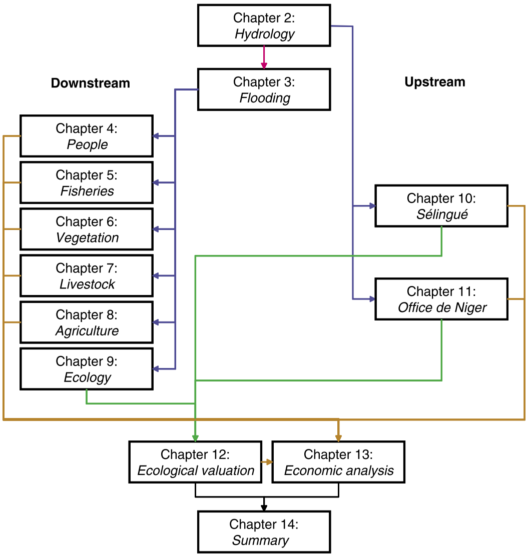

Fig. 1.4. Outline of the study.

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

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

Acknowledgements

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

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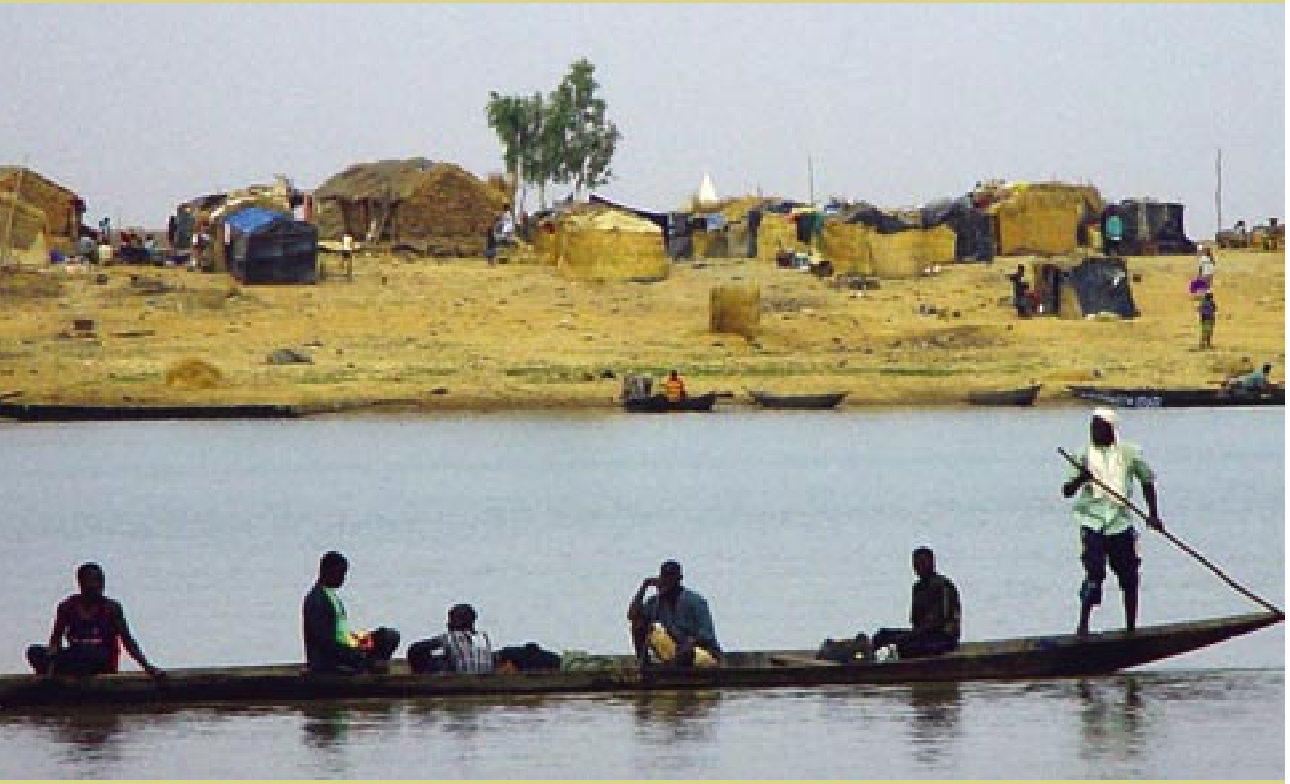


2
HYDROLOGY OF THE UPPER NIGER

Leo Zwarts
Navon Cissé
Mori Diallo

2.1 Introduction

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

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

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

2.2 The hydrological regime

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

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

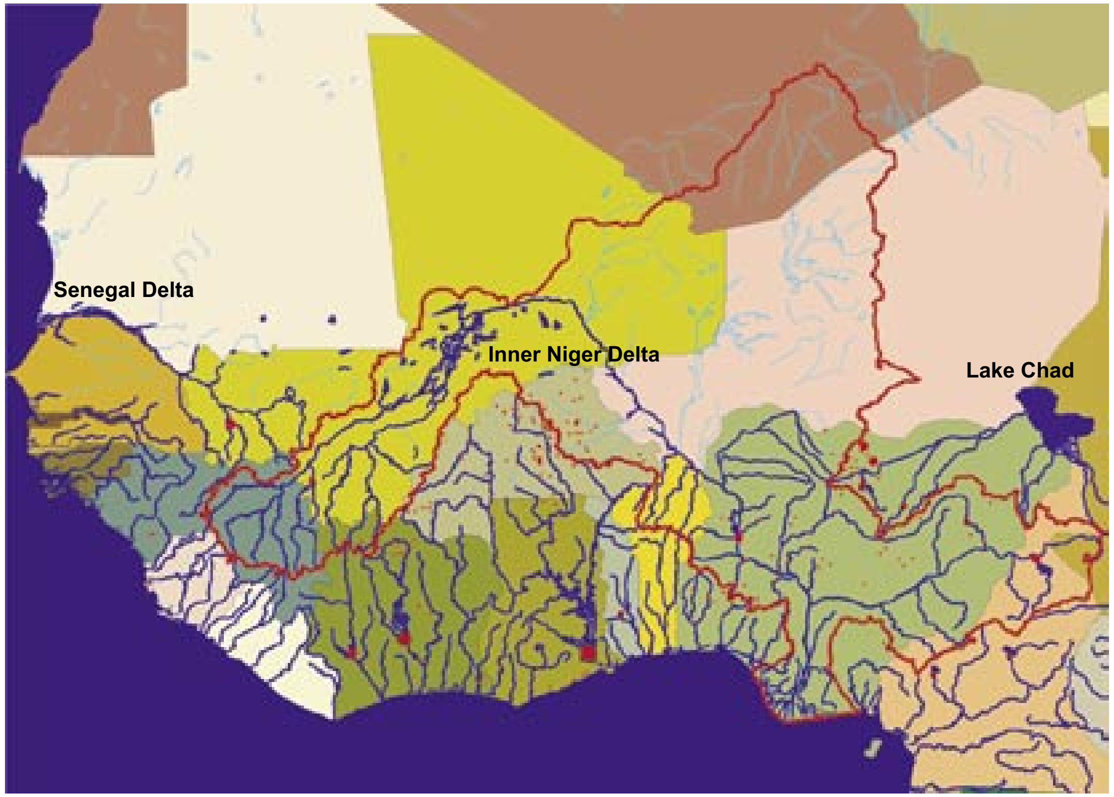


Fig. 2.1. The Niger Basin (red outlining). The Niger originates in Guinea and Ivory Coast, passes Mali, Niger and enters the Atlantic Ocean in Nigeria. The Niger Basin also extends over Algeria, Burkina Faso, Benin, Chad and Cameroon.

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

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

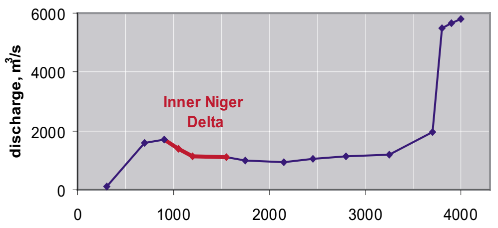


Fig. 2.2. Average annual river discharge of the Niger as a function of the distance from its origin. The Inner Niger Delta (indicated with a red line) is situated between Ségou (900 km) and Tombouctou (1500 km).

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

This study focuses on the hydrology of the Upper Niger River. The Upper Niger is defined as the Niger basin up to and including the Inner Delta. The total inundated area covered by the Inner Delta, which is a network of tributaries, channels, swamps and lakes,

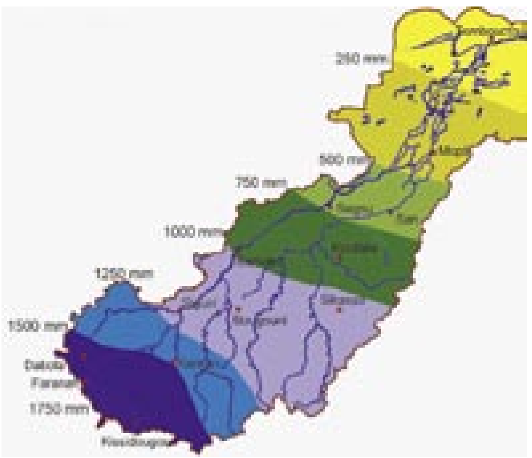


Fig. 2.3. Annual precipitation (mm/ year) in the basin of the Upper Niger shown as five different zones (Source: Quensière et al. 1994a). Thirteen meteorological stations are indicated with red dots.

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

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

- Climate
- Groundwater
- Seasonal variations
- Dams and reservoirs

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

Climate

The annual rainfall in the Upper Niger varies between less than 250 mm in the North-East and over 1750 mm in the South-West (Fig. 2.3). In general the climate of Mali is semi-arid to arid with a clear dry season (December – May). The rainy period covers three months in the semi-arid zone, 5-7 months in the Sudan zone and 8 months in the Guinean zone. As shown in Fig. 2.4, in all zones the rainfall reaches

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

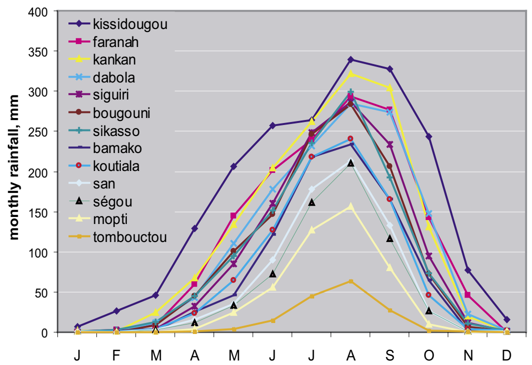


Fig. 2.4. Average monthly rainfall (mm) in the period 1961 - 1990 at 13 sites situated in the Upper Niger Basin (see Fig. 2.3).

its peak in August. Fig. 2.4 gives the average rainfall per month over a period of 30 years. Between years the variation is large, especially in the semi-arid zone. As a consequence of this natural variation there is also a large fluctuation in the river discharge.

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

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

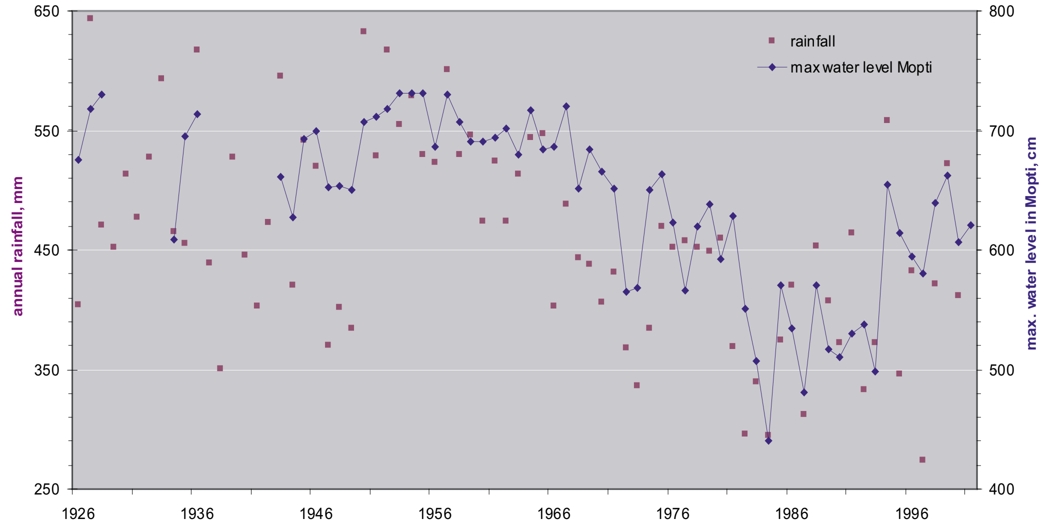


Fig. 2.5. Variation in annual rainfall in Inner Delta and maximum water level in Mopti (cm). Rainfall is averaged over 11 stations: Bandiagara, Djenné, Gao, Goundam, Ke-Macina, Markala, Mopti, Niafunke, San, Ségou and Tombouctou.

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

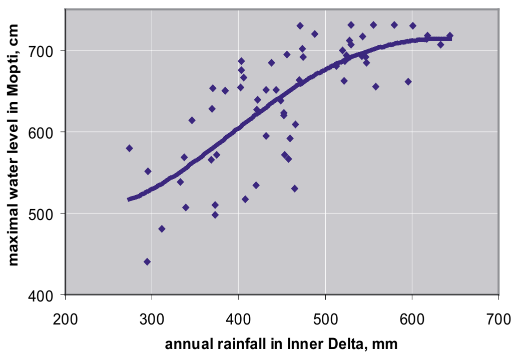


Fig. 2.6. The relationship between local rainfall in the Inner Delta and the maximum water level in Mopti.

Groundwater

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

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

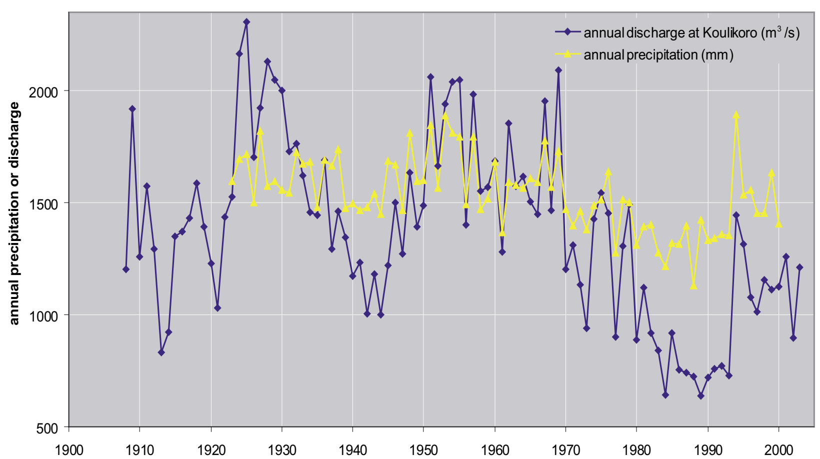


Fig. 2.7. The annual river discharge at Koulikoro (m^3/s), 60 km downstream of Bamako, and the annual rainfall (mm/year) in the Inner Niger basin upstream of Bamako.

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

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

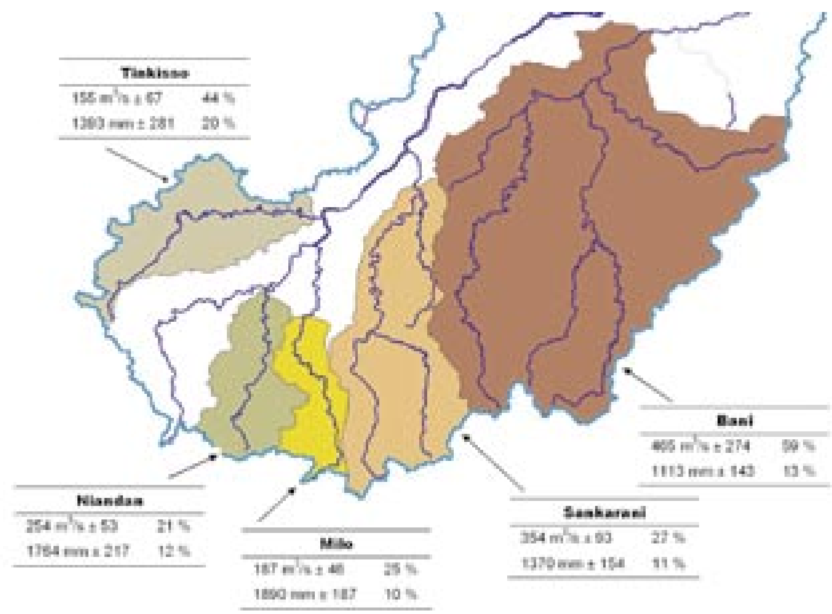


Fig.2.8. Average ± standard deviation of the rainfall (mm/year) and the river discharge (m^3/s) in five different basins in the Upper Niger. The right column in the tables gives the relative standard deviation (SD as % of the mean). Source: Mahé *et al.* (1997).

Seasonal variation in the river discharge

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

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

Reservoirs and dams

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

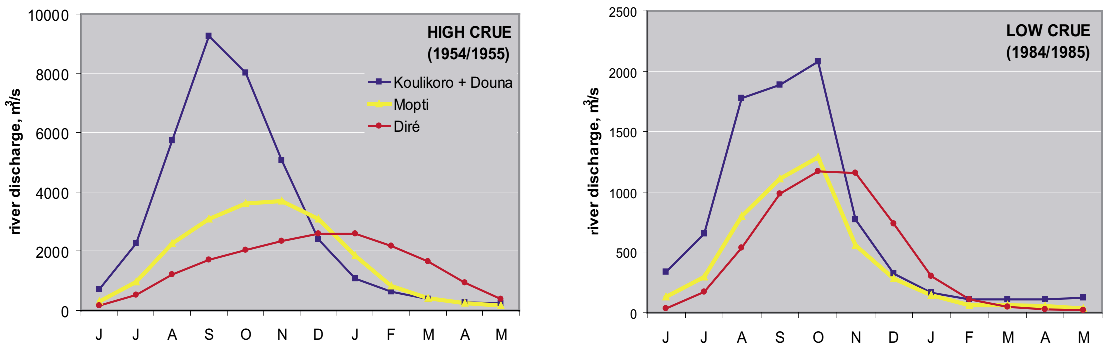


Fig. 2.9. Monthly discharge of the Niger River (Koulikoro) and the Bani River (Douna) combined, compared to the discharge at Mopti in the southern Inner Delta and Diré in the north-eastern part of the Inner Delta.

2.3 Dams, reservoirs and other water users

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

Sélingué

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

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

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

Table 2.3. Main characteristics of the Sélingué dam.

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

The water level in the reservoir varies during the season (Fig. 2.9). The water is high from September to January, decreases gradually from February to June and increases from June to August. There is hardly any variation in water level between the years. In nearly all years the water level decreases with about 7 meter between January and June. There were two events that deviated from the usual annual pattern. In the first two years after establishment of the dam, 1982 and 1983, the water level in the period of September to January was one meter below the average level of following years. In 1999 the water had gone down 14 metres, some four metres below the lowest gate level.

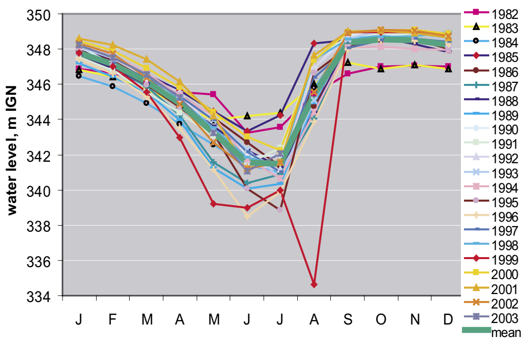


Fig. 2.10. Seasonal variation in water level (m IGN) in the Sélingué reservoir. Source: EDM.

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

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

Level (m)	Area (km^2)	Volume (km^3)
338	0	0
341	110	0.08
342	132	0.20
343	165	0.36
344	201	0.58
345	250	0.76
346	300	1.05
347	340	1.38
348	390	1.67
349	450	2.14

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

period. For the time being, we will use the inflow data as given by EDM.

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

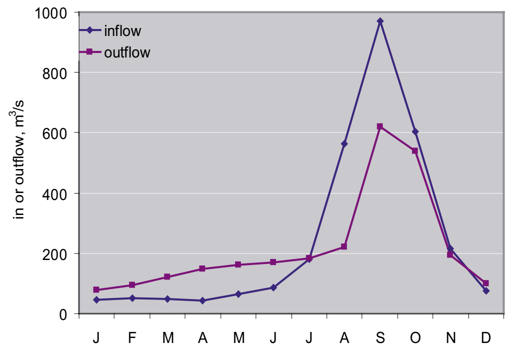


Fig. 2.11. The monthly inflow and outflow of the Sélingué reservoir, averaged over the period 1982 – 2003. Source: EDM.

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

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

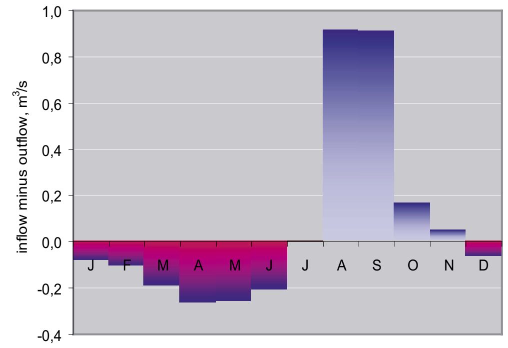


Fig. 2.12. The difference as m^3/s between monthly inflow and outflow in the Sélingué reservoir (average for 1982 – 2003). Source: EDM.

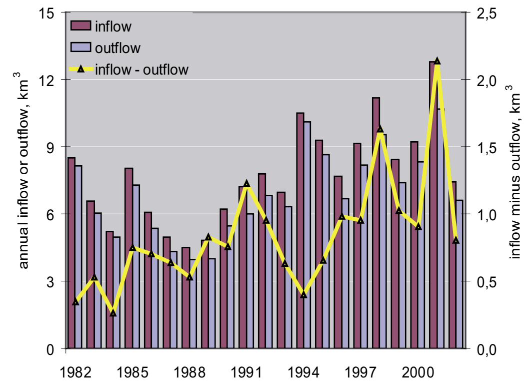


Fig. 2.13. The yearly inflow into and outflow from the Sélingué reservoir (km^3, left scale) and the difference between both, the 'water loss' (km^3, right scale. Source: EDM.

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

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

Markala dam

Markala Barrage

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

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

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

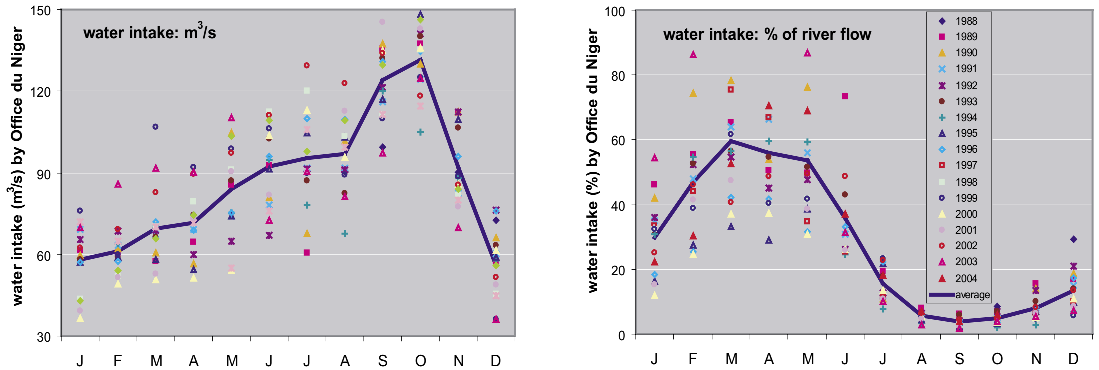


Fig. 2.14. Monthly water intake by Office du Niger at the Markala barrage since 1989 (left graph) and the monthly water intake as % of the river discharge at Koulikoro in the same month (right graph).

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

Sotuba

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

Fomi (planned)

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

Sotuba dam

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

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

Talo and Djenné (planned)

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

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

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

Tossaye (planned)

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

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

Other water users

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

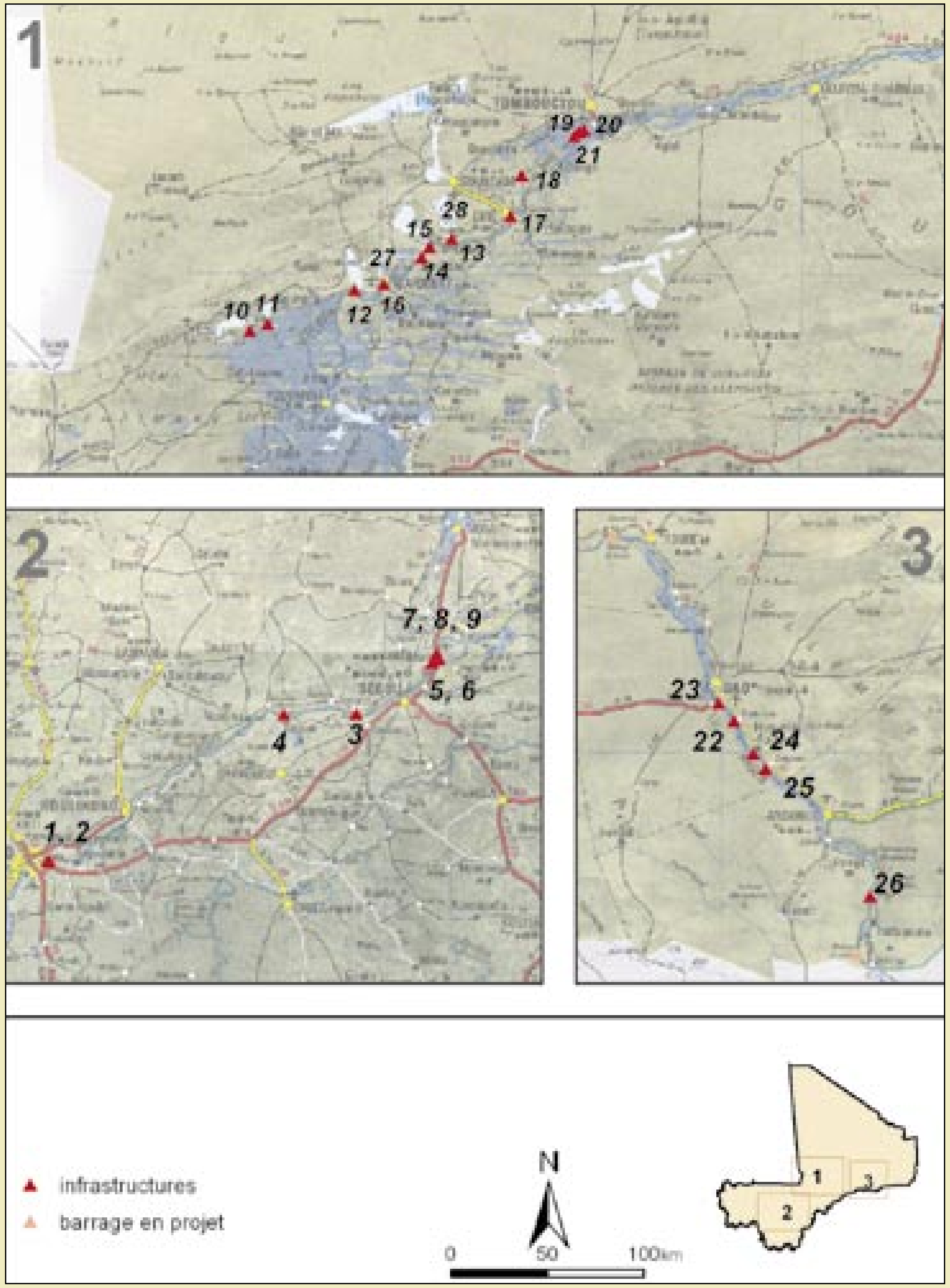
one of the few sources of information on these small-scale schemes. From August to December the potential evapo-transpiration of rice changes from 9 mm/day to 5.7 mm/day. The percolation shows more variation, but is normally in the order of 5.5 to 7 mm/day. This implies that the water demand for the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

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

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

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

Box 2.1.



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

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

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

2.4 Human impact on river discharge

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

The statistical approach

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

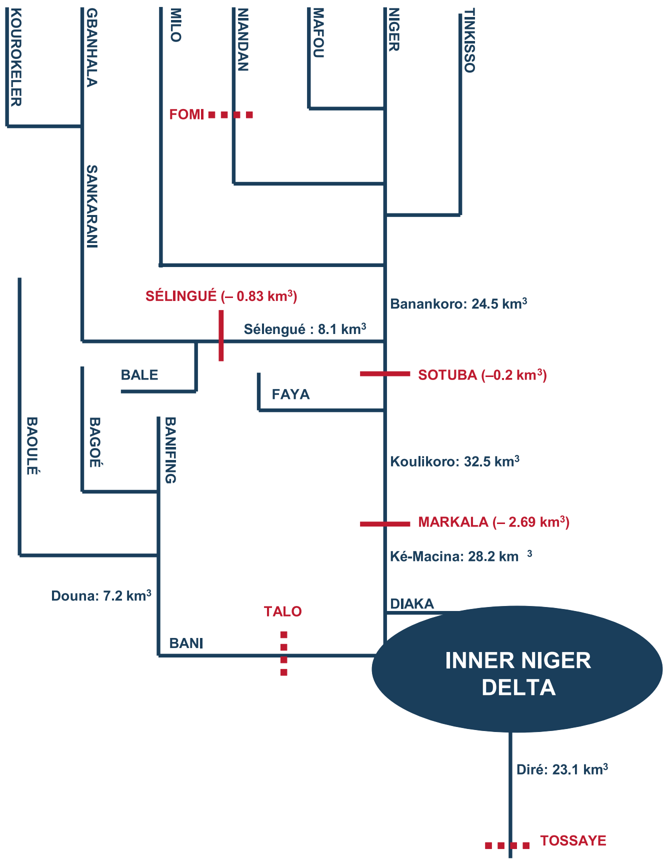


Fig. 2.15. Average river discharge (km^3/year) in the Upper Niger averaged over 29 years (1970-1998).Note: The tributaries are indicated in blue, the dams in red and the river discharge in black; Fomi, Talo and Tossaye are newly planned dams. Source: modified after Hassane *et al.* 2000.

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

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

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

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

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

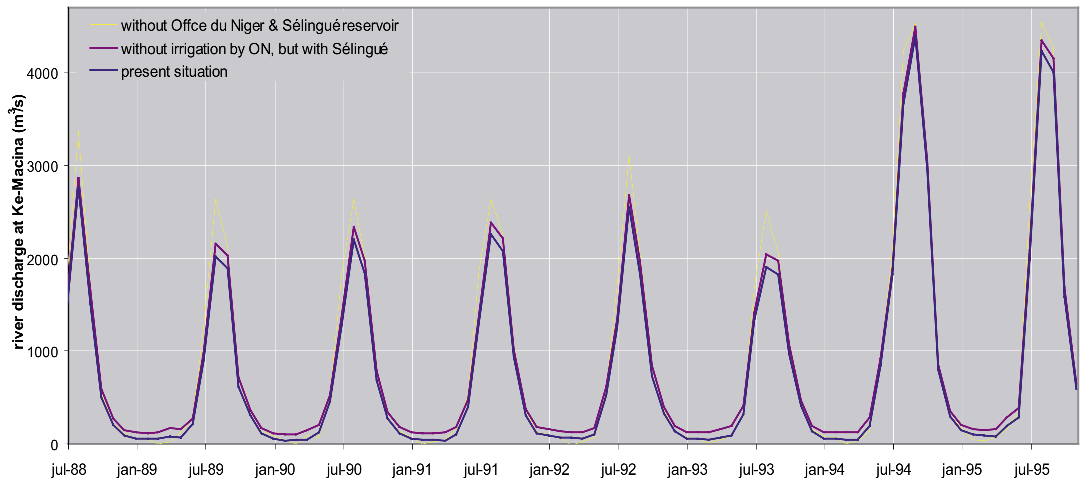


Fig. 2.16. Variation in monthly river discharge (m^3/s) at Ké-Macina (the entrance of the Inner Delta) between July 1988 and December 1995. Note: The actual variation is shown with a yellow line. A blue line gives the flow if there would be no irrigation by Office du Niger and a purple line the combined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

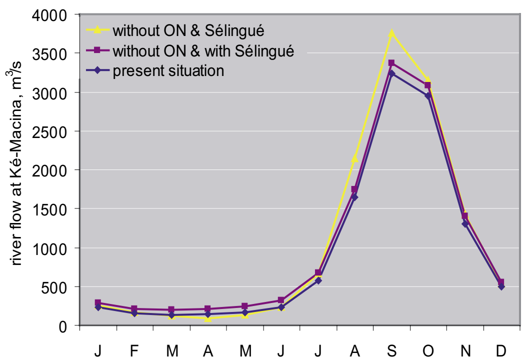


Fig. 2.17. The average monthly effect of Office du Niger and Sélingué on the river discharge at Ke-Macina. For further explanation, see Fig. 2.16.

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

Water-balance model

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

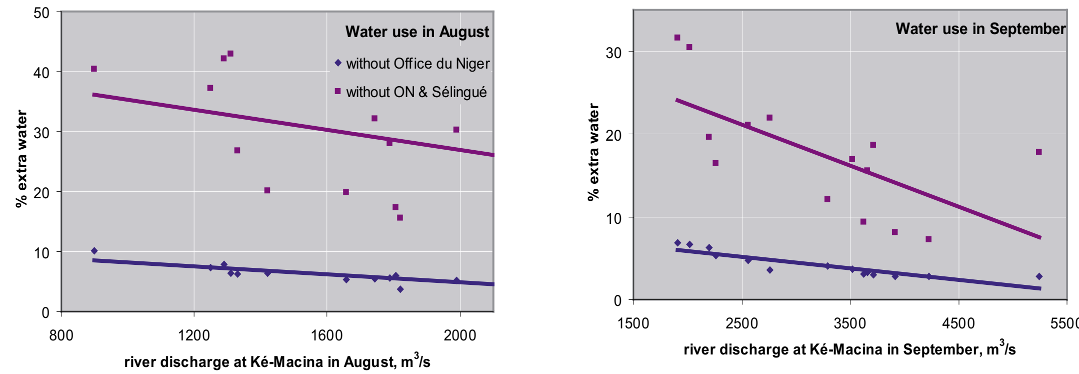


Fig. 2.18. The relative effect (%) on the river discharge in Ké-Macina in August (left graph) and September (right graph) of Office du Niger and Office du Niger plus Sélingué as a function of the total river discharge.

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

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

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

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

Model run 1: irrigation by ON but no hydropower

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

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

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

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

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

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

Model run 2: irrigation and hydropower

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

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

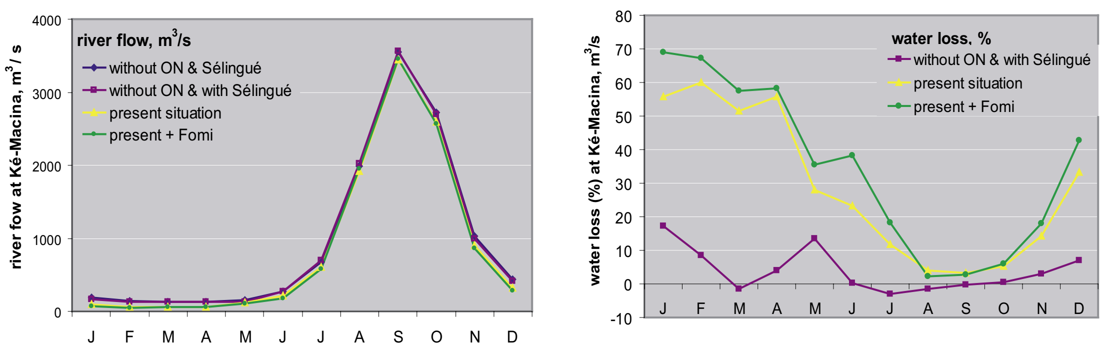


Fig. 2.19. Model run 1: The average monthly flow of the Niger at Ké-Macina (left panel), calculated over the period of 1980-2001. Four conditions are compared: (1) the natural situation (no dam, no irrigation), (2) only the Sélingué dam, (3) Sélingué + irrigation by Office du Niger (current situation),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

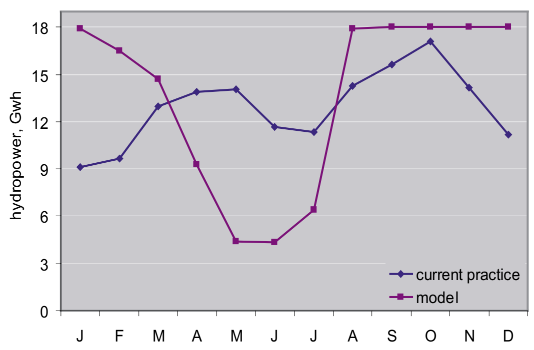


Fig. 2.20. Hydro-power produced at Sélingué in the present situation averaged over 22 years (1982-2003; see Appendix 2) compared to a model in which the total annual electricity production is maximized, given a demand of 18 Gwh. Source: EDM and WL|Delft Hydraulics.

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

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

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

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

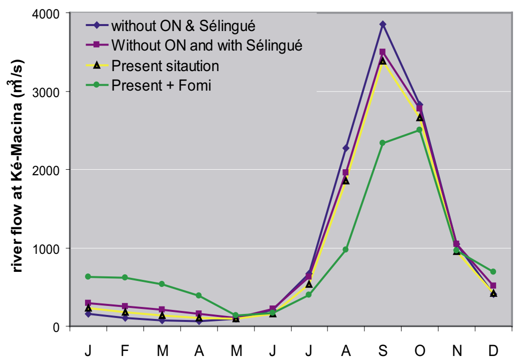


Fig. 2.21. Model run 2: The average monthly flow of the Niger at Ké-Macina, calculated over the period 1980-2001. The four condition are the same as in Fig. 2.19, but in contrast to model run 1, the two reservoirs are used to produce electricity. Source: WL|Delft Hydraulics & DNH.

2.5 Scenarios

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

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

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

Table 2.7. Scenarios.

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

2.6 Conclusions

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

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

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

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