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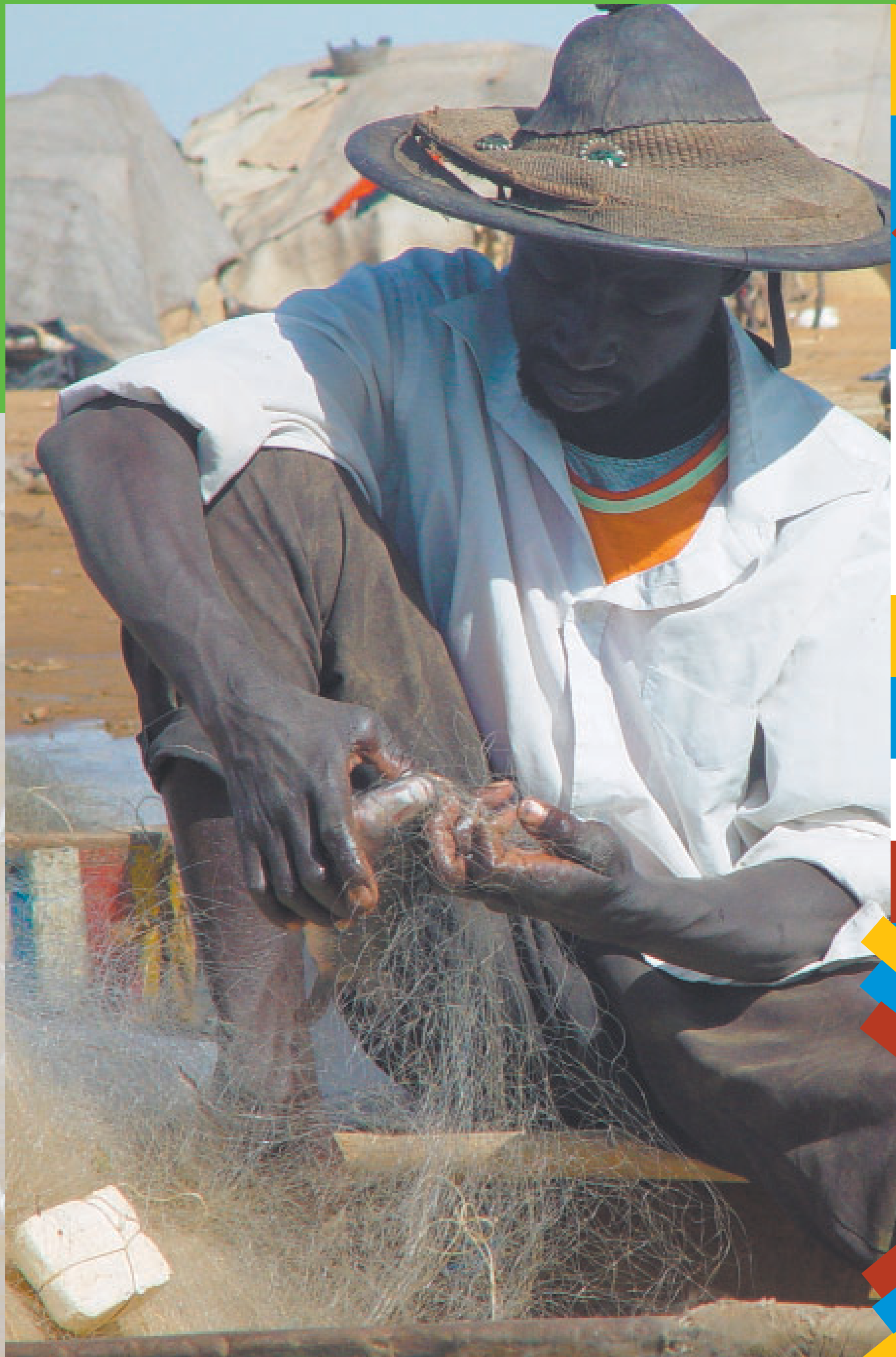
PREM
Poverty Reduction and Environmental Management

water for food and ecosystems

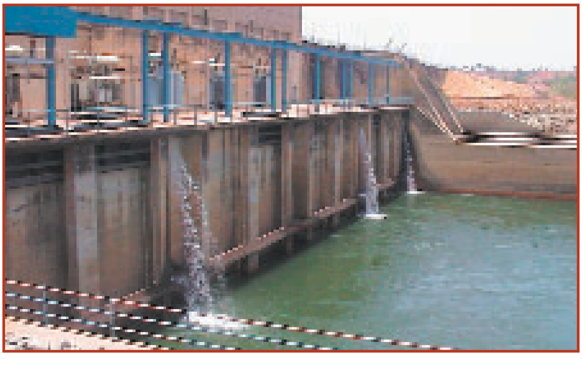
The Niger, a lifeline

Effective water management in the Upper Niger Basin

Leo Zwarts, Pieter van Beukering, Bakary Kone, Eddy Wymenga



The Niger, a lifeline



Introduction

Water shortage has been identified by the United Nations Environment Programme 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 hydro-electric and hydro-agricultural irrigation schemes (Figure 1).

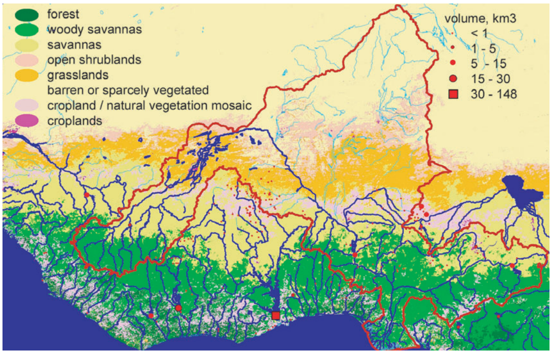


Figure 1.The Niger Basin (red outlining). The Niger originates in Guinea and Ivory Coast, passes through Mali and Niger, and enters the Atlantic Ocean from Nigeria. The Niger Basin also extends over Algeria, Burkina Faso, Benin and Cameroon. The existing dams are indicated by red dots.

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 hydro-electric 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 hydro-electric 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. Figure 2 shows how irrigation takes a fixed amount of water throughout the year, while hydro-electric 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 km^3 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?

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 water management in the Upper Niger Basin, 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. The tentative outcomes of the study are described in this executive summary.

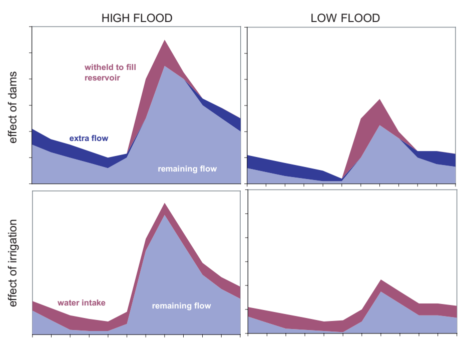


Figure 2 Schematic hydrological effects of dams and water intake for irrigation during the flood cycle in years with a high and low flood. The flood cycle in the Western Sahel zone runs from June to December. Lowest flood levels occur from March to May.

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 m³/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.

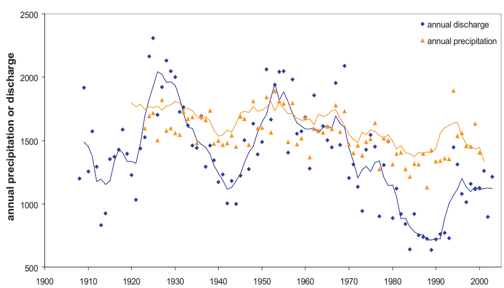


Figure 3 Annual rainfall in the Upper Niger region and discharge of the river at Koulikoro.

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 (Figure 3).

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 (Figure 4) 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.

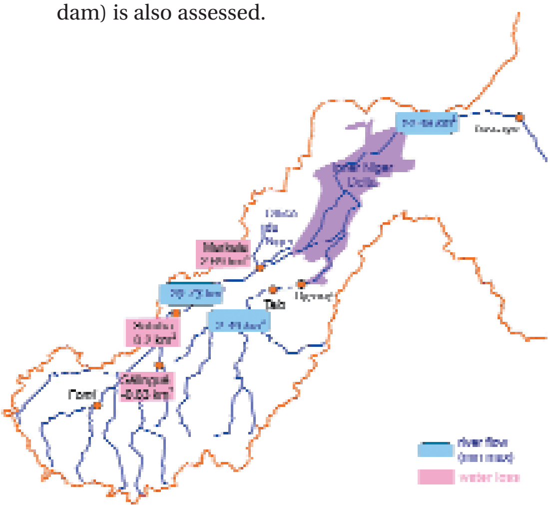


Figure 4 Catchment area of the Upper Niger Basin with the Niger and its tributaries, the position of the Inner Niger Delta, the Office du Niger irrigation zone and present and newly planned dams. Annual river flow is indicated as well as the water loss at the realised dams.

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 km2), 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 km² in the “Delta mort”, Office du Niger uses 2.7 km³ 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 m³/s of water from August to November and around 60 m³/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 m³/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 (Figure 5).
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 m³/s. Under these extreme conditions,

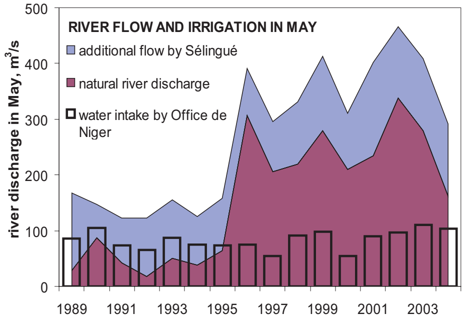


Figure 5 Level of dependency of Office du Niger on additional flow provided by Sélingué in the months of May during wet and dry years.

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 m³/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,

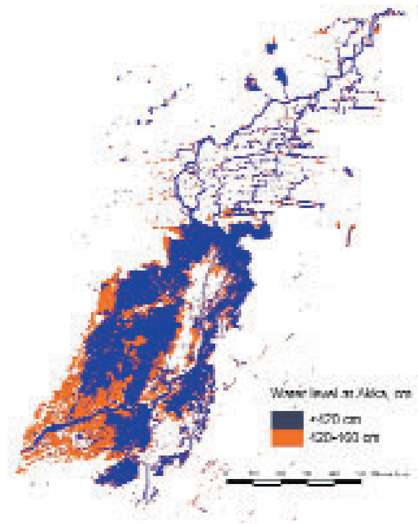


Figure 6 The impact on the inundated area of the Inner Niger Delta if the Fomi dam reduces the flood level from 460 to 415 cm.

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 km². The impact of irrigation and reservoirs on the flooded surface is indicated in Figure 6. Depending on the overall climate, the management of the Sélingué reservoir has lead to an average decline of the maximum inundated area of 600 km². Water intake by the Office du Niger and the (envisaged) Fomi dam cause an additional decline of 300 and 1,400 km², respectively (Figure 7).

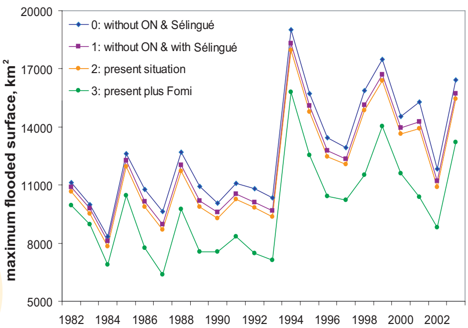


Figure 7 The impact of the two dams and the water intake for irrigation on the inundated area in the Inner Niger Delta.

Ecology

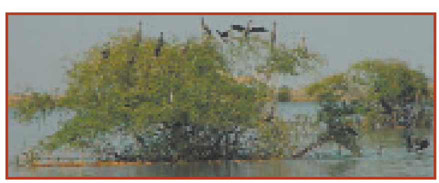
At first glance, the floodplains of the Inner Delta seem to be undisturbed natural ecosystems. The river takes its own course and the flooding is hardly hampered by dams, dikes and sluices. Extensive fields of floating grass ("bourgou"), wild rice and water lilies are present in and around the low lying 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.

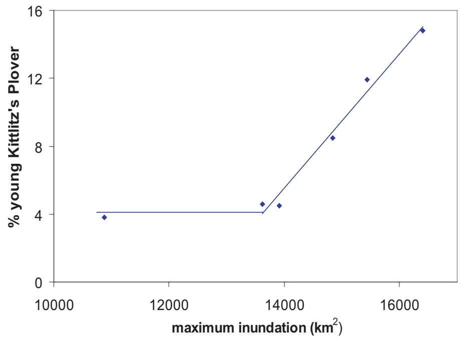
Biodiversity

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, as shown for the Kittlitz Plover in Figure 8. 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. 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.

Figure 8 Proportion of first year birds of the Kittlitz Plover, a resident African wader, after six different breeding seasons.



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 (see Figure 9) 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.

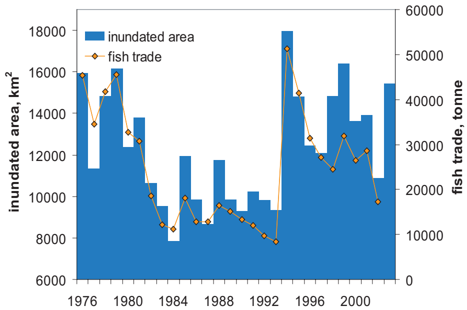


Figure 9 Annual trade (tonne fresh fish equivalents) of dry and fresh fish in the Inner Niger Delta and the inundation area in the Delta.

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 (Figure 10). 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.

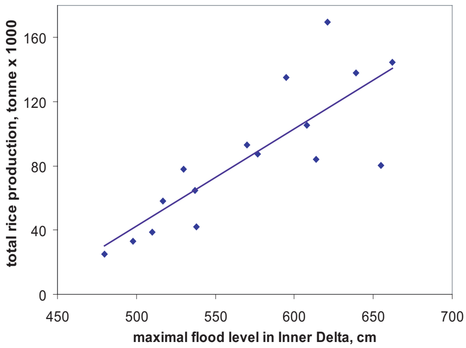


Figure 10 Relationship between maximum flood level (in cm) and the rice production in the Inner Delta and area of ORS (in 1,000 tonnes).

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. 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 4,300 tonnes less (4.9%) as a result of Sélingué (see Figure 11). Without the irrigation of the Office du Niger zone, rice production in the Inner Delta would be 8,900 tonnes greater (10.4%). The Fomi dam would have an even bigger impact: a decrease of 40%, or 34,500 tonnes. The yellow line in Figure 11 shows the production levels required to feed the people of the Inner Delta, assuming an annual consumption of 80 kg of rice per person. The Fomi dam would significantly reduce food security in the Inner Niger Delta.

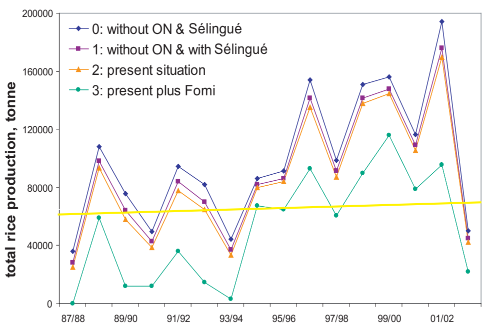


Figure 11 Rice production in the Inner Niger Delta for the four scenarios.

These losses are amply compensated for by irrigation at Sélingué (yielding 6,000-7,500 tonnes of rice per year) 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. The number of navigational days for the four scenarios at various water levels is shown in Figure 12. 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.

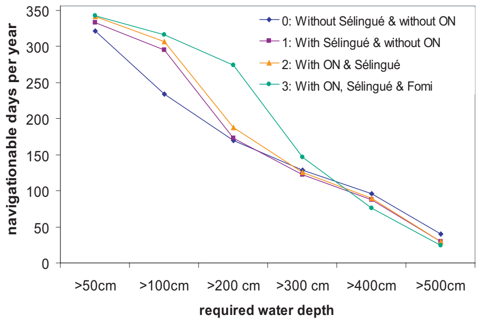


Figure 12 Average seasonal variation of navigational depths at Mopti based on simulations for the period 1982-2002 (in number of days in an average year).

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. The framework of the impact pathway

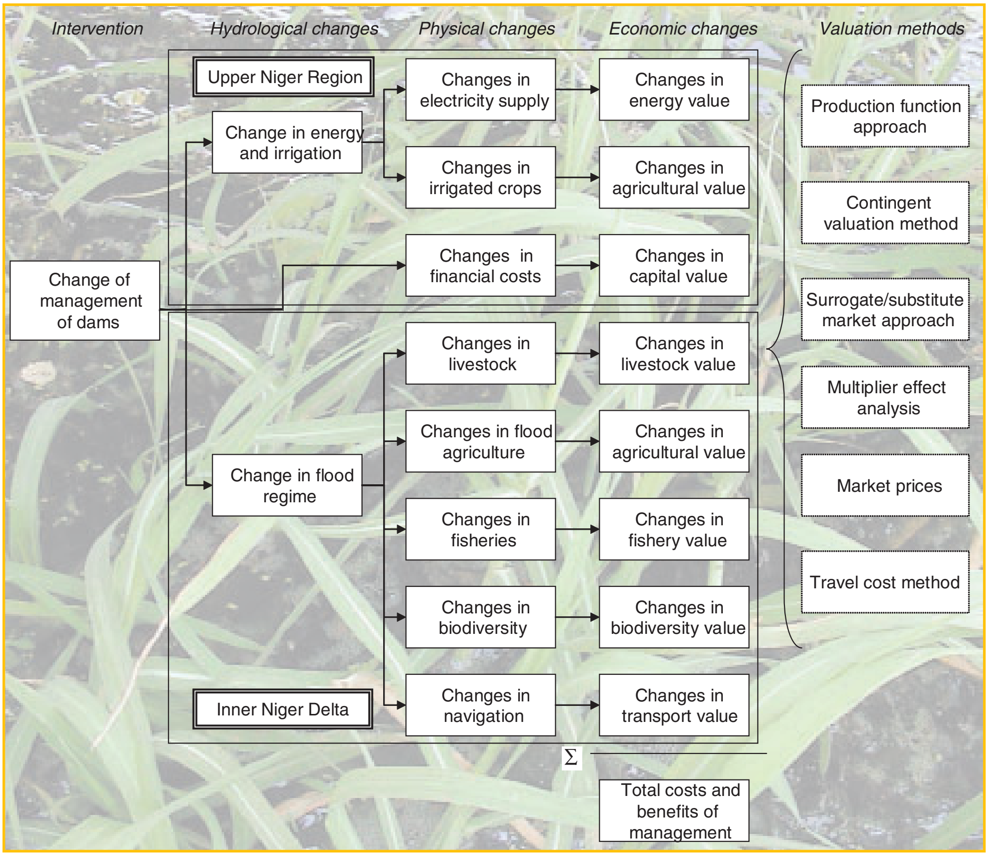


Figure 13
Impact pathway of the economic evaluation procedure of management of the Upper Niger Basin.

is shown in Figure 13 and represents the physical and socio-economic processes resulting from varying the management of dams and irrigation schemes in the Niger River.

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. As shown on the right-hand side of Figure 13, 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.

As shown in Figure 13, 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.

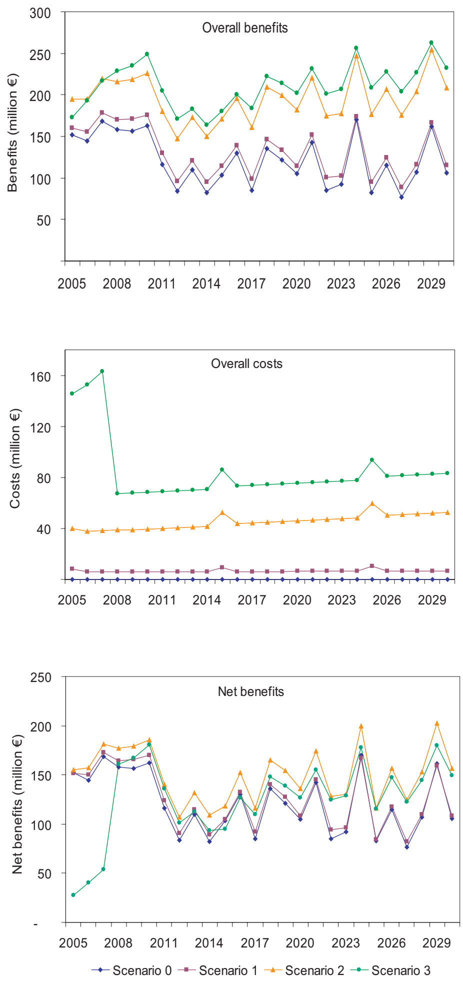


Figure 14 Overall costs and benefits of the four scenarios over time (2005-2030). The annual variation of benefits is partly due to the random fluctuation in rainfall which is calculated on the basis of past trends in the Upper Niger Region. The same climate trend is applied to all four scenarios.

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 (Aylward et al. 2001). Due to increased failure and deterioration of the infrastructure, this fraction increases by 1.25% each year. The aggregated costs over time are summarised in the middle part of Figure 14. 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

Figure 14 presents the overall costs and benefits for the four scenarios, over the full period of 2005 to 2030. If solely considering the benefits, which are shown in the upper part of Figure 14, 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.

The lower part of Figure 14 indicates 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 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 in Figure 14, 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%.
Table 1 shows the NPV 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 economic value of each scenario. Both columns show that 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. Table 1 shows the marginal NPV 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 (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 different sectoral benefits are shown in Figure 15. 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. Figure 15 also shows that a society without dams (scenario 0) mainly generates income through fisheries and livestock, as it did around 50 years ago.

Table 1 The net present values (NPV) of the net-benefits of the four 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) resembling the absence of dams and irrigation schemes (26 years, discount rate 5%).

Scenario	NPV of overall net-benefits (million € per year)	NPV of marginal net-benefits (million € per year)
Scen0: Without Sél & without ON	132	-
Scen1: With Sél & without ON	137	4.8
Scen2: With ON & Sél	159	26.4
Scen3: With ON, Sél & Fomi	124	-8.5

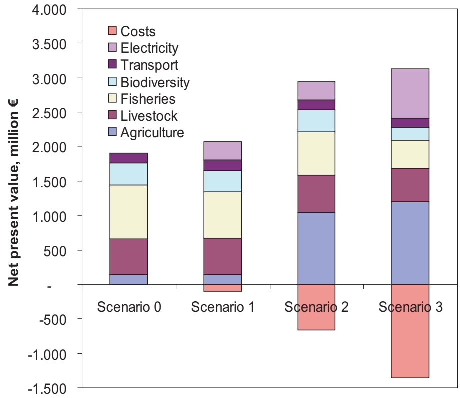


Figure 15 Allocation of the Net Present Value of the related costs and benefits of the four scenarios (26 years, discount rate 5%).

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. Figure 16 shows the allocation of the overall benefits between the Inner Niger Delta and the upstream region.

The Upper Niger region includes all those districts in Mali and Guinea in which dams generate economic activities such as irrigated agriculture and hydropower.

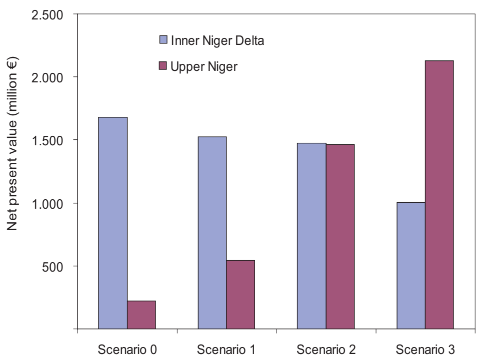


Figure 16 Spatial distribution of the overall benefits divided between the Inner Niger Delta and the upstream region, which includes Mali and Guinea (26 years, discount rate 5%).

In Mali these districts are Segou, Macina, Niono and Yanfolila. Figure 16 clearly shows that 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 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.

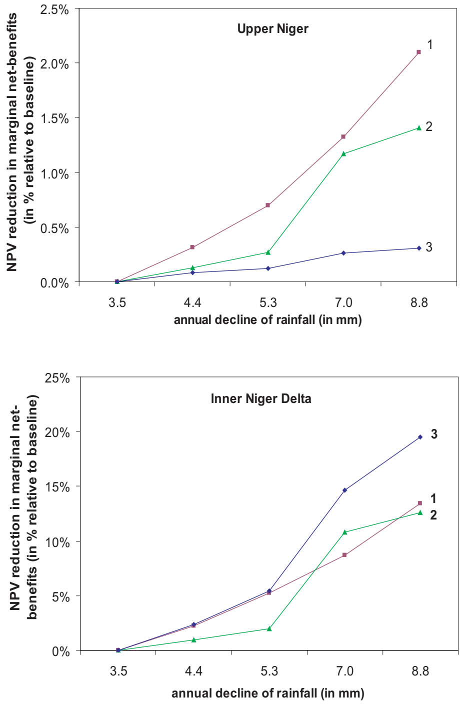


Figure 17 Sensitivity analysis of the impact of more extreme climate conditions on the NPV of the net-benefits (in million €).

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 results of this sensitivity analysis are shown in Figure 17, both for the Inner Niger Delta and the upstream region. Both regions 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.

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 km^2. 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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Colofon

ISBN 90-807150-5-0
Photos: Leo Zwarts
Layout and print: Brandsma Offset Ferwerd

This report is an executive summary of Zwarts, L., P. van Beukering, B. Kone & E. Wymenga 2005.
The Niger, a lifeline. Effective water management of the Upper Niger Basin. ISBN 90-807150-6-9

Acknowledgements

We thank DNH, DRAMR, EDM, ON, ODRS, OPM, ORM and ORS for their cooperation. We also appreciate the support of the Dutch Embassy in Bamako. This study was financed by the Dutch Partners for Water programme 'Water for Food and Ecosystems' and by the PREM-programme of the Dutch Ministry of International Cooperation.

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The Niger, a lifeline

Economic and ecological interests in effective water management in the Upper Niger Basin; an executive summary

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