomi Dam is somewhat improved so that the losses in the Inner Niger Delta are at least compensated for by the gains in the Upper Niger region. Nevertheless, the addition of the dams still leads to a decline in the additional net-benefits. This sensitivity test shows how biodiversity considerations in the Inner Delta by itself do not fully change economic decisions, yet by making it part of the equation, biodiversity can play a crucial role.

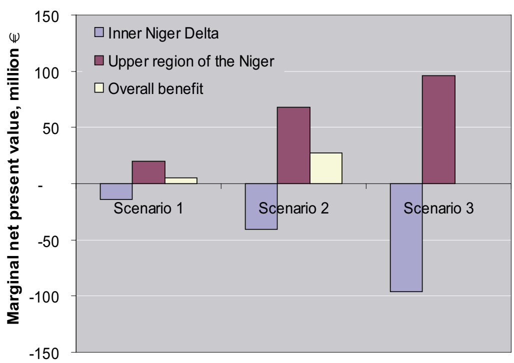


Fig. 13.20. Sensitivity analysis of the impact of the decimation of the biodiversity value on the NPV of the net-benefits(in million €).

13.6 Conclusions

By combining information provided by hydrologists, ecologists, engineers, fishery experts, and agriculturalists, the economic analysis is the final step in a long series of scientific exercises. Despite the fact that simplifying assumptions were made, several conclusions can be drawn:

- The economic value of dams in the Niger River depends predominantly on the amount of water diverted from the river. The Sélingué and the Markala dam appear to be economically feasible. They jointly generate €26.4 million of benefits per year to the society at large. The addition of the Fomi dam to the two existing dams reduces economic prosperity by €35 million per year.
- The benefits are comprised of various sectors and vary widely depending on the level of water diversion from the Niger River. The additional financial costs of the Fomi dam are only partly compensated by additional electricity and agricultural benefits. Moreover, the indirect loss in fisheries, livestock and biodiversity downstream dominate these direct revenues. These negative downstream effects are less pronounced in case of the Office du Niger and Sélingué.
- Besides changes in the absolute level of welfare, dams are likely to cause transfers of benefits from one region to the other. The results clearly show that with each additional dam, benefits are transferred from the Inner Niger Delta to the Upper Niger region. This transfer is especially large in case of the addition of the Fomi dam, which substantially benefits Guinea at the expense of the economy in Mali.
- Dams in the Niger have mixed effects on poverty. The population of the Inner Delta experience a significant decline in per capita income with an increase of the number of dams. The per capita economic benefits of the Upper Niger population show an opposite relationship with the number of dams. The average river-related benefit per person increases with each additional dam from €44 (no dams), to €48 (Sélingué) and €68 (Sélingué and

Markala). The Fomi dam is expected to reduce the river associated welfare of the involved Malinese population from €68 to €52 per capita.
- Finally, the sensitivity analysis of climatic conditions reveals that especially the Inner Delta and, to a lesser degree, the Upper Niger regions suffer from increased drought. The vulnerability of the Inner Niger Delta is substantially enhanced by the construction of the Fomi Dam.

14
SUMMARY AND CONCLUSIONS

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14.1 Introduction

Many people living in the semi-arid, western Sahel fully depend on the Senegal and Niger River. Because both rivers are subject to enormous seasonal variation in rainfall and river flow, the performance of the river-dependent economic activities vary simultaneously. A popular solution to this climate dependency in the western Sahel has been the development of hydro-electric and hydro-agricultural irrigation schemes.

It is widely questioned whether the direct and indirect costs of such mega-investments are properly estimated. Besides the economic feasibility (i.e. direct costs and benefits) of additional dams, it is still unclear what the indirect effects of hydro-electric and hydro-agricultural schemes are on downstream beneficiaries of rivers. These beneficiaries include fishermen, cattle breeders, shipping companies and farmers, as well as the biodiversity of the river and connected floodplains.

The main objective of this study is to determine the role of dams and irrigation schemes in the overall economy and ecology of the Inner Niger Delta and the upstream region in Mali and Guinea. An integrated assessment has been conducted to determine the direct and indirect costs and benefits of different management regimes in the Niger River, starting with an analysis of potential changes to the hydrology, then subsequent ecological impacts and finally the social and economic effects. The results of this multidisciplinary research have been summarised in the following sections. Moreover, several lessons for policy makers have been drawn.

14.2 Hydrology

With its origins in Guinea, the Niger flows through Mali, and finally spills into the Atlantic Ocean 4200 km from its source. The water discharge of the Niger River fluctuates significantly over time. These fluctuations are both natural and man-made. This study's hydrological assessment increased our understanding of the Upper Niger River's hydrology, highlighting natural variations as well as the impact of human-made structures.

Natural variations

The annual rainfall in the catchment area of the Upper Niger amounts to an average of 1,500 mm and varies between 1,100 and 1,900 mm. Although the river discharge of the Niger is determined by rainfall, its annual variation between 600 and 2,300 m^3/s is much more pronounced than that of rainfall. This can be explained by the fact that peak river flow is not only dependent on the rainfall of preceding months, but also on groundwater aquifers. Because groundwater levels are determined by rainfall during previous years, the river flow declines during a series of dry years. This is what occurred during the period of dry years in the mid-eighties known in western Africa as 'La Grande Sécheresse' (the Great Drought), when the flow of the Niger River declined to unprecedented low levels. Years with peak discharges in September below 4,000 m^3/s occurred only twice between 1900 and 1980; in the last 20 years, they have rarely been above this level.

Dams

The recent decrease in flow of the Niger River cannot be solely attributed to reduced rainfall and depleted groundwater aquifers. Dams and irrigation schemes in the Upper Niger region are also expected to have had a measurable hydrological impact. This study analyses the impact of two existing man-made structures in the Niger River: the Markala barrage (Office du Niger, ON) and the Sélingué dam. The potential impact of a planned dam in the Upper Niger region in Guinea (the Fomi dam) is also assessed.

The **Sélingué** dam, which was constructed in 1982, is presently the only hydropower reservoir in the Upper Niger. Theoretically, the capacity of the Sélingué hydropower plant is 47.6 MW. Yet, with its size of 2.2 km^3 (equivalent to 6.8% of the average river discharge) the volume of the Sélingué reservoir is limited. Due to evaporation from the reservoir's surface (34.2 km^2), approximately 0.5 km^3 of water flow is lost annually. The role of Sélingué in the hydrology of the Inner Delta varies considerably between the wet and dry seasons. On average, 1.8 km^3 of river flow is stored in the reservoir during the wet period (August to September). In years of high river discharge, this is equivalent to only 10-20% of the peak flow of the Niger. However, in years of low discharge, this fraction increases to as much as 20-30%. The water stored in the Sélingué reservoir during the rainy season is gradually released throughout the rest of the year. Without these 'releases' from Sélingué, river discharge in the dry period would be around 0.2-0.4 km^3 per month; they add 0.2 km^3 per month to the natural discharge. This is particularly critical during years with a low flood, when river flow in the Inner Niger Delta from March to May is largely dependent on the management of Lac Sélingué.

The construction of the **Fomi** dam in a tributary of the Niger in Guinea, is still under consideration. The Fomi project involves a hydropower plant of a maximum installed capacity of 90 MW, as well as hydro-agricultural activities over an irrigated area of 30,000 ha. Its reservoir is scheduled to be 2.9 times larger than Sélingué. If water management at the Fomi dam is similar to that of Sélingué, it is expected that the impact on the flow during the wet and dry periods will be comparable, yet with a magnitude around 2.9 times greater. Three other dams are planned in the Niger River basin: the **Talo** dam and **Djenné** dam in the Bani tributary, and the **Tossaye** dam downstream of the Inner Niger Delta between Tombouctou and Gao. The effects of these dams have not (yet) been integrated into our analysis.

The **Office du Niger** irrigation zone is currently the only large water user in the Upper Niger. To irrigate more than 700 km^2 in the "Delta mort", Office du Niger uses 2.7 km^3 of water per annum. This is equivalent to 8.3% of total annual river flow. The impact of this water intake on the hydrological regime of the Inner Niger Delta varies from year to year. Because the water intake remains practically constant, annual water use by the Office du Niger irrigation zone declines to 4% of total flow in years with high flow, but increases to 15% of total flow in years with low flow. The intake ratio also varies seasonally. The Office du Niger takes around 100 m^3/s of water from August to November and around 60 m^3/s from December to April. That is equivalent to only a small fraction in the flood period, but up to 50-60% of water in the dry period. The irrigation practices of the Office du Niger in the dry season are therefore largely dependent on the water released from the Sélingué reservoir.

Dependencies

The dams, irrigation schemes and natural processes of the Inner Delta all contribute to the current hydrological system. In years with limited rainfall, the natural discharge of the Niger river is insufficient to feed the water requirements of Office du Niger. In May, for example, the natural river flow is only 40 m^3/s, while the water consumption of the Office du Niger irrigation zone is at least twice this amount. During six consecutive years, from 1989 to 1995, it was only due to the additional flow provided by the Sélingué reservoir that Office du Niger received the required quantity of water.

The remaining flow in the Inner Niger Delta is dependent on water discharge from Sélingué and the water intake at the Office du Niger, which in dry years sometimes amounts to less than 60 m^3/s. Under these extreme conditions, the water level in the Inner Delta reaches critically low levels. As a result, water becomes concentrated in a few areas in the low-lying central Inner Delta. Fishermen make the most of these conditions by emptying the remaining water bodies (such as Lac Walado) of fish. In the longer term, such practices are very detrimental to fish stocks. Consequently, a minimum flow is required to prevent unsustainable fish stock depletion in the central Inner Delta and pressure on remaining biodiversity.

In this study, this minimum required flow is set at 50 m^3/s. Maintaining this flow also ensures that international obligations between Mali and Niger are secured. With the minimum requirement of a set 50 m3/s flow, the water intake by the Office du Niger during the lowest flood period is at its maximum possible level. In other words, future expansion of the irrigation fields by the Office du Niger is only feasible if further improvements in water use are achieved. The water efficiency in this irrigation zone has already been significantly improved. In the 1980s, the production of one kilogram of rice required c. 30,000 litres of water. Nowadays, around 7,500 litres per kilogram is required. At the same time, production levels and the spatial extent of agriculture has increased over the last two decades. A still more efficient water use is crucial, and not beyond reach.

Scenarios

To assess the impact of the three man-made structures in the Upper Niger region, four hypothetical scenarios were simulated and analysed. These scenarios are used as central reference points throughout this study:

- *Scenario 0.* Without Office du Niger & Sélingué: In this scenario, neither Sélingué nor Office du Niger are present in the Upper Niger. This hypothetical situation acts as a 'baseline', illustrating the natural hydrological state more than 50 years ago;
- *Scenario 1.* Without Office du Niger & with Sélingué: In this scenario, Sélingué is still present but Office du Niger is absent;
- *Scenario 2.* With Office du Niger & with Sélingué: This scenario reflects the present situation, in which Sélingué and Office du Niger are in full operation;
- *Scenario 3.* With Office du Niger, Sélingué and Fomi: This scenario is similar to the present scenario but includes the existence of the proposed Fomi dam. The main purpose of this scenario is to evaluate the impact of this planned dam.

On the basis of historic information, statistical relationships between hydrology, flooding, ecology and socio-economics are estimated for these four scenarios and extrapolated for a future period of 2005 to 2030. The length of this period ensures enough time for the main environmental impacts to come into effect, yet is also sufficiently short to make some prediction about future developments. It is assumed that the negative trend in rainfall in the Upper Niger region of -3.5 mm per year will continue and that the climate variability of +/- 30% will remain unchanged.

Flooding

Hydropower and irrigation deliver distinct benefits, but the downstream impacts of such developments are also evident. As river flow is reduced, one of the largest riverine floodplains in the world, the Inner Niger Delta, is affected. The flooding of this area completely depends on the river because local rainfall is limited.

A water balance model revealed that the water level in the Inner Delta from August to October is on average 5-10 cm lower due to irrigation of the Office du Niger zone, and another 15 cm lower due to the Sélingué reservoir. A statistical analysis supplemented these estimates by comparing different long-term series of hydrological measurements. The analysis accurately predicts the water level in the middle of the Inner Delta on the basis of river flow information for both the Niger and the Bani during the previous months. According to this analysis, the Fomi dam will reduce the peak flood level by another 45 cm.

Satellite images clearly show the flooded areas of the Inner Delta. By comparing images of different flood levels over time, it is possible to describe flooding as a function of flood level. This statistical relationship permits the estimation of the maximum areas of inundation during the last half century. The inundated area varies between 8,000 and 25,000 km^2. Depending on the overall climate, the management of the Sélingué reservoir has lead to an average decline of the maximum inundated area of 600 km^2. Water intake by the Office du Niger and the (envisaged) Fomi dam cause an additional decline of 300 and 1,400 km^2, respectively.

14.3 Ecology

At first glance, the floodplains of the Inner Delta seem to be undisturbed natural ecosystems. The river takes its own course and the flooding is hardly hampered by dams, dikes and sluices. Extensive fields of floating grass ("bourgou"), wild rice and water lilies are present in and around the low lying lakes in the central Inner Delta (Lac Debo, Walado Debo). Moreover, the area hosts millions of waterbirds and other wildlife.

Human impact

Though one of the few free flowing floodplains in the Sahel, the human impact on this area is still significant. Firstly, fishing pressure is excessively high. Secondly, the floodplains are grazed by two million cattle and four million sheep and goats. This has a severe impact on the natural vegetation and is one

of the reasons the once ubiquitous flood forests are on the edge of extinction. Moreover, the bourgou fields in Lac Debo are largely planted by local people. Similarly, rice is planted and harvested each year, weeds like wild rice are removed manually and after the harvest the rice stubble is often burned. Finally, the water diversion upstream has a major impact on the floodplain ecosystem, essentially because of reduced flooding. These factors make the current Inner Delta a semi-natural habitat; nevertheless, it is one of last large floodplains of the world with unprecedented ecological values.

Habitats

The highly productive vegetation in the Inner Delta is a vital link in the flood plain ecosystem. For example, the floating *bourgou* fields are indispensable as a nursery habitat for juvenile fish, providing both protection and food. The *bourgou* fields act as a key habitat for a number of piscivorous bird species, and as the flood retreats it provides food for the omnipresent livestock. Besides its ecological value, the economic significance of *bourgou* to the fisheries and agricultural sectors is substantial. Other typical floodplain habitats include low-lying Cyperus-grasslands, wild rice and the rapidly disappearing flood forests. The main vegetation types reveal a clear zoning in relation to water depth. Bourgou grows where the water depth is more than 3 metres. Rice grows in water with a depth of approximately 2 meters.

Using the flooding model in combination with a vegetation map (both resulting from this study and derived from satellite images) we estimated the changes in habitats following the 4 scenarios of hydrological interventions. By reducing the water level in the Inner Delta, the optimal conditions for *bourgou* and rice change. The Fomi dam is expected to reduce the extent of floating *bourgou* fields (a key habitat) by 62% relative to the present situation. Newly created wetland habitats such as irrigated rice paddies, lakes and stagnant swamps in the irrigation zone of the Office du Niger, do not compensate for the loss of valuable habitats in the Inner Delta.

Biodiversity

The Inner Niger Delta is one of the largest Ramsar sites in the world and is considered to be a biodiversity hotspot. It accommodates two of the largest known breeding colonies of herons and cormorants in Africa. In addition, this delta supports up to 3-4 million staging waterbirds, both residents and migrants from all over Europe and adjacent Asia. Though under severe human pressure, aquatic wildlife like the Hippopotamus, West African Manatee and Monitor Lizard, is still present. The central area of lakes in the Delta, comprising Lac Debo and Walado Debo, plays a key role in the ecological functioning of the Delta. This low-lying area not only supports humid and shallow habitats at low water levels when nearly the entire Delta is dry, but also provides excellent feeding opportunities for waterbirds in the form of shallow bourgou fields and grasslands with a high biomass of benthic fauna.

Our study reveals that the state of wildlife (i.e. quality and quantity of biodiversity) heavily depends on maximum flood levels and the existence of water bodies during the period with the lowest water level. It seems that the (maximum) flood level in the Inner Delta determines the recruitment of the Afro-tropical water birds. In addition, flood levels play a qualifying role in the mortality rates of populations of African resident waterbird species as well as Palearctic migrant species. Feeding conditions, which are strongly related to flooding, largely determine this, but a contributing factor is human exploitation. In particular during low floods these populations are vulnerable to human pressure. The hydrological and related ecological conditions in the Inner Delta therefore have a qualifying impact on the population size of breeding and staging waterbird species. The latter include a wide range of species of European conservational concern, such as the Purple Heron, Glossy Ibis, Garganey, Black-tailed Godwit, Collared Pratincole, Great Snipe and Caspian Tern. These migratory species help illustrate the interrelations between different wetland ecosystems thousands of miles apart.

The relationship between flood levels and ecological value means that hydrological interventions upstream inevitably affect the ecological value of the Inner Delta. Ecological valuation shows that the ecological quality of irrigated rice fields, in terms of species diversity and abundance, is only 6% of a comparable area of bourgou fields in the Inner Delta. The Fomi dam will reduce the ecological value of the Inner Delta by at least 36%, but due to cascading effects the impact on survival of waterbirds and other wildlife is much greater at low floods. This implies that, if the Fomi dam were built, the last large breeding colonies of cormorants, ibises, herons and egrets in West Africa will be pushed to the edge of existence. The Fomi dam may also lead to significantly lower population levels of several waterbird species, both residents and migratory species of European conservational concern.

14.4 Sectors

A number of economic activities downstream are heavily affected by hydrological interventions upstream. When evaluating the economic feasibility of investments in the Upper Niger Basin, these indirect costs and benefits are rarely taken into account.

Fisheries

Elderly fishermen in the Inner Delta still remember catching Nile Perches 1.5 m in length and longer. All fishermen in the Inner Delta know that in the last 30 to 40 years, fish catches have significantly reduced in size. Over time fishing pressure has intensified due to an increase in the number of fish traps, hook lines and fishing nets. At present, 300,000 people in the Inner Delta depend on fisheries for their livelihood. When the floodplains are exposed during the period when the flood recedes, fish are easy to catch because they are enclosed in (temporary) lakes and concentrated in creeks and the riverbed. Nowadays, nearly all fish are captured long before the next flood arrives. Therefore, the catch of the following year will depend on the numbers of young fish born in the preceding flooding period. Nile Perches in the Inner Delta no longer have time to reach a size of over 1.5 meters.

The flood levels in the Delta also influence fish production. The close relationship between annual fish trade in Mopti and flood levels of the preceding year helps gauge the average impact of Office du Niger and Sélingué on the region's fish trade. Fish trade in the Inner Delta would be 6% higher in the absence of the Office du Niger irrigation zone and an additional 13% higher without the Sélingué reservoir. The analysis predicts that current fish trade will be reduced by 37% if the Fomi Dam is constructed.

These losses are partly compensated by fishing gains in Lac Sélingué, where about 4000 tonnes of fish are captured annually.

Cattle

Each year, herders in the Sahel decide how far north they will move at the beginning of the rainy season. After the short rainy season, the grass withers and the herders move south again, where they let their cows graze on stubble fields of rice, millet, sorghum or on the savannah vegetation. Cattle in the vicinity of the Inner Delta have much better feeding opportunities on the dried-up floodplains. This explains why 60% of the 5 million cows in Mali are concentrated in the regions around Mopti and Tombouctou where the floodplains of the Inner Delta are located.

During the Great Drought, many cows died and herders lost more than half their cattle. This was due to reduced food resources as a consequence of the lack of rain and the reduction of the inundated area of the Inner Delta by two thirds. The situation further deteriorated due to overgrazing. Up till now, the livestock is not yet back at its pre-Great Drought level. Our calculations reveal that the number of cattle, sheep and goat in the regions of Mopti and Tombouctou would be on average 4 to 5% higher per year in the absence of the Office du Niger irrigation zone and the Sélingué reservoir. The maximum amount of livestock is likely to be reduced by 10-15% if the Fomi dam is constructed.

Rice

As in other Sahel countries, the annual rainfall in Mali has a dominant effect on the rural economy, especially in the drier part of the country. The production of millet, sorghum and rice decreases sharply if the annual rainfall drops below 400 mm. Although rice farmers in the Inner Delta also depend on rain in the weeks before the flood covers their rice fields, production remains mainly determined by flood duration. The rice grows along with the rising water level and needs to be covered by water for 3 months. Most rice is cultivated in areas inundated by one to two meters of flood water. During the Great Drought, the flood level decreased by 220 cm. Farmers responded to the Great Drought by growing rice at lower elevations in the inundated zone. On average, however, they moved their crops down by only 80 of the 220 cm decrease in water level. The farmers in the Delta could not move production further down because there is insufficient space to farm at these lower elevations. The inability of farmers to respond to low flood levels is the main reason for declining rice production in dry years.

Rice production in the Inner Delta varies from year to year, with flood level and, to a lesser degree, rainfall. The average production amounts to 86,000 tonnes, including the area of ORM and ORS. At low floods this drops to 25,000 tonnes and with high floods a maximum of 170,000 tonnes can be reached. Based on the strong correlation between rice production and peak flood level, it has been estimated that farmers on average produce 8900 tonnes less (10.4%) as a result of Sélingué. Without the irrigation of the Office du Niger zone, rice production in the Inner Delta would be 4300 tonnes greater (4.9%). The Fomi dam would have an even bigger impact: a decrease of 40%, or 34,500 tonnes, and hence significantly reduce food security in the Inner Niger Delta.

These losses are amply compensated for by irrigation at Sélingué (yielding 6,000-7,500 tonnes of rice) and in the Office de Niger irrigation zone (320,000 tonnes). In particular, the irrigation zone of the Office du Niger stands out as being crucial for rice production. Today, domestic Malian rice production supplies 90% of national demand; Office du Niger accounts for 40% of this domestic production. Not without reason is the area called the granary of rice of Mali. Throughout the years, the irrigation zone of Office du Niger has provided a secure food source, independent of rainfall and flood performance. Even during the drought periods of the early 1970s and the mid 1980s there were no significant decreases.

Transport

The Niger river plays an important role in the transport of goods and people. Particularly during the wet season, boats are the most popular means of transport in the Delta. Not only does river transport allow people and goods to reach remote places, transport by boat is also relatively inexpensive compared to road transport. Dams and irrigation schemes have an impact on the navigation potential of the Niger River by reducing the water level in the wet season while providing additional flow during the dry season. Reducing the deep-water navigational period, specifically affects larger boats with maximum capacities of around 400 people and 350 tonnes of goods. The additional depth of the Niger in the dry season is particularly useful for smaller boats with capacities of around 10-20 people and 1-5 tonnes of freight. Big boats need at least 3 to 4 meters of water to operate, while smaller boats can still navigate at a depth of 1 meter. Comparing Scenario 0 (no dams) and Scenario 3 (three dams), shows that the latter scenario would lead to an additional 82 days of navigation for the smaller boats while the operational season of the larger boats would be reduced by 20 days.

14.5 Economics

In estimating the costs and benefits associated with dams in the Niger River basin we are not taking a novel approach. Cost-Benefit Analysis (CBA) is an indispensable economic tool in any large infrastructure project. Dams are no exception. Traditionally, a CBA was performed using a limited set of parameters. In most cases the costs were restricted to the direct capital investment, construction costs and operational costs. Likewise, only direct (measurable) benefits, such as power generation, irrigation benefits and tourism were taken into account. Nowadays, social and environmental effects are increasingly considered in the planning of dams, through the application of an extended CBA. This analysis requires economic valuation of indirect costs and benefits.

Impact pathway approach

To determine the indirect costs and benefits, underlying processes need to be examined. In this study, this began with an assessment of potential changes to the hydrology, then subsequent ecological impacts and finally the social and economic effects. This so-called "impact pathway approach" is a methodology that proceeds sequentially through the pathway, linking causes to impacts, and then valuing these impacts.

Having established and tabulated the full range and significance of the effects, changes are then valued in monetary terms. The main impact pathways covered include agriculture, fisheries, livestock, biodiversity, energy supply and transport. Different valuation techniques are used for these benefits. The most commonly used valuation technique in this study is the production function approach which estimates production levels as a function of the water level or flooding area in the Inner Niger Delta. For most of the economic sectors considered, statistical production functions have been estimated. These were incorporated in the integrated model simulating the four scenarios. The main indicator of the model is the net-benefit of each scenario, which expresses the overall welfare level subtracted by the financial costs of the dams and irrigation schemes. Ultimately, a sensitivity analysis was conducted to test the robustness of the final outcome, in relation to a number of crucial parameters such as climate change.

Another important dimension of the impact pathway approach is allocation of the welfare in the different scenarios. Besides having an impact on the absolute level of welfare in Mali and Guinea, establishing dams in the Upper Niger region is likely to generate a transfer of economic benefits from one region to another. The model has therefore been designed at the district level so that a distinction can be made between benefits that occur in the Inner Niger Delta (i.e. livestock, agriculture, fisheries, biodiversity and transport) and those that are generated in the upstream region (i.e. electricity and irrigated crops).

Financial costs

The cost benefit analysis of the three man-made structures in the Upper Niger is somewhat unusual because it compares the Office du Niger irrigation zone and the Sélingué dam, which were established a long time ago, with the Fomi dam, which is yet to be built. To make a fair comparison, we consider a future time period of 2005 to 2030, in which we assume all dams can be active and subsequently generate benefits. However, the cost side of the analysis is more complicated because, as opposed to the investments in the Fomi dam, the initial investments in Office du Niger and the Sélingué dam have already been made. These 'sunk costs' can therefore not be avoided by future decisions.

The presence of sunk costs does not imply that Office du Niger and the Sélingué dam are free of costs. Despite the fact that the initial investments were sometimes made decades ago, the dams still require maintenance and operational expenditures.

In addition, the dams required capital that could have been spent on alternative economic activities in Mali (i.e. opportunity costs) and therefore need to be valued accordingly. As such, we assume that the opportunity cost of capital is 8% of the actual capital stock. In the early stages, the operational and maintenance (O&M) costs of the dam and the irrigation scheme are assumed to be 2% of the value of the capital stock. Due to increased failure and deterioration of the infrastructure, this fraction increases by 1.25% each year. Clearly, the Office du Niger irrigation zone and the Fomi dam are significantly more costly than the Sélingué dam. This difference is largely due to the continuous expansion of both irrigation schemes. The Office du Niger is assumed to expand its irrigation scheme by 1,500 ha per annum.

Economic benefits

If solely considering the benefits, it is clear that more dams lead to higher overall benefits. Each year, the benefits of scenario 3 (i.e. the present situation including the Fomi dam) exceed the benefits of scenario 2 (i.e. present situation with Sélingué and Office du Niger), which in turn exceed the benefits of scenario 1 (1 dam). In other words, large-scale intervention can lead to higher revenues for society at large. Yet, higher benefits do not necessarily imply higher net-welfare levels. The cost of each scenario should also be taken into account.

Net-benefits are defined as the overall benefits minus the overall costs. The ranking of the scenarios on the basis of net-benefits changes over time. Due to the high initial investments in the Fomi dam, scenario 3 generates low net-benefits in the first few years but these increase as soon as the Fomi dam gradually goes into full operation. The net-benefits of scenario 2 exceed those of scenario 3 throughout the full period. From the fluctuations of the net-benefits, it can also be concluded that dams are slightly more beneficial during years of abundant rainfall. In other words, the Inner Niger Delta particularly suffers from the diversion of water from the Niger River in years of water scarcity.

Net present value

The next step in analysing the benefits and costs of the four scenarios is to sum up the individual benefits over time to create a single welfare measure. This requires assumptions about the time period considered and the discount rate at which net-benefits are aggregated. Economists aggregate values over time by converting them into the net present value (NPV) through the principle of discounting. Discounting is the practice of placing lower values on future benefits and costs compared to present benefits and costs, reflecting people's preferences for the present rather than the future. The discount rate applied in this study is 5%.

The net present values represent the total economic value of each scenario. Scenario 2 (i.e. with Office du Niger and the Sélingué dam) generates the highest discounted net-benefits while scenario 3 (i.e. Office du Niger, Sélingué and Fomi dam) generate the least NPV. This suggests that the construction of the Fomi dam would have a negative impact on the overall economy.

To analyse the individual economic impact of the three combinations of dams and irrigation schemes, the difference between the dam scenarios and the baseline scenario (0) should be considered. These marginal net-benefits of the three dam scenarios are calculated by subtracting the overall net-benefits of the baseline scenario (0) from the net-benefits of scenario 1, 2 and 3. By looking at the difference between scenario 2 and 3, the additional net-benefit of the Fomi dam to the present situation (Office du Niger and Sélingué) can be determined. By building the Fomi dam, society at large will lose €35 million per year (i.e. €8.5 + €26.4 million). The Sélingué dam generates additional annual net-benefits of almost €5 million. The Office du Niger irrigation zone is the most economically feasible project of the three, generating aggregated net-benefits of almost €22 million per year (i.e. €26.4 - €4.8 million).

Poverty and equity

Besides changing the overall welfare level, the dams and irrigation schemes cause sectoral and regional shifts within society. For example, changes in welfare are brought about by changes in various sectors of the economy. The negative values represent the accumulative financial costs of each scenario. The costs clearly increase disproportionally with addition of the Fomi dam. Although these additional costs are partly compensated for by additional electricity and agricultural benefits, the loss in fisheries, livestock and biodiversity are also substantial. The impacts of the Office du Niger and the Sélingué dam are much less pronounced. A society without dams (scenario 0) mainly generates income through fisheries and livestock, as it did around 50 years ago. No electricity is produced and agriculture remains rather limited.

An important dimension of the study is the spatial distribution of benefits in the different scenarios. Besides changes in the absolute level of welfare, dams are likely to cause transfers of benefits from one region to another. The Upper Niger region includes all those districts in Mali and Guinea in which dams generate economic activities such as irrigated agriculture and hydropower. In Mali these districts are Segou, Macina, Niono and Yanfolila. With each additional dam built, benefits are transferred from the Inner Niger Delta to the upstream region. This transfer is especially significant in scenario 3.

Dams along the Niger River have mixed effects on poverty. The population of the Inner Delta experiences a decline in per capita income as the number of dams increases. However, the per capita economic benefits for the Upper Niger population show a positive relationship with the number of dams and irrigation schemes. The average annual river-related benefit per person increases with each additional dam from €44 (no dams), to €48 (Sélingué) and €68 (Sélingué and Office du Niger). The Fomi dam is expected to reduce the annual river-associated welfare of the affected Malinese population from €68 to €52 per capita.

Climate sensitivity

Due to the complexity of the hydrology of the Upper Niger River Basin and the limited availability of data, a number of assumptions have been made to enable an integrated analysis of the dams and irrigation schemes in the Upper Niger Basin. These assumptions need not be problematic as long as the results are robust vis-à-vis changes in the assumed parameter values. A crucial assumption in this study concerns the climatic conditions in the Upper Niger Basin. On the basis of the previous 75 years, it was estimated that rainfall declines by 3.5 mm each year. Due to the overall trend of global warming, this rate of decline may well accelerate over the coming decades. To test the impact of more rapid climate change, the reduction in rainfall was increased by 25%, 50%, 100%, and then 150% for the different scenarios. The Inner Delta and the upstream region suffer from increased drought, albeit to a different degree. For all three scenarios, the Inner Niger Delta is much more vulnerable to drought than that of the Upper Niger. The vulnerability of the Inner Niger Delta would be enhanced by the construction of the Fomi Dam.

14.6 Conclusions and policy recommendations

This integrated assessment was conducted to determine the role of dams and irrigation schemes in the overall economy and ecology of the Inner Niger Delta and the upstream region. By combining information on hydrology, ecology, fisheries and agriculture, several important lessons can be drawn:

- Nearly one million people earn their livelihoods in the Inner Delta as fishermen, cattle breeders or farmers. They fully depend on the natural resources found within an area of 50,000 km2. The annual production of fish, cattle and rice is determined by river discharge and is insufficient to feed local people in the drier years. That is why many people have abandoned the drier parts of the Inner Delta in the past 40 years. Further migration can be expected if additional water is diverted upstream.
- The economic value of dams in the Niger River depends predominantly on the amount of water diverted from the river. The Sélingué and Office du Niger appear to be economically feasible. They jointly generate €26.4 million of benefits per year to society at large. The further addition of the Fomi dam is expected to reduce economic prosperity by €35 million per year.
- The economic feasibility of Office du Niger is subject to a number of crucial assumptions. In dry years, the economic feasibility of Office du Niger depends on the water releases by the Sélingué dam. Moreover, the increased productivity of the Office du Niger region from 2-3 tonnes of rice per hectare to the present 4-6 tonnes per hectare is a prerequisite for its economic feasibility. Further improvement of the irrigation efficiency is not only possible but also essential for additional expansion of the irrigated area of Office du Niger.
- The benefits are felt by various sectors and vary widely depending on the level of water diversion from the Niger River. The additional financial costs of the Fomi dam are only partly compensated by additional electricity and agricultural benefits. Moreover, the indirect losses for fisheries, livestock and biodiversity downstream dominate these direct revenues. The negative downstream effects are less pronounced in case of the Office du Niger irrigation zone and the Sélingué dam scenario.
- Besides changes in the absolute level of welfare, dams are likely to cause transfers of benefits from one region to another. The results clearly show that with each additional dam, benefits are transferred from the Inner Niger Delta to the upstream Upper Niger region.

All in all, this study shows that improving the performance of the existing infrastructure as well as the economic activities in the Inner Niger Delta itself is a significantly more efficient way to increase economic growth, reduce poverty and protect the environment in the region than the building of a new hydropower plant.

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APPENDIX 1 RAINFALL AND RIVER DISCHARGE IN THE BASINS OF FIVE TRIBUTARIES OF THE UPPER NIGER

Table I.1 provides the river discharge (Q, m^3/s) and average rainfall (P, mm) in five basins. See Figure 2.3 for the location. The table is copied from Mahé et al. (1997).

sd = standard deviation, cv = coefficient of variation (sd/x %)

Table I.1. Data on river discharge (Q, m^3/s) and average rainfall (P, mm) in 5 basins

	BANI		SANKARANI		TINKISSO		MILO		NIANDAN	
Year	Q	P	Q	P	Q	P	Q	P	Q	P
1951	770	1371	496	1640	247	1878	281	2384	344	2095
1952	828	1296	385	1441	197	1456	227	2000	273	1838
1953	837	1271	458	1557	229	1728	229	1945	317	2023
1954	909	1350	506	1657	240	1788	270	2077	310	2119
1955	890	1270	420	1503	224	1681	269	2055	356	2010
1956	563	1128	323	1330	258	1440	156	1710	221	1608
1957	798	1319	471	1595	229	1726	221	2243	322	2041
1958	801	1212	320	1324	190	1479	202	1961	284	1635
1959	712	1112	367	1409	226	1510	190	2030	268	1842
1960	616	1185	368	1411	208	1584	241	1979	282	1948
1961	645	1102	329	1341	198	1444	139	1658	171	1552
1962	555	1222	436	1533	224	1495	218	2227	294	1947
1963	517	1186	391	1452	215	1597	192	1830	223	1855
1964	759	1337	454	1565	191	1771	174	1812	240	1617
1965	728	1193	338	1391	177	1605	180	1803	270	1849
1966	670	1158	328	1502	170	1518	172	1827	224	1637
1967	724	1204	451	1567	227	1534	227	2147	296	1973
1968	670	1090	363	1357	123	1332	196	2025	298	1897
1969	697	1225	500	1610	283	1574	284	2097	361	2045
1970	528	1150	261	1355	155	1232	164	1519	170	1128
1971	363	1062	296	1291	126	1278	164	1780	225	1582
1972	175	985	271	1265	114	1262	188	1891	260	1678
1973	162	932	261	1280	88.9	1333	146	1805	159	1643
1974	312	1127	343	1396	168	1496	194	1933	281	1885
1975	357	1140	435	1341	138	1440	203	1685	219	1601
1976	242	1147	346	1405	148	1454	200	1920	290	1944
1977	168	951	248	1216	82.7	1142	141	1686	212	1565
1978	218	1088	398	1375	85.5	231	196	2048	283	1909
1979	258	1098	452	1365	127	1252	231	1900	260	1807
1980	214	999	241	1260	75.2	1249	127	1690	153	1514
1981	295	1026	337	1355	102	1347	191	1950	239	1918
1982	164	999	304	1295	78.1	1192	153	1728	279	1874
1983	70.7	784	175	1064	79.3	1120	143	1696	213	1572
1984	113	883	205	1118	59.6	1102	116	1700	194	1482
1985	175	955	256	1209	83.2	1262	163	1872	235	1677
1986	145	984	238	1178	70.7	1102	125	1785	237	1669
1987	135	846	179	1072	66.7	1220	131	1724	240	1700
1988	179	1044	225	1154	67.3	1231	129	1654	171	1367
1989	186	981	279	1250	58.1	1236	115	1916	251	1733
mean	465	1113	345	1370	155	1393	187	1890	254	1764
sd	274	143	93	154	67	281	46	187	53	217
Cv	59	13	27	11	44	20	25	10	21	12

Results of five multiple regression analyses with river discharge in the basin (m^3/s) as function of rainfall (mm) in the same year (yr^0), the year before (yr^1) and two year before (yr^2). The original data are given by Mahé et al (1967) and reproduced above. The effect of rainfall is only shown if its effect is significant. The rain three years before (yr^3) is also entered into the equations, but is significant in none of the five analyses. The equations contains the following variables:

a = constant
b = regression function
SE = standard error of the regression function
P = significance

BANI (R^2 = 0.863)			
	B	SE	P
A	-1796.422	158.003	0.000
yr0	1.102	0.181	0.000
yr1	0.566	0.190	0.006
yr2	0.360	0.175	0.048

SANKARANI (R^2 = 0.861)			
	B	SE	P
A	-421.009	50.909	0.000
yr0	0.559	0.037	0.000

MILO (R^2 = 0. 689)			
	B	SE	P
A	-405.111	75.712	0.000
yr0	0.184	0.025	0.000
yr1	0.092	0.025	0.000
yr2	0.037	0.023	0.000

NIANDAN (R^2 = 0.753)			
	B	SE	P
a	-118.853	35.421	0.002
yr0	0.212	0.020	0.000

TINKISSO (R^2 = 0.561)			
	B	SE	P
a	-131.035	43.764	0.005
yr0	0.143	0.031	0.000
yr1	0.062	0.030	0.049

APPENDIX II SÉLINGUÉ: WATER LEVEL, INFLOW, OUTFLOW AND ELECTRICITY PRODUCTION

II.1 Official statistics

Lac Sélingué is managed by Office de Développement Rural de Sélingué (ODRS) and Direction Nationale de l'Energie du Mali (EDM). Because the electricity production depends on the artificial river discharge, the water level is accurately registered in the reservoir and downstream of the dam. This also holds for the outflow of the reservoir. The latter is split up for spillway and turbinated water. Also the amount of irrigated water is known. The inflow is not measured but estimated from the (change in) water level in the reservoir. This Annex provides the data split up per year and per month. The data are analysed in Chapter 2.

Table II.1. Water level in the reservoir (m IGN)

year	J	F	M	A	M	J	J	A	S	O	N	D	mean
1982	346.89	346.64	346.01	345.57	345.42	343.24	343.55	345.49	346.60	347.01	347.04	347.00	345.87
1983	346.82	346.44	345.71	344.84	343.99	344.18	344.38	346.03	347.24	346.90	347.12	346.86	345.87
1984	346.47	345.89	344.94	343.75	342.57	341.43	340.98	345.78	348.50	348.49	348.50	348.30	345.46
1985	347.92	347.40	346.58	345.64	344.48	343.33	344.26	348.34	348.50	348.52	348.50	348.28	346.81
1986	347.91	347.32	346.46	345.44	344.12	342.70	341.34	344.76	348.08	348.52	348.54	348.22	346.12
1987	347.68	346.98	345.88	344.24	341.58	340.38	340.88	344.04	348.28	348.60	348.50	348.14	345.43
1988	347.66	346.90	346.02	345.04	343.60	342.24	341.32	344.44	348.50	348.64	348.30	347.82	345.87
1989	347.18	346.42	345.58	343.96	341.24	340.08	340.36	344.92	348.59	348.84	348.62	348.10	345.32
1990	348.16	347.15	346.28	345.11	344.16	341.88	341.96	346.90	348.81	348.86	348.70	348.14	346.34
1991	347.53	346.77	345.58	344.39	343.06	341.48	342.38	347.46	348.68	348.86	348.88	348.58	346.14
1992	348.14	347.48	346.40	345.55	343.40	341.50	341.15	346.94	348.63	349.00	349.03	348.64	346.32
1993	348.11	347.52	346.60	345.42	343.98	342.28	340.66	345.10	348.56	349.08	348.91	348.50	346.23
1994	348.15	347.63	346.64	345.38	344.19	341.74	340.68	344.42	348.10	348.16	347.99	347.94	345.92
1995	347.68	347.10	345.96	344.70	343.18	340.08	338.85	346.66	348.08	348.58	348.56	348.02	345.62
1996	347.40	346.58	345.27	343.50	341.16	338.50	339.90	343.90	348.00	348.50	348.46	348.27	344.95
1997	347.74	347.20	346.38	345.35	343.96	342.14	341.02	346.38	348.06	348.50	348.58	348.41	346.14
1998	348.17	347.55	346.54	345.16	343.50	341.82	341.44	347.42	348.54	348.68	348.71	348.96	346.37
1999	347.78	347.01	345.54	342.96	339.20	339.00	339.98	334.62	348.96	348.98	348.97	348.86	344.32
2000	348.45	347.90	346.93	345.85	344.44	343.02	342.27	347.38	348.94	349.06	349.10	348.88	346.85
2001	348.60	348.24	347.42	346.15	344.20	341.24	341.58	347.63	349.00	349.05	348.90	348.64	346.72
2002	348.34	347.74	346.39	344.86	342.69	341.22	341.56	345.58	348.91	349.08	349.03	348.72	346.18
2003	348.24	347.50	346.55	345.26	343.23	341.08	342.08						344.85
mean	347.77	347.15	346.17	344.91	343.24	341.57	341.48	345.44	348.36	348.57	348.52	348.25	345.92

Table II.2. The inflow into the reservoir (m^3/s)

year	J	F	M	A	M	J	J	A	S	O	N	D	mean
1982	41.78	39.05	36.17	56.94	78.68	142.30	269.16	620.35	1083.63	534.83	227.40	93.02	269.30
1983	44.69	42.43	33.74	41.87	53.32	137.93	232.09	614.45	691.93	408.55	128.78	54.61	207.91
1984	35.55	28.67	37.77	38.13	53.79	75.96	118.83	448.04	612.49	374.80	110.94	45.17	165.65
1985	26.49	24.35	32.95	36.53	46.20	59.13	182.72	746.94	1082.60	596.31	161.80	47.20	254.59
1986	27.64	30.17	34.37	52.20	59.25	68.29	90.96	367.67	906.03	451.17	184.94	38.48	192.72
1987	34.88	63.36	26.86	37.50	47.81	52.80	91.95	335.01	608.70	414.60	143.10	25.87	157.05
1988	30.57	53.93	19.65	21.84	34.56	51.13	119.04	350.18	656.00	303.70	50.62	20.53	142.80
1989	45.70	30.98	26.94	36.07	44.31	38.39	94.92	422.20	606.33	355.43	99.27	33.47	153.37
1990	22.96	42.64	29.20	28.02	86.87	88.63	213.23	609.06	634.87	423.03	134.26	40.12	197.06
1991	37.30	51.87	28.29	26.38	56.16	80.39	249.52	651.42	778.95	490.90	210.52	73.47	228.87
1992	31.16	58.95	52.27	25.71	47.68	91.15	207.88	566.85	1106.91	522.34	166.97	79.00	246.84
1993	26.53	45.14	69.10	37.29	70.31	78.93	138.54	485.62	864.94	544.49	196.85	81.04	220.52
1994	27.06	46.43	66.96	26.26	61.14	97.65	221.97	419.13	1004.29	1145.24	676.67	191.05	333.03
1995	81.82	86.35	47.59	51.11	68.65	69.68	78.46	701.74	1135.11	859.89	267.14	82.09	294.89
1996	81.24	74.09	71.12	72.04	94.43	77.20	88.46	432.89	913.62	711.89	216.35	77.31	243.09
1997	51.18	61.42	59.37	48.24	76.21	97.69	266.94	687.05	1191.31	631.02	211.03	87.32	289.86
1998	54.33	53.03	71.84	47.20	69.35	110.15	233.72	1021.81	1216.06	992.50	264.72	98.01	354.57
1999	64.46	72.67	69.94	76.18	77.29	36.10	118.63	429.57	1094.03	764.49	297.44	97.79	266.94
2000	83.31	42.61	68.26	50.31	77.24	154.35	209.40	679.77	972.38	768.34	286.96	104.01	292.64
2001	53.94	38.84	50.99	75.65	66.22	94.96	237.04	735.48	2369.47	786.97	251.50	112.98	405.99
2002	56.42	51.00	87.10	48.62	68.99	87.77	171.99	508.24	857.02	578.93	222.53	76.06	235.30
2003	48.70	60.54	63.71	41.36	65.13	107.20	338.54						103.60
mean	45.80	49.93	49.28	44.34	63.80	86.26	180.64	563.50	970.79	602.83	214.75	74.22	246.20

Table II.3. The outflow from the reservoir (m^3/s)

year	J	F	M	A	M	J	J	A	S	O	N	D	mean
1982	32.73	45.03	74.73	75.85	69.78	300.27	272.26	455.30	985.03	473.18	204.92	108.34	258.41
1983	45.66	61.24	77.43	94.36	102.63	98.63	210.34	468.10	551.65	430.38	76.44	65.03	191.05
1984	57.09	63.57	96.98	112.10	122.79	132.02	136.67	109.96	539.00	363.60	98.93	53.83	157.29
1985	58.75	69.39	98.62	110.34	123.62	132.51	108.63	286.01	1017.76	568.89	140.87	53.67	230.77
1986	61.48	91.88	106.77	131.97	148.36	151.97	157.00	146.44	466.21	349.12	150.94	82.48	170.43
1987	86.84	110.66	133.98	170.86	201.85	94.94	70.12	153.50	117.00	315.64	104.51	77.67	136.84
1988	74.39	102.37	93.49	108.23	128.60	131.54	161.70	154.67	149.94	231.64	98.79	74.24	126.03
1989	82.18	106.77	99.31	162.76	183.68	74.98	83.75	149.44	126.12	258.47	104.63	90.85	127.18
1990	59.58	66.41	93.24	130.56	146.95	218.79	216.18	167.84	340.87	385.69	132.86	112.56	173.14
1991	89.28	103.92	137.57	117.56	137.77	98.14	201.07	172.83	527.89	442.95	155.14	92.66	190.05
1992	79.82	105.65	133.96	160.68	152.63	195.93	216.25	193.27	688.06	426.51	134.60	112.21	216.69
1993	88.99	94.10	129.32	155.74	175.49	183.15	205.84	211.85	392.34	450.37	196.68	117.08	200.60
1994	68.14	91.20	131.56	150.90	148.13	245.30	270.08	203.47	553.18	1115.05	677.09	179.05	320.35
1995	88.82	117.79	152.96	163.99	163.18	205.13	115.64	203.36	945.12	742.98	238.53	152.64	274.21
1996	125.15	157.98	151.72	177.17	178.52	130.01	50.95	229.30	450.40	601.65	206.37	82.52	211.93
1997	98.29	79.49	96.02	134.85	166.32	205.64	320.08	284.72	961.27	511.92	173.06	81.73	259.73
1998	54.67	102.52	126.88	172.62	181.59	202.61	227.64	243.39	1009.29	942.71	237.57	127.31	302.91
1999	124.15	123.10	185.77	257.69	211.23	24.24	81.43	189.47	509.73	735.99	273.91	90.51	234.49
2000	114.04	103.14	129.48	145.58	177.30	242.02	251.26	215.38	707.53	711.32	251.60	112.14	263.91
2001	66.90	63.22	115.06	175.57	234.82	264.10	223.84	210.40	1580.72	757.16	239.87	130.40	338.28
2002	69.47	108.56	196.38	190.65	201.55	153.96	158.79	218.20	381.39	528.25	202.52	101.01	209.80
2003	94.32	128.39	125.12	149.27	203.67	224.89	291.75						173.91
mean	78.22	95.29	122.11	147.70	161.84	168.67	183.24	222.23	619.07	540.16	195.23	99.90	219.80

Table II.4. The outflow as % of the inflow

year	J	F	M	A	M	J	J	A	S	O	N	D	mean
1982	78.33	115.31	206.62	133.21	88.69	211.01	101.15	73.39	90.90	88.47	90.11	116.47	95.95
1983	102.17	144.32	229.48	225.37	192.48	71.51	90.63	76.18	79.73	105.34	59.36	119.07	91.89
1984	160.59	221.73	256.76	293.99	228.28	173.80	115.02	24.54	88.00	97.01	89.17	119.17	94.95
1985	221.78	284.97	299.30	302.05	267.58	224.10	59.45	38.29	94.01	95.40	87.06	113.71	90.64
1986	222.43	304.54	310.65	252.82	250.40	222.54	172.60	39.83	51.46	77.38	81.62	214.35	88.43
1987	248.97	174.65	498.81	455.63	422.19	179.81	76.25	45.82	19.22	76.13	73.03	300.23	87.13
1988	243.34	189.83	475.78	495.56	372.12	257.27	135.84	44.17	22.86	76.27	195.16	361.63	88.26
1989	179.82	344.65	368.63	451.23	414.53	195.31	88.23	35.40	20.80	72.72	105.40	271.44	82.92
1990	259.49	155.75	319.32	465.95	169.16	246.86	101.38	27.56	53.69	91.17	98.96	280.56	87.86
1991	239.36	200.35	486.30	445.64	245.34	122.07	80.58	26.53	67.77	90.23	73.69	126.12	83.04
1992	256.16	179.22	256.28	624.97	320.12	214.95	104.03	34.10	62.16	81.65	80.61	142.04	87.79
1993	335.47	208.45	187.14	417.70	249.59	232.05	148.58	43.62	45.36	82.71	99.92	144.48	90.97
1994	251.76	196.42	196.48	574.61	242.28	251.19	121.68	48.55	55.08	97.36	100.06	93.72	96.19
1995	108.55	136.41	321.44	320.87	237.68	294.39	147.39	28.98	83.26	86.40	89.29	185.94	92.99
1996	154.05	213.23	213.32	245.92	189.06	168.41	57.59	52.97	49.30	84.51	95.39	106.73	87.18
1997	192.06	129.42	161.72	279.56	218.23	210.50	119.91	41.44	80.69	81.13	82.01	93.59	89.60
1998	100.63	193.34	176.60	365.71	261.86	183.94	97.40	23.82	83.00	94.98	89.75	129.90	85.43
1999	192.62	169.40	265.63	338.29	273.30	67.15	68.64	44.11	46.59	96.27	92.09	92.55	87.84
2000	136.89	242.03	189.69	289.34	229.54	156.81	119.99	31.68	72.76	92.58	87.68	107.82	90.18
2001	124.03	162.75	225.65	232.07	354.62	278.13	94.43	28.61	66.71	96.21	95.38	115.42	83.32
2002	123.12	212.87	225.47	392.12	292.16	175.42	92.33	42.93	44.50	91.25	91.01	132.80	89.16
2003	193.68	212.07	196.38	360.95	312.71	209.79	86.18						
mean	170.76	190.84	247.77	333.11	253.67	195.53	101.44	39.44	63.77	89.60	90.91	134.60	89.28

Table II.5. The amount of turbinated water (m^3/s)

year	J	F	M	A	M	J	J	A	S	O	N	D	sum
1982	30.34	45.03	74.73	75.85	69.78	75.48	78.66	75.57	97.53	72.83	57.82	37.19	790.81
1983	45.66	61.24	77.43	94.36	102.63	98.63	95.41	108.19	103.21	93.84	76.44	65.03	1022.06
1984	57.09	63.57	96.98	112.10	122.79	132.02	136.67	109.96	62.96	76.95	65.73	53.83	1090.65
1985	58.75	69.39	98.62	110.34	123.62	132.51	108.63	97.28	113.13	110.28	78.30	53.67	1154.52
1986	61.48	91.88	106.77	131.97	148.36	151.97	157.00	146.44	129.73	125.24	93.36	82.48	1426.68
1987	86.84	110.66	133.98	170.86	201.85	94.94	70.12	153.50	117.00	125.01	83.59	77.67	1426.01
1988	74.39	102.37	93.49	108.23	128.60	131.54	161.70	154.67	131.12	119.22	98.79	74.24	1378.37
1989	82.18	106.77	99.31	162.76	183.68	74.98	83.75	149.44	126.12	122.15	104.63	90.85	1386.63
1990	59.58	66.41	93.24	130.56	146.95	218.79	216.18	167.84	134.97	160.73	128.65	112.56	1636.46
1991	89.28	103.92	137.57	117.56	137.77	98.14	201.07	172.83	149.09	139.33	109.18	92.66	1548.40
1992	79.82	105.65	133.96	160.68	152.63	195.93	216.25	193.27	171.14	164.72	128.99	112.21	1815.25
1993	88.99	94.10	129.32	155.74	175.49	183.15	205.84	211.85	163.02	176.26	164.66	117.08	1865.50
1994	68.14	91.20	131.56	150.90	148.13	245.30	270.08	203.47	194.98	225.46	187.18	135.84	2052.23
1995	88.82	117.79	152.96	163.99	163.18	205.13	115.64	203.36	238.70	230.37	178.89	152.64	2011.48
1996	125.15	157.98	151.72	177.17	178.52	130.01	50.95	229.30	224.68	232.95	163.64	82.52	1904.58
1997	98.29	79.49	96.02	134.85	166.32	205.64	320.08	284.72	227.96	203.35	156.03	81.73	2054.46
1998	54.67	102.52	126.88	172.62	181.59	202.61	227.64	243.39	221.08	201.59	165.20	127.31	2027.12
1999	124.15	123.10	185.77	257.69	211.23	24.24	81.43	189.47	203.76	211.35	173.48	90.51	1876.19
2000	114.04	103.14	129.48	145.58	177.30	242.02	251.26	215.38	215.14	201.51	155.40	112.14	2062.39
2001	66.90	63.22	115.06	175.57	234.82	264.10	223.84	210.40	275.18	255.07	211.30	130.40	2225.84
2002	69.47	108.56	196.38	190.65	201.55	153.96	158.79	218.20	220.60	232.27	156.01	101.01	2007.44
2003	94.32	128.39	125.12	149.27	203.67	224.89	291.75						
mean	78.11	95.29	122.11	147.70	161.84	158.45	169.22	178.02	167.67	165.74	130.35	94.45	1668.94

Note: the spill can be calculated from the difference between outflow and turbinated water.

Table II.6. The electricity production (MWH)

year	J	F	M	A	M	J	J	A	S	O	N	D	sum
1982	3229	4484	7747	7678	6944	63	5973	6049	7191	6990	5657	4014	66166
1983	5021	6177	8178	8911	9442	7943	8108	9179	9116	9510	8081	7163	96957
1984	6119	6481	9535	9939	9927	9461	9126	9225	7752	8253	7466	6415	99834
1985	6863	7363	10683	10965	11700	11115	9211	9486	9797	11253	89	7174	105949
1986	7172	9348	11461	12742	13574	12062	11466	11735	11967	13538	10574	9782	135540
1987	10240	11085	14028	15564	16104	6297	4752	11180	11888	13677	10029	9220	134102
1988	8674	10683	10083	10316	11656	10376	11548	11884	13220	13828	11471	8806	132541
1989	9414	10481	10249	14653	14861	4873	5490	11895	13221	14238	12320	10135	131843
1990	7008	6885	10518	12754	13547	16578	14418	14881	14303	17917	14955	13334	157506
1991	10306	10673	14117	10916	11864	11783	13922	15600	15352	15142	12644	11232	153775
1992	9897	11310	14406	15412	13549	14124	14126	15375	15860	18167	15163	13643	171205
1993	10584	9846	14156	15207	16064	14236	13631	15375	16125	19267	19007	14050	177857
1994	8170	9565	14431	14756	13699	18120	16900	15312	17705	18992	17444	15397	180772
1995	10281	11824	15911	15218	14129	14323	6431	16228	20467	22240	19916	17680	184723
1996	14116	12841	15254	15340	13363	8312	3117	16644	20449	22898	17106	9878	169285
1997	11426	8191	10397	13146	15191	15601	19265	21110	19598	21198	17602	9831	183080
1998	6572	10659	13774	16581	16133	15072	14682	20524	19090	18609	18503	15103	185526
1999	14249	12380	18849	21209	14074	1481	5099	13773	19662	21434	19126	11072	172473
2000	13542	11337	14404	14643	16734	19296	18647	18876	20678	20473	17666	13638	200273
2001	8097	6913	13190	17857	21857	19342	14059	18173	22205	25791	24211	15410	207646
2002	8407	11302	20741	17873	17049	10993	10283	17631	22140	25130	17965	12317	192128
2003	11314	12954	13485	14521	17937	15814	18989						
mean	9123	9672	12982	13918	14063	11694	11329	14292	15609	17074	14143	11204	155303

Table II.7. The water intake (m^3/s) for irrigation

year	J	F	M	A	M	J	J	A	S	O	N	D	mean
1982													
1983													
1984								0.38					
1985													
1986													
1987	0.78	0.78	0.44	0.50	0.44	0.16	0.80	1.54	1.66	1.87	1.11	0.21	0.86
1988	0.95	0.70	0.83	1.05	1.02	0.18	0.00	1.70	1.53	2.17	1.78	0.24	1.01
1989	0.38	0.59	0.71	0.81	0.58	0.12	0.48	1.03	1.62	1.98	0.93	0.40	0.80
1990	1.20	1.98	2.27	2.33	1.90	0.25	0.00	1.23	2.13	2.35	1.95	0.61	1.51
1991	1.86	2.37	2.47	2.63	1.29	0.35	1.12	1.32	1.59	2.01	1.16	0.54	1.55
1992	1.28	2.31	2.07	2.15	0.76	0.20	0.26	0.78	1.02	1.77	0.67	0.84	1.17
1993	1.41	2.29	2.41	2.59	0.87	0.05	0.20	0.79	1.05	1.48	0.76	0.38	1.18
1994	0.76	1.69	1.71	1.75	0.63	0.05	0.10	0.29	0.45	0.74	0.35	0.24	0.72
1995	0.81	1.55	1.87	1.87	0.77	0.04	0.00	0.16	0.87	1.21	0.98	0.00	0.84
1996	0.56	1.69	1.80	1.80	0.69	0.23	0.00	0.23	0.77	1.21	1.39	0.44	0.89
1997	0.40	1.23	1.49	1.66	0.69	0.27	0.00	0.29	1.05	1.53	1.89	1.00	0.95
1998	0.35	1.08	1.92	2.16	2.16	0.63	0.00	0.26	1.06	1.53	1.89	1.00	1.17
1999	0.35	1.08	1.92	2.16	1.53	0.00	0.00	0.00	0.78	1.53	1.89	1.00	1.02
2000	0.19	1.08	1.92	2.16	1.53	1.53	1.08	0.26	1.26	1.39	1.77	0.99	1.26
2001	0.91	2.02	2.34	2.37	2.48	0.72	0.00	0.22	0.14	0.00	1.01	0.00	1.01
2002	1.09	2.20	1.89	1.89	1.07	0.00	0.99	0.93	1.49	1.40	0.65	0.54	1.17
2003	0.62	1.78	2.45	2.06	1.69	0.00	0.00						
mean	0.82	1.55	1.79	1.88	1.18	0.28	0.30	0.67	1.15	1.51	1.26	0.53	1.07

Hydropower production

This section, which is based on Paschier *et al.* (2004), reports a time series of hydropower generation. The Section provides an insight into the actually generated energy compared with firm energy and theoretical power capacity. Fig. II.1 shows the relation between the average monthly turbine flows and the average monthly reservoir level. Apparently the turbines operate up to a reservoir level of +349m, although in some publications the normal maximum water level of the reservoir is stated as +348.5 m.

Fig. II.2 shows the relation between the turbine flows and the generated energy per month.

Theoretically the installed capacity of 47.6 MW could produce 34.8 GWh per month under the condition that all four turbines are available and the available head is maximum, or in other words: the reservoir is full. The figure shows that the maximum generated energy was around 25 Gwh/month, so around 70 % of the theoretical value. The specified firm energy of 18 MW corresponds to about 13 GWh/month. In about 50% of the months the firm energy is generated or exceeded. Fig. II.3 shows the reservoir level in relation to the monthly generated energy.

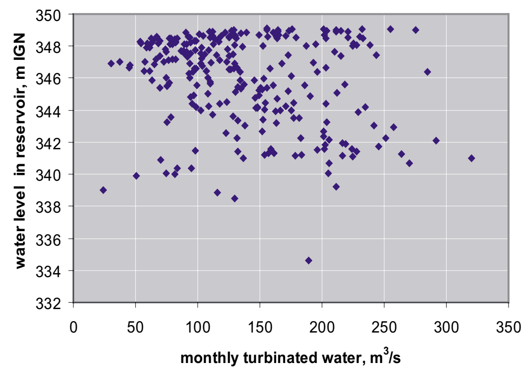

Fig. II.1. Sélingué: turbine flow versus reservoir level

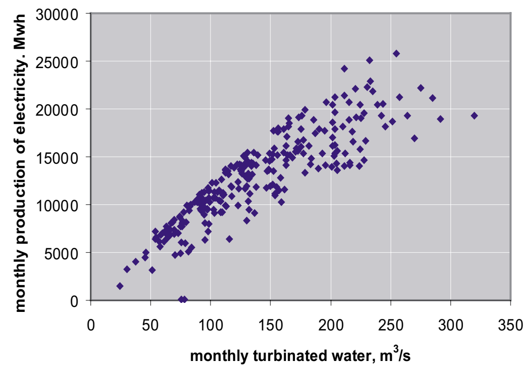

Fig. II.2. Sélingué: average turbine flow versus monthly generated energy

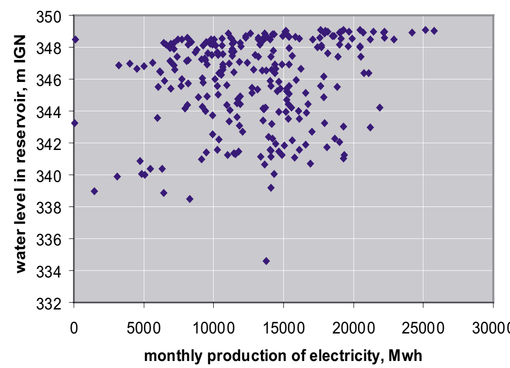

Fig. II.3. Sélingué: reservoir level versus monthly generated energy.

APPENDIX III MONTHLY WATER INTAKE BY OFFICE DU NIGER AND RIVER DISCHARGE IN THE SAME MONTHS AT KOULIKORO

This annex provides the monthly water intake by Office du Niger (m^3/s) since August 1988 and river discharge in the same months at Koulikoro (m^3/s) for the same 17 years. The average yearly water use by ON is not related to the river discharge. Hence, the relative water use increases at a low river flow: from 6% at the high flow (1995) to 16% at a low flow (1990).

The relative water intake is described with the following function:

% intake = 5156 flow-0.926

where:

% intake = annual intake as % of average annual river discharge at Koulikoro

flow = average annual river discharge (last column of second table).

Table III.1. Water intake by Office du Niger (m^3/s).

year	J	F	M	A	M	J	J	A	S	O	N	D	mean
1988								91	99	142	90	73	
1989	62	61	58	65	86	93	61	91	136	138	112	58	85
1990	60	62	61	57	105	81	68	102	138	130	113	66	87
1991	69	63	67	69	74	78	92	92	116	125	82	60	82
1992	66	69	69	60	65	67	92	91	121	141	113	76	86
1993	58	59	67	75	87	103	87	83	132	140	107	63	88
1994	57	64	71	75	76	95	78	68	120	105	88	58	79
1995	57	59	58	55	74	92	105	103	117	148	110	59	86
1996	57	58	72	69	76	96	110	110	131	135	96	76	91
1997	72	65	70	72	55	76	106	100	112	115	80	45	81
1998	44	52	70	80	91	113	120	104	111	135	82	46	87
1999	76	60	107	92	99	106	90	89	110	125	89	36	90
2000	37	49	51	51	54	104	113	96	135	136	86	61	81
2001	39	52	53	73	91	82	90	113	146	143	78	49	84
2002	62	69	83	90	97	111	129	123	134	118	85	52	96
2003	70	86	92	90	110	73	90	81	97	125	70	36	85
2004	43	54	66	75	104	109	98	109	130	146	84	56	90
mean	58	61	69	72	84	92	95	97	124	131	92	56	86

Table III.2. River discharge at Koulikoro (m^3/s).

year	J	F	M	A	M	J	J	A	S	O	N	D	mean
1988	174	130	95	87	111	140	529	1660	3100	1660	628	248	715
1989	133	109	88	128	172	126	310	1120	2190	2020	720	340	624
1990	142	83	77	105	137	258	627	1520	2460	2010	798	352	717
1991	198	132	105	105	133	254	776	1645	3165	2590	1110	401	887
1992	182	131	126	133	136	256	720	1430	2870	2020	840	363	770
1993	182	112	118	136	169	238	488	1560	2210	2000	1050	451	729
1994	185	117	125	125	127	385	1000	1960	4230	5060	3050	865	1441
1995	347	214	175	187	192	350	479	2330	4880	4360	1590	592	1312
1996	310	226	171	165	239	290	496	1840	3680	3660	1340	439	1075
1997	216	148	93	107	158	298	935	1820	3790	2910	1220	439	1014
1998	190	135	112	138	158	349	738	2220	4100	3890	1280	444	1151
1999	235	154	173	228	237	**52**	386	1680	3890	3800	1860	630	1114
2000	304	200	136	138	175	398	833	1773	3438	3813	1693	562	1126
2001	255	124	111	151	235	317	827	2424	5533	3335	1175	567	1258
2002	248	150	203	184	197	228	568	1891	3137	2487	1026	386	896
2003	128	100	78	77	127	231	890	2748	5169	3151	1292	502	1212
2004	193	178	125	106	150	296	542	1567	3352	2508			
mean	194	131	117	128	156	258	613	1709	3173	2729	1138	417	900

Note: The water intake at December 2004 is still unknown; the average has been filled in order to be able to calculate the average intake for 2004.

APPENDIX IV FLOW AND SURFACE AS A FUNCTION OF WATER LEVEL IN EIGHT ZONES WITHIN THE INNER NIGER DELTA

This Annex describes the flow and surface as a function of water level in eight zones, as presented in Figure 3.13. The parameters given in this Annex are estimated by Passchier *et al.* (2004) to arrive at a water balance of the Inner Delta.

Table IV.1. Main parameters underlying the water balance model for eight zones in the Inner Niger delta.

Flow, m^3/s	Water level, m	Width, m	Area, ha	Flow, m^3/s	Water level, m	Width, m	Area, ha
Kouakourou (length 15 km)				Mopti (length 50 km)			
0.0	266.32	9,833	14,749	0.0	260.12	722	3,608
23.9	266.35	10,451	15,677	4.9	260.20	760	3,800
135.8	266.47	13,339	20,009	27.6	260.54	936	4,679
320.7	266.61	18,097	27,145	63.4	260.95	1,214	6,069
571.6	266.76	24,550	36,825	109.8	261.37	1,574	7,871
911.9	266.91	33,306	49,958	170.1	261.79	2,042	10,208
2,024.9	267.20	61,297	91,945	352.6	262.62	3,434	17,169
4,073.2	267.50	112,812	169,218	659.6	263.45	5,776	28,879
7,843.1	267.79	207,623	311,435	1,176.0	264.29	9,715	48,576
14,781.2	268.08	382,116	573,174	2,044.5	265.12	16,341	81,706
27,550.3	268.38	703,258	1,054,887	3,505.5	265.95	27,486	137,432
51,050.9	268.67	1,294,298	1,941,447	5,962.8	266.79	46,233	231,165
Upper Diaka (length 100 km)				Bouna (length 70 km)			
0.0	267.16	265	2,652	0.0	258.38	297	2,080
1.8	267.24	290	2,896	3.1	258.51	315	2,204
11.2	267.58	412	4,119	17.3	259.01	397	2,779
28.7	267.99	639	6,395	40.5	259.63	531	3,714
55.9	268.41	993	9,929	71.5	260.26	709	4,964
98.2	268.83	1,542	15,417	112.9	260.88	948	6,634
273.5	269.66	3,717	37,170	244.9	262.13	1,693	11,849
696.1	270.49	8,961	89,613	480.7	263.38	3,023	21,162
1,714.9	271.33	21,605	216,047	901.8	264.63	5,399	37,796
4,171.3	272.16	52,087	520,867	1,654.0	265.88	9,644	67,506
10,093.4	272.99	125,576	1,255,758	2,997.4	267.13	17,224	120,568
24,371.0	273.83	302,751	3,027,508	5,396.7	268.38	30,763	215,339

Flow, m³/s	Water level, m	Width, m	Area, ha
Lower Diaka (length 50 km)			
0.0	258.38	232	1,158
0.8	258.42	259	1,294
5.0	258.58	403	2,017
13.9	258.78	703	3,513
29.3	258.98	1,224	6,119
56.1	259.18	2,132	10,659
193.7	259.58	6,469	32,344
611.3	259.98	19,628	98,142
1,878.3	260.38	59,560	297,798
5,722.8	260.78	180,725	903,625
17,388.6	261.18	548,384	2,741,920
52,786.6	261.58	1,663,994	8,319,970
Mayo Kotia (length 84 km)			
0.0	260.12	199	1,668
0.8	260.17	218	1,829
5.1	260.37	315	2,642
13.2	260.62	498	4,185
26.1	260.87	789	6,629
46.5	261.12	1,250	10,501
134.2	261.62	3,137	26,351
354.4	262.12	7,872	66,122
906.9	262.62	19,752	165,920
2,293.2	263.12	49,564	416,341
5,771.9	263.62	124,372	1,044,721
14,501.1	264.12	312,084	2,621,509

Flow, m³/s	Water level, m	Width, m	Area, ha
Akka (length 40 km)			
0.0	258.38	3,755	15,019
24.9	258.46	4,344	17,375
162.8	258.76	6,863	27,450
428.1	259.15	10,377	41,509
807.7	259.53	14,299	57,194
1,314.2	259.92	18,627	74,507
2,764.4	260.69	28,503	114,013
4,872.4	261.46	40,007	160,026
7,738.3	262.23	53,137	212,547
11,462.4	263.00	67,894	271,577
16,144.6	263.76	84,278	337,113
21,885.1	264.53	102,290	409,158
Diré South (length 175 km)			
0.0	256.85	114	1,991
3.1	257.18	120	2,095
17.3	258.52	147	2,569
39.7	260.18	189	3,315
68.7	261.85	244	4,278
106.0	263.52	315	5,521
218.1	266.85	525	9,194
404.8	270.18	875	15,311
715.8	273.52	1,457	25,498
1,233.5	276.85	2,426	42,461
2,095.8	280.18	4,041	70,710
3,531.7	283.52	6,729	117,752

APPENDIX V INNER NIGER DELTA (FLOOD LEVEL AND INUNDATED AREA), RIVER FLOW AND WATER USE

This Annex presents the main data on the maximum flood level and flooding surface in the Inner Delta, river discharge of Niger and Bani and water use by Sélingué and Office du Niger.

V.1 Historic trends

The columns of Table V.1 describe the following:

- *Column A:* year. If in another column the hydrological year is meant (1 May – 30 April), 1956 is 1956/57, etc.
- *Column B:* date at which the maximal water level was reached in Mopti; if there was more than one day with the same maximum, the first date was taken.
- *Column C:* maximum water level on the gauge of Mopti (260.92 m IGN).
- *Column D:* as B, but for Akka.
- *Column E:* as C, but for Akka (258.38 m IGN).
- *Column F-K:* the percentage of flooding during the hydrological year, calculated for all daily water level measurements in Akka from 1976 – 2004. A few missing data have been estimated from the water level measurements in the nearby station of Niafunké three days later.
- *Column L:* maximal inundated surface, derived from the maximal water level in Akka (column E), using the function:

  $km^2 = 0.000075*cm^3 - 0.01145*cm^2 + 14.9106*cm + 993.6$,
  where:
  km^2= flooded surface,
  cm = water level in Akka

- *Column M:* Rainfall average of 11 stations in and around the Inner Delta (see Figure 2.5).
- *Column N-P:* Monthly River discharge (m^3/s) in Ke-Macina in August, September and October. The data for the last two years were not yet available and estimated from river discharge measured at Koulikoro minus the water intake at Markala by ON, using the function:

  Ké-Macina=0.9222*(Koulikoro - ON)+15.714.

- *Column Q-S:* Monthly River discharge (m^3/s) in Douna in August, September and October.
- *Column T-V:* Water taken from the river by Office du Niger (see also Annex III). No data are available before 1987; for missing years we used an average value. Missing data are indicated in different colour.
- *Column W-Y:* Difference between inflow and outflow in the Sélingué reservoir (see also annex 2). Since the data for the last year was not yet available, the average value for the foregoing five years is used as estimate.

V.1 Scenarios

Table V.2 shows the predicted maximal flood level and flooded surface area in the present situation (scenario 0) and scenarios 1 "without ON & with Sél", scenario 2 "without ON & Sél and scenario 3 "present plus Fomi". The columns describe the following:

- *Column A:Year*
- *Column B-D:* Monthly river discharge (m^3/s) at Douna + Ké-Macina in August, September and October.
- *Column E-H:* Maximal water level in Akka. The level for the scenario's 'without ON & Sél', 'without ON & with Sél' and 'present plus Fomi' were derived using a series of connected regression equations; see explanation below. The level given for 'present situation' refers to the actual measurements.
- *Column I-L:* Maximal flooded surface, derived from the water level given in column B to E, using the equation:

  $km^2 = 0.00007*cm^3 - 0.0032*cm^2 + 13.408*cm + 1044.2$,
  where
  km^2= flooded surface,
  cm = water level in Akka, given in column E-H.

V.1 Effect of the reduced river flow on the flood level in Akka

The data provided in Table V.1 of this Annex are used to calculate the average water level in Akka in October, such as derived from the sum of the river flow in Ke-Macina and Douna in September. The used function was:

cm = EXP(LN(river flow)*0.341+3.182),
where:
cm = water level in Akka in October, river flow = the combined monthly flow at Ke-Macina and Douna in September.

For the present situation, the sum is taken of the actual river flow in Ke-Macina + Douna. The predicted water level for the scenario "without ON & with Sél" is this sum (column N-S of table 1) minus the water used by ON (column T-V of table 1), for the scenario "without ON & Sél" sum (column N-S) minus the sum of water used by ON and Sélingué (column N-Y). The predicted water level with the Fomi ("present plus Fomi") is derived from the present river flow plus the difference between inflow and outflow in Sélingué (column W-Y) multiplied with 2.9.

In the same manner, the water level in Akka in November is estimated from the combined river flow in Ke-Macina and Douna, using the following equation instead:

cm = EXP(2.775 + 0.164*LN(flow-Oct) + 0.173*LN(flow-Sep) + 0.066*LN(flow-Aug)),
where
cm = water level in Akka in November,
flow-Oct = the combined monthly flow at Ké-Macina and Douna in October,
flow-Sept = as flow-Oct for September and
flow-Aug = as flow-Oct for August.

The water level in November is multiplied by the ratio of predicted surface in a given scenario and predicted surface in the present surface to estimate the predicted maximal inundated surface (column E, F and H in table 2). Since the maximal water level is reached in October or November (column G), the difference between the prediction for average in November and the derived maximum is small.

To check the calculations, the maximal water level is also calculated for the predicted water level in October. The deviation from the maximum derived from the November series is small and differs for most years with only a few centimetres. We took the predicted November level to derive the maximum water level, since the water level in Akka is more frequently at its maximum in November than in October.

Table V.1. Maximum flood level and flooding surface in the Delta, river discharge of Niger & Bani, and water use by Sélingué & Office du Niger.

A	B	C	D	E	F	G	H	I	J	K	L	M
	MOPTI				AKKA						INNER NIGER DELTA	
	max. water level				flooding time (%) at different levels						max. inundation	annual rain
year	date	cm	date	cm	500cm	400cm	300cm	200cm	100cm	0cm	km2	mm
1956	29-okt	686	2-dec	553	21.0	40.4	53.6	64.5	78.7	100.0	18421	523
1957	18-nov	730	16-dec	625	36.6	54.6	66.1	75.7	81.4	100.0	24151	601
1958	1-nov	707	11-dec	575	28.4	49.2	65.0	75.7	92.9	100.0	20040	530
1959	31-okt	691	10-dec	570	23.8	42.9	55.2	65.0	74.6	100.0	19662	547
1960	1-nov	691	3-dec	580	25.7	44.3	57.1	67.5	77.0	89.9	20423	474
1961	1-nov	694	26-nov	550	19.9	36.9	48.6	59.3	68.9	80.1	18209	524
1962	4-nov	702	12-dec	590	28.4	47.0	60.1	70.2	79.5	88.3	21209	474
1963	16-nov	680	8-dec	558	20.5	40.2	52.7	63.4	70.8	98.6	18779	513
1964	3-nov	717	1-dec	587	25.1	39.9	51.4	64.5	81.4	87.7	20970	544
1965	1-nov	684	30-nov	564	21.0	41.5	53.0	63.1	76.2	93.7	19216	548
1966	9-nov	686	30-nov	543	17.2	35.5	47.8	59.0	74.3	82.5	17722	403
1967	11-nov	720	4-dec	602	28.1	45.6	57.7	67.5	76.0	83.9	22183	488
1968	25-okt	651	29-nov	521	10.1	35.8	49.7	63.4	74.9	93.2	16261	443
1969	1-nov	684	12-dec	586	27.3	46.2	57.4	66.1	74.3	83.3	20892	438
1970	22-okt	666	29-nov	510	4.1	30.9	43.4	52.2	62.0	81.1	15569	406
1971	20-okt	651	19-nov	510	7.7	29.8	43.4	53.6	62.0	71.3	15569	432
1972	7-okt	565	8-nov	445	0.0	18.6	37.4	53.6	64.5	77.9	11971	368
1973	3-okt	568	27-okt	425	0.0	13.9	31.4	41.0	48.4	68.3	11020	337
1974	18-okt	650	19-nov	519	7.9	30.9	47.0	54.1	59.8	67.2	16133	385
1975	26-okt	663	23-nov	529	12.6	33.6	46.7	56.8	66.1	79.8	16780	470
1976	21-nov	623	16-dec	504	3.3	33.6	48.9	60.1	70.8	86.6	15202	452
1977	10-okt	566	7-nov	421	0.0	10.7	29.0	42.1	53.0	71.3	10838	458
1978	22-okt	620	18-nov	486	0.0	28.4	43.4	55.5	66.1	78.1	14145	452
1979	6-okt	638	12-nov	507	5.7	31.1	44.0	53.8	65.0	76.8	15384	449
1980	9-okt	592	30-okt	442	0.0	13.9	32.8	43.2	53.8	69.7	11823	460
1981	15-okt	628	2-nov	468	0.0	24.0	38.3	48.4	61.7	81.4	13152	369
1982	29-sep	551	23-okt	406	0.0	6.0	29.8	43.4	56.0	77.9	10179	296
1983	14-okt	507	27-okt	380	0.0	0.0	22.7	39.9	51.4	70.5	9122	339
1984	19-okt	440	30-okt	336	0.0	0.0	14.2	32.2	45.4	70.2	7556	295
1985	13-okt	571	3-nov	433	0.0	11.7	29.5	40.4	50.3	71.9	11392	375
1986	8-okt	534	29-okt	388	0.0	0.0	23.0	34.4	47.3	80.3	9436	420
1987	17-okt	481	9-nov	359	0.0	0.0	20.8	35.5	46.4	85.8	8341	312
1988	8-okt	571	23-okt	429	0.0	12.0	28.1	39.6	49.7	74.0	11204	453
1989	5-okt	517	2-nov	388	0.0	0.0	22.7	35.8	45.6	77.3	9436	408
1990	9-okt	510	1-nov	374	0.0	0.0	24.9	39.1	49.7	80.1	8892	373
1991	5-okt	530	31-okt	397	0.0	0.0	29.0	41.5	52.5	86.3	9801	465
1992	7-okt	538	26-okt	387	0.0	0.0	23.8	39.6	51.9	88.5	9396	333
1993	6-okt	498	31-okt	376	0.0	0.0	25.1	39.1	51.9	93.4	8968	373
1994	28-okt	655	1-dec	534	16.1	34.4	48.4	59.8	70.5	87.4	17111	558
1995	24-okt	614	19-nov	485	0.0	23.5	38.8	48.9	60.7	100.0	14088	346
1996	17-okt	595	11-nov	443	0.0	16.4	35.2	45.9	55.5	94.5	11872	432
1997	13-okt	580	10-nov	436	0.0	14.8	34.7	47.0	58.7	90.7	11534	274
1998	25-okt	639	19-nov	486	0.0	24.9	38.3	50.0	61.2	100.0	14145	422
1999	26-okt	662	23-nov	511	8.7	32.0	44.5	53.8	62.0	89.3	15631	522
2000	23-okt	608	22-nov	465	0.0	22.1	39.9	52.5	62.6	98.9	12992	412
2001	19-okt	621	15-nov	470	0.0	23.0	39.6	51.4	62.8	100.0	13259	
2002	8-okt	538	1-nov	411	0.0	8.5	30.3	41.8	53.0	90.7	10395	
2003	16-okt	649	13-nov	496	0.0	29.5	46.2	55.7	65.6	90.7	14709	

Table V.1. Maximum flood level and flooding surface in the Delta, river discharge of Niger & Bani, and water use by Sélingué & ON (continued).

A	N	O	P	Q	R	S	T	U	V	W	X	Y
	river discharge in Aug, Sep or Oct (m^3/s)						water use (m^3/s)					
	Ké-Macina			Douna			Office du Niger			Sélingué		
year	aug	sep	oct	aug	sep	oct	aug	sep	oct	aug	sep	oct
1956	2170	4460	5460	807	2170	2000						
1957	3540	5570	4390	1350	2660	2870						
1958	2260	4140	5850	1490	3080	2270						
1959	2830	4920	4280	866	2540	3510						
1960	3440	5390	4230	1080	2250	2450						
1961	2880	5080	4640	1390	2920	2170						
1962	3070	5840	3110	662	2160	2290						
1963	2270	4410	5600	613	1840	1990						
1964	3480	4900	5430	1490	3190	3190						
1965	2650	4530	4720	1060	1970	2190						
1966	2470	4380	4370	421	1880	2550						
1967	3110	5390	4720	1230	3000	2660						
1968	3070	4080	6070	871	1770	1420						
1969	3320	5660	3550	1090	2130	1610						
1970	2220	4630	5340	867	2410	2090						
1971	2920	4790	2880	652	1790	1230						
1972	2380	3350	3390	323	729	511						
1973	2360	3320	2640	518	815	345						
1974	3150	4670	2200	884	1450	942						
1975	2830	4670	4140	594	1510	1490						
1976	2300	3060	4460	367	555	690						
1977	1250	3050	4170	149	701	643						
1978	2260	3750	2420	468	861	727						
1979	3860	4470	3840	373	1280	859						
1980	1480	3430	3140	423	1120	614						
1981	2630	3810	1870	793	1420	823						
1982	1680	3070	2630	365	753	417	90	100	130	165	99	62
1983	1570	2530	1830	140	288	240	90	100	130	146	140	-22
1984	1420	1410	2080	99	254	288	90	100	130	338	73	11
1985	1740	3420	1640	311	657	517	90	100	130	461	65	27
1986	826	2770	2560	216	590	391	90	100	130	221	440	102
1987	1210	1860	2080	151	335	339	90	100	130	182	492	99
1988	1420	2760	2100	500	1190	807	91	99	142	196	506	72
1989	899	2020	1510	370	1010	574	91	136	138	273	480	97
1990	1290	2200	1890	640	553	380	102	138	130	441	294	37
1991	1310	2260	1840	539	875	496	92	116	135	440	241	84
1992	1250	2560	2080	225	701	454	91	121	141	374	419	96
1993	1330	1910	1820	227	688	422	83	132	140	274	473	94
1994	1820	3660	1830	915	1470	1610	68	120	105	216	451	30
1995	1990	4280	4390	449	891	823	103	117	148	498	190	117
1996	1600	3170	4000	510	817	672	110	131	135	204	463	110
1997	1610	3300	2710	502	992	570	100	112	115	402	230	119
1998	1930	3570	3500	801	1560	1500	104	111	135	778	207	50
1999	1520	3460	3520	1290	2120	1590	89	110	125	240	584	29
2000	1620	3050	3500	818	1259	958	96	135	136	464	265	57
2001	1650	4290	3170	617	1165	787	113	146	143	525	789	30
2002	1647	2785	2200	338	573	558	123	134	118	290	476	51
2003	2475	4692	2807	834	1552	1577	81	97	125	482	415	57
2004	1360	2987	2194	331	657	518	109	130	146			

Table V.2. Predicted maximal flood level and flooded surface area in the present situation (scenario 2) and the scenarios 0 “without ON & Sél”, 0 “without ON & with Sél and 3 “present plus Fomi”.

A	B	C	D	E	F	G	H	I	J	K	L
	flow at Douna + Ké-Macina			predicted maximum level at Akka (cm)				predicted max. inundation (km²)			
	aug	sep	oct	Sc.0	Sc.1	Sc.2	Sc.3	Sc.0	Sc.1	Sc.2	Sc.3
year	present situation			maximum				maximum			
1982	2045	3823	3047	417	412	406	390	11135	10903	10645	9949
1983	1710	2818	2070	392	387	380	365	9980	9803	9518	8959
1984	1519	1664	2368	351	344	336	306	8344	8100	7843	6903
1985	2051	4077	2157	448	440	433	398	12619	12260	11933	10467
1986	1042	3360	2951	410	395	388	330	10778	10134	9854	7748
1987	1361	2195	2419	384	366	359	284	9624	8951	8684	6366
1988	1920	3950	2907	449	436	429	382	12679	12037	11734	9760
1989	1269	3030	2084	415	397	388	319	10912	10197	9854	7534
1990	1930	2753	2270	394	382	374	324	10080	9578	9273	7537
1991	1849	3135	2336	417	404	397	345	11094	10549	10243	8346
1992	1475	3261	2534	411	394	387	321	10794	10113	9811	7478
1993	1557	2598	2242	402	384	376	308	10357	9669	9354	7123
1994	2735	5130	3440	551	540	534	497	19000	18297	17951	15813
1995	2439	5171	5213	501	490	485	443	15734	15098	14780	12542
1996	2040	4037	3972	462	449	443	398	13433	12762	12442	10408
1997	2112	4292	3280	453	442	436	394	12930	12362	12084	10229
1998	2731	5130	5000	503	491	486	422	15865	15140	14840	11508
1999	2810	5580	5110	528	516	511	470	17468	16700	16400	14025
2000	2438	4309	4458	482	471	465	424	14555	13946	13625	11578
2001	2267	5455	3957	494	476	470	396	15291	14259	13907	10369
2002	1985	3358	2758	433	418	411	358	11836	11192	10874	8815
2003	3309	6244	4384	512	500	496	456	16415	15700	15433	13218
2004	1691	3644	2711								

APPENDIX VI FISH PRODUCTION IN THE INNER NIGER DELTA

This Annex presents the background data for fish production, split up for fresh and dry (= dried + smoked) fish and for auto-consumption, informal local trade within the Inner Delta and trade in Mopti (see Table VI.2). Table VI.1shows the total average production (kg/year) per fisherman (either active or non-active) of dry and fresh fish. The total production is the sum of the amount sold on the market (indicated as “trade”), the auto-consumption and the local trade. The auto-consumption of dry fish is estimated at 7.20 kg/year/fisherman and the local trade at 12.96 kg/year/fisherman. The auto-consumption of fresh fish is estimated at 27.92 kg/year and the local trade at 34.56 kg/year/fisherman. The estimates are obtained by dividing the total production (Table 5.3) by the number of fishermen, such as re-estimated by us (see text in Chapter 5). The table also provides the total trade as % of the total production. The last column shows the maximal water level in Akka (cm) in the previous year. To convert the data to production per active fisherman or per family (usually the economical unit), all production figures have to be multiplied by 3.57 or by 10.

Table VI.1. The total average production (kg/year) per fisherman (either active or non-active) of dry and fresh fish.

year	dry fish		fresh fish		TOTAL	% trade			Akka
	trade	total	trade	total		dry	fresh	total	cm
1977	67.32	87.48	4.03	66.51	350.84	76.96	6.45	63.52	504
1978	50.68	70.84	2.81	65.29	295.54	71.54	4.50	56.69	421
1979	61.30	81.46	1.95	64.43	329.18	75.25	3.12	61.12	486
1980	66.01	86.17	2.25	64.73	344.80	76.61	3.61	62.88	507
1981	47.02	67.18	1.54	64.02	282.34	69.99	2.46	54.66	442
1982	43.52	63.68	2.02	64.50	271.47	68.34	3.24	52.85	468
1983	25.78	45.94	2.24	64.72	214.04	56.12	3.59	40.20	406
1984	16.25	36.41	2.63	65.11	183.46	44.64	4.21	30.23	380
1985	15.35	35.51	1.07	63.55	178.96	43.23	1.71	28.48	336
1986	24.62	44.78	1.40	63.88	209.43	54.98	2.24	38.88	433
1987	17.14	37.30	0.98	63.46	184.67	45.95	1.56	30.69	388
1988	17.18	37.34	0.84	63.32	184.68	46.01	1.34	30.69	359
1989	21.76	41.92	0.79	63.27	199.52	51.91	1.27	35.85	429
1990	19.83	39.99	0.74	63.22	193.18	49.58	1.18	33.74	388
1991	17.29	37.45	0.94	63.42	185.15	46.18	1.51	30.87	374
1992	15.27	35.43	1.37	63.85	179.00	43.10	2.19	28.49	397
1993	11.64	31.80	2.87	65.35	168.71	36.61	4.60	24.13	387
1994	9.23	29.39	4.65	67.13	162.64	31.40	7.44	21.30	376
1995	60.65	80.81	13.22	75.70	338.34	75.05	21.16	62.17	534
1996	46.13	66.29	18.51	80.99	296.42	69.59	29.63	56.82	485
1997	35.50	55.66	11.11	73.59	254.49	63.78	17.79	49.70	443
1998	31.33	51.49	8.69	71.17	234.38	60.84	13.91	46.08	436
1999	27.39	47.55	9.62	72.10	222.84	57.60	15.39	43.28	486
2000	35.46	55.62	12.18	74.66	250.97	63.75	19.50	49.64	511
2001	29.46	49.62	9.21	71.69	229.00	59.37	14.75	44.81	465
2002	32.41	52.57	6.75	69.23	235.86	61.65	10.80	46.41	470
2003	19.95	40.11	1.94	64.42	191.56	49.74	3.10	34.02	411

Table VI.2. Annual production (ton) of dry & fresh fish, given separately for trade (registered and total) and local consumption by the people in the Inner Delta (auto-consumption by the fishermen and trade with other local people in the Delta). The total production (last column) is expressed as fresh weight, using the multiplier of 3.25 (or 3.17 in recent years) to convert the weight of dry fish into flesh weight.

year	dry fish (smoked + dried)						fresh fish						dry+fresh
	trade		local consumption			total	trade	local consumption				total	Total
	register	total	fisherm.	non-fish.	total		total	active	inactive	non-fish.	total		
1977	7706.141	13713.386	1466.565	2639.816	4106.381	17819.767	820.867	3030.900	2656.112	7039.511	12726.523	13547.390	71461.634
1978	5859.436	10427.101	1481.230	2666.215	4147.445	14574.546	578.995	3061.209	2682.673	7109.906	12853.788	13432.783	60800.057
1979	7157.681	12737.380	1496.043	2692.877	4188.920	16926.299	404.659	3091.822	2709.500	7181.005	12982.326	13386.985	68397.458
1980	7784.976	13853.676	1511.003	2719.806	4230.809	18084.485	472.727	3122.740	2736.595	7252.815	13112.149	13584.876	72359.453
1981	5600.084	9965.573	1526.113	2747.004	4273.117	14238.690	326.116	3153.967	2763.961	7325.343	13243.271	13569.387	59845.131
1982	5235.650	9317.049	1541.374	2774.474	4315.848	13632.897	432.959	3185.507	2791.600	7398.597	13375.704	13808.663	58115.577
1983	3132.824	5574.986	1556.788	2802.219	4359.007	9933.992	484.357	3217.362	2819.516	7472.583	13509.461	13993.818	46279.293
1984	1994.652	3549.563	1572.356	2830.241	4402.597	7952.160	574.534	3249.536	2847.711	7547.309	13644.556	14219.090	40063.609
1985	1894.389	3386.258	1588.080	2858.543	4446.623	7832.881	235.808	3282.031	2876.189	7622.782	13781.002	14016.810	39473.673
1986	3318.427	5485.758	1603.960	2887.129	4491.089	9976.847	312.439	3314.851	2904.950	7699.010	13918.812	14231.251	46656.004
1987	2431.169	3855.640	1620.000	2916.000	4536.000	8391.640	219.986	3348.000	2934.000	7776.000	14058.000	14277.986	41550.815
1988	2462.157	3904.784	1636.200	2945.160	4581.360	8486.144	190.141	3381.480	2963.340	7853.760	14198.580	14388.721	41968.689
1989	3149.454	4994.782	1652.562	2974.612	4627.174	9621.956	182.145	3415.295	2992.973	7932.298	14340.566	14522.711	45794.067
1990	2898.226	4596.355	1669.088	3004.358	4673.445	9269.800	171.246	3449.448	3022.903	8011.621	14483.971	14655.217	44782.067
1991	2553.293	4049.318	1685.778	3034.401	4720.180	8769.498	220.608	3483.942	3053.132	8091.737	14628.811	14849.419	43350.288
1992	2277.465	3611.877	1702.636	3064.745	4767.382	8379.259	322.885	3518.782	3083.663	8172.654	14775.099	15097.984	42330.576
1993	1753.232	2780.486	1719.663	3095.393	4815.055	7595.541	686.204	3553.969	3114.500	8254.381	14922.850	15609.054	40294.563
1994	1403.911	2226.491	1736.859	3126.347	4863.206	7089.696	1121.067	3589.509	3145.645	8336.924	15072.079	16193.146	39234.659
1995	9317.716	14777.152	1754.228	3157.610	4911.838	19688.990	3221.304	3625.404	3177.102	8420.294	15222.800	18444.104	82433.322
1996	7157.308	11350.918	1771.770	3189.186	4960.956	16311.874	4554.949	3661.658	3208.873	8504.497	15375.028	19929.977	72943.568
1997	5563.526	8823.307	1789.488	3221.078	5010.566	13833.873	2761.965	3698.275	3240.961	8589.542	15528.778	18290.743	63250.830
1998	4958.277	7863.431	1807.383	3253.289	5060.672	12924.102	2181.522	3735.258	3273.371	8675.437	15684.066	17865.588	58834.992
1999	4379.073	6944.859	1825.457	3285.822	5111.278	12056.138	2437.752	3772.610	3306.105	8762.191	15840.906	18278.658	56496.615
2000	5724.962	9079.332	1843.711	3318.680	5162.391	14241.723	3119.958	3810.336	3339.166	8849.813	15999.315	19119.273	64265.535
2001	4805.029	7620.392	1862.148	3351.867	5214.015	12834.407	2383.222	3848.440	3372.557	8938.311	16159.308	18542.530	59227.599
2002	5337.462	8464.788	1880.770	3385.385	5266.155	13730.943	1762.560	3886.924	3406.283	9027.695	16320.902	18083.462	61610.551
2003	3318.633	5263.086	1899.577	3419.239	5318.817	10581.903	511.591	3925.793	3440.346	9117.972	16484.111	16995.702	50540.335

APPENDIX VII LIFESTOCK IN THE REGION OF SÉGOU, MOPTI AND TOMBOUCTOU

The analysis in chapter 7 is based upon annual counts of number of cattle, sheep & goat in the regions of Mopti and Tombouctou. The original data for these regions, as well as for Ségou, are given in this appendix. Chapter 7 (section 7.3 - Data availability) describes how the series were assembled.

Table VII.1. Number of livestock over time (in million animals).

Year	Mopti		Segou		Tombouctou	
	Cattle	Sheep & goat	Cattle	Sheep & goat	Cattle	Sheep & goat
1982	1.86	2.63	0.74	0.00	0.96	3.40
1983	1.56	3.07	0.72	0.00	0.77	2.46
1984	1.76	3.09	0.60	1.30	0.63	2.28
1985	0.00		0.56	1.31	0.51	2.01
1986	0.82		0.58	1.27	0.38	2.21
1987	0.85	2.51	0.55	1.15	0.31	1.84
1988	0.90	2.60	0.65	1.30	0.32	1.93
1989	0.93	2.94	0.67	1.34	0.33	1.98
1990	0.95	2.98	0.67	1.42	0.33	2.10
1991	1.01	3.27	0.74	1.59	0.47	2.51
1992	1.14	2.59	0.77	1.67	0.48	2.64
1993			0.79	1.75	0.49	2.73
1994	1.24	2.89	0.81	1.84	0.51	2.87
1995			0.84	1.93	0.52	3.01
1996			0.86	2.03	0.54	3.16
1997	1.28	3.03	0.89	2.13	0.47	2.51
1998	0.00		0.91	2.24	0.57	3.49
1999	1.34	3.27	0.94	2.35	0.59	3.66
2000	1.38	3.44				
2001	1.38	3.44				

APPENDIX VIII ESTIMATION OF DENSITY AND TOTAL NUMBER OF WATERBIRDS IN THE INNER NIGER DELTA

Introduction

From a low- and slow-flying plane, it is easy to detect bird concentrations within the Inner Delta. This gives a trained ornithologist the opportunity to estimate bird numbers. By plane, it takes about 2-3 days to cover the entire Inner Delta and obtain a rough estimate of the total number of large, conspicuous bird species, such as ducks and large herons. This method is not suitable for smaller bird species (Girard & Thal 1999, 2000, 2001, van der Kamp et al. 2002).

An alternative census method for large wetlands such as the Inner Delta consists of ground surveys in a selection of representative areas. For the Inner Delta, systematic bird counts during the last 13 years are now available from the central lakes (Lac Débo-Walado, Korientzé) (e.g. van der Kamp. et al. 2002; see chapter 9), an area of 460 km^2. This area, however, is not a representative sample of the floodplains in the Inner Delta. It covers about 2% of the entire floodplain but constitutes 70% of all waters in the Inner Delta at a water level of 0 cm at Akka, As long as the water level is less than 300 cm, the census area still covers about 20% of the water bodies in the Inner Delta (Fig. AVIII.1). The low-lying position of the Débo-Walodo-Korientzé-lakes explains why most waterbirds become concentrated here when *no* water occurs anymore elsewhere in the Inner Delta (apart from stagnant water in some permanent lakes). Even during a décrue of less than 200 cm at Akka, waterbird numbers in the Niger Delta remain stable due to further concentration in the central lakes. Thus, although the census area is not representative for the Inner Delta, counts at low flood levels can still be used to reliably monitor waterbirds in a relatively easy way.

It takes about 5-7 days to systematically count about sixty bird species in the central lake area. No attempt has been made to correct for underestimates of species living in hiding or otherwise being easily overlooked. Moreover, small bird species, such as Yellow Wagtail and other passerines, have not been counted. To also cover such species, an alternative census method was adopted, i.e. complete counts in small plots of known size. The large variation in bird density, the likelihood

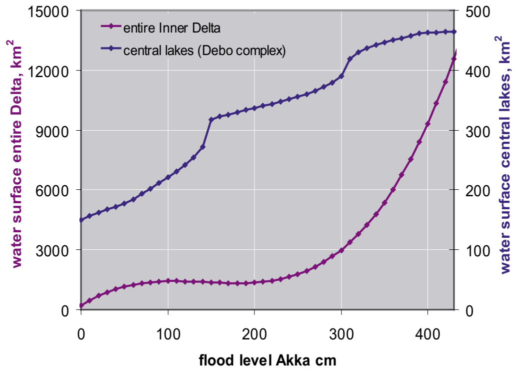

Fig. VIII.1. The flooded surface in the entire Delta and in the central lakes (i.e. census area; see Fig. VIII.xx) as a function of flood level (Akka, cm)

of numerous samples having zero birds and logistical problems voted against random sampling in a large number of plots. Instead, stratified sampling was chosen as the proper census method in the Inner Delta. Bird counts were performed in specified vegetation types under various water depths. The vegetation map (chapter 6) was used to determine the surface of main habitat types, such as bourgou and ricefields. For each flood level, the digital flooding model (chapter 3) enabled the calculation of the total surface of the flooded area. In combination with the vegetation map, the surface of bourgou, ricefield and other habitats on dry ground and standing in 10, 20, … 500 cm of water could then be determined. Stratified sampling in each of these habitats and water categories would allow the calculation of an average bird density per habitat. These figures were used to arrive at an educated guess of the total number of waterbirds in the entire Inner Delta.

Methods

Census methods are fully described by Van der Kamp et al. (2005). For the present Chapter it suffices to elaborate on plot sampling only, as it constitutes the basis for the calculation of total bird numbers in the Inner Delta.

For stratified plot sampling to be successful, the precise size of plots had to be known and all birds present had to be recorded. Length and width of plots were measured with a laser beam in an adapted binocular, or calculated from GPS-markings at the corners of plots (the latter method checked by measuring and counting steps in the field). This enabled the calculation of plot surface. Habitat type, vegetation height, vegetation density and water depth were recorded for each plot on pre-printed forms.

The census method was based on the assumption that all birds in the plots had to be recorded. To meet this criterion, several techniques were used, all of which were accompanied by shouting, hand-clapping and throwing mud into the vegetation to assure that all birds were flushed and recorded. This was achieved by (a) walking parallel transects by 2 or 3 persons with between-person distances of 20-50 m (depending on vegetation density/height, to assure full coverage), (b) crisscrossing a plot by one observer while the other watched from the side and kept note of birds, (c) encircling small plots and flush birds with noise and throwing mud, and (d) boating transects in water deeper than about 1 m, using observation belts of varying width (20->100 m) for the various bird species (clearly, a Great Egret can still be spotted when >100 m away, but for Snipe a narrower belt had to be used).

While plot-sampling, a keen eye was also kept on neighbouring fields because flushing birds was hardly ever confined to the plot at hand. In order to reliably count birds in the near-distance, it was necessary to keep track of birds which had already been flushed there some time before. This was rather easy, as the Inner Delta constitutes a flat environment with wide vistas. When a particular area had been thoroughly disturbed by the counting team(s), hundreds of meters were silently passed without counting, to resume plot-sampling in an area where all birds were still present.

For each plot, a subjective assessment was made whether all birds present had been recorded, or not. The latter figures were not used in the calculation of bird densities per habitat.

Fig. VIII.2. The distribution of 612 sites where bird density counts in plots were made.

All density counts were performed between 1 November and 15 March 2001/2002 and 2002/2003. Alltogether 613 counts were made, most of which near the central lakes. Other sites visited were Mopti and surroundings, Pora in the south and Lac Télé in the very north (Fig. AVIII.2).

The total number of waterbirds in the Inner Niger Delta can be estimated by multiplying the average bird density (numbers per km^2) with the total surface of the area. The size of the inundation area in the Inner Niger Delta varies between 8000 and 25000 km² (chapter 3.7). To improve the estimate, the inundation zone has been divided into 14 vegetation types (chapter 6), the same vegetation types in which birds were censused by means of stratified plot sampling. In the final analysis the 14 vegetation types were reduced to 6 major types. Bourgou, ideré, poro and Nénuphar were collectively named 'bourgoutière. Three types of grasslands were joined, whilst another 5 vegetation types only fond in stagnant water (kouma, loubou, horia, garsa, daroun) were classified as "stagnant". Most plot counts were performed in bourgoutière, wild rice, cultivated ricefields and grassland.

Since bird density not only varied per vegetation type, but also with water depth, the latter was routinely registered for each plot. Combining the digital elevation model (chapter 3.5) and the vegetation map (chapter 6) enabled the calculation of the area per category of water depth separately for each vegetation type. Unfortunately, on basis of the flooding model the category "wet ground" could not be distinguished from "dry ground". Assuming that the width of the wet zone along the water's edge was 5 m, on average, the total surface can be calculated since the total length of the shoreline can be derived from the digital elevation model (Fig. AVIII.3). The higher the flood level, the longer the shoreline, but during receding tide the total length of the water's edge is even longer, due to the presence of isolated lakes. The many temporary lakes at a water level of 200 – 300 cm at Akka explain why the relation between length of shoreline and water level at Akka is not straight but curved. Using the relationship given in Fig. AVIII.3, the surface of the "wet water depth=0 cm" can then be calculated.

Rice is found relatively high in the inundation zone (Fig. AVIII.4). That is why nearly all cultivated rice is already dry at a water level of 250 cm, while at the same level wild rice is mostly found in shallow water. A part of the bourgou and nearly all grassland is found in even deeper water. Furthermore, the category "wild rice + Nénuphar" has been joined with wild rice and the category "bourgou + Nénuphar" with bourgou.

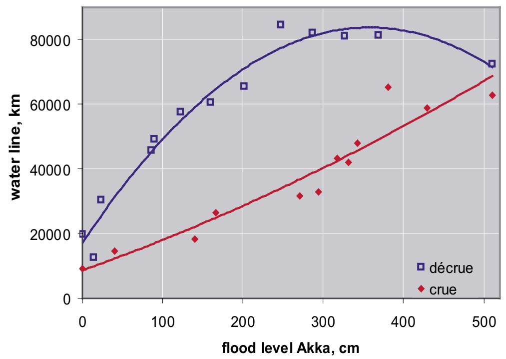

Fig. VIII.3. The length of shoreline as a function of the water level at Akka (cm) during incoming and receding water. The length of shoreline is derived from the inclusive models (see chapter 3.5).

Bird density per vegetation type

Table AVIII.1 gives the average bird density for seven habitat types. A selection has been made for bird species for which the mean density exceeded 1 birds per 100 ha. Species composition differs greatly between the six habitats. Also, bird density appears to be high in stagnant wetland, and remarkably low in wild rice.

Bird density per vegetation and water depth

There is a large variation in bird density per vegetation type, largely explained by water depth as shown for bourgou plots in Fig. AVIII.5. A real waterbird as the Cormorant was only observed if there was more than 40 cm of water. On the other hand, typical land birds such as Crested Lark, Cisticola and Prinia were usually only seen in bourgou on land.

Table AVIII.2 shows that in each habitat bird density is very low when the ground was dry. High bird densities were recorded when the ground was still wet or covered with shallow water. Characteristic for bourgou is that many birds can still feed in deep water in this habitat type. This follows from the much greater floating power of bourgou as compared to other vegetation types. Moreover, the buoyancy of the stems increases the shallower the water becomes, forming increasingly dense mats on the surface with declining water depth. This change in buoyancy enables the light-weight Squacco Heron to start feeding already on bourgou when the water depth is still 80 cm, whereas the heavier-weight Great Egret only arrives on bourgou when the water depth is less.

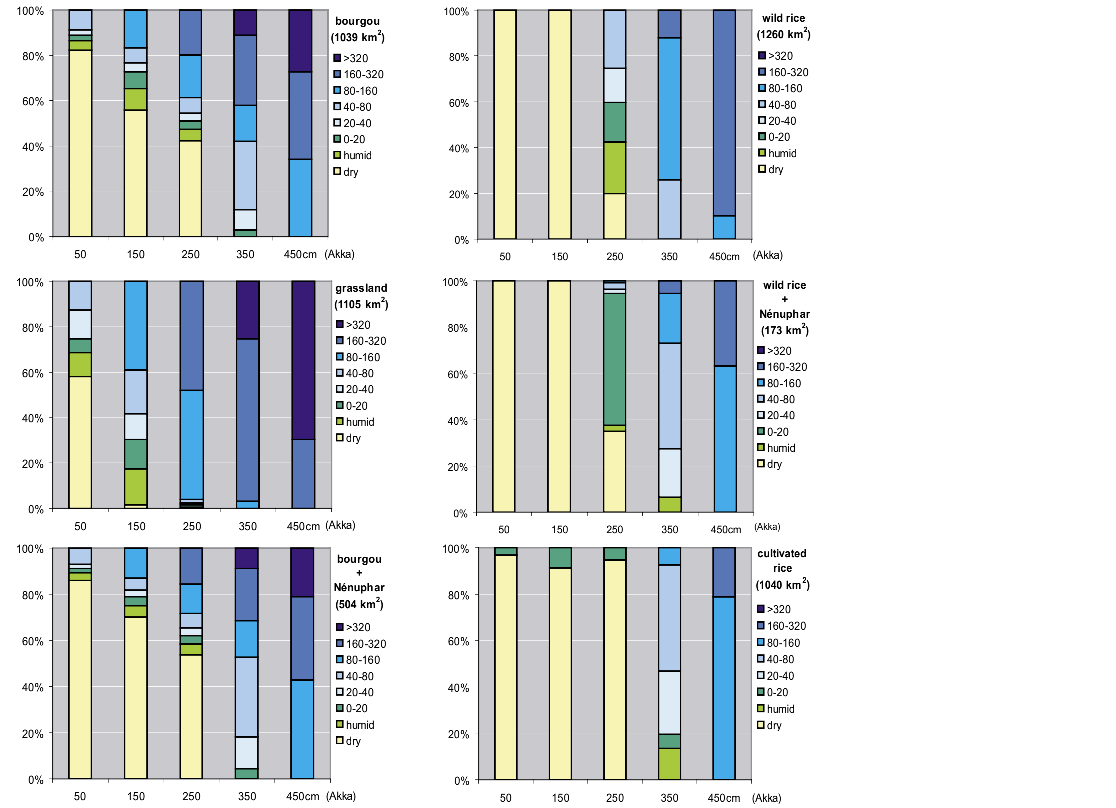

Fig. VIII.4. The surface area (%) of six vegetation types under various water depths. The latter has been calculated separately for five different flood levels (cm at Akka).

Estimate of total bird numbers

The data presented so far allows an estimate of the total number of birds in the Inner Delta between November and March (Table AVIII.3). The densities are multiplied with the surface of the different habitats. The total surface of the specified habitats (Fig. AVIII.2) amounts to 5121 km², being the zone covered by water at a flood level of 360 cm. Thus, we still ignore ca. 20,000 km² of the higher floodplains. The density of waterbirds is extremely low, however, in the high zone, unless the water level is higher than 360 cm. Table AVIII.3 shows that the Inner Delta accommodates an estimated 3 to 4 million wetland-related waterbirds. This estimate would be much lower if the flood level stands at 450 cm. At this water level, the zone of shallow water lies outside the 5121 km² used in our calculations.

Table VIII.1. Average bird density per 1000 ha in six habitat types. Summated numbers are also given for heron species, hens + Jacana, waders and passerines.

Bird species	cult.rice	bourgou	grass	wild rice	mimosa	stagnant	mean
Long-tailed Cormorant	0	1596	13	6	0	330	855
African Darter	0	60	0	0	0	0	30
Grey Heron	55	272	7	426	0	77	214
Purple Heron	41	450	22	6	185	297	293
Great Egret	0	148	0	0	0	121	96
Yellow-billed Egret	0	212	41	0	0	719	218
Little Egret white morph	82	231	249	40	926	342	226
Little Egret black morph	0	20	12	0	0	0	12
Cattle Egret	3715	658	247	1309	0	871	1041
Squacco Heron	129	1292	45	15	295	2385	1025
Great Bittern	0	56	0	0	0	0	30
Glossy Ibis	0	86	0	0	0	363	98
Lesser Moorhen	0	3	0	0	556	0	18
Purple Swamphen	0	124	0	0	0	567	145
African Jacana	377	642	0	1	0	151	389
Lesser Jacana	34	205	0	42	0	1029	260
Black-winged Stilt	898	727	434	0	0	1459	706
Collared Pratincole	5589	1606	2219	349	0	115	1711
Greater Painted-snipe	0	37	0	0	0	6	20
Spur-winged Lapwing	543	253	366	155	0	28	246
Common Ringed Plover	23	292	1403	3	0	6	267
Little Ringed Plover	4	140	0	0	0	593	152
Kittlitz´s Plover	298	384	1702	0	0	0	369
Spotted Redshank	120	4	10	0	0	0	17
Marsh Sandpiper	0	16	47	0	0	0	12
Common Greenshank	122	6	76	0	0	0	24
Wood Sandpiper	844	3301	3332	379	869	7896	3187
Common Snipe	94	59	0	28	0	72	52
Great Snipe	27	14	188	0	201	0	32
Little Stint	1152	1554	6836	37	0	1962	1754
Curlew Sandpiper	0	57	2698	0	0	51	258
Ruff	9150	4844	8992	106	0	21251	7152
Yellow Wagtail	1957	5266	4339	1217	6491	17206	5919
Sedge Warbler	0	1620	0	17	7599	33897	5807
Bluethroat	0	141	0	0	2451	0	146
Crested Lark	1653	1095	867	433	936	74	879
Zitting Cisticola	0	179	66	131	0	25	117
Prinia spec.	0	65	0	6	2377	0	104
TOTAL	26981	27778	34263	4718	22940	91958	33938
herons	4054	3445	625	1796	1406	5175	16502
hen / jacana	412	973	0	43	611	1747	3786
waders	18905	13334	28338	1059	1069	33503	96208
passerines	3610	8368	5272	1804	19854	51202	90110
number of counts	64	327	45	74	15	87	612

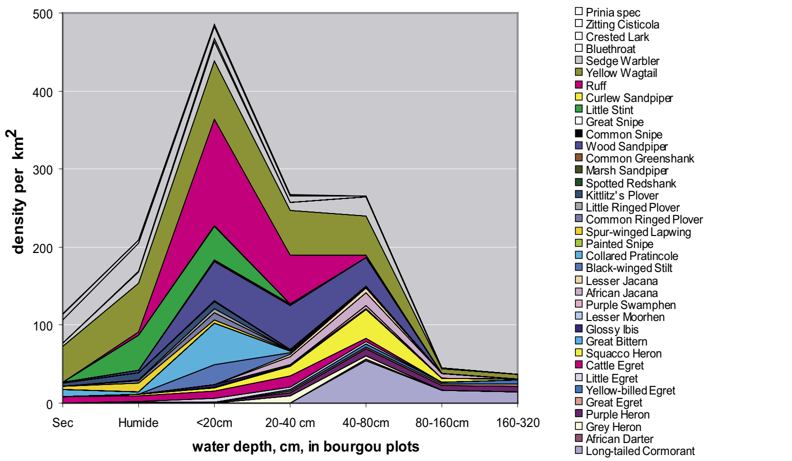

Fig. AVIII.5. Average bird density in bourgou per 100 ha on dry and wet ground and in five classes of water depth.

Table VIII.2. Average bird density per 100 ha in five habitat types on dry and wet ground and in five different classes of water depth.

habitat	species	dry	humid	<20cm	20-40cm	40-80cm	80-160cm	160-320cm	total
stagnant	herons	8.4		8.2	6.0	8.9	0.1	6.7	5.2
	hen, jacana	0.0		0.5	5.4	3.9	0.0	0.0	1.7
	waders	0.0		150.6	11.6	13.6	0.1	0.0	33.5
	passerines	1.4		19.8	25.5	39.0	84.3	0.0	51.2
grassland	herons	0.0	0.2	1.6					0.6
	hen, jacana	0.0	0.0	0.0					0.0
	waders	0.0	10.5	73.8					28.3
	passerines	0.0	5.1	3.0					5.3
bourgou	herons	0.8	1.1	2.3	4.9	6.5	1.6	1.6	3.5
	hen, jacana	0.0	0.0	0.0	1.3	2.7	0.6	0.0	1.0
	waders	1.8	8.0	34.0	12.8	4.2	0.1	0.0	13.4
	passerines	8.8	11.7	12.3	7.8	7.6	0.7	0.6	8.4
wild rice	herons	0.1	4.3	2.3	0.0	0.6	0.1		1.8
	hen, jacana	0.0	0.0	0.0	0.0	0.4	0.0		0.0
	waders	0.0	0.8	1.8	0.7	1.8	0.0		1.1
	passerines	0.3	1.4	3.1	0.7	2.7	0.0		1.8
cultivated rice	herons	0.8	14.7	2.2	7.5	0.5	1.5	0.0	4.1
	hen, jacana	0.0	0.0	0.1	0.0	3.7	0.0	0.0	0.4
	waders	0.9	36.2	36.4	0.0	0.3	1.0	0.0	18.9
	passerines	0.3	4.0	12.8	0.4	0.4	0.0	0.0	3.6
stagnant	number of density counts	1		14	7	21	30	1	74
grass		10	21	14					45
bourgou		22	23	78	51	90	38	25	326
wild rice		16	16	25	7	8	2		74
cult.rice		9	13	10	2	19	9	2	64

The estimated numbers may be compared with the counts performed by plane, with the maximum numbers counted in the central lakes and/or with counts at nocturnal roosts. In general, the estimated numbers are higher than what we would expect from the evidence obtained so far. In some cases, for instance Cormorants, the estimate is evidently much too high. Deviations from reality are to be expected, since the standard deviations are large and the number of samples is still limited.

Table AVIII.3 is based on average bird densities in the 28 categories (four habitat types and seven classes of water depth). We know, however, that during the *décrue* the surface of dry habitats will increase (see yellow bars in Fig. AVIII.3). Simultaneously, the area of suitable habitat for nearly all waterbirds will decrease in concert with the receding flood. As a consequence, unless the birds disappear from the Inner Delta, bird density must increase. In other words, we expect that the total numbers given in table AVIII.3 are underestimated at low flood levels and overestimated at high flood levels. To give an example: assuming a constant bird density, the number of Purple Herons during the décrue would decrease from 106,000 to 14,000. To what degree this apparent decrease really occurs, depends on whether densities of Purple Herons condense when their preferred habitat contracts. Unfortunately, the data set is still too small to divide the 28 categories in five more flood level classes. The next section shows an alternative way to check whether bird density remained constant or not under changes in water depth.

Table VIII.3. Number of birds present in the Inner Delta, as estimated from the surface of habitats and water depth classes (Fig. AVIII.4), and average bird density for these habitats and depth classes (Fig. AVIII.5; table AVIII.2).

Flood level (Akka, cm)	50 cm	150 cm	250 cm	350 cm	450 cm
Long-tailed Cormorant	68,599	91,049	139,067	366,015	172,957
African Darter	2,857	2,283	3,802	13,198	3,012
Grey Heron	8,499	11,615	40,163	47,150	15,558
Black-headed Heron	191	361	445	10,072	290
Purple Heron	14,247	25,661	47,153	105,906	70,567
Great Egret	3,751	10,791	20,464	33,636	35,089
Yellow-billed Egret	6,932	10,721	22,713	47,572	35,001
Little Egret white morph	11,971	20,253	12,251	32,595	11,092
Little Egret black morph	1,238	1,180	803	3,612	0
Cattle Egret	241,543	212,359	334,723	463,642	106,591
Squacco Heron	55,113	63,877	67,864	233,536	31,600
Great Bittern	1,320	1,979	1,604	4,584	0
Glossy Ibis	1,362	3,444	2,273	3,332	0
Purple Swamphen	6,014	4,887	5,571	24,021	1,365
African Jacana	23,597	34,719	36,941	244,827	32,655
Lesser Jacana	8,492	7,463	20,243	61,773	0
Black-winged Stilt	19,896	44,864	17,628	145,396	0
Collared Pratincole	207,002	231,127	148,570	65,343	0
Greater Painted-snipe	1,819	1,393	1,491	7,023	0
Spur-winged Lapwing	169,718	158,824	153,786	46,033	37,500
White-headed Lapwing	8,029	8,029	8,029	0	0
Common Ringed Plover	47,844	77,235	16,649	6,828	0
Little Ringed Plover	2,020	5,373	3,318	3,628	0
Kittlitz´s Plover	151,912	125,882	47,767	32,146	0
Spotted Redshank	370	805	244	15,535	9,065
Common Greenshank	1,714	3,688	389	15,712	9,065
Wood Sandpiper	170,535	276,996	162,742	420,146	30,132
Common Snipe	884	2,151	9,864	17,515	327
Great Snipe	5,125	7,704	1,064	4,376	0
Little Stint	197,276	405,050	86,834	147,216	0
Curlew Sandpiper	61,171	122,069	10,544	1,033	0
Ruff	306,965	578,624	157,129	994,282	0
Yellow Wagtail	1,258,554	801,676	698,954	773,523	66,132
Sedge Warbler	109,830	113,685	89,780	146,474	2,113
Bluethroat	2,705	6,946	4,248	2,482	293
Crested Lark	586,618	425,674	336,904	146,065	8,895
Zitting Cisticola	121,199	80,088	71,462	3,325	1,077
Prinia spec.	9,099	8,176	8,015	5,353	585
TOTAL	3,899,659	3,996,319	2,795,200	4,703,010	682,404

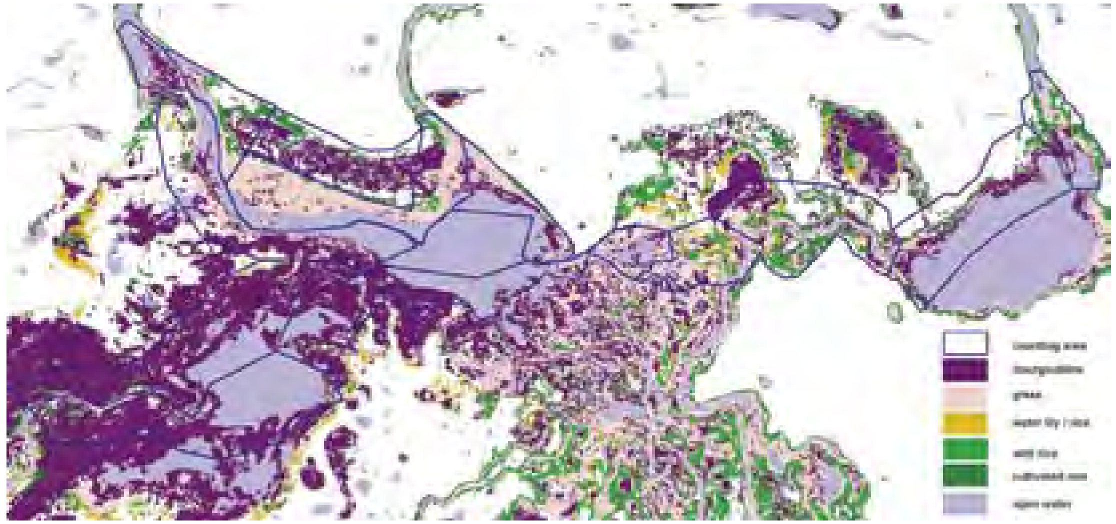

Fig. VIII.6. The 16 census areas in Lac Débo, Walado and Korientzé (borders indicated with blue lines). The distribution of bourgou (purple), grass (pink) and wild rice (green) is shown, taken from Fig.6.3).

Bird density per vegetation type , water depth and flood level

This section investigates whether birds start feeding in higher densities when the remaining wetlands further contracts during the course of the décrue. For this analysis, we used the bird counts performed in the area of the central lakes (Walado, Débo, Korientzé) during the last few years (van der Kamp et al. 2002). Table AVIII.4 gives the average number of waterbirds present in the central lakes between November and March, separately for five different flood levels. It is obvious that numbers for almost all species increase in parallel with a decrease of flood level. Since each count covers the same 460 km^2, independent of flood level, this indicates that overall bird density increases at a lower flood level. With the data summarised above, it is possible to indicate to what degree this observed trend is due to a shift in the surface of the 28 distinguished sub-habitats during the décrue.

Fig. AVIII.6 shows the sites where bird counts in the central lakes were performed, and the distribution of the vegetation types (Fig. 6.3). Within the census area, bourgoutière is the most common habitat (143 km^2 bourgoutière and 25 km^2 bourgoutière mixed with Nénuphar). Extensive grasslands come into existence when the large floodplains fall dry, e.g. north of Lac Débo (54 km^2); the remaining area (188 km^2) is mainly open water. We used the digital flooding model for the 460 km^2 of the central lakes to calculate the surface of the various water depth classes per habitat at different flood levels. Assuming that there are no birds on the open water and in the few ricefields, and also that bird density in the 28 sub-habitats would not vary with flood level, the predicted numbers for the census area can be calculated. The numbers counted can now be compared with the estimated numbers (Table AVIII.4).

Table AVIII.4 shows that the estimated numbers are, on average, (much) higher than the actual counts. The difference is large for species living in hiding or widely dispersed, such as the Purple Heron, Squacco Heron or Wood Sandpiper. These species, marked in bold in the last column, are apparently regularly missed in the integral counts. In contrast species living in flocks are very difficult to catch with the density counts. Hence a species like the Black-tailed Godwit,

Table VIII.4. The numbers of waterbirds counted in Lac Débo/Walado/Korientzé between November and March in four years (1998-1999 until 2001-2002), split for five flood levels (Akka, cm). Also the average number for all water levels is given, as well as the maximum number ever counted. These numbers may be compared to the predicted number per flood level, such as derived from the density counts (for explanation see text). Species, marked in bold in the last column, are regularly missed in the integral counts.

	Average number counted 1998 -2001					predicted numbers, based on density counts					counts		estimated
water level	50cm	150cm	250cm	350cm	450cm	50cm	150cm	250cm	350cm	450cm	max	average	average
Long-tailed Cormorant	617	5067	7600	7000	2767	5989	15143	20149	33558	15818	12412	4610	18131
African Darter	19	32	69	65	28	249	452	369	1194	367	153	43	526
Grey Heron	5350	4750	2633	517	29	871	2310	1278	2180	332	6959	2656	1394
Black-headed Heron	1	0	0	0	0	25	93	43	77	33	4	0	54
Purple Heron	2600	2733	2033	1233	188	1281	4122	7092	10706	6804	4804	1758	**6001**
Great Egret	1583	1933	1267	1767	336	385	1991	3394	4389	3412	5539	1377	2714
Yellow-billed Egret	107	455	793	680	367	613	1764	3086	6157	3936	1648	480	3111
Little Egret	7167	3267	1767	583	107	924	3482	747	1503	228	11270	2578	1377
Cattle Egret	767	900	892	933	617	15129	12260	5450	2428	167	1755	822	7087
Squacco Heron	350	533	933	542	166	5074	13442	7098	14491	2130	2001	505	8447
Bittern	0	2	2	0	0	142	629	115	253	0	29	1	**228**
Glossy Ibis	3833	4917	2717	567	3	176	1340	168	120	0	11377	2407	361
Purple Swamphen	135	85	31	5	1	525	961	470	1682	127	176	51	**753**
Lesser Jacana	3	0	0	0	0	784	1600	542	2129	0	3	1	**1011**
African Jacana	150	223	180	85	26	2216	6065	5471	6911	1964	356	133	**4525**
Greater Painted-snipe	0	0	0	0	0	159	281	104	469	0	2	0	**203**
Black-winged Stilt	1500	2027	967	217	17	1712	11588	1306	672	0	3167	945	3056
Collared Pratincole	1167	1133	1533	933	70	18808	29045	6666	925	0	18310	967	11089
Spur-winged Lapwing	417	360	217	113	45	7943	8461	2670	160	74	674	230	3862
Common Ringed Plover	3467	2567	1033	145	1	3125	7883	1104	155	0	4743	1443	2453
Little Ringed Plover	10	10	8	3	0	261	2215	245	107	0	33	6	566
Kittlitz¥s Plover	1267	433	183	17	0	12025	12668	2984	182	0	2225	380	5572
Spotted Redshank	650	2067	933	202	0	29	172	18	1	0	4557	770	44
Marsh Sandpiper	190	102	30	3	0	73	363	40	11	0	202	65	97
Common Greenshank	1600	1433	867	210	2	85	301	34	3	0	2525	822	85
Green Sandpiper	1	0	0	0	0	27	203	100	43	37	2	0	**82**
Wood Sandpiper	243	107	50	13	1	13462	45998	8767	16984	175	431	83	**17077**
Common Snipe	52	11	3	0	0	260	176	54	120	0	135	13	**122**
Great Snipe	5	1	1	0	0	115	737	146	117	19	3	1	**227**
Little Stint	15000	10000	4033	667	2	12533	58360	6229	645	0	16823	5940	15553
Curlew Sandpiper	2593	1333	267	32	3	2874	7160	842	28	0	3791	846	2181
Ruff	28333	25833	13733	3600	3	20703	90668	11377	7127	0	48921	14301	25975

Table VIII.5. The data from Table AVIII.4 summarised for herons and waders. The ratio between the number counted and the estimated number derived from the samples is also given.

flood level (cm)	50	150	250	350	450	average
Herons						
actual counted	22177	19673	13136	6858	1821	12733
based on samples	24749	41673	28574	42619	17054	30934
Waders						
actual counted	56803	47757	24092	6265	192	27022
based on samples	97831	285366	49312	38579	2433	94704
herons: ratio	0.90	0.47	0.46	0.16	0.11	0.41
waders: ratio	0.58	0.17	0.49	0.16	0.08	0.29

of which up to 27,000 birds can be present in the central lake-area, was never met in the density plots. For the same reason, the estimated number for the Glossy Ibis is evidently too low.

When the counted and estimated numbers are compared per flood level, (many) more birds seem to occur in the central lake at lower flood levels. This increase is much larger for the counts than for the numbers derived from the samples. Note that in the latter case, we assumed for the moment that the bird density remained the same for all flood levels. From this, one may conclude that bird density indeed increases as the available wetlands contract.

Conclusions

Although Chapter 9 will provide further interpretation of the data, the main conclusions of this appendix may be summarised as follows:

- Bird density is maximal on bourgou fields and low in wild rice vegetation. Also, the vegetation in stagnant water attracts many birds, but this habitat is rare in the Inner Delta.
- Depending on water level, only part of the Inner Delta is intensively use by the waterbirds. The zone with shallow water attracts most birds. Bourgou fields in deeper water are also exploited by waterbirds, due to the buoyancy of the stems. Only very few birds feed on the floodplains after the ground has became dry.
- During the décrue wetlands contract. As a consequence bird density increases in the few remaining wetlands.
- The density counts reveal that the Inner Delta is more important for some species than assumed so far. This mainly involves species living in hiding or widely dispersed.

APPENDIX IX COST BENEFIT ANALYSIS OF AFRICAN DAMS

Several extended Cost Benefit Analysis (CBA) studies have been carried out in the past. The World Commission on Dams (WCD 2001) investigated eight projects in great detail. Two of these are situated in Africa: (1) the Orange River Development Project in South Africa; and (2) the lake Kariba dam in Zambia and Zimbabwe. A third interesting study in Africa, which was commissioned by IUCN, focussed at the effects the Maga Dam on the Waza-Logone floodplain area in Cameroon (Loth 2004).

IX.1 Orange River Development Project (South Africa)

The pilot study by the WCD is a detailed assessment of the Orange River Development Project (ORDP), which was commissioned by the South African government in 1963. The ORDP consists of two dams in the Orange River Basin. It was in essence a politically motivated project aimed at providing benefits for the white farmers in South Africa. The major goals of the project included provision of irrigation for agriculture, water supply for industrial use, generation of hydropower and others. The projected costs were US$ 571 million (1998 prices). The actual cost overrun, which amounted to 438%, were mainly due to the omission of inflation estimates in the original costing and large schedule slippages in the implementation period.

With the displacement of 1,260 coloured farmers and their families, social impacts were numerous. Due to the Apartheid regime in place, black and coloured workers were not compensated while white farmers were compensated generously. Environmental impacts were not considered in the original planning, but effects have been recorded. Most notably an increase in Blackfly costing the livestock sector US$ 330,000 annually.

On the benefit side, while only 50% of the projected area is irrigated, crop production is much higher than initially anticipated. The higher production ranges from 166% for vegetables to 457% of projected production for winter cereals. Hydropower generation is at 106% of the projected amount, while the value of generated power was 9% higher than anticipated. Flood control is another benefit of the project, with flood peaks more than halving. The last benefit that has been measured is the impact on tourism, with around 200 jobs being created.

Although this pilot case study has investigated and found a wealth of information on the actual impacts, costs and benefits, there is insufficient information to assess ex post the economic feasibility of the project including all additional costs and benefits.

IX.2 Lake Kariba area (Zambia and Zimbabwe)

The Kariba dam lies in the Zambezi river along the border of the two countries. The main goal was hydropower generation for Zambia and Zimbabwe. The hydropower plant has a total capacity of 1320 MW and supplies power to both countries. Construction began in 1955 in 2 phases. The first phase was finished ahead of schedule in 1962, the second ran late by 5 years in 1976 due to unexpected geological conditions and political unrest between the two countries.

Costs were budgeted at £ 79 million for phase 1 and £ 52.9 million for phase 2. Actual costs were £ 77 million for phase 1 and £ 147.3 million for phase 2. The rate of return was projected at 16.5% and eventually came to 14.5% for the project as built.

Social costs have mainly been the displacement of people. It was estimated that the project would affect some 29,000 people, in reality, 57,000 people were displaced. The budget for relocation programmes was £ 4 million, but didn't increase when the number of people proved to be higher than expected. Also, no livelihood options or consultation were provided. A related impact of the displacement on the environment was the relocation to wildlife habitats. Other important environmental impacts include modification of downstream hydrology; the flooding of the delta, causing the death of mangroves and lowered shrimp production; lake pollution around urban settlements and changing fish stocks to more lacustrine species.

In addition to hydropower benefits, other unexpected benefits were generated by the project. As a result of the low cost of the generated hydropower, electricity priced dropped by 30%, while overall prices rose by more than 75%. Tourism has been the main unexpected benefit. A thriving industry around the lake, with more than 1,000 hotel beds, developed. Irrigational benefits were not planned, but at present around 2,700 ha around the lake are irrigated. The last benefit worth mentioning is the fishing industry that developed on the lake, albeit that the large share is not accrued by the people directly around the lake, but by capital-intensive companies from outside the area.

As with the Orange River case, not enough information on the monetary values of indirect costs and benefits is available to accurately assess the economic performance.

IX.3 Waza Logone floodplain (Cameroon)

The third study is the IUCN study on the Waza Logone floodplain in Cameroon (Loth 2004). Of the three cases discussed here, this one has the most significance for the Mali case. Cameroon is, like Mali, a sub-Saharan country with several similar characteristics. Similar to most Malian dams, the Maga dam project is a low dam with an shallow reservoir. The dam was built in the Logone River in 1979. It is a 30 km long dam and created a 400-km^2 reservoir. It was built as a multipurpose dam, with hydropower generation and irrigation of 10.000 ha as main goals. The dam and embankments deprived the floodplain of its natural occurring floods, causing severe environmental and social effects. People dependent on the wetland services downstream for their livelihoods, such as fishing, rice and sorghum production, were severely affected by the sudden alteration of the hydrological regime. Quantified socioeconomic consequences are estimated at more than € 2 million annually. The livestock owners were struck the hardest, with damages calculated at about 1.5 million per year.

Because of this, a programme was established aimed at restoring the Waza Logone floodplain area as a wetland ecosystem. In the project, the irrigational facilities still play a major role, but have now been incorporated in a more integral ecosystems approach. An extensive analysis was performed on the programme wherein an extended CBA was conducted. Three options for re-inundation of the floodplain were investigated, all of which proved to be economically feasible and desirable above the present situation. Under full flooding the area provided benefits of about €11 million annually, boiling down to € 90 per capita. After the dam building, economic losses added up to about € 2.5 million per year, and were carried by one third of the population. Per capita losses were calculated at € 60. Flood release measures would cost between €3 and 12 million over 5 years. Benefits created would lie at €1.4 – 2.7 million per year. Net present values lie between €6 – 8.4 million. Added economic value would be € 53 per person.

APPENDIX X NET PRESENT VALUE

Most projects and scenario's yield benefits at least intermittently over its lifetime, and usually they incur costs over that lifetime. Because the distribution of these costs and benefits may vary for different scenarios over time, they need to be converted to net present values (NPV) by discounting both categories of values. Discounting is the practice of placing lower values on future benefits and costs as compared to present benefits and costs, reflecting peoples' preferences for the present rather than the future. The usual way to deal with temporal effects in the analysis is to apply a discount rate to future impacts. Suppose an annual damage of the value X $ will occur over a period of T years, and a discount rate of r per cent is applied, then the present value of the total damage over time is:

$$\sum_{t=0}^{T} X / (1+r)^t$$

The present value of the damage X in any given year with t>0, $X/(1+r)^t$, is smaller than the value X in year t=0. From the equation it can be seen that the higher the discount rate r and the higher the number of years (t), the lower the discounted value of future damage in any given year.

The choice of the appropriate discount rate remains a controversial issue because it may have a significant impact on the outcome of the analysis. The usual way to deal with this is to apply different discount rates so as to allow the decision-maker to choose the most appropriate rate. In this study we follow this practice and report values for several discount rates for the main impacts where possible.

If all effects are measured in monetary terms, the aggregation is straightforward: Simply sum the total discounted annual net benefits. This results in the TEV expressed in Net Present Value (*NPV*) terms:

$$NPV = \sum_t (B_t - C_t)\cdot(1+r)^{-t}$$

where B is all benefits over time and C is all costs over time. The scenario with the highest *NPV* is most preferred from an economic point of view. For example, if the '3-dams' scenario generates higher discounted net-benefits than the '2-dams' scenario, the following condition would hold:

- $NPV_{3\ dams} > NPV_{2\ dams}$

APPENDIX XI BACKGROUND ON WETLAND VALUATION

The literature on valuation and evaluation of wetlands, like the Inner Niger Delta, is well developed. A recent meta-analysis of wetland valuation studies reported over 190 studies, providing 215 value observations (Brander *et al.* 2004). Wetland valuation studies often focus on one particular value (i.e. biodiversity, recreational). However, the range of economic functions being performed by the eco-system values of wetlands varies widely. It could be production of agricultural commodities, provision of waste assimilation services or of amenity values. Each such good or service again may or may not be marketed. This implies that the economic linkages differ.

Accordingly, alternative methods of valuation have been suggested (Freeman 1993). While household production function approaches (Mäler 1992) are based on the revealed preference approach, stated preference approaches have also spawned a large literature in the context of non-marketed goods and services (Hanneman 1992) develops this approach referred to in the literature as the contingent valuation method. See Freeman (1993) on the linkages between alternative approaches to valuation and consumer theory.

Economic benefits derived from wetlands have also been estimated using alternative approaches (see Söderqvist, Mitsch & Turner, 2000). As explained by Acharya (2000), the production function approach measures the welfare change accruing to a household as the sum of the producers' and consumers' surplus accruing to the household out of the use of an environmental good or an eco-system service in production or in consumption. This approach will be the most applied method in the study on the Inner Niger Delta. Alternatively, contingent valuation studies may be used to value wetland amenities (Turner *et al.*, 2000).

Each of these approaches integrates into utility theory in different ways and is an extension of the cost–benefit methodology. The latter was used in a large number of early studies as an empirical counterpart of Fisher, Krutilla & Ciccheti's (1972) evaluation of the development versus conservation argument. They argued that if the development option implies some irreversible transformation of an area, it is always optimal to develop less of the area. Hanley & Craig (1991) used the same framework to determine the relative value of preservation and afforestation of a peatland in the 'flow country' of Northern Scotland.

Other studies ignore ecological benefits. Kosz (1996) argues for instance that in the context of a stretch of wetland area along the River Danube, 'it would be highly efficient for the Austrian economy to build a hydro-electric power station, if there were no ecological benefits at all'. The assumption implicit in the statement 'if there were no ecological benefits' would not now be defensible. To sum up, we have come a long way since those studies and ecological processes are being studied to determine linkages with economic value.

Alternatively, the production function approach can be incorporated into inter-temporal models of renewable resource use (Acharya & Barbier 2000). In such integration exercises, the ecological function affects the rate at which a renewable resource increases and thereby impacts off-take from it. Such models depict long-run equilibrium of the resource in terms of steady values for effort put into extraction and resource stocks. However, most models set up for valuation treat wetland areas as being a proxy variable for stocks. This variable is then treated as having a similar impact on harvest rates as the amount of effort put in for resource extraction (Ellis and Fisher 1987; Barbier & Strand 1998).

APPENDIX XII LIST OF ABBREVATIONS

A&W	Altenburg & Wymenga ecological consultants (Pays-Bas)
CPS	Cellule de Planification et de Statistique du Ministère du Développement Rural
DNH	Direction Nationale de l'Hydraulique
DNSI	Direction Nationale de la Statistique et de l'Informatique
DRAMR	Direction Régionale de l'Appui au Monde Rural
EDM	Direction Nationale de l'Energie du Mali
IER	Institut d'Economie Rurale
IRD ex-ORSTOM	Institut français de Recherche pour le Développement
IVM	Institute for Environmental Studies, Free University, Amsterdam
MDR	Ministère du Développement Rural
ODRS	Office de Développement Rural de Sélingué
ON	Office de Niger
OPM	Opération Pêche Mopti
ORM	Opération Riz Mopti
ORS	Opération Riz Ségou
ORSTOM	Institut français de Recherche scientifique pour le développement en coopération
RIZA	Institut de gestion intégrale des eaux douces et de l'assainissement, Pays-Bas
UICN	Union mondiale pour la nature
WI	Wetlands International – Sévaré, Dakar, Wageningen
WMO	World Meteorological Organisation

Hydrological interventions (i.e. dams and irrigation schemes) aim to increase economic independence and food security in the unstable Sahel environment. Tapping the Niger's flow, however, is not without consequences. The costs and benefits of expensive hydrological structures have to be carefully balanced. In this study we incorporate downstream interests into our analysis.

Downstream outcomes are inherently difficult to quantify, and are therefore often omitted in similar enquiries. The aim of this study is to develop a decision-support system for effective river management in the Upper Niger, in which ecological and socio-economic impacts and benefits of dams and irrigation systems can be analysed in relation to different water management scenarios. Multidisciplinary in nature, this study draws on the fields of hydrology, ecology and environmental economics.