

The Economic and Ecological Effects of Water Management Choices in the Upper Niger River: Development of Decision Support Methods

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ABSTRACT *One million people in the Inner Niger Delta make a living from arable farming, fisheries and livestock. Upstream dams (one built for electricity generation and one for irrigation) affect this downstream multifunctional use of water. Additionally, the Inner Niger Delta, which is one of the largest Ramsar sites in the world, is a hotspot of biodiversity and accommodates two of the largest known breeding colonies of large wading birds in Africa and in addition, is a vital part of the eco-regional network, supporting up to 3 to 4 million staging waterbirds, residents and migrants from all over Europe and western Asia. The hydrological and related ecological conditions in the Inner Delta largely determine the population size of these waterbird species. The major aim of the three-year study was to develop a decision-support system for river management in the Upper Niger, in which ecological and socio-economical impacts and benefits of dams and irrigation systems can be analysed in relation to different water management scenarios. The study involves various components: hydrology, arable farming, livestock, fisheries, ecology and socio-economics. An economic analysis has been conducted to determine the role of dams in the economy of the Inner Niger Delta and the Upper Niger region. By innovatively combining the above information on hydrology, ecology, fisheries, and agriculture, the study shows that building new dams is not an efficient way to increase economic growth and reduce poverty in the region. In fact, such efforts are counter-effective. Instead, development efforts should be aimed at improving the efficiency of the existing infrastructure, as well as of current economic activities in the Inner Niger Delta itself. This approach will also provide greater certainty for the essential eco-regional network functioning of the Inner Delta.*

Introduction

For the communities living in the semi-arid, western Sahel zone, the Senegal and Niger rivers are lifelines. 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

climatic uncertainty in the western Sahel zone has been the development of hydroelectric and hydro-agricultural irrigation schemes, aiming at reducing economic dependence and increasing food security. Sharing of water along a major river system both, between and within countries presents difficult choices for water managers. In West Africa, the task is particularly daunting, considering the water demands in the Sahel.

The Niger River is the third longest river in Africa (4200 km), and while its drainage basin is shared by 10 West African countries, next to Nigeria (25.7%), Mali (25.5%) and Niger (24.8%), two of the driest countries in the region, contain the largest parts of the river basin area. Rising in Guinea and Ivory Coast, the Niger River flows northeast into Mali, bends to the southeast downstream of Tombouctou, flowing across western Niger and forming part of the international boundary between Niger and Benin, then enters Nigeria and flows predominantly south, finally entering the Atlantic Ocean through an extensive delta (Figure 1).

The area of the Niger River basin in Guinea and Ivory Coast combined, forms only 5.3% of its total area (Table 1). However, as 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 km³/yr) actually exceeds the quantity entering Nigeria from Niger (i.e. 36 km³/yr), about 1800 km further downstream. This reduction is, among others, due to the enormous decline in runoff in the Inner Delta in Mali through evaporation, combined with absence of runoff entering the left bank in Mali and Niger (the Sahara desert region).

To better illustrate the choices available to water and land managers, a three-year study was performed in the Niger basin to test the consequences of different water allocations, primarily intended for hydro-electricity, irrigation and floodplain inundation (Zwarts *et al.*, 2005). Using socio-economic and ecological cost/benefit analysis, the study characterized the effect of dams and irrigation systems on various sectors, including agriculture, livestock, fisheries, river navigation and ecology. The analysis considered both direct costs

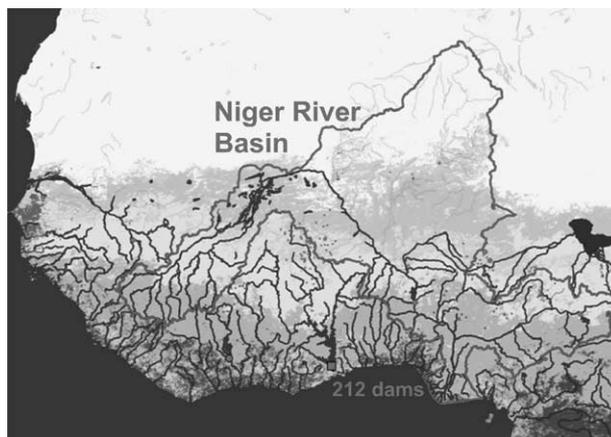


Figure 1. The Niger Basin. The Niger originates in Guinea and Ivory Coast, passes through Mali and Niger and enters the Atlantic Ocean in Nigeria. The Niger Basin also extends over Algeria, Burkina Faso, Benin, Chad and Cameroon. The existing dams are indicated by dots. *Source:* FAO (2005).

Table 1. Total surface area of the Niger basin (2 273 946 km²) partitioned among the 10 countries. These figures are compared to the area per country. Average annual rainfall in the basin area is presented as an indication for the contribution of each country to the river system

Country	Total area of the country (km ²)	Area of the country within the basin (km ²)	As % of total area of basin	As % of total area of country	Average annual rainfall in the basin area (mm)		
					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				

Source: FAO (internet site).

and benefits and indirect costs and benefits, including the valuation of biodiversity in the Inner Niger Delta. The study developed four scenarios to test whether a decision-support system would be feasible for river management. To enable realistic quantification of the downstream effects of the four selected options, the study focused on the hydrology of the Upper Niger River, but included the entire basin from its origins in Guinea and Ivory Coast, to Tombouctou in Mali, including the Inner Delta, as shown in Figure 2. The total inundated area of the Inner Delta, a network of tributaries, channels, swamps and lakes can cover around 30 000 km² in the flood season, equivalent to about 11% of the upstream catchment area, and is included in the 41 195 km² that was designated a Ramsar Site in January 2004.

Figure 2 also shows there are three existing dams, one being constructed and three in various planning phases.

The study was conducted by an inter-disciplinary team of hydrologists, ecologists, engineers, fishery experts and agronomists, each discipline dealing with the effects of the four scenarios on its sector before, in the final step, an economic analysis was performed based on the combined information (Zwarts *et al.*, 2005).

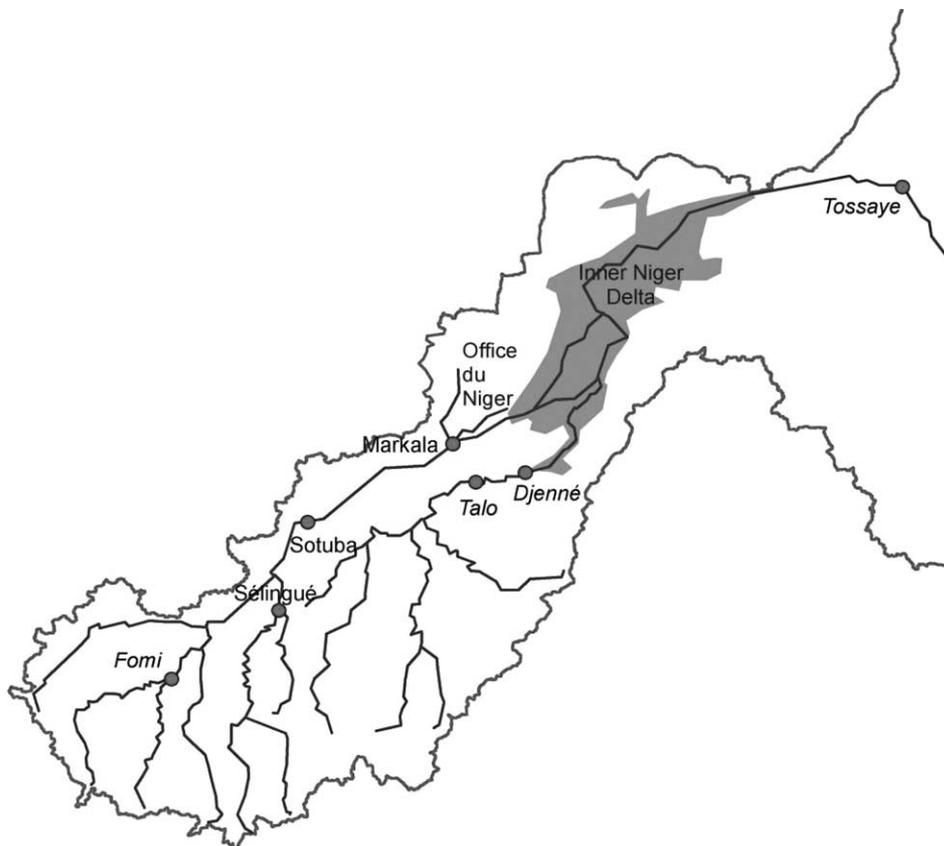


Figure 2. The Upper Niger Basin with three existing dams (Sélingué, Sotuba, Markala), one under construction (Talo) and three under study (Fomi, Djenné and Tossaye)

The Hydrological Regime of the Upper Niger

The Niger River enters Mali through various tributaries from Guinea. The main tributary, the Bani, originates in Ivory Coast and southwest Mali. The total catchment area of the Bani (129 000 km²) is almost as large as the remainder of the Upper Niger basin upstream of the Inner Niger Delta (147 000 km²).

After a rapid increase in discharge, due to abundant rainfall in Guinea, Ivory Coast and south-western Mali, reaching values of the order of 1000 m³/s at Koulikoro, the flow through the Inner Delta results in a gradual decrease in discharge. The river ‘loses’ part of its potential flow between Ségou, at 900 km from its source, and Tombouctou, at 1500 km, due to evaporation. Supply from the Bani tributary, which flows into the Niger River at Mopti (1150 km from the source) does not compensate for the ‘losses’ in the Inner Delta. Subsequently, there is hardly any inflow for a long stretch and the discharge remains rather stable, until another humid region is passed in the lower reaches of the Niger River, shortly before it enters the Atlantic Ocean.

La Grande Sécheresse, the Great Drought, in the early 1980s was a major catastrophe for the population of the Sahel. Rainfall was low, but the decline in river flow was even greater. Figure 3 illustrates a time series of rainfall and river discharge, measured upstream of the Inner Niger Delta, just below the capital of Mali, Bamako. Discharge includes groundwater aquifer contributions, and analysis of a series of dry years and direct groundwater measurements by Mahé *et al.* (2000), confirmed that river discharge remains low until groundwater levels have recovered after about two years.

River discharge is markedly seasonal, and shows a time delay of between two and three months in peak flow before and after passing through the Inner Niger Delta. Moreover, residence time of water in the Delta is longer at high flows than at low ones, as illustrated in Figure 4 for monthly discharge in 1954/55 (high) and 1984/85 (low).

The Upper Niger has three dams, one is under construction (Talo) and three more dams (Fomi, Djenné and Tossaye) are currently being considered for construction (see Table 2). The Sélingué dam in the Sankarani River, with a reservoir of 2.2 km³, has been used for

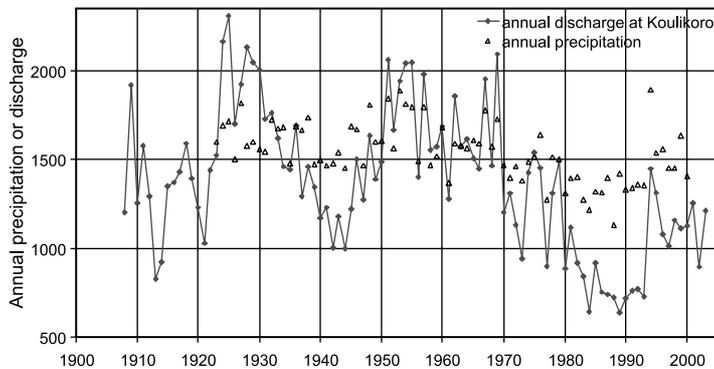


Figure 3. Annual river discharge at Koulikoro (m³/s), 60 km downstream of Bamako, and annual rainfall (mm/year) in the Inner Niger basin upstream of Bamako

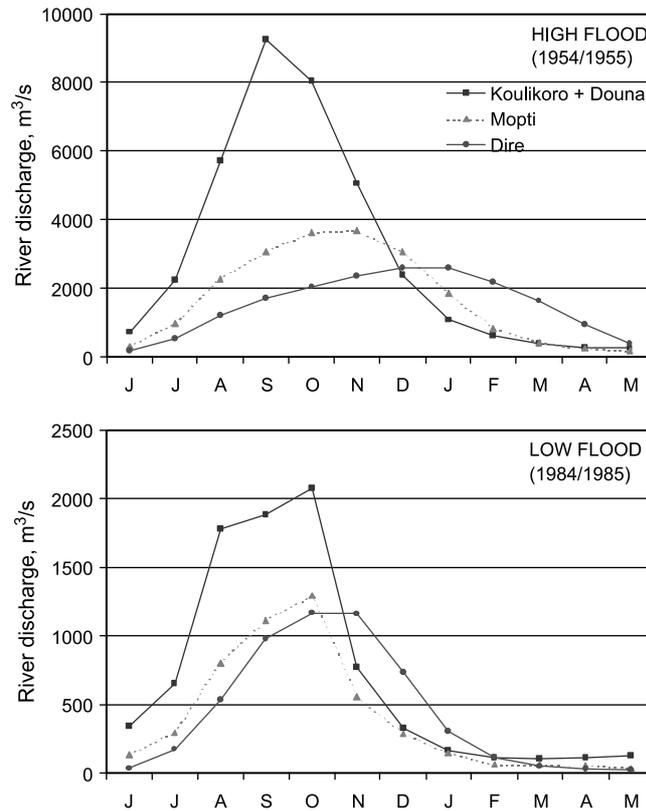


Figure 4. Monthly discharge of the Niger River (Koulikoro) and the Bani River (Douna) combined, compared to the discharge at Mopti in the southern Inner Delta and Diré in the northeastern part of the Inner Delta

hydropower since 1982. The Sotuba dam, in operation since 1929, serves a very small hydropower plant, located directly downstream from Bamako. Because of its small size, this reservoir has hardly any hydrological impact on the Niger River basin. The Markala dam, opened in 1947, is a diversion dam, just downstream of Ségou. It is used to irrigate the area of the Office du Niger, largely planted to rice.

Material and Methods

Operation of three dams is examined in detail in the study: the Sélingué dam, the Markala dam, hereafter called ‘Office du Niger’, because it primarily supports that irrigation scheme, and the proposed Fomi dam. The benefits and costs of expensive hydrological structures have to be carefully balanced. In this study, downstream interests have been incorporated in the analysis. Downstream effects are inherently difficult to quantify and are therefore often omitted in similar studies.

To assess the impact of the three man-made structures in the Upper Niger region, four scenarios were analysed.

Table 2. Existing and planned dams in the Upper Niger

Name of dam	Year	Type	Storage volume	Water use & loss
<i>Existing dams</i>				
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
<i>Planned dams</i>				
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	?

- Scenario 0. In this scenario, neither Sélingué nor Office du Niger is present in the Upper Niger. This scenario serves as a ‘baseline’, illustrating the ‘natural’ hydrological state as existing more than 50 years ago, but updated.
- Scenario 1. In this scenario, Sélingué is present, but not the Office du Niger.
- Scenario 2. This scenario reflects the present situation, in which Sélingué and Office du Niger are in full operation.
- Scenario 3. In this scenario the proposed Fomi dam is assumed to be in operation. The main purpose of this scenario is to evaluate its impact.

The study applied standard models developed for river flows (RIBASIM; Passchier *et al.*, 2004), and for estimating the Inner Niger Delta floodplain inundation area, multiple satellite images were used within the digital flooding model of Zwarts *et al.*, (2003) that enabled calibration of water levels at known river stage points with inundation area.

Modelling the Operation of Dams in the Upper Niger

WL|Delft Hydraulics and the Malian Direction National de l’Hydraulique (DNH) used the RIBASIM model (Passchier *et al.*, 2004) to analyse downstream effects of irrigation, the Sélingué dam and the Fomi dam, taking 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 discharges upstream of the various structures were entered as forcing functions:

- Inflow into the Sélingué reservoir has been measured on site.
- Inflow into the future Fomi reservoir was derived from several Guinean hydrological stations (FRIENDS database; Sangaré *et al.*, 2002).
- River discharge at Koulikoro was used to estimate the flow at the Markala dam.
- River discharge at Douna was used to estimate the inflow into the future Talo reservoir.

These data were used in combination with net evaporation from the dam reservoirs and the operation of the Sélingué reservoir to maximize hydropower (peak demand 18 GWh), as well as considering the impact of the planned Fomi dam, a reservoir with a

volume 2.9 times that of the Sélingué reservoir. According to the model results (Figure 5), if hydropower was maximized, the Fomi dam would have a significant impact on the Niger river discharge into the Inner Niger Delta.

Flooding of the Inner Niger Delta: Estimating Inundation Area from Water Depth Measurements

Using satellite imagery and the digital flooding model (Zwarts & Grigoras, 2005), the inundation area was calculated as a function of water levels at Akka (centre of the Delta). However, this model had to take into account the difference in behaviour between an advancing flood and a receding flood, and the effect of rainfall in the Delta during an advancing flood. As a consequence, many areas that remain dry at high water levels may be flooded at lower water levels. From 24 satellite images, water maps were first constructed, and two different algorithms were used for advancing and receding water. In the ‘inclusive algorithm’, areas were considered flooded when covered by water at a certain water level *and* all lower levels. In the ‘exclusive algorithm’, an area is considered flooded, if it is covered by water at this water level *OR* at a lower water level. In Figure 6, the actual inundation areas as a function of water level at Akka derived from the water maps is compared to the areas calculated according to the inclusive and exclusive model.

The exclusive model for advancing water is appropriate for a situation with low local rainfall, while for the high rainfall situation, the inclusive model is more appropriate. However, since the deviation between the two models is small during advancing water, Figure 6 gives one regression to describe the relationship between water level and flooded surface. The exclusive model for receding water is appropriate for years with a very low peak level of the flood, during which many isolated lakes are not filled with water, while the inclusive model is appropriate for years with a high flood, but will always result in

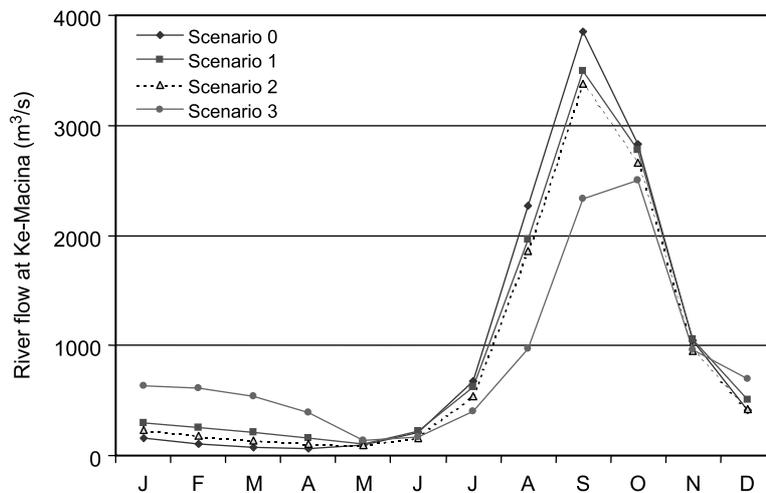


Figure 5. Average monthly flow of the Niger at the entrance of the Inner Delta (Ke-Macina), calculated over the period 1980 – 2001. Source: WL|Delft Hydraulics & DNH).

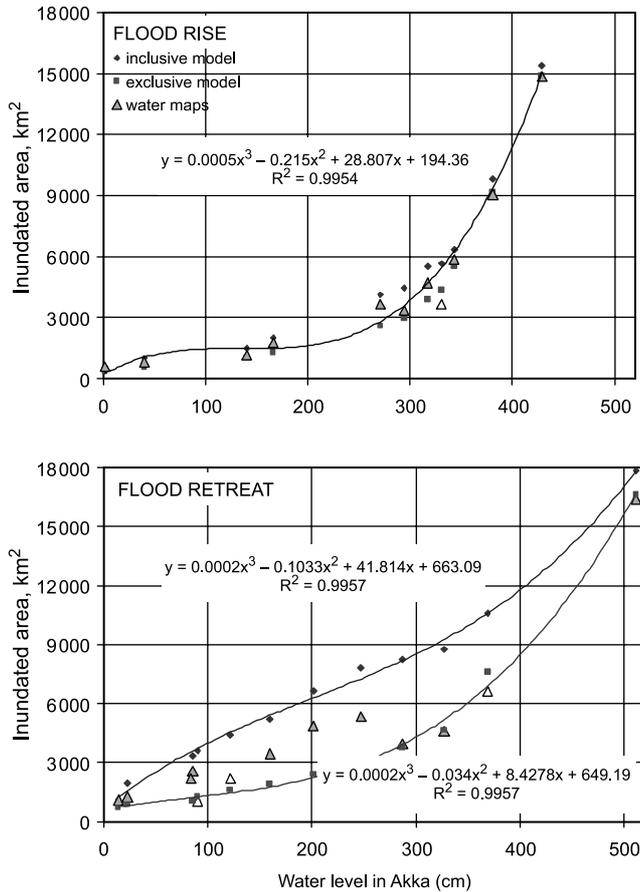


Figure 6. Inundated area (km²) of the Inner Niger Delta as a function of the water level during advancing water (top) and receding water (bottom), according to the inclusive and exclusive models. The inundated areas derived from 24 water maps are shown in solid triangles (full coverage) and open triangles (only southern part of the Delta)

overestimation of the flooded area. Because of the large differences between the two models for receding water, the regression equations for both models are shown in Figure 6. On the basis of these results, the inundated area, and its spatial distribution can be reliably predicted as a function of water level, essential for calculating the potential impact of changes in the Niger’s flow. Figure 7 shows the predicted inundation area in the Inner Niger Delta for the four scenarios during the period 1980 to 2004.

Upstream and Downstream Interests within the Inner Niger Delta

About 1 million people are dependent for their livelihoods on the Inner Niger Delta. Within the irrigation scheme of the Office du Niger, and in the reservoirs of the Sélingué and Markala dams, more than 300 000 people derive direct benefits, in addition to the

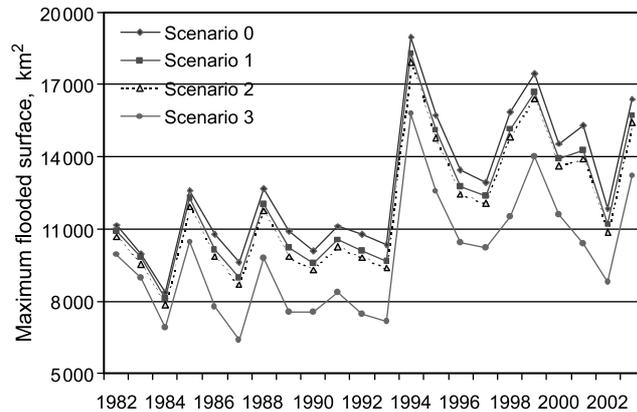


Figure 7. Year-to-year variation in the surface of the maximum inundated area in the Inner Delta. The effect of the Office du Niger and the Sélingué and future Fomi reservoirs are indicated

fact that 40% of Mali's total rice needs are produced in the Office du Niger. The Inner Niger Delta is not homogeneous; it contains several semi-permanent water bodies, vital for fishing. After recession of the floodwater, livestock (cattle, sheep and goats) have access to aquatic grasses, which is only allowed after the rice has been harvested. Therefore, three distinct, interlinked production systems are dependent on the floods from the Niger River.

Fisheries

All fishermen in the Inner Delta realize that during the last 30 to 40 years the size of the fish catch has declined significantly as a result of the continuously increasing fishing intensity, as witnessed by the larger number of fish traps, hook lines and fishing nets. During the *décrué* (flood recession), fish are easily caught, as they become trapped in (temporary) lakes and concentrated in creeks and the riverbed. Currently, nearly all fish is captured long before the next flood. The catch of the following year therefore mainly depends now on the young fish born in the preceding flood period.

About one-third of the population in the Inner Delta depends on fisheries for their living. However, fish is not a secure food source in the Inner Delta. Welcomme (1986), analysing the annual fish catch in the Inner Delta for the years 1967–75, found that in years with high floods the catches were three times higher than in years with low floods. Laë (1992a, 1992b), analysing a longer time series (1966–89), concluded the same. He related the annual catches to the Niger discharge at Koulikoro of the preceding year, as well as to the maximum inundated area in the Inner Niger Delta, as calculated by Olivry (1995).

Since 1967, fish catches in the Inner Niger Delta have been registered by l'Opération Pêche de Mopti (OPM). The annual catch is closely related to the maximum flood level (Figure 8), for which, shown in Figure 7, the maximum flood levels in October/November of the preceding year have been used, as most fish are caught during falling water in the first half of the year.

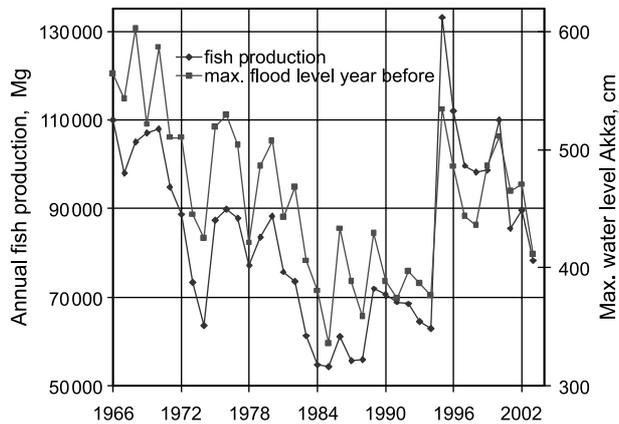


Figure 8. Fluctuation in annual fish catch in the Inner Delta between 1966 and 2003 compared to the fluctuation in the flood level (Akka, cm) in the year before. *Sources:* OPM (fish) and DNH (flood level).

Despite the gradual increase in the population of fishermen in the Delta, fish production did not increase during the last 27 years. This suggests that the biological limit of fish production has been reached, as also suggested by Kodio *et al.* (2002). Fish older than one year have become increasingly scarce in the Inner Delta (Quinsière 1994). The close relationship between annual fish trade in Mopti and flood level in the preceding year allows estimation of the average impact of water withdrawals by dams. Fish trade would have been 6% higher without Office du Niger, an additional 13% without Sélingué reservoir; construction of the Fomi Dam would lead to a reduction of 37%.

Livestock and Food Supply

The major part of the floodplain of the Inner Delta is covered by a floating aquatic wild rice (*Oryza longistaminata*), rice planted for consumption (*Oryza glaberrima*) and two plant species locally known as didéré (*Vossia cuspidata*) and bourgou (*Echinichloa stagnina*). Transhumance in the Sahel, including feed supply for cattle in the floodplain, has been studied extensively. The biomass of bourgou increases during the crue (flood) to reach a dry mass of 20–30 Mg/ha during the flood, of which around 5 Mg consist of leaves and stems above the water table and 15–25 Mg/ha of stems growing below the water surface (Hiernaux & Diarra, 1986; François *et al.*, 1989). The contribution of the underwater stems to the available feed supply is substantial. Bourgou productivity depends critically upon a suitable range of water depths of 3–5 m during the growing season. A digital elevation model was used to calculate the area suitable for its growth, as livestock production, as tested by regression analysis, is strongly correlated with its yield, and so the effect of the four scenarios on livestock production could be tested.

The maximum sustainable livestock population is limited by the availability of bourgou in the Inner Delta and thus by the flow of the Niger and Bani Rivers into the Delta. Thus,

maximum livestock number will be negatively affected by construction of the Fomi dam (Scenario 3). The strongest impact is expected on sheep and goats in Tombouctou (10 to 15%), for cattle between 2 and 4%.

Rice

Rice farmers in the Inner Delta produce on average 86 000 Mg of rice (*Oryza glaberrima*) annually, with a large year-to-year variation. On the basis of annual statistics of the Direction Régionale de l'Appui au Monde Rural (DRAMR) in Mopti, Kuper & Maïga (2002) concluded that in good years not more than 10% is traded and almost nothing in poor years. The analysis in this paper is also based on these data and on the reports of DRAMR in Tombouctou. The analysis could be extended to a longer period on the basis of reports from Opération Riz Ségou (ORS) and Opération Riz Mopti (ORM).

Similar to bourgou, floating rice requires a well-defined range of water depths (100–200 cm) to enable germination and grain maturation. In the analysis, this has been taken into account, and maximum water level data for ORS and ORM have been analysed separately to enable derivation of a combined regression function for the four scenarios. Figure 9 illustrates the annual variation in rice production, and shows a strong effect of the planned Fomi dam.

Within the 74 000 ha irrigated area of the Office du Niger, 320 000 Mg of rice is produced annually, and this gravity-fed scheme is considered highly successful, independent of rainfall and flood performance. The administrative area is much larger than the irrigation area, and considerable expansion is anticipated, as elaborated in the regional development plan (Schéma directeur de développement, Sogréah-BCEOM-Betico, 1999). Within the economic analysis that is performed, the production statistics from the Office du Niger have been taken into account, for example total production and yield per hectare is well documented, and surprisingly the water use efficiency has

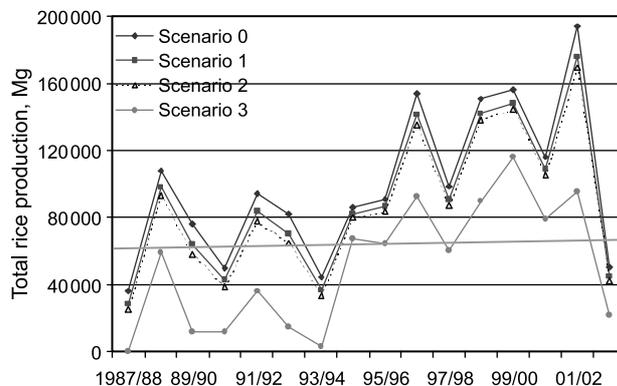


Figure 9. Annual variation in total rice production in Opération Riz Ségou and in the region of Mopti (including Opération Riz Mopti) in the present situation and in three alternative other scenarios. The scenario 2 line shows rice requirements to feed an increasing population of 750 000 persons in 1987 to 850 000 people in 2002, with 80 kg rice per capita per year

greatly improved from around 35 000l/kg rice to just 8000l/kg, with further efficiencies possible.

Economics of Dams and Irrigation in the Upper Niger

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 5000 GWh/annum and 2 million ha, respectively. A review of 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, p. 9).

Although Mali's hydroelectric and hydro-agricultural potential has yet to be fully realized, it is widely questioned whether the costs and benefits of such mega-investments have been properly estimated. Apart from the economic feasibility (i.e. direct costs and benefits) of additional dams, the indirect effects of hydroelectric and hydro-agricultural schemes on downstream beneficiaries of rivers are still unclear.

Costs

Direct costs for dam construction projects vary significantly as a result of site characteristics. The World Commission on Dams (WCD, 2001) conducted a worldwide survey on the costs of dams and their results have been used to estimate operation and maintenance costs. Indirect costs and benefits have been estimated using the 'impact pathway approach', on the basis of a series of methodological steps, including definition of the boundaries of the study (the four scenarios), identifying significant impacts, physically quantifying these impacts, and finally calculating the monetary values and conducting a sensitivity analysis.

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, that were established a long time ago, with the Fomi dam, which is yet to be built. To make a fair comparison, for all dams an operational period of 2005 to 2030 has been assumed. In valuing the capital costs, the following assumptions have been made. First, depreciation of the capital stock is set to 0.5% per year. Of the rehabilitation costs from the past, 25% is assumed 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). To account for ageing 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. International funding agencies and national donors have covered most of the investments in dams and irrigation schemes in Mali. The opportunity cost of capital has been set to 8% of the actual capital stock. Various sources have been consulted to estimate capital and rehabilitation costs for the two existing dams, including the Office du Niger area

(Schreyger, 2002; Slob, 2002), and for the proposed Fomi dam (Agence Canadienne pour le Développement International, 1999).

Benefits

Benefits for each sector have been estimated directly (in €) from the available production information, including fisheries, livestock, agriculture and transport, as well as indirect benefits of biodiversity. For the period 2005–2030, a simulated flooding area scenario for the Niger Delta has been applied to all sectors (Figure 10), in which the projected climate change has been taken into account.

Fisheries are heavily affected by changes in the inundated area (Figure 11). The short-term fluctuations are caused by the standard variation in climate conditions. Scenario 0 generates the highest benefits, as each additional dam in operation leads to a further reduction in the fisheries industry. The differences in fish catch are particularly large during wet years.

Livestock is valued on the basis of meat production (Figure 12). It is assumed that on average 2% and 8% of the sheep and goats, and cattle, respectively is marketed each year (Annual reports, Direction Générale de l'Élevage). The year-to-year fluctuations are smaller than for fisheries due to the mobility of the herds. However, livestock is vulnerable to long-term droughts, as demonstrated by its collapse in the period 2010 to 2013, which is modelled as extremely dry. Another lesson from Figure 12 is that in extremely wet years (i.e. 2005 to 2010) the presence of dams can actually benefit cattle, sheep and goats. 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 are the cattle. By dampening the extreme peak flows and thus creating a more optimal 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 years with exceptionally little rain.

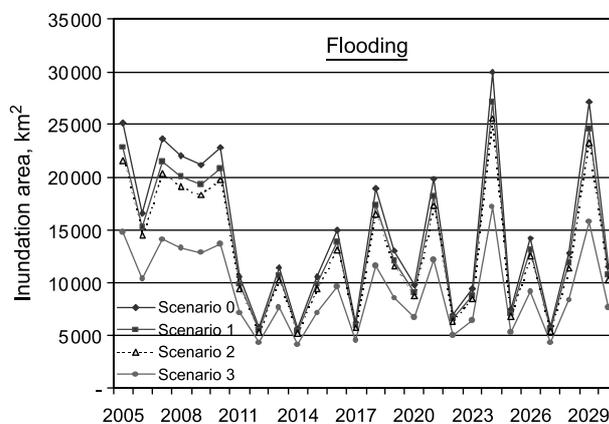


Figure 10. Simulated flooding area for the four scenarios (in km²)

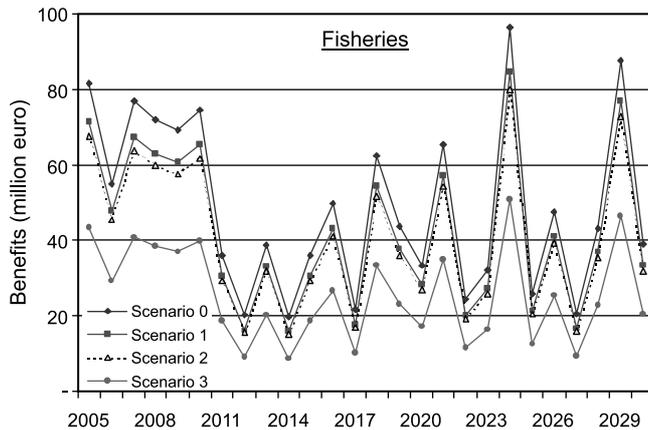


Figure 11. Benefits in the fishery sector over time in the four scenarios (in M€/year)

The agricultural sector in and around the Inner Delta can be subdivided into irrigated agriculture and flood-related agriculture and separate production functions have been applied in the simulation model. For reasons of simplicity, the value added of rice and other crops has been set to FCFA 95 000 and 75 000 per Mg, respectively. Figure 13 shows the simulated scenarios for the agricultural sector.

The main contribution to agricultural production in Mali comes from the Office du Niger of which the area is assumed to expand by 1500 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 area will be developed over a period of 15 years, at 2000 ha per year.

The results of the model simulation for the transport sector are shown in Figure 14. 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

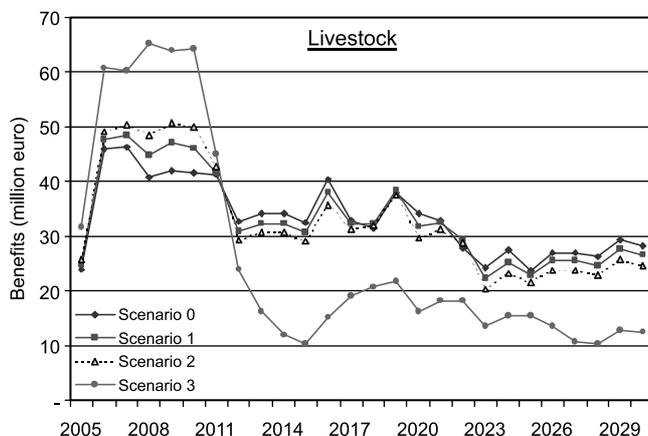


Figure 12. Benefits in the livestock sector over time in the four scenarios (in M€/year)

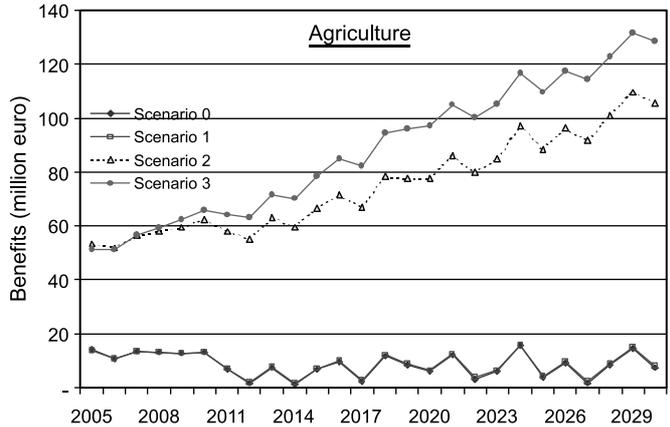


Figure 13. Benefits in the agricultural sector over time in the four scenarios (in M€/year)

not, scenario 0 (no dams) and scenario 3 (Fomi) switch positions. In extremely dry years the system with the Fomi dam performs better in transport terms, while in wet years the absence of dams is preferred.

The Inner Niger Delta is a Ramsar Wetland Site of International Importance, designated under seven of the possible eight criteria, thus it is important for its biodiversity values. For example, it accommodates two of the largest known breeding colonies of large wading birds in Africa and in addition, is a vital part of the eco-regional network supporting up to 3 to 4 million staging waterbirds, residents and migrants from all over Europe and Asia (van der Kamp *et al.*, 2005). The hydrological and related ecological conditions in the Inner Delta largely determine the population size of these waterbird species.

Behaviour of migratory water birds reveals the interrelations between different wetland ecosystems, thousands of miles apart. An example is the direct relationship between breeding population size of Purple Herons in Europe and water levels in the

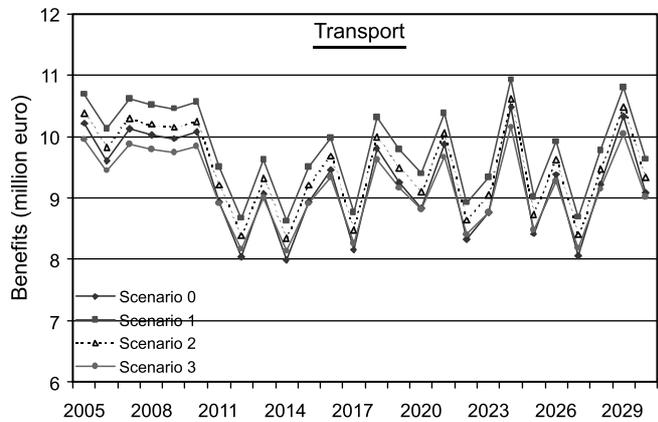


Figure 14. Benefits in the transport value over time in the four scenarios (in M€/year)

Inner Niger Delta, where they reside outside their breeding season. This international connection represents an economic value. To capture this value, a survey was carried out in the Netherlands in which Dutch citizens were asked about their willingness to support protection of birds in the Netherlands and in sub-Saharan Africa (van Beukering & Sultanian, 2005). The average willingness to pay has been estimated at around €15 per household per year. If extrapolated across Europe, the fund available for migratory bird protection would be more than €2 billion. It is assumed that 1% of this amount is available for bird protection in Mali in 2005. The results of the simulation modelling are shown in Figure 15. Birds in the Inner Niger Delta depend heavily on *bourgou*, which does not grow well in extremely deep waters, so that 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. The reduction in flooded area 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 exploitation.

Cost Benefit Analysis

The Present Value (calculated at a discount rate of 5%) of the *overall* net benefits of the four scenarios were aggregated over the full period and expressed as annual values, respectively. These values represent the total net economic value of each scenario. Scenario 2 generates the highest net benefits, while scenario 3 generates the lowest. This implies that construction of the Fomi dam will have 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) were considered. These additional net benefits of the three dam scenarios have been calculated by subtracting the overall net benefits of scenarios 0 from those of scenarios 1, 2 and 3. The difference between scenarios 2 and 3 represents the additional net benefit of the Fomi dam

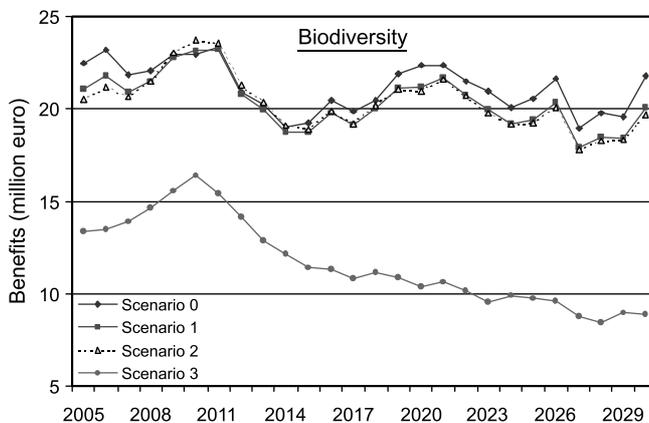


Figure 15. Benefits from biodiversity over time in the four scenarios (in M€/year)

Table 3. Present value (PV) of the net benefits of the four dam scenarios

Scenario	Overall		Marginal	
	PV of net-benefits (in million €)	PV of annual net-benefits (in million € per year)	PV of net-benefits (in million €)	PV of annual net-benefits (in million € per year)
Scenario 0	1903	132	–	–
Scenario 1	1971	137	68.5	4.8
Scenario 2	2283	159	380.2	26.4
Scenario 3	1781	124	– 121.8	– 8.5

compared to the present situation (Markala and Sélingué). By building the Fomi dam, society at large will lose more than M€ 500 (i.e. M€ 121 + M€ 380), which implies an annual loss of M€ 35 (i.e. M€ 8.5 + M€ 26.4) as shown in Table 3. The Sélingué dam generates additional net benefits of M€ 68.5 until 2030. The Markala dam is economically the most attractive dam of the three by generating aggregated net benefits of M€ 312 (i.e. M€ 380 – M€ 69), which is equal to almost M€ 22 per year (i.e. M€ 26.4 – M€ 4.8).

The Net Present Value for each sector, shown in Table 4, demonstrates that while scenario 3 brings most benefits, the costs are higher, so that NPV is lower than for the existing situation, scenario 2. When NPV is assessed spatially, as the dams are progressively added, the economic benefit is gradually transferred from downstream to upstream (Figure 16), implying that people are likely to move away from the Delta into formal irrigation schemes, as has been shown in other studies. Sensitivity analyses on assumptions about climate change, discount rate, etc. show that while the magnitude of the differences between the four scenarios change, the overall result does not change.

Conclusions

In this integrated study, combining information on hydrology, ecology, fisheries and agriculture, the role of dams and irrigation schemes in the overall economy and ecology of the Inner Niger Delta and the Upper Niger region were examined.

Almost 1 million people depend on the natural resources within an area of 50 000 km² in the Inner Delta for their livelihoods as fishermen, arable and livestock farmers. Annual production of fish, cattle and rice is determined by river discharge and is insufficient to feed the local population in the drier years, so that 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 quantity of water diverted from the river. Sélingué and Office du Niger appear to be economically feasible. On an annual net benefit basis, they jointly generate M€ 26.4 (Present Value). The addition of the Fomi dam is expected to reduce economic revenue by M€ 35 per year.

Table 4. Overview of the sectoral benefits and costs of the four scenarios (PV: present value, M€/year)

Scenario	Net benefits				Transport	Electricity	Costs	Net PV
	Agriculture	Livestock	Fisheries	Biodiversity				
No dams (Scenario 0)	9.6	36.6	53.9	22.5	9.8	–	–	132.4
Sélingue (Scenario 1)	9.8	37	46.6	21.7	10.4	18.5	– 6.8	137.2
Sélingue & Markala (Scenario 2)	72.9	37	44.3	21.7	10	18.5	– 45.7	158.7
Sélingue, Markala & Fomi (Scenario 3)	83.7	33.5	28.3	13	9.7	49.7	– 94	123.9

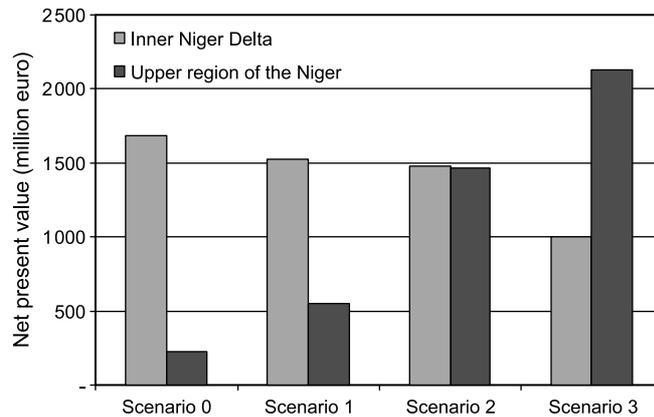


Figure 16. Spatial distribution of the overall benefits divided between the Inner Niger Delta and the Upper Niger region, which includes Mali and Guinea

The economic feasibility of Office du Niger critically depends on a number of assumptions. In dry years, the economic feasibility of Office du Niger depends on the water releases by the Sélingué dam. Moreover, maintaining the productivity of rice in the Office du Niger region at the present 4 – 6 Mg/ha is a prerequisite for its economic feasibility. Further increasing the irrigation efficiency appears technically feasible, and is essential for additional expansion of the irrigated area of the Office du Niger.

The benefits are shared by the various sectors, and vary widely depending on the level of water diversion from the Niger River. The costs of the Fomi dam will only partly be recovered from the additional electricity and agricultural benefits. Moreover, the indirect losses for fisheries, livestock and biodiversity downstream greatly exceed the direct revenues. The negative downstream effects are less pronounced for the Office du Niger irrigation zone and the Sélingué dam.

Next to negative effects on the absolute level of welfare, dams are likely to cause transfers of benefits from one region to another. The analyses indicate that with each additional dam, benefits are transferred from the Inner Niger Delta to the upstream Upper Niger region.

This study shows that improving the performance of the existing infrastructure and of the economic activities in the Inner Niger Delta 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.

The methodology used in this study has the potential to be developed into a powerful decision-support system within the Upper Niger basin and within the overall Niger Basin, to assist managers to clearly define policy choices within national processes, but also within the Niger Basin Authority.

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References

- Agence Canadienne pour le Développement International (1999) *Etudes de réactualisation du dossier de faisabilité du barrage de Fomi*: Rapport de faisabilité (Montréal: SNC-Lavalin International).
- Beukering, P. J. H. van & Sultanian, E. (2005) *How important are birds to us?* Results of a survey on the perception of the environment by the Dutch. Working Paper (Amsterdam: Institute for Environmental Studies).
- François, J., Rivas, A. & Compère, R. (1989) Le pâturage sémi-aquatique à *Echinochloa stagnina* (Retz.) P. Beauvois, Etude approfondie de la plante 'bourgou' et des bourgoutières situées en zone lacustre du Mali *Bulletin des Recherches Agronomiques de Gembloux*, 24, pp. 145–189.
- FAO (2005) Available at: <http://www.fao.org/ag/agl/aglw/aquastat/damsafrica/index.stm>
- GoM (2002) Poverty Reduction Strategy Paper. Document prepared and adopted by the Government of Mali, 29 May.
- Hiernaux, P. & Diarra, L. (1986) *Bilan des cinq années de recherches (sept 1979 – sept 1984) sur le production végétale des parcours des plaines d'inondation du fleuve Niger au Mali central*. Document de programme AZ 142 (Bamako: CIPEA).
- IDA & IMF (2003) Joint Staff Assessment of the Poverty Reduction Strategy Paper of the Republic of Mali. International Development Association (IDA) and International Monetary Fund (IMF), 13 February, Washington DC.
- Kamp, J. van der, Fofana, B. & Wymenga, E. (2005) Ecological values of the Inner Niger Delta, in: L. Zwartz, P. van Beukering, B. Kone & E. Wymenga (Eds) *The Niger, A Lifeline: Effective Water Management in the Upper Niger Basin*. Project Report on a study carried out under the Partners for Water Programme 'Water for Food and Ecosystems' and the Poverty Reduction and Environmental Management (PREM) Programme of the Dutch Ministry of Foreign Affairs, pp. 155–176 (Lelystad: RIZA/Sévaré & Wageningen: Wetlands International/ Amsterdam: Institute for Environmental Studies/ Veenwouden: A&W ecological consultants).
- Kodio, A., Morand, P., Diénépo, K. & Laë, R. (2002) Dynamique de la pêche du delta intérieur du Niger revisitée à la lumière des données récentes, in: D. Orange, R. Arfi, M. Kuper, P. Morand & Y. Poncet (Eds) *Gestion intégrée des ressources naturelles en zones inonables tropicales*, pp. 431–453 (Paris: IRD).
- Kuper, M. & Maïga, O. (2002) Commercialisation du riz traditionnel dans le delta intérieur du Niger (Mali), in: D. Orange, R. Arfi, M. Kuper, P. Morand & Y. Poncet (Eds) *Gestion intégrée des ressources naturelles en zones inonables tropicales*, pp. 639–660 (Paris: IRD).
- Laë, R. (1992a) Impact des barrages sur les pêcheries artisanales du delta central du Niger, *Cahiers Agricultures*, 2, pp. 14–21.
- Laë, R. (1992b) Influence de l'hydrologie sur l'évolution des pêcheries du delta central du Niger, de 1966 à 1989, *Aquatic Living Resources*, 5, pp. 115–126.
- Mahé, G., Olivry, J. C., Dessouassi, R., Bamba, F. & Servat, E. (2000) Relations eaux de surface—eaux souterraines d'une rivière tropicale au Mali, *Comptes rendues de l'Académie des Sciences Série IIa*, 330, pp. 689–692.
- Olivry, J. C. (1995) Fonctionnement hydrologique de la cuvette lacustre du Niger et essai de modélisation de l'inondation du Delta intérieur, in: J. C. Olivry & J. Boulègue (Eds) *Grands bassins fluviaux périatlantiques: Congo, Niger Amazone*, pp. 267–280 (Paris: IRD).
- Passchier, R., Maaten, R. & Meijer, K. (2004) *Integrated Water Resources Modelling of the Upper Niger River (Mali)* (Delft: WL|Delft Hydraulics).
- Quensière, J. (1994) *La Pêche dans le Delta central du Niger* (Paris: ORSTOM/Karthala).
- Sangaré, S., Mahé, G., Paturel, J.-E. & Bangoura, Y. (2002) *Bilan hydraulique du Niger en Guinée*, Système d'Observation du Cycle Hydrologique de l'Afrique de l'Ouest et Centrale (AOC-HYCOS). Available at: <http://aochycos.ird.ne/HTMLF/JOURNAL/bilanhydro-gu.PDF>.
- Schreyer, E. (2002) La période 1932–1982. De la 'mission Béline' à l'Office du Niger, in: P. Bonneval, M. Kuper & J.-P. Tonneau (Eds) *L'Office du Niger, grenier à riz du Mali*, pp. 68–73 (Paris: Karthala).
- Slob, A. (2002) Le rôle des bailleurs de fonds. Une coopération réussie entre bailleurs et gouvernement malien, in: P. Bonneval, M. Kuper & J.-P. Tonneau (Eds) *L'Office du Niger, grenier à riz du Mali*, pp. 97–99 (Paris: Karthala).

- Sogréah-BCEOM-Betico (1999) *Etude de schéma directeur de développement pour la zone Office du Niger: diagnostic de la situation actuelle*, Rapport Principal + rapport Infrastructure hydraulique (Ségou: Document Office du Niger).
- Welcomme, R. L. (1986) The effects of the Sahelian drought on the fisheries of the Central delta of the Niger River, *Aquatic Fisheries Management*, 17, pp. 147–154.
- WCD (2001) *Report of the World Commission on Dams* (Cape Town: WCD).
- Zwarts, L., Grigoras, I. & Dubbeldam, W. (2003) *A Digital Flooding Model of the Inner Niger Delta: A First Analysis of Remote Sensing Data*, Mali-PIN 03-01 (Lelystad: RIZA).
- Zwarts, L. & Grigoras, I. (2005) Flooding of the Inner Niger Delta, in: L. Zwarts, P. van Beukering, B. Koné & E. Wymenga (Eds) *The Niger, A Lifeline: Effective Water Management in the Upper Niger Basin*, Project Report on a study carried out under the Partners for Water Programme 'Water for Food and Ecosystems' and the Poverty Reduction and Environmental Management (PREM) Programme of the Dutch Ministry of Foreign Affairs, pp. 43–77 (Lelystad: RIZA/Sévaré & Wageningen: Wetlands International/ Amsterdam: Institute for Environmental Studies/ Veenwouden: A&W ecological consultants).
- Zwarts, L., Beukering, P. van, Koné, B. & Wymenga, E. (2005) *The Niger, A Lifeline: Effective Water Management in the Upper Niger Basin*, Project Report on a study carried out under the Partners for Water Programme 'Water for Food and Ecosystems' and the Poverty Reduction and Environmental Management (PREM) Programme of the Dutch Ministry of Foreign Affairs, (Lelystad: RIZA/Sévaré & Wageningen: Wetlands International/ Amsterdam: Institute for Environmental Studies/ Veenwouden: A&W ecological consultants).