Prepared for:

DG Rijkswaterstaat RIZA

Integrated Water Resources Modelling of the Upper Niger River (Mali)

Final Report

February, 2005

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List of Abbreviations

DNHE	Direction National d'Hydraulique et d'Energie
FAO	Food and Agriculture Organization
FRIENDS	Flow Regimes from International Experimental and Network Data (UNESCO Database)
GHENIS	Projet de Gestion Hydro-écologique du Niger Supérieur
MIDIN	Modélisation Intégrée sur le Delta Intérieur du Niger.
PWS	Public Water Supply
RIBASIM	River Basin Simulation Model
WRM	Water Resources Management

1 Introduction

In this Final report, an overview is given of the activities in the present project. The following topics will be summarized:

- hydrology of the Niger River and especially the Inner Delta
- approach of the study
- schematization of the region of study in the RIBASIM model
- data collection and validation
- assessment of the geometry of the Inner Delta using GIS coverages
- derivation of the inflow hydrographs of the model (Guinee)
- implementation of RIBASIM
- calibration of the model
- results of the simulations with RIBASIM
- course in the application of RIBASIM to staff members of DNHE
- final courses on water resources management and the use of RIBASIM in WRM.

These topics will be discussed in the following chapters of this report, with the exception on the details of the courses given at DNHE. A summary of the first course is given in Annex E. The final courses are planned to be held in the middle of October 2004.

1.1 Setting of the Project

The following description has been taken from the Project description on the internet site of RIZA:

Mali is inhabited by approx. 10 million people living in a basically agricultural community, a large part of which exists at the subsistence level. Almost the entire population lives in the semi-arid south, with the exception of one million people who depend on the natural resources of the Inner Delta, an inland riverine floodplain along the southern edge of the Sahara desert. The main economic activities in the Inner Delta are agriculture, cattle farming and fishing. Due to the high fish productivity of the Inner Delta, Mali is one of the largest fish producers in sub-Saharan west Africa. Beside hundreds of thousands of African birds, the Inner Delta harbours millions of migratory and wintering water birds which breed in Europe and Asia. These water birds provide a major source of protein and additional income for the local people.

The natural resources of the Inner Delta fully depend on the presence of water. Without water the area would be a desert, since local rainfall is limited and is highly variable from year to year. Thus, the ecological and economic significance of the Inner Delta depends on the input of river water upstream. Consequently, each intervention influencing the river discharge upstream has an impact on the Inner Delta. Together with its partners (Wetlands International and two Dutch companies: Alterra and Altenburg & Wijmenga), RIZA has launched a project proposal aimed at collection of quantitative data on the hydrology of the river and the socio-economic and ecological values of the natural resources of the Inner

Delta, following on from the ongoing Mali-PIN project executed by Wetlands International, Alterra, RIZA and Altenburg & Wijmenga (funded by the Dutch Ministry for Agriculture, Nature Management and Fisheries and the Dutch Ministry for Development cooperation).

One of the objectives of the new project is to determine the effect of the two dams near Sélingué and Markala on the hydrology of the Niger. Since it is also the intention to quantify the relationship between annual river discharge and the socio-economic and ecological functioning of the Inner Delta, it must be possible to indicate the economic and ecological impact of the two dams on the Inner Delta. The collected data will also be used as basic information in several other new projects of Wetlands International, Alterra, RIZA and Altenburg & Wijmenga (e.g. national inventory of Malian wetlands, management planning of wetlands within the Inner Delta, including regeneration of floating grass vegetation (bourgou) and forests in the inundation zone of the Inner Delta).

1.2 Aim of the project

In the Technical Proposal, the aim of the project has been defined as:

> *The project forms part of a larger project and as such its general aim is the provision of specific information on the impact of changes in the water resources infrastructure on the water resources situation downstream in the Niger River delta. The emphasis will be placed on the impact of the existing and possibly newly introduced reservoirs in the upper part of the river basin on the flow regime of the Niger. This information will be used by other parties in the project (e.g. ecologists) for further analysis of the total integrated system of the Niger delta.*
> *The second aim of the project is the introduction of state-of-the-art techniques for modelling of water resources systems and the training of the local agencies in the application of such techniques.*

The results of the aim of the project are presented in this Final Report. A summary of the training in the use of RIBASIM at the office of DNHE at Bamako is given in Annex F.

1.3 Review Foregoing Studies

In the first phase of the project, a literature survey was made of the most relevant publications on the hydrology of the Upper Niger and especially the impact of reservoirs on the Inner Delta. The most relevant information from this survey is given in the Inception Report in Annex 3 and 4. Annex 3 deals specifically with a complete model of the Inner Delta that is still available on-line on the internet. The Annex 4 discusses other publications. The information summarized in these annexes are used in this report as background information on the region of study and comparison between the various types of modelling applied to the Inner Delta.

2 Hydrology of the Inner Delta

2.1 Niger River Basin

There is already a lot of literature available on the general hydrology of the Niger River in Africa. As can be seen on Figure 1 the Niger River basin belongs to the largest river basins in Africa. The total length is about 4200 km. The river covers 7.5% of the continent and spreads over ten countries. Rising in Guinea, the river flows northeast into Mali. East of Timbuktu, 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.

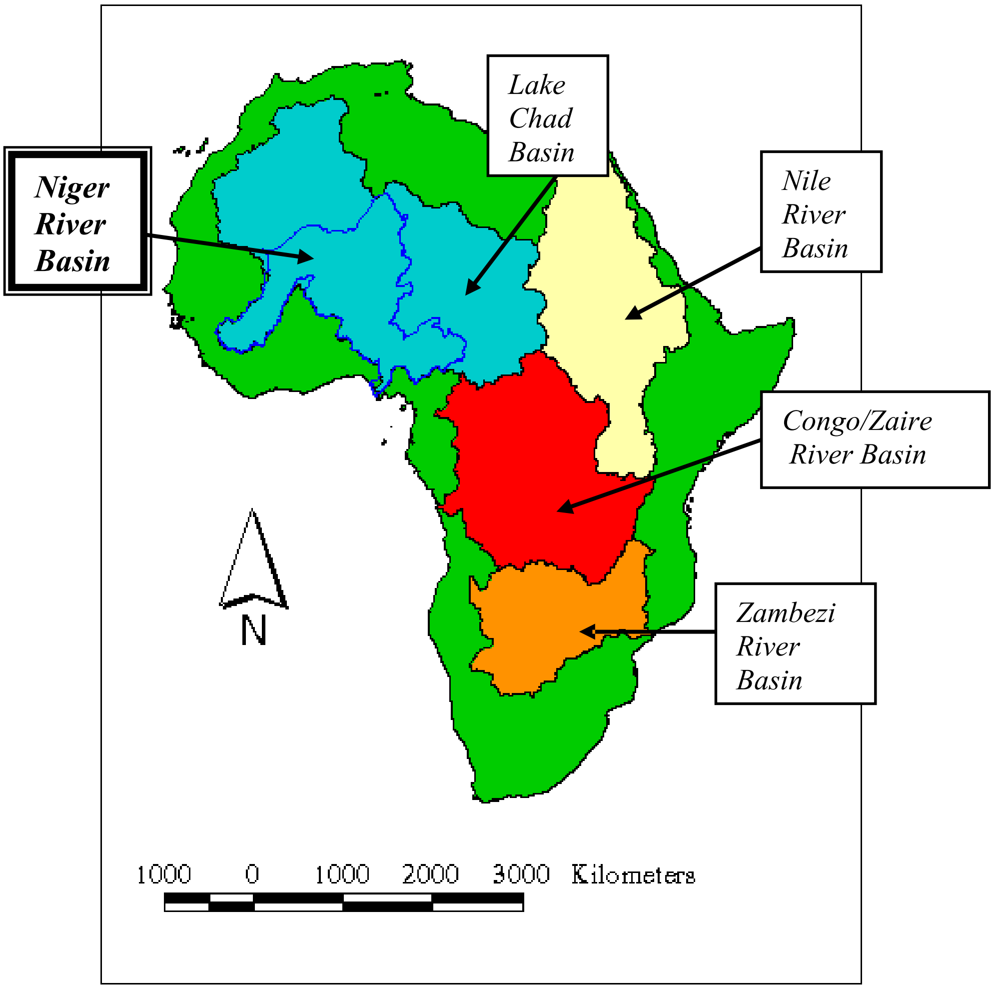


Figure 1 Major African River Basins (Source: Maidment)

A closer look at the Niger River basin is given in Figure 2, with an indication of the location of the Inner Delta. In this study, which focuses on the hydrology of this delta region, only that part of the basin upstream from the Inner Delta is included. From this figure it is evident that this is only a small part of the total basin, which has a major basin area in Niger in which it flows south towards the Atlantic Ocean.

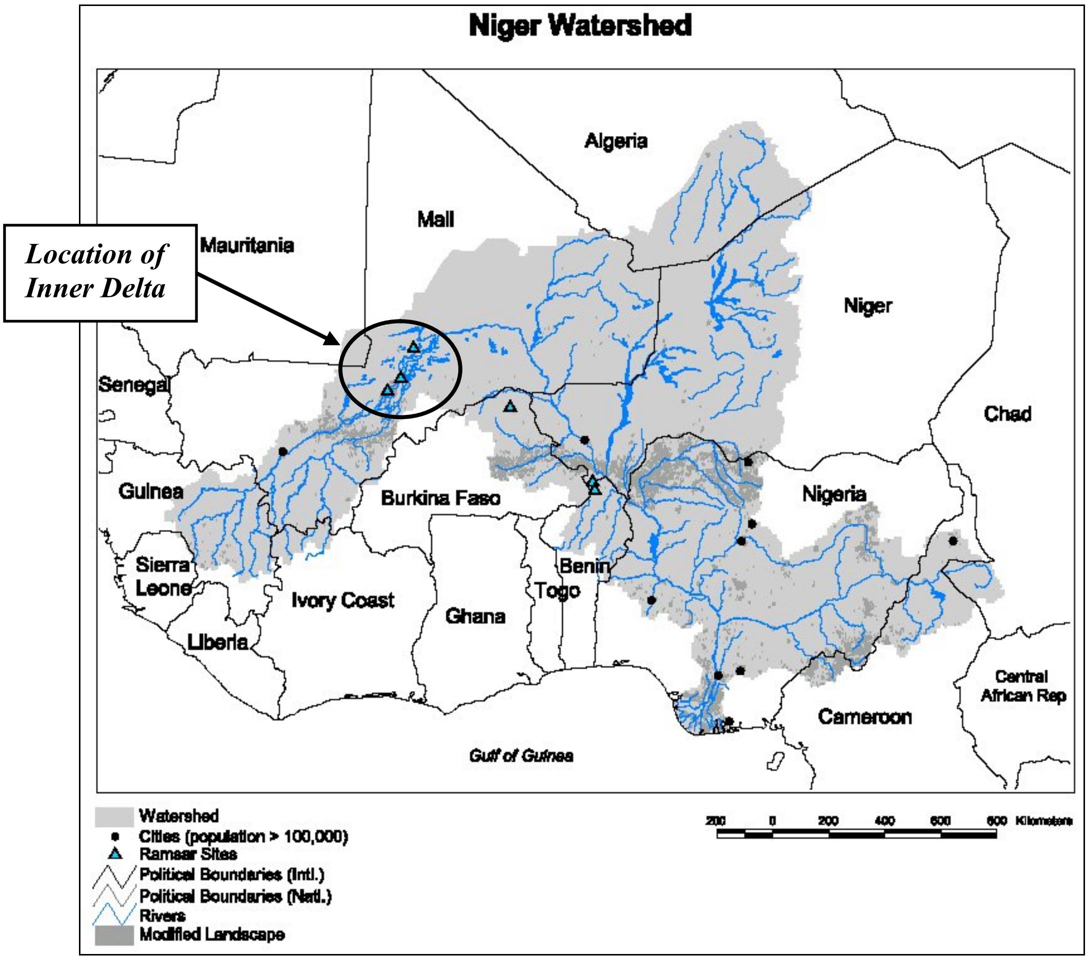


Figure 2 Map of the Niger River Basin (Ref. Revenga et al., 1998 [1])

In Figure 3 a more detailed image is given of the full Inner Delta, showing also the extension of the inundated area (light blue) and the principal water bodies (dark blue, rives and lakes). The irrigated area of the Office du Niger, with an intake on the Niger River at Markala weir, is shown in the far West of the map. In the northern region, downstream from the location of Diré, a number of lakes is visible that do only have a weak connection to the Inner Delta and which have been left out of the present analysis.

[1] *Revenga et al, 1998, Watersheds of the World – Ecological Value and Vulnerability, World Resources Institute.*

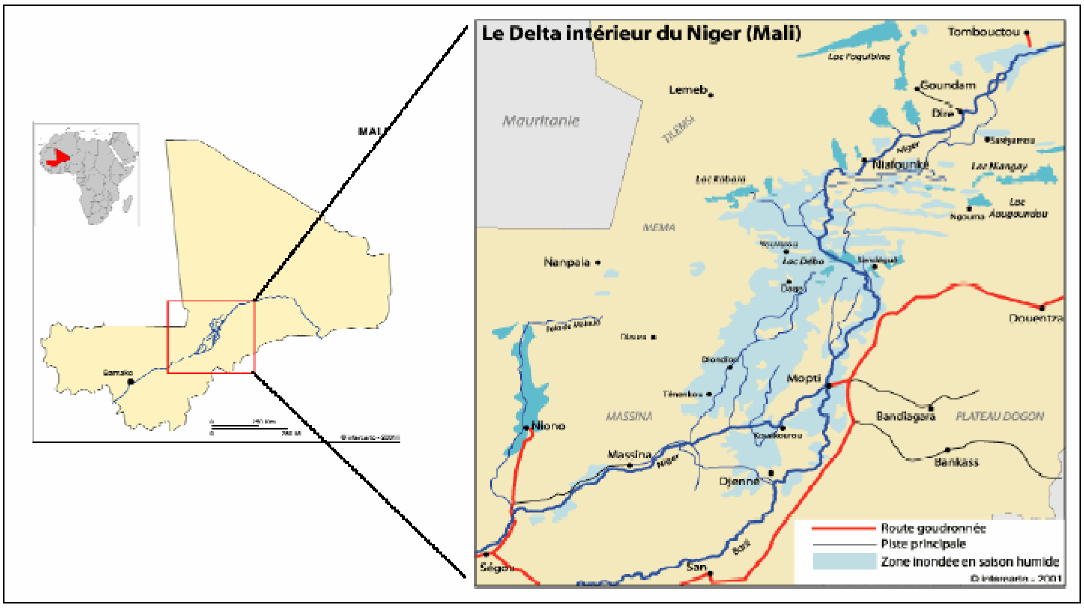


Figure 3 Further detail of the Inner Delta with extension of inundated area and principal water bodies (Source: Marie-Laure de Noray, 2003)

The climate of Mali is in general semi-arid to arid, with a clear dry season (December – May) and a rainy season with most of the rainfall in July/August. As can be seen in Figure 4 this overall pattern is presented over the full length of the country, but with very significant differences in rainfall depth between the South-West (relatively wet) to the North-East (very dry).

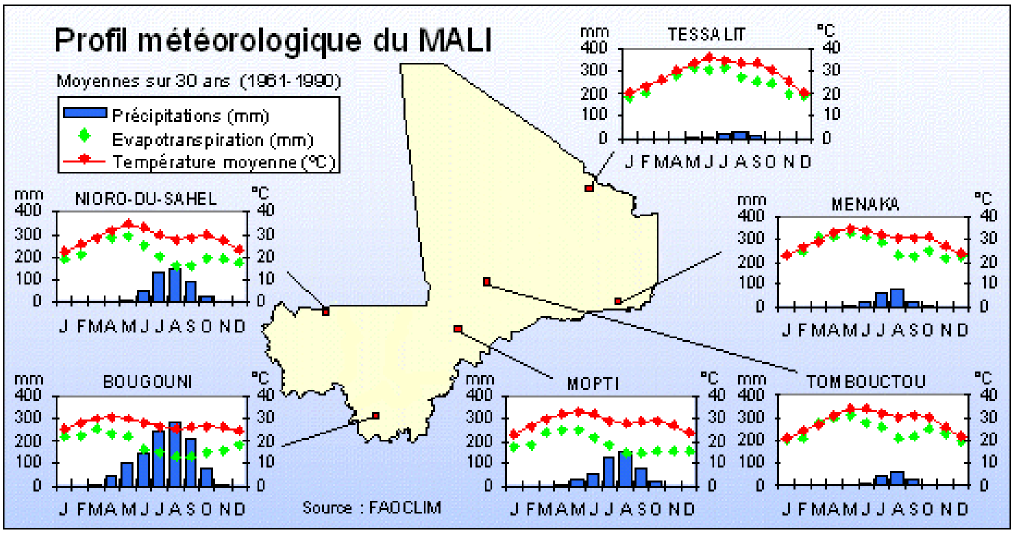


Figure 4 Meteorology of Mali (source: FAO internet site)

2.2 Hydrological regime of the Niger River

Information on the Niger River Basin provided by FAO indicates that most of the Niger River basin is located in Nigeria (25.7%), Mali (25.5%) and Niger (24.8%). Table 2-1gives general information on the extent of the Niger River Basin and the various countries that form part of the basin (source: FAO internet site).

Table 2-1 Summary of basin characteristics of the Niger river

COUNTRY	TOTAL AREA OF THE COUNTRY (KM^2)	AREA OF THE COUNTRY WITHIN THE BASIN (KM^2)	AS % OF TOTAL AREA OF BASIN (%)	AS % OF TOTAL AREA OF COUNTRY (%)	AVERAGE ANNUAL RAINFALL IN THE BASIN AREA (MM/YEAR)		
					min.	max.	mean
Guinea	245.857	96.880	4.3	39.4	1240	2180	1635
Côte d'Ivoire	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	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**	**-**	**283**	**1625**	**697**

The area of the Niger River basin in Guinea is only 4% of the total area of the basin, but the sources of the Niger River are located in this country. The quantity of water entering Mali from Guinea (about 40 km^3/yr) is greater than the quantity of water entering Nigeria from Niger (36 km^3/yr), about 1800 km further downstream. This is due among other reasons to the enormous reduction in runoff in the Inner Delta in Mali through seepage and evaporation combined with almost no runoff from the whole of the left bank in Mali and Niger (the Sahara desert region).

The Niger River enters Mali through various tributaries from Guinea, which come together in Mali. In Figure 5 the various tributaries in Guinea are shown. On the border with Guinea the most important reservoir Sélingué is located on the Sankarani tributary of the Niger River.

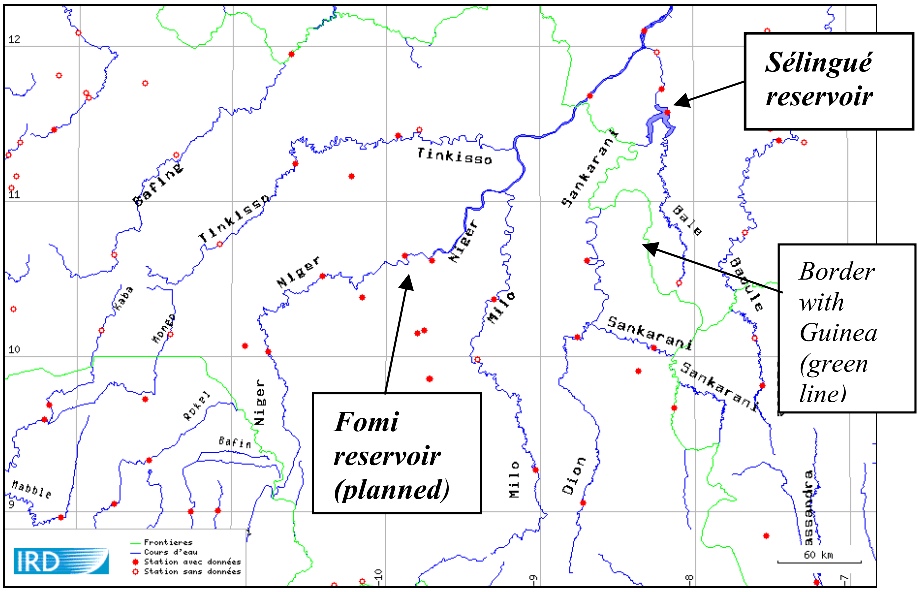


Figure 5 Tributaries of the Niger River in Guinea with (planned) reservoirs

In Mali there are four climate zones in the basin area and rainfall ranges from 1500 mm in the south to less than 50 mm in the north. The water in the Niger River is partially regulated through dams. The Sélingué dam on the Sankarani River is mainly used for hydropower, but also permits the irrigation of about 60,000 ha under double cropping. Two diversion dams, one at Sotuba at the city of Bamako, and one at Markala, just downstream of Ségou, are used to irrigate the area of the Office du Niger (equipped area of about 54,000 ha). Some of the main characteristics of the Sélingué dam are given in Table 2-2.

Table 2-2 Main characteristics of the Sélingué dam

CHARACTERISTIC	VALUE
Basin area	34,200 km^2
Crest length	2600 m
Height	23 m
Total storage volume	2166.7 MCM
Effective storage volume	1928.7 MCM
Dead storage volume	238 MCM
Design flood discharge	3600 m^3/s
Minimum working level	340 m
Normal level	348.5 m
Exceptional low level	339.5 m

Sélingué was put into service in 1981 and its main functions are:

- Production of hydropower (4 x 11.9 Mw)
- Irrigation of an area of 1500 ha directly downstream from the dam
- Regulation of the river discharge on the Sankarani tributary of the Niger River
- Providing fishery

It is not clear what are the priorities that are set at this reservoir, but in practice it is evident that the production of hydropower is the activity which dictates the operation of the dam. This is clear from Figure 6 which shows for the year 1999 the progressive lowering of the water level at Sélingué dam due to continuous outflow for hydropower production and the sudden drop in discharge at Koulikoro once the storage volume reaches dead storage at the end of May 1999.

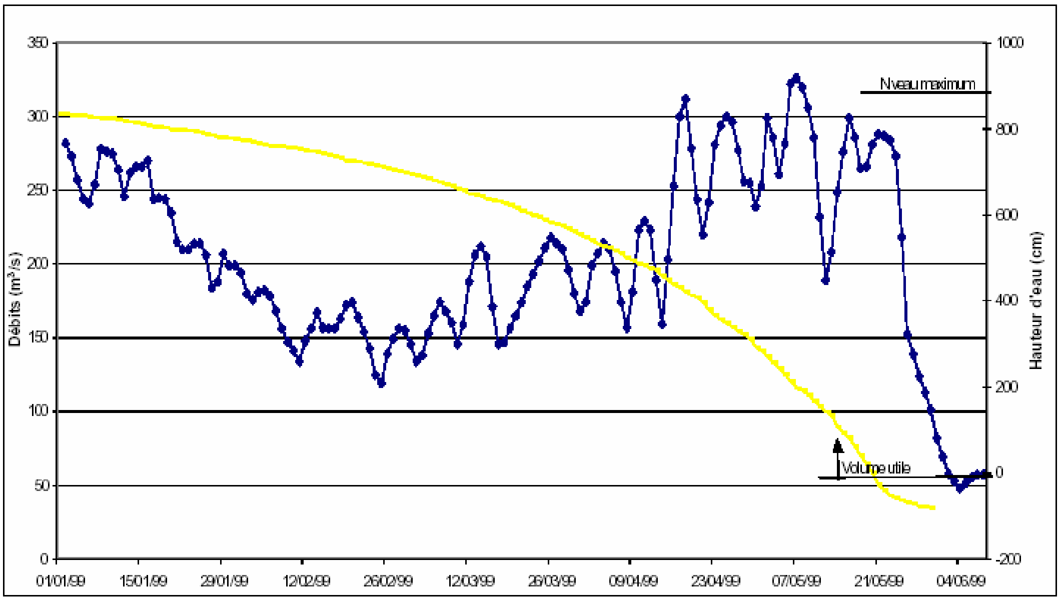


Figure 6 Flow at Koulikoro (blue line with marker) and water level at Sélingué in 1999

Another very small hydropower plant is located directly upstream from Bamako at Sotuba. This structure is not important for this study because the storage volume is too small to have any noticeable impact on the hydrology of the Niger River.

For the irrigation in Mali, the Markala weir is more important as this is the location of the water intake for the area named Office du Niger. However, here only the amount of water that is taken from the river is important for the hydrology of the Inner Delta. As will be discussed later in the description of the input files for the modelling of the Upper Niger River system, the Markala weir itself has hardly any impact on the hydrology as its storage volume is very small. This is due to the small possible change in water level (only about 30 cm) and the absence of a storage reservoir (the water is only stored in the main bed of the river, confined by dikes).

The irrigation potential has been estimated at 556,000 ha by FAO, of which about 200,000 ha fully controlled and the rest for partially controlled schemes. At present about 187,000 ha are equipped in the Niger basin, but of this 57,000 ha are already abandoned and of the remaining 130,000 ha actually irrigated more than 60% need to be rehabilitated. Irrigation water requirements for double rice cropping in the Niger River valley range from over 30,000 m^3/ha per year in the southwest to nearly 50,000 m^3/ha per year in the northern part according to the information provided by FAO.

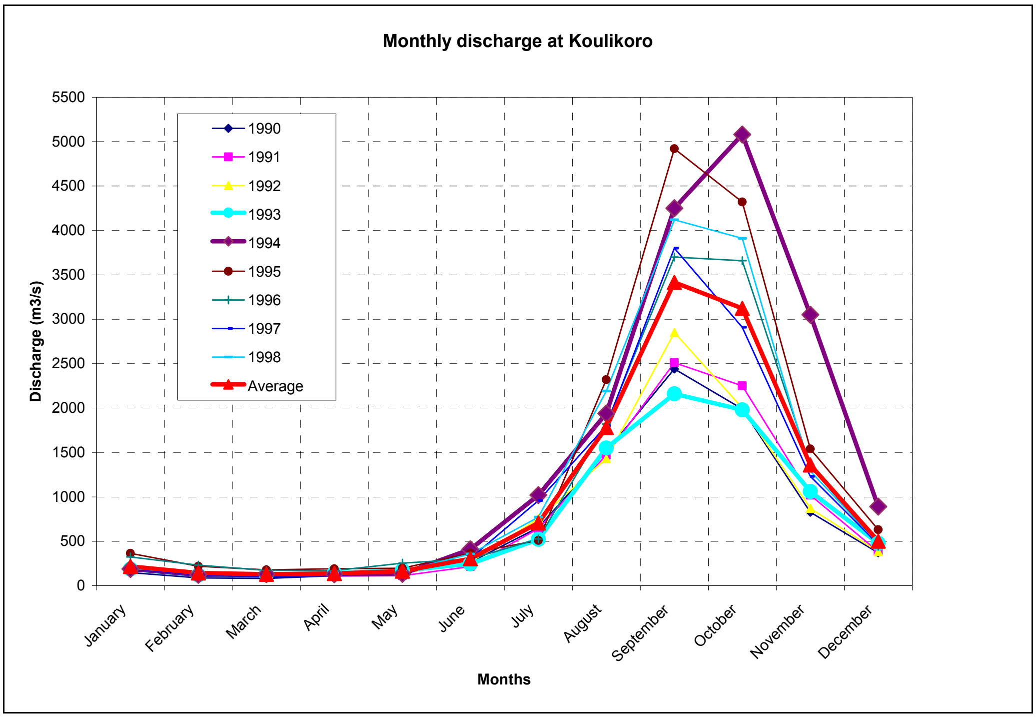


Figure 7 Monthly discharges for the period 1990 – 1998 (and average value) at Koulikoro

In Figure 7 the monthly discharge at Koulikoro is shown for the years 1990 – 1998, together with the average over this period. The year 1993 is a typical dry year (yearly average 728 m^3/s) and 1994 a typical wet year (1445 m^3/s), while the yearly average is in the order of 1000 m^3/s. The tremendous difference in monthly discharge between the dry season (December - July) and the wet season (August – November) is evident.

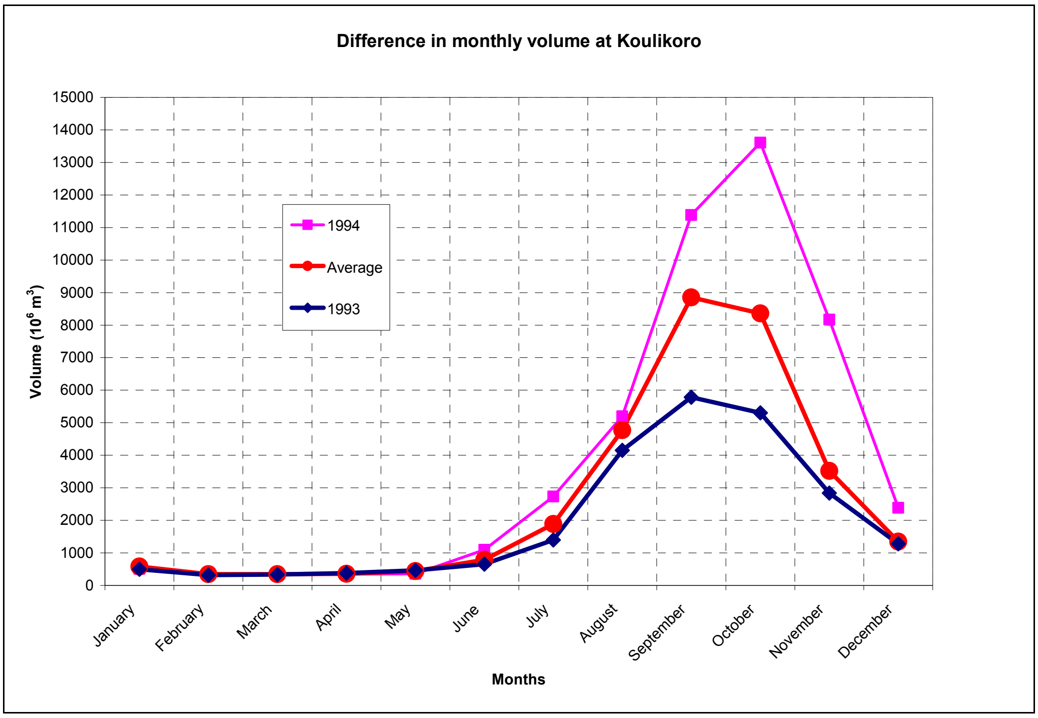


Figure 8 Monthly volume of discharge at Koulikoro for dry year (1993), wet year (1994) and average conditions

In Figure 8 the monthly volume of flow is shown for a dry year (1993), a wet year (1994) and for average conditions in the period 1990 – 1998. This illustrates again very clearly the marked difference between dry and wet year conditions during the flood season. However, in the dry season there is hardly any difference.

The overall average discharge of the Niger River along its course from Guinea to the point of outflow into the Atlantic Ocean is shown in Figure 9.

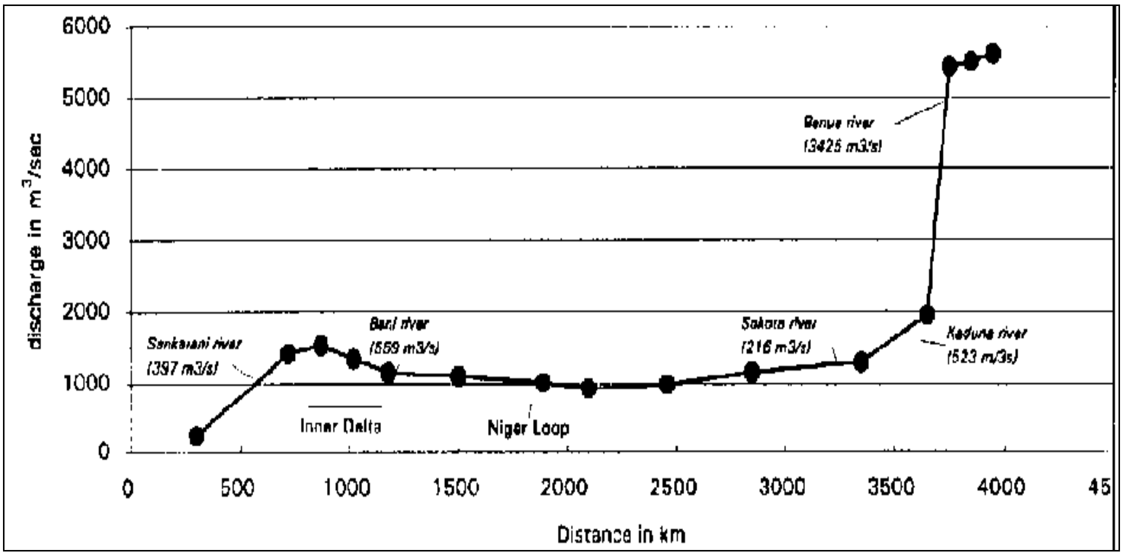


Figure 9 Average discharge of the Niger River along its course

As can be seen in this figure, after a rapid increase in discharge due to abundant rainfall in Guinea, reaching values in the order of 1000 m^3/s at Koulikoro, the passing of the Inner Delta results in a gradual decrease in the discharge, despite the entering of the major tributary of the Bain river. For a long stretch afterwards there is hardly any inflow and the discharge remains rather stable, until another wet region is passed in the lower reach of the Niger River shortly before entering the Atlantic Ocean.

2.3 Hydrological regime of the Inner Delta

The total inundated area covered by the Inner Delta, which is a network of tributaries, channels, swamps and lakes, can reach about 30,000-35,000 km^2 in flood season (Hassane, 1999). The delta area is swampy and the soil sandy. Consequently, the river 'loses' nearly two-thirds of its potential flow between Ségou (at 900 km from its source) and Timbuktu (at 1500 km) due to seepage and evaporation, the latter being aggravated by the fact that the river here touches the southern flanks of the Sahara desert.

All the water from the Bani tributary, which flows into the Niger River at Mopti (at 1150 km), does not compensate for the 'losses' in the inner delta, as the total flow further downstream still decreases rather than increases (Figure 9). The average 'loss' is estimated at 31 km^3/year, but varies considerably according to the years: it was 46 km^3 during the wet year of 1969 and about 17 km^3 during the dry year of 1973.

The hydrological regime of the Inner Delta is determined by the extension of the floodable area. The Inner Delta of the Niger River has a major influence on the form of the 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 (see Figure 10 from "*Vers une gestion concertée de l'eau dans le bassin du fleuve. Niger Marcel Kuper, Adamou Hassane, Didier Orange*").

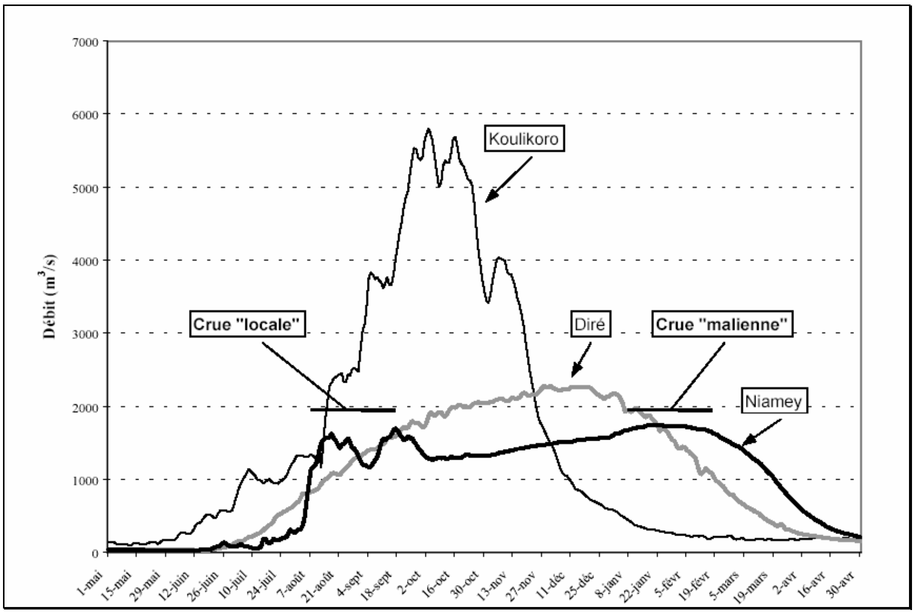


Figure 10 Flood propagation from Koulikoro through the Inner Delta (Doré) to Niamey.

As can be seen in this figure, the original form of the flood at Koulikoro, with a discharge in the order of 5000 – 6000 m^3/s, is attenuated completely in the Inner Delta and at Diré the maximum discharge is in the order of 2000 – 2500 m^3/s. Further attenuation occurs further downstream, as can be seen for the hydrograph drawn at Niamey, but the main change in flood wave is due to the Inner Delta. The fact that the flood wave becomes very flat, i.e. the water has a relatively long residence time in the delta, also implies that a major volume is lost by evapo(transpi)ration.

More details on the layout of the Inner Delta and its intricated system of lakes and connecting channels are given in Chapter 5.

2.4 Foregoing studies

2.4.1 GHENIS Project

The most important study that has been made thus far of the Niger River system is the GHENIS project. This project had a very wide scope and for the present study the chapters on hydrology and modelling in the report of the GHENIS project provide important information.

In Annex J (p. 31-40) of the report of the GHENIS project, an excellent hydrological database has become available, which allow direct access to hydrological, meteorological as well as hydro-ecological and hydro-chemical data. In the Annex I to the report, with the title 'Modelisation', a summary is given of the hydrodynamic modelling of the Niger River, including the reservoirs. Interesting in this chapter is especially the study of the impact of new reservoirs, among which Fomi, on the hydrological regime of the river at Bamako. Use is made of the conceptual hydrological model NAM and the hydrodynamic model MIKE11 for the Sélingué and Markala reservoirs. A number of scenarios have been studied:

- the new Fomi reservoir with multiple-purpose operation: flood control, hydropower and irrigation
- alternative operation of Markala: hydropower and discharge control downstream
- alternative operation of Sélingué - multiple-purpose operation: flood control, hydropower and irrigation
- hydropower production at Kénié
- increase in water intake by the Office du Niger

In the Final Report of the GHENIS project, not all results of the modelling are presented, but in this Annex three interesting results are reproduced:

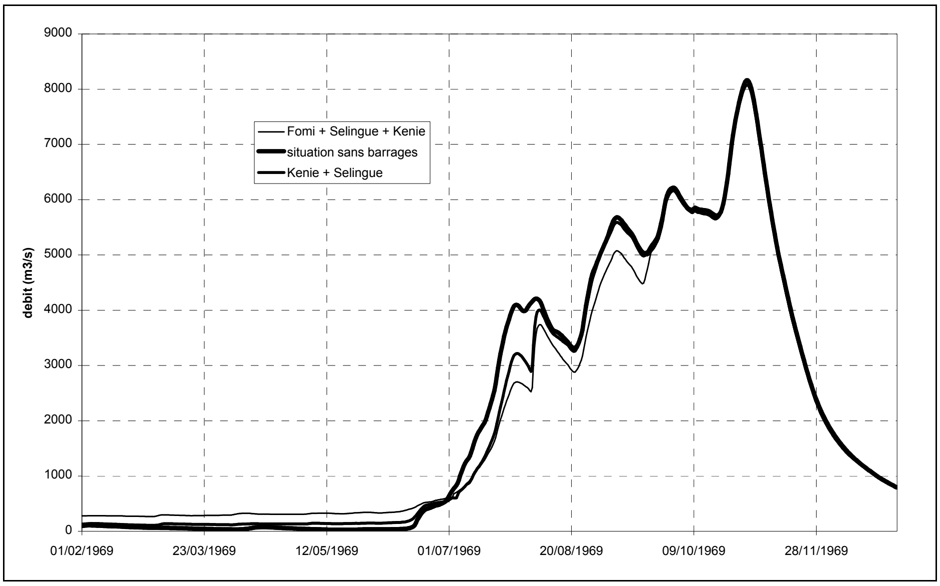


Figure 11 Impact of the existing Sélingué and newly planned Kénié and Fomi on the discharge at Bamako in a **wet** year

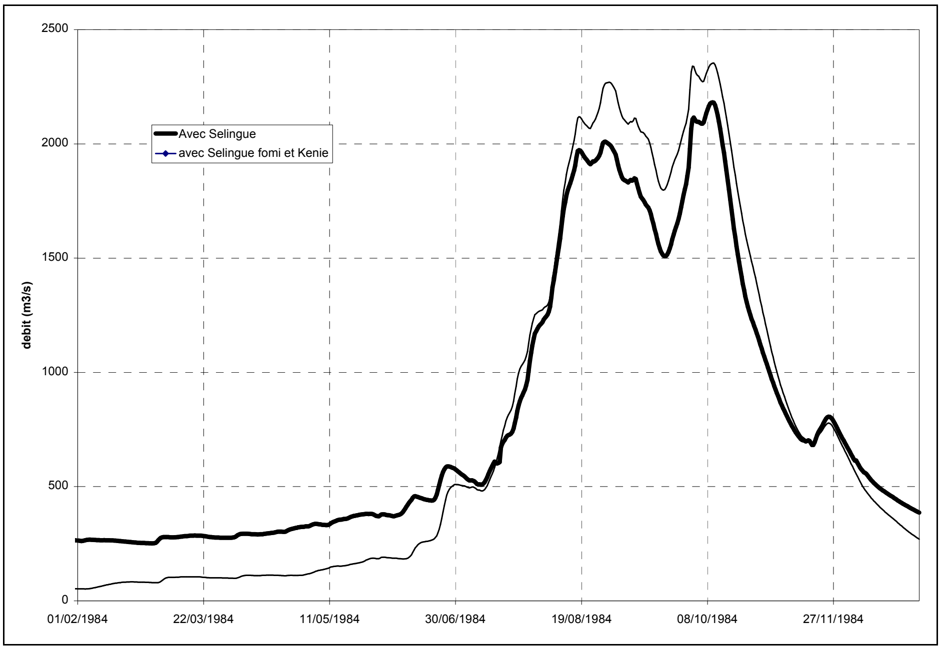


Figure 12 Impact of the existing Sélingué and newly planned Kénié and Fomi on the discharge at Bamako in a **dry** year

It is interesting to see that for a wet year the impact of the existing and new reservoirs is visible in the start of the flood period, but the effect is zero at higher discharges. This is due to the fact that at that stage the reservoirs have been filled and the water entering the reservoirs is passed without any significant changes over the spillways. There is a clear impact, though, for drier years, especially with the Fomi reservoir that has a reservoir volume that is more than double the volume of Sélingué.

2.4.2 Impact of the reservoirs on the hydrology of the Inner Delta

In their study, Hassane et al.[2] state clearly that the filling of Sélingué leads to a delay in the occurrence of the flood at Sankarani (directly downstream of the dam). Once the reservoir has been filled, there is hardly an effect as the spillways of the Sélingué dam pass on all the flood water. This effect is also notable at Koulikoro and at Ké-Macina, but the effect of Sélingué is evidently more pronounced during low flow periods.

[2] *Hassane A., M. Kuper & D. Orange: Influence des aménagements hydrauliques et hydro-agricoles du Niger supérieur sur l'onde de la crue du delta intérieur du Niger au Mali.*

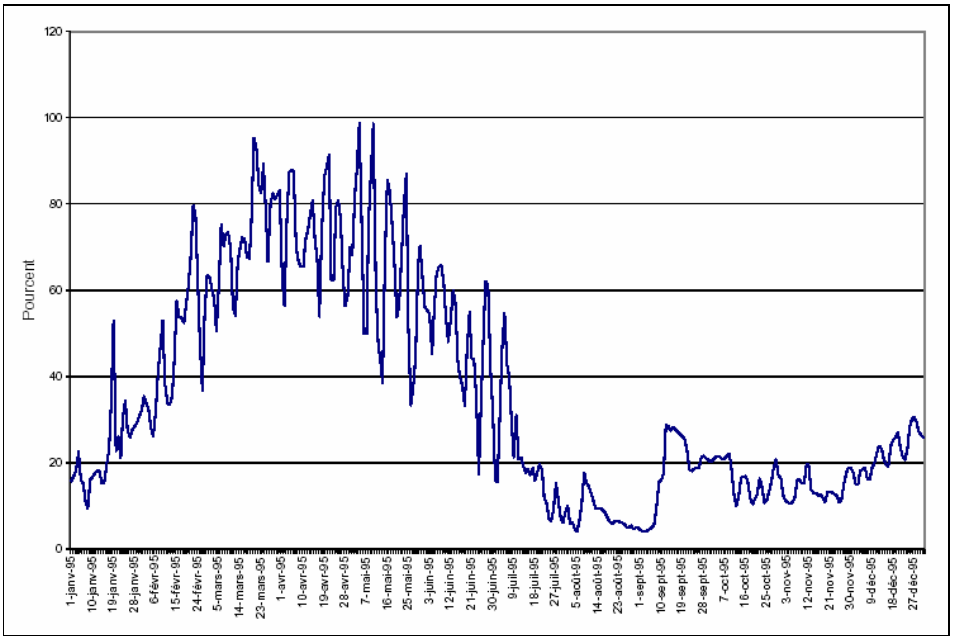


Figure 13 Contribution of Sélingué at Koulikoro in 1995 (in %).

The maximum volume of Sélingué is 2,2 km^3 and the average flow volume at Sankarani for the period 1982-1998 is about 7.0 km^3, i.e. the volume of the reservoir is about 30% of the yearly inflow. The inflow from the other tributaries, measured at Banankoro is 20 km^3/year, while the total at Koulikoro is 28.6 km^3. This implies that the average volume of the Sélingué reservoir represents about 7.6% of the yearly average flow at Koulikoro.

The authors conclude that:

1. the impact of Sélingué during low flow is very important
2. the impact during floods is limited, because the maximum volume of the reservoir represents at the most 7.6% of the total flow at Koulikoro

3 Approach of the study

In order to make an assessment of the impact of existing reservoirs and the implementation of newly planned reservoirs, the RIBASIM model has been used. This model is based on a water balance approach using a time step between 10 days to one month and allows for the simulation of various types of structures (intakes, diversions, reservoirs, run-of-river hydroplants, etc.) and a large number of demand units such as public water supply, industrial water use and, especially, irrigation demand. The latter is calculated using a special agricultural module. An important aspect of the use of the RIBASIM model is the possibility to include a very detailed reservoir operation schedule with all the details of the structure as well as different types of outlets.

The RIBASIM model makes use of a schematization of the region of study in a combination of nodes (representing physical items such as reservoirs, intakes, etc.) and links (essentially connecting the various nodes). This schematization includes all present and planned infrastructure in order to allow for comparisons between model simulations. A list of the existing and planned infrastructural items in this study is given below:

Existing:

- Sélingué reservoir
- Sélingué irrigation intake
- Sotuba intake
- Bamako PWS intake
- Markala irrigation intake
- Inner Delta lakes (several)

Planned:

- Fomi reservoir
- Talo reservoir

In Figure 14 an overview is given of the Upper Niger River system (upstream from the Inner Delta) with the location of the existing and planned structures.

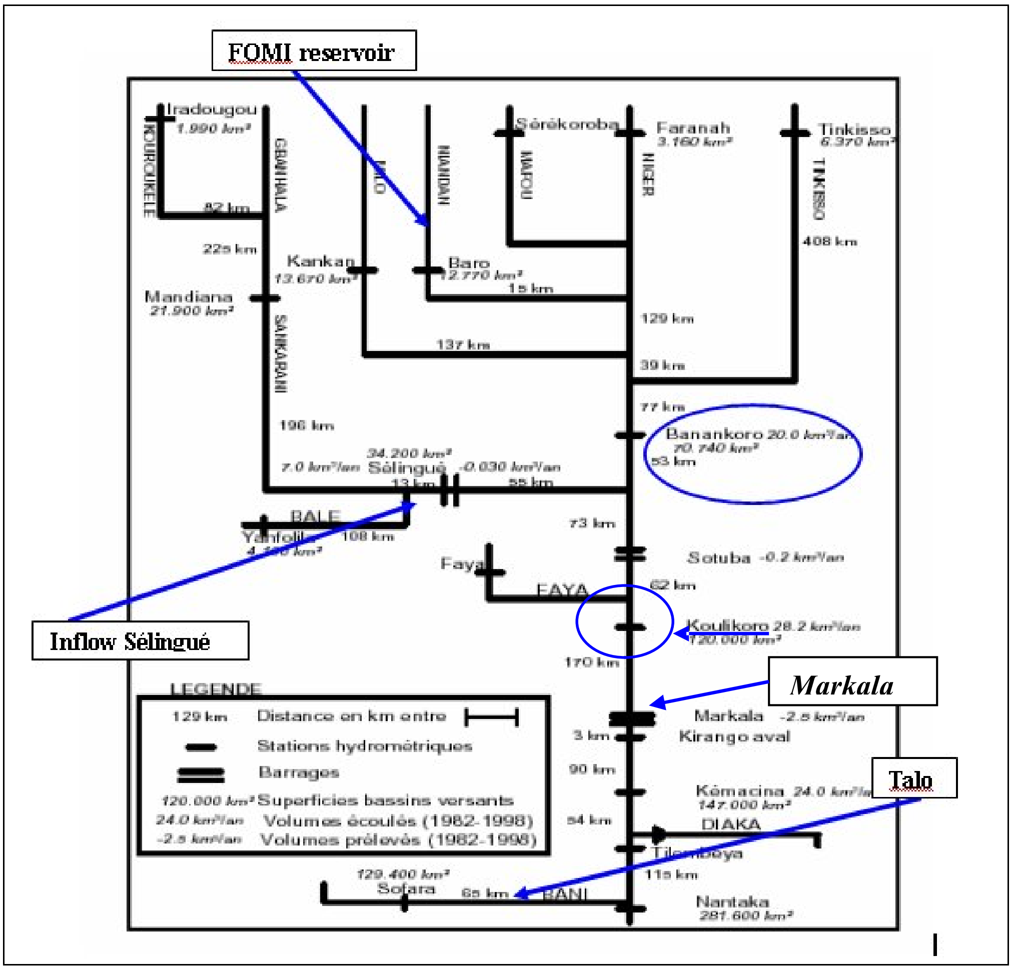


Figure 14 Overall outline of the Upper Niger system with locations of reservoirs

The full RIBASIM schematization that is used in this study is shown in Figure 15, with details on Figure 16 and Figure 17.

Once the schematization of the region has been completed, the various types of input data need to be prepared. A distinction can be made between time series (e.g. inflow, precipitation) and fixed data such as size of reservoir, capacity of intakes, etc.

For the application of the RIBASIM model a time step of 15 days is used. A period of 20 years is used (1980 – 2000).

The analysis is done by making changes to either the layout or the input data and compare the results. Changes in the layout refer to the addition of a future reservoir to the simulation and compare to the situation without the reservoir. By changing the input data (e.g. water demand), the impact of other future situations can be simulated.

On the basis of these simulations, conclusions can be drawn on the behaviour of the system and the feasibility of future implementations of infrastructural works. It also allows for the assessment of the impact of certain changes in both the internal and external situation, i.e. the changes in irrigation conditions or the changes in climate (e.g. decrease in rainfall). An important outcome is often the judgment whether or not a certain development plan is feasible (e.g. the increase in irrigation area).

In this study, the emphasis is placed on the assessment of the impact of the existing and newly planned surface water reservoirs on the hydrological behaviour of the Inner Delta, with emphasis on the occurrence and extension of the flooding of the region.

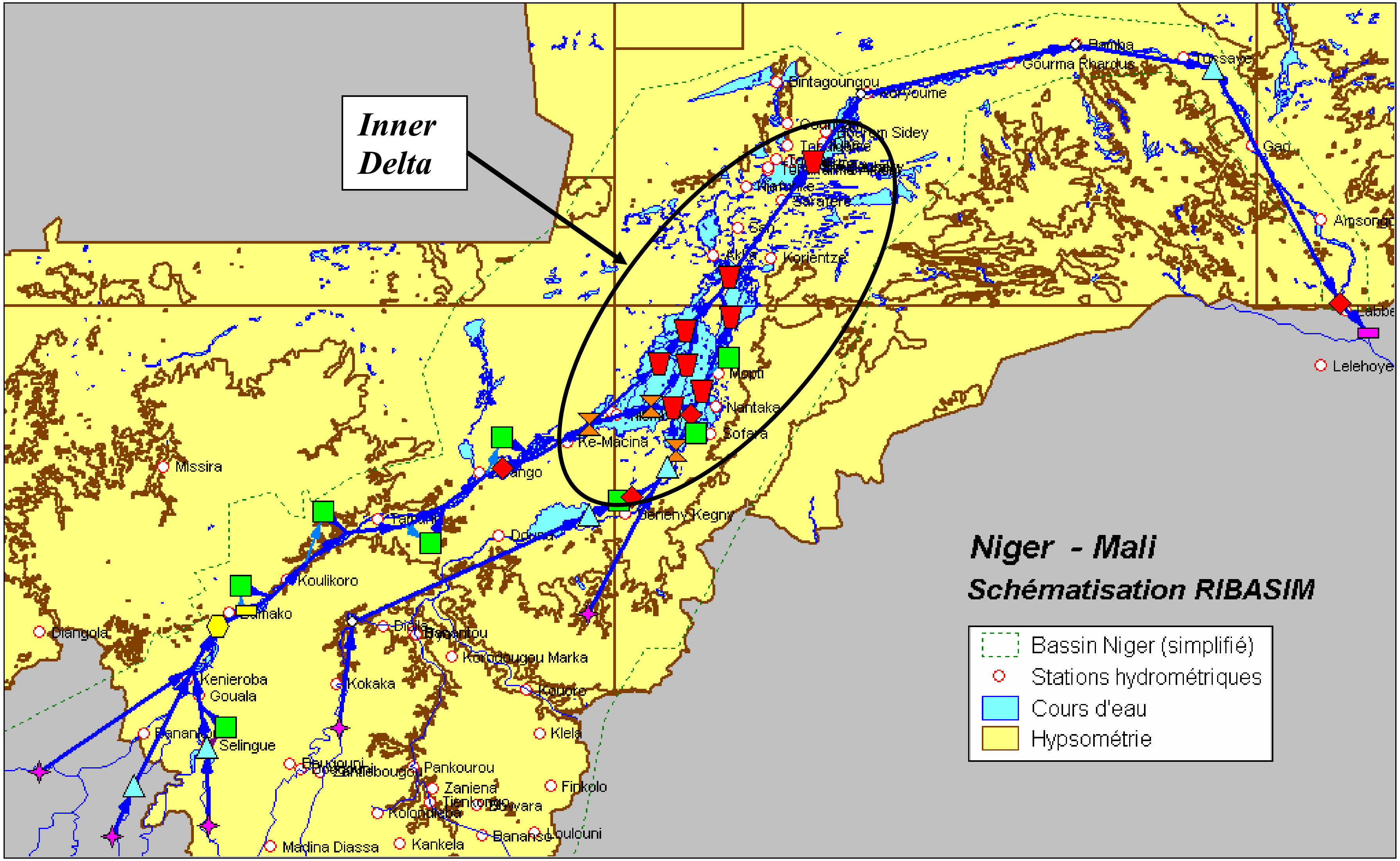


Figure 15 RIBASIM Schematization of the Niger River system in Mali

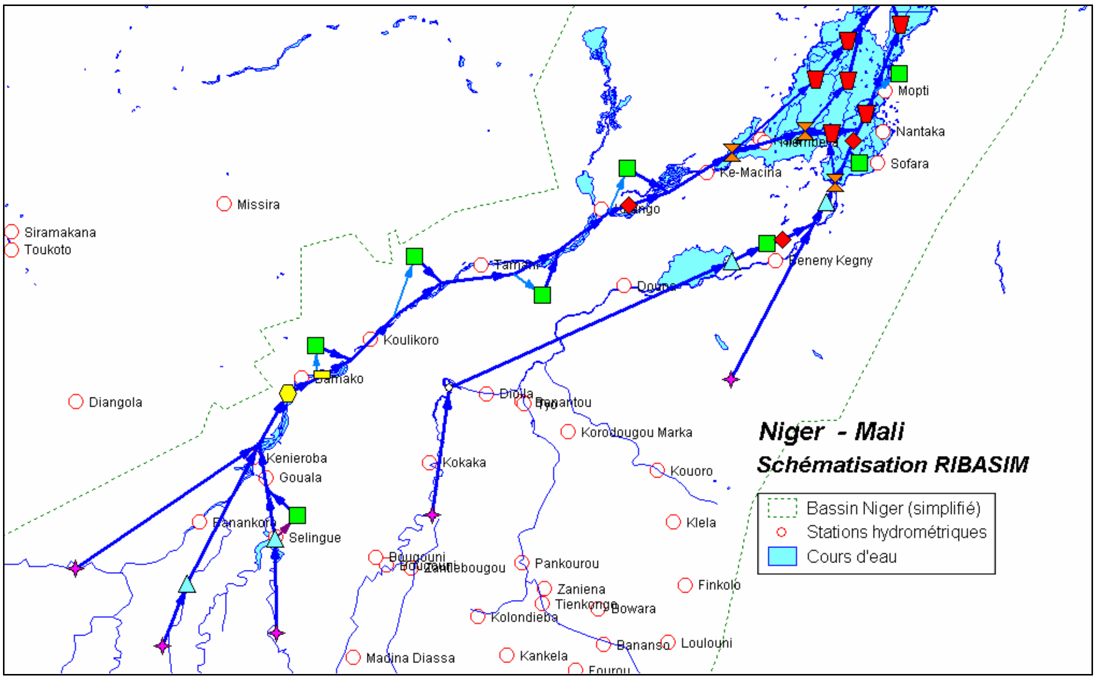


Figure 16 Southwest part of the RIBASIM simulation network

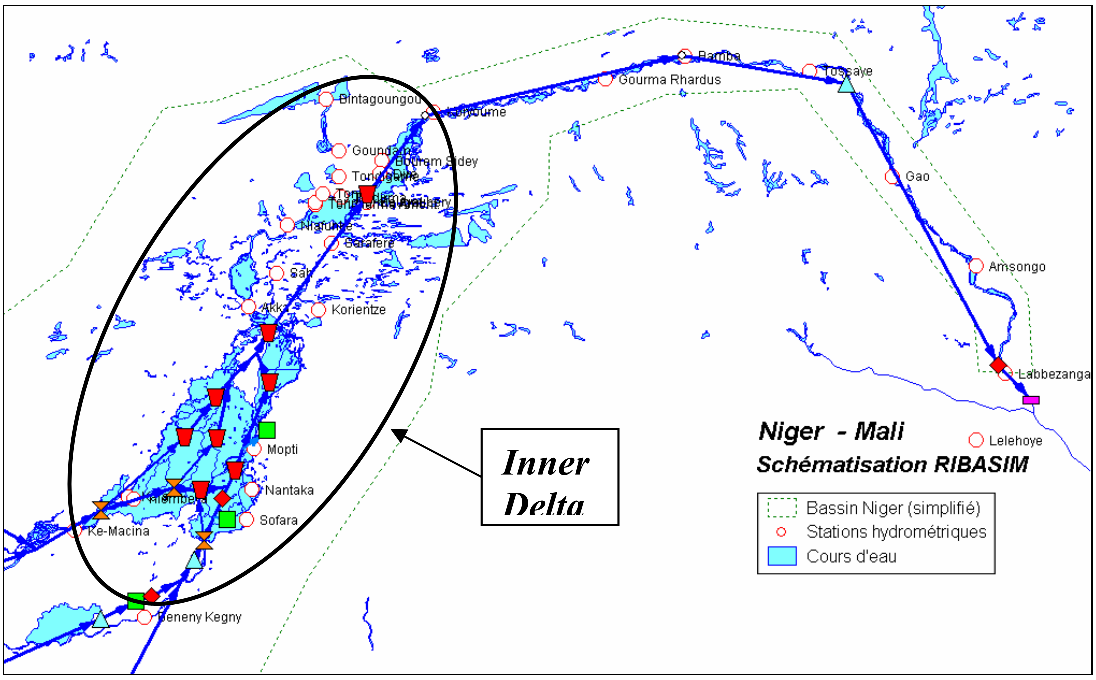


Figure 17 North-East part of the RIBASIM simulation network

4 Data Collection and Validation

In order to build up the model of the Inner Delta and subsequently calibrate the model, it is necessary to collect various types of data. The data collection has included the following types of data:

- hydro meteorological series (mainly monthly values):
  - precipitation
  - evaporation
  - water levels
  - discharges
- characteristics of existing and planned reservoirs
- geometry of the inner delta
- existing and future values of water demand (irrigation, PWS)

4.1 Precipitation

For the precipitation is it more difficult to obtain series for the period of 1980 – 2000 as DNHE has no access to this data. Monthly precipitation for Mali can be obtained from the meteorological office, but for a certain price. The same applies for data in Guinea, but then of course there is the problem of obtaining the data from Conakry. As the precipitation data are less crucial than the discharges, the data have been obtained from internet sites that publish monthly values for many countries in the world, although for a limited number of stations.

The rainfall on the Inner Delta itself is based on the station of Macina. It is evident that this is only a minor input in this arid region. The total volume of rainfall during the flood season is in the order of 100 m^3/s, which is less than 10% of the total inflow into the Inner Delta.

4.2 Evaporation

Evaporation is needed e.g. for losses from the reservoirs and the Inner Delta. As indicated earlier, for the evaporation values, use is made of an average value per month as this value varies only slightly over the years in comparison to precipitation. The evaporation values are given in graphical form by Brunet-Moret et al. (1986) for four locations in the Inner Delta: Kenie, Koumbaka, Tin Adjar and M'Bouna. Moreover they mention a total evaporation for Tin Ajar, which has a dry micro-climate, of 3170 mm, and for M'Bouna, which has a humid micro-climate, of 2500 mm. Based on this information daily and monthly evaporation was determined (See Table 4-1).

Table 4-1 Evaporation at M'Bouna and Tin Adjar (values in mm)

MONTH	M'BOUNA		TIN ADJAR	
	Average daily	Monthly	Average daily	Monthly
January	4.5	139.5	7.5	232.5
February	5.5	154	7.5	210
March	6.5	201.5	8	248
April	7.5	225	10	300
May	9	279	10.5	325.5
June	10	300	11.3	339
July	8	248	9	279
August	5.5	170.5	6.8	210.8
September	6	180	7.5	225
October	7	217	9.5	294.5
November	7	210	9	270
December	5.5	170.5	7.5	232.5
Yearly	-	*2495*	-	*3166*

The evaporation at M'Bouna is used for all nodes in the Inner Delta, except for Diré, for which the evaporation of Tin Adjar is taken. The same monthly evaporation values are repeated for all years of the simulation.

4.3 Water levels and discharges

Water level and discharge values are needed for the chosen period of simulation 1980 – 2000. The series are needed for stations both in Mali and in Guinea. Of course series of monthly values in Mali are easily obtainable from the DNHE and have been provided by them for the required period. For stations in Guinea data can either be obtained from the hydrological service in Conakry or by sources in internet. Within the context of the present study, a visit to Conakry for data collection has not been considered given the costs involved. Another reason is that monthly discharge values are available on various internet sites. The main problem with this source is data reliability. For this reason data have only be collected from 'official' sites such as the FRIEND (UNESCO) database. On this internet site, a large list of stations is available in Guinea. An overview is provided in Annex B. Although this is a very impressive list, not all of the stations have data and for many the data series are rather short (i.e. less than the period 1980 – 2000).

4.3.1 Locations of the stations

The Niger River originates from Guinea and for this reason it is necessary to have inflow hydrographs for the various locations in Guinea that can be used in the RIBASIM model. An important factor is the existence of a planned reservoir in Guinea, the Fomi reservoir, which forces the introduction of inflow hydrographs for the region upstream and downstream of this location.

For the Bani river, no inflow hydrographs are required for the upper region in Guinea as there are other measuring stations further downstream within Mali. However, the existence of a planned reservoir (Talo reservoir) on the Bani forces the use of two inflow hydrographs, for the basin area upstream from this dam and the region downstream from the dam.

In theory it is also necessary to distinguish in regions upstream and downstream from a river intake, such as those placed in the model for irrigation areas. However, most of those regions are very small and do not noteworthy influence the hydrology of the Niger River. This does not apply to the Office du Niger irrigation area, with the intake at Markala, but in this case the inflow to the Niger River downstream from Markala can be neglected (actually the river is losing water in this reach, especially by evaporation in the inundated areas) and thus no extra inflow hydrograph is required here.

In summary the following locations require inflow hydrographs for the RIBASIM model:

On the Niger:
- Sélingué
- Niger at Banankoro (border with Mali)
- Upstream from Fomi
- Downstream from Fomi

On the Bani:
- Upstream from Talo
- Downstream from Talo

The location of the reservoirs is shown on the map of the upper Niger basin (Figure 5) and in the general schematization of the Niger River (Figure 14).

4.3.2 Sources of data

Discharge hydrographs for monthly values in Mali were provided by DNHE. An example is shown in Figure 18 for a number of stations along the Niger River.

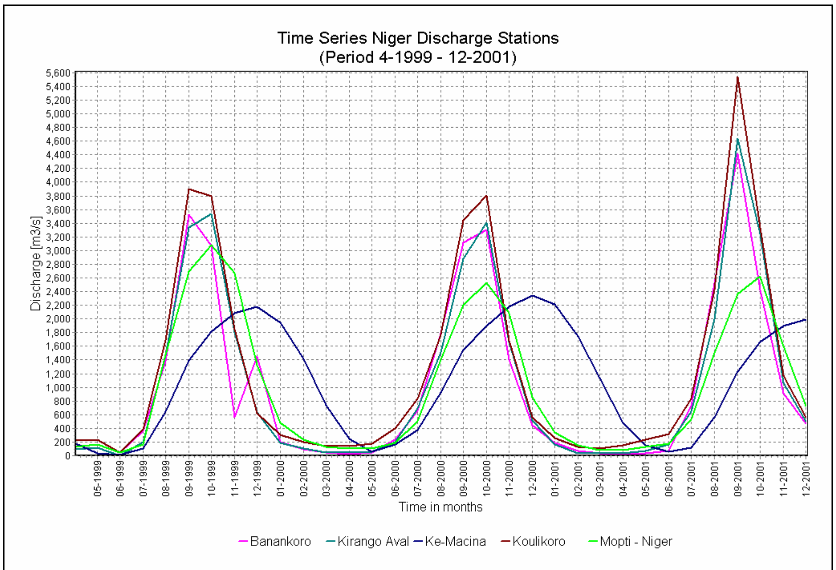


Figure 18 Time series of discharge stations on the Niger in Mali

For the inflow to the Sélingué reservoir, data area available on the monthly average inflow to the reservoir, together with volume changes over the month, power generation and irrigation water provision. The inflow and outflow hydrographs are shown in Figure 19. These data will be compared to available monthly hydrographs of upstream stations.

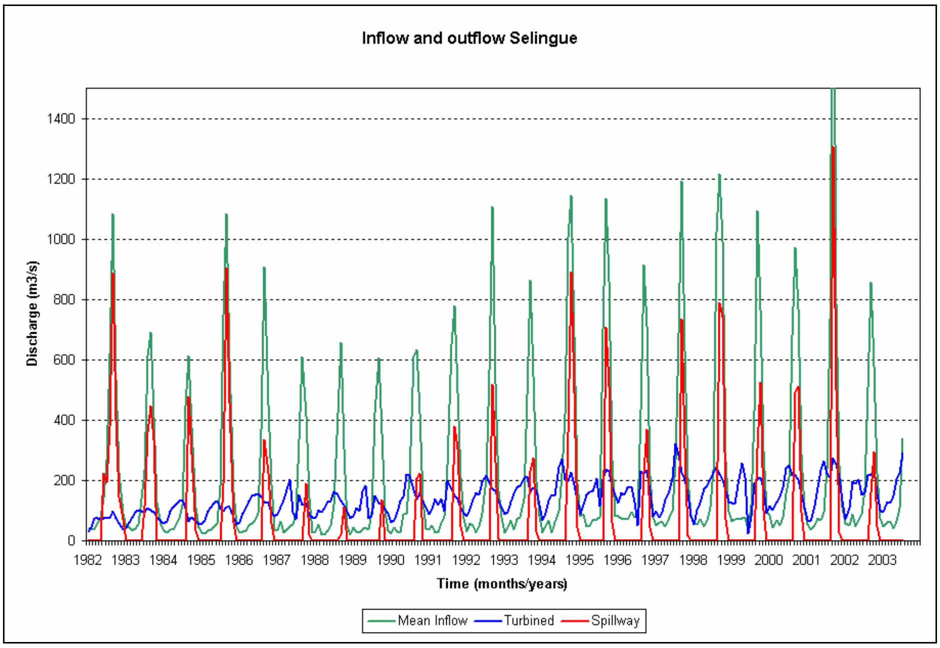


Figure 19 Inflow and outflow components at the Sélingué reservoir (1982 – 2003)

For the inflow hydrograph of the Niger at the Mali border, use is made of the available monthly hydrographs at the station of Banankoro.

In order to arrive at a reasonable estimate of the inflow of the various tributaries of the Niger River in Guinea for the region around the Fomi reservoir, it is necessary to make use of the sparse data resources available on this region. The main source of data is the internet, where the FRIENDS (UNESCO) database provides hydrographs of some key stations in Guinea (see Figure 20).

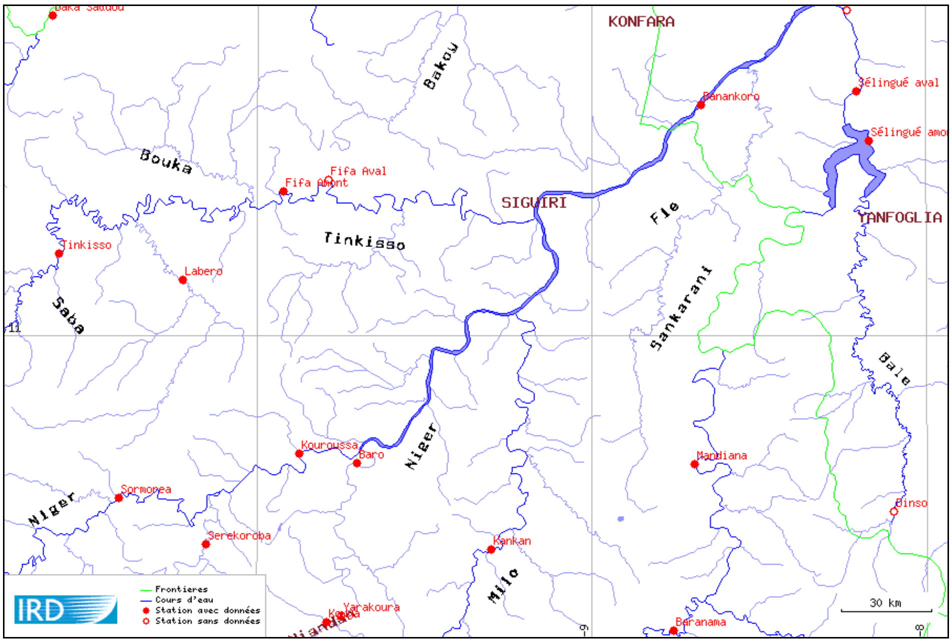


Figure 20 Hydrological stations on the Niger tributaries in Guinea

However, the daily data themselves are not freely available, only graphs can be produced. Therefore the monthly discharges have been derived from the daily hydrographs by an estimation of the average monthly values directly from those graphs (see Figure 21).

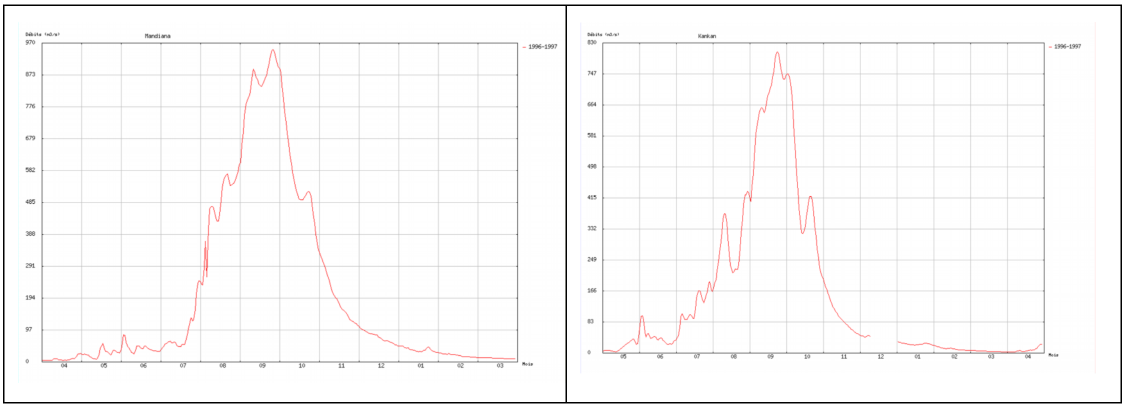


Figure 21 Examples of daily hydrographs for key stations in Guinea: a) Mandiana (1996-1997) b) Kankan (1996-1997)

In Table 4-2 the stations are given for which discharge hydrographs of daily values are available.

Table 4-2 List of discharge measurement stations and available series of data

NAME	RIVER	BASIN AREA	PERIOD (STARTING 1980)
Baranama	Dion	590	1996 – 2002
Baro	Niandan	12,600	1999 – 2002
Faranah	Niger	3,180	1980 – 2003
Fifa Amont	Tinkasso	-	1996 – 2001
Kankan	Milo	9,900	1997 - 2001
Kouroussa	Niger	18,000	1980 – 2001
Mandiana	Sankarani	21,900	1995 – 2002
Tinkisso	Tinkisso	6,400	1996 – 2001

The information of these stations was used for the derivation of the monthly inflow hydrographs for RIBASIM by averaging the daily values from graph. An example of the results is shown in Figure 22.

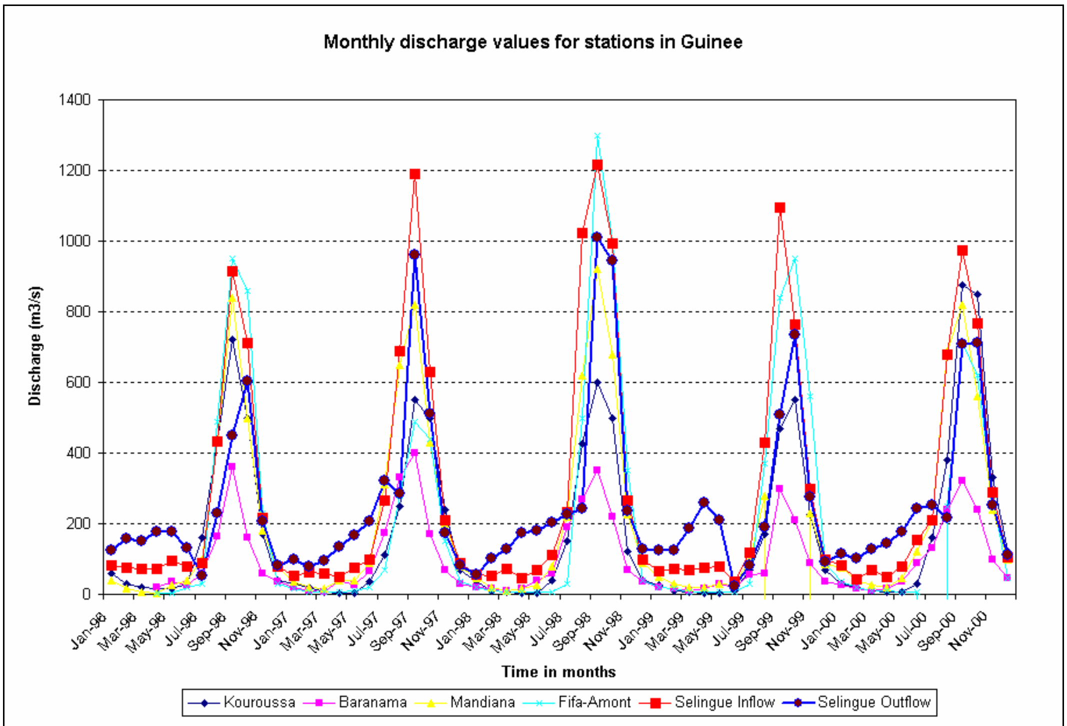


Figure 22 Example of monthly discharge values of stations in Guinea, with in/outflow Sélingué

The information from the river stations in Guinea can only be used for inflow hydrographs that belong to the same river basin as the station. For other (nearby) locations, a correction has to be made for the difference in rainfall volume. This is done by calculating a relationship between the monthly average rainfall in the corresponding basin of the station and the region that represents the variable inflow node of RIBASIM. For this purpose, monthly rainfall data have been obtained (see Table 4-3).

Table 4-3 List of rainfall stations used in the study

STATION	SERIES	LONG.	LAT.	ALTITUDE
Boke	1922 – 1996	-14.32	10.93	69
Dabolo	1921 – 1990	-11.1	10.7	438
Kankan	1921 – 1996	-9.3	10.38	384
Kissigoudou	1921 – 1996	-10.1	9.18	525
Siguiri	1922 – 1997	-9.17	11.43	366

The averages are calculated for the period 1980 – 1997. This corresponds roughly with the simulation period of the RIBASIM calculations (1980 – 2000).
In the following pages (Figure 23), some examples are given of inflow hydrographs on the Niger tributaries in Guinea. The final inflow series used in the modelling are given in tables in Annex C.

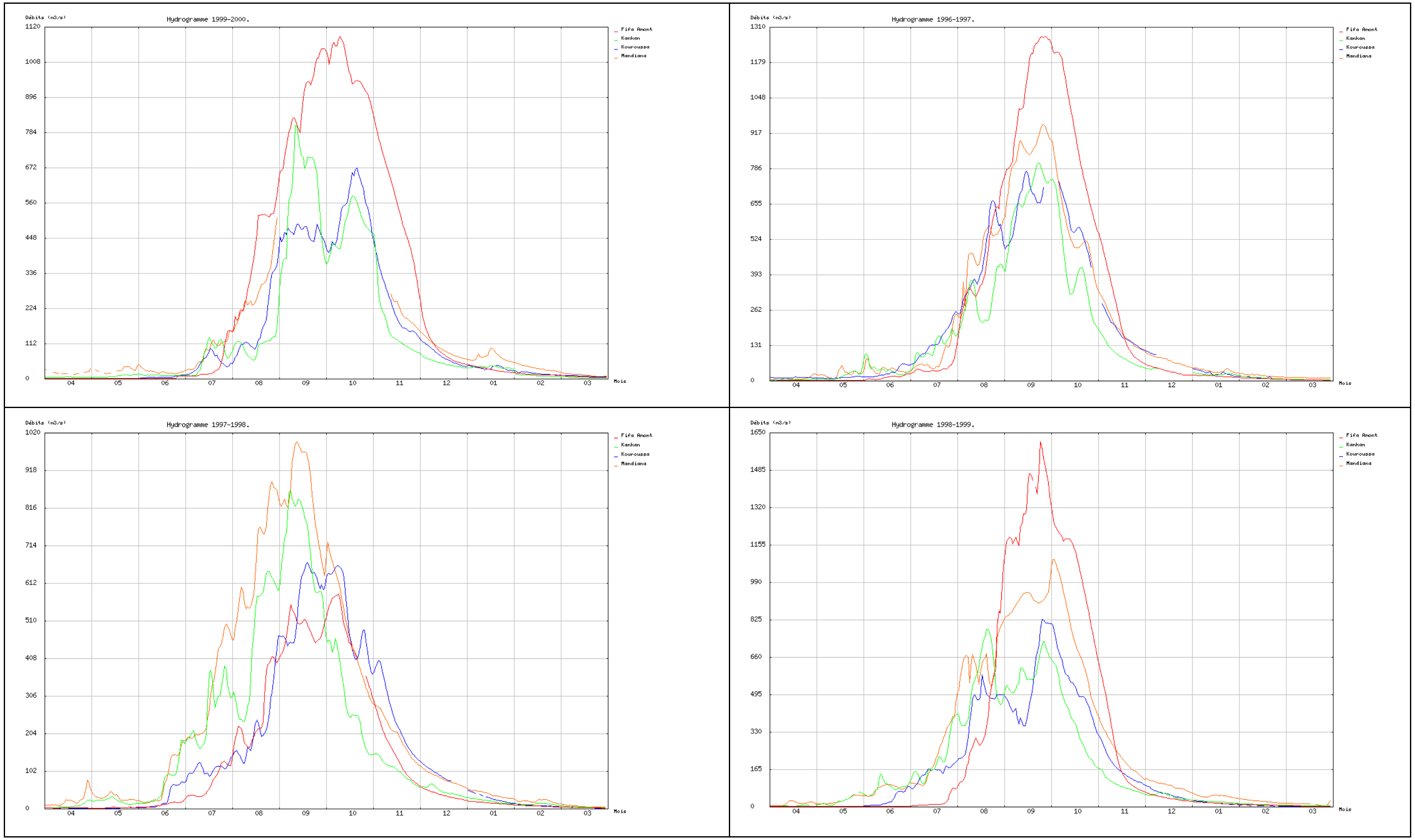


Figure 23 Discharge hydrographs of the Niger tributaries in Guinea for the years 1996 – 2000

4.4 Characteristics of existing and planned reservoirs

4.4.1 Physical characteristics

For the implementation of RIBASIM, the characteristics are required of both the existing and newly planned reservoirs. The following reservoirs have been included in the schematization of the model:

NAME	STATUS
Sélingué	Existing
Fomi	Planned
Talo	Planned
Tossaye	Planned

The reservoir of Markala has not been included in the schematization, because the possible variation in volume is negligible compared to the average discharge and, especially, the volume of the storage variation in the Inner Delta. This is due to the very limited possibility of water level variation at Markala (30 cm) and relatively small inundation area (only river bed, no flood plains).

The Tossaye reservoir is located downstream from the Inner Delta and therefore it has no direct influence on the hydrology of the Delta. If the construction of this reservoir is effectuated in the future, it may be interesting to contemplate the operation of the reservoir for ensure the minimum flow requirements at the border of Mali / Niger at Gao. At present the reservoir is not included in the simulations, partly also because there are yet hardly any data available on its future characteristics.
There are also plans for a ‘Djenné reservoir’, in the lower reach of the Bani tributary, upstream of the Inner Delta. However, there is no information about these plans, although the volume seems to be in the order of 400 Mm^3.

The following characteristics of the reservoirs are introduced in the model:

- physical characteristics of the dam (height, tail level, etc.)
- relationship water level – volume – surface area
- relationship water level – outflow (bottom gates, spillway, turbines, etc.)
- characteristics of the power generation
- precipitation, seepage, evaporation, etc. on / from the lake
- operation rules

Especially the latter can be used for simulations with various scenarios in order to find better / optimum ways of operation of the reservoir in view of power generation, irrigation water demand and ecological (low-flow) requirements. The latter include the impact on the Inner Delta, i.e. whether it is possible to influence the hydrology of the Inner Delta by changing the operation rules of the reservoir without affecting negatively the other water users.

For some of the newly planned reservoirs, not all the data are readily available. In that case, estimations have been made either from other sources (e.g. topographical maps) or estimated from the other characteristics.

Details on the reservoir characteristics are given in Annex C.

4.4.2 Net evaporation

For reservoirs a fixed time series for the *net* evaporation is used, expressed in mm/day. Fixed means that the series is the same for all years. The net evaporation is the result of average precipitation and evaporation at the water surface of the reservoir. On the basis of the actual water surface area in a time step, RIBASIM calculates the loss due to evaporation. The series in the table in Annex C is for Bamako; it was used for all reservoirs.

4.4.3 Hydropower

The existing Sélingué reservoir and the planned Fomi reservoir contain hydropower equipment. The data used in the model are given in Annex C. For Sélingué more detailed information was provided by DNHE, which is reproduced in Annex D.

As no detailed information is available for the hydropower equipment, the efficiency and the applied capacities for lower heads are estimates.

Fomi power plant
Details for this future power plant are also given in Annex C. As no detailed information is available for the hydropower equipment, the efficiency and the applied capacities for lower heads are estimates.

Sotuba power plant
At Sotuba, opposite the city of Bamako, a run-of-river power plant is operational since 1920. It has a capacity of 5.2 MW. The estimated head between intake and outlet is 4 m.

4.4.4 Operation rule curves

For the simulation of the operation of reservoirs rule curves apply. In RIBASIM three curves are used. As no specific information about the operation of the Niger reservoirs is available, the curves are set at ‘standard’ values: respectively full reservoir or lowest gate level (=dead storage level).

Flood control curve
The flood control curve indicates the maximum storage (per month) in order to keep space for accommodation of floods, so that floods can be stored in stead of spilled, and causing flooding problems downstream. For all reservoirs the flood control curve is set at full reservoir storage level.

Firm storage curve
The firm storage curve indicates the amount of water that should be kept in the reservoir to satisfy the firm downstream demands throughout a critical dry period. For all reservoirs the firm storage curve is set at the lowest gate level.

Target storage curve
The target storage curve applies for maximum hydropower energy generation. It indicates the optimum balance over time between creation of head and avoidance of spilling. It will be located between the flood control curve and the firm storage curve. For all reservoirs the target storage curve is set at full reservoir storage level.

4.5 Geometry of the Inner Delta

There is hardly any reliable published information available on the geometry of the Inner Delta, i.e. the relationship between water levels and volume / surface area. This information is, however, crucial for the model simulations and therefore a separate activity has been undertaken to derive this type of information. This will be discussed separately in Chapter 5.

4.6 Water demand

There are several types of water demand. The most important distinction can be made between consuming and non-consuming water demand.
Consuming water demand refers to e.g. irrigation and public water supply, for which water is actually taken from the river and (partly) consumed. Only a small percentage of the intake is returned again to the river.
Non-consuming water demand may prove very important in the case of the Inner Delta. It refers to certain minimum flow values (sometimes levels, but more often discharges). This can be based on ecological values (i.e. maintenance of certain environmental characteristics) or legal requirements (e.g. the flow passed the border from Mali to Niger).

4.6.1 Consuming water demand

In Mali the main consuming water demand is irrigation, followed by public water supply (PWS).

Irrigation

The following irrigation systems are included in the model schematization:

- Périmètre Sélingué, operational since 1981, supplied via a water intake in the Sélingué reservoir.
- Périmètre Office du Niger, operational since 1943
- Périmètre Baguinéda, operational since 1920.
- Périmètre Talo, planned, to be served from Talo reservoir
- Périmètre Office du Riz Mopti

The following systems are included in the schematization, but are not used in the present modelling activities :

- Périmètre Djenné, served by the Barrage de Djenné
- PérSégou1
- PérSégou2

Details on the irrigation areas, efficiencies and return flows are given in Annex C. The data were supplied by DNHE-Bamako, unless otherwise stated. Water demands for input in RIBASIM are crop water demands expressed in mm/day and to be supplied from the irrigation network, so in addition to the fixed amounts of water that the crops are supposed to receive directly from rain. In RIBASIM terms this is simulated by a so-called Fixed Irrigation Node. The water demand to the river or reservoir is higher: demand at field level divided by the irrigation efficiency. For all irrigated areas an irrigation efficiency of 50% was used in the simulations.

The main irrigation area belongs to the Office du Niger, with the intake at the Markala barrage. Not only is this the major irrigation area of Mali, but there are also many plans to extend the irrigated area substantially. Whether such extensions are feasible might be determined using the present modelling system once more details on the planned extensions become available in the future.

It is much more difficult to estimate the water demand of the PWS. Major cities like Bamako and Ségou obtain their drinking water from the Niger River, but no reliable data have (yet) been obtained. In the present model, only the PWS for Bamako is included. Just upstream of Bamako a Public Water Supply node represents the public and industrial water demands of the Bamako area. The demand is set at 5 m^3/s; the return flow to the Niger is assumed at 75 %.

Diversions

The irrigated areas are supplied via intakes from the river or the reservoir. The Sélingué irrigated area takes water from an inlet directly at the reservoir. Its lowest inlet level is assumed to be equal to the firm storage level of the Sélingué reservoir, which is +339 m.
At the intake for the irrigated area of the Office du Niger, the Niger is tried to be kept at a minimum level of +300.5 m by the Markala weir. This weir creates a sort of reservoir with a spilling level of +300.5 m. However, diverting 100 m^3/s (the ‘official’ capacity of the intake) for 1 month continuously corresponds to a volume of about 260 Mm^3. The storing capacity of the Markala weir will probably not be larger than 50-100 Mm^3. If the demand to a reservoir in one time step is several times its volume, a simulation with RIBASIM on a monthly basis is not suitable, and neither on a half-monthly or 10 day basis. Therefore the regulating effect of the Markala weir is simulated via a relation between river flow at Koulikouro and actually diverted flows to the Office du Niger between 1990 and 1997. (Hassane, 1999).

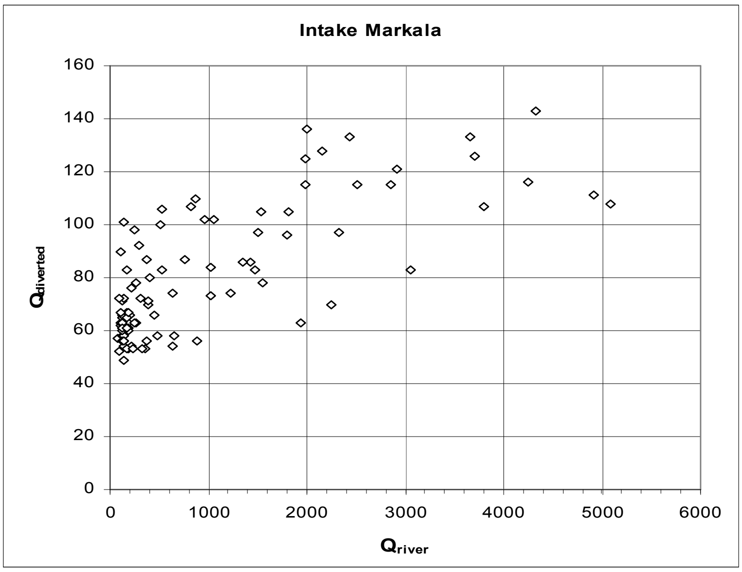


Figure 24 River discharge - water intake relation at Markala

In Table 4-4 the relationship is given between the river discharges in the Niger river and the diverted water at Markala intake.

Table 4-4 Relationship river flow – divertible flow at Markala

River flow m3/s	Divertible flow m^3/s
0	0
100	80
1000	100
4000	130
10000	130

From Hassane (1999) it appears that for high river discharges more than the ‘official’ capacity of the intake of 100 m^3/s can be taken. However, a field visit to this location indicated that this is doubtful given the deteriorated conditions of the intakes and the widespread growth of vegetation in the canals.

4.6.2 Non-consuming water demand

As remarked earlier, non-consuming water demand includes both environmental flows and legally agreed flows.
The assessment of environmental (minimum) flows is still in its infancy and there are many mainly empirical methods to calculate such flows. For the Niger River there are yet no values available, so assumptions had to be made.
Legally agreed values of minimum flows are established for the border of Mali and Niger. Here a minimum flow of 50 m^3/s has been established and this is used in the modelling as a low flow requirement at this location. Although this demand may have consequences for the hydrology of the Inner Delta, in practice there is hardly any relation as there is no control

mechanism (such as flow gates) to control the flow through the delta. As remarked earlier, the implementation of the Tossaye reservoir may be instrumental in the provision of the required minimum flow at the Niger border.

In the present setup of the model the following estimated minimum flows are included (either active or inactive):

- Minimum flow at outflow of Niger from Mali to Niger (50 m^3/s).
- Minimum flow downstream of Markala weir, the inlet to the Office du Niger irrigated area (40 m^3/s).
- Sanitary flow downstream of Djenné reservoir (5 m^3/s).
- Sanitary flow downstream of Talo reservoir (10 m^3/s).

5 Assessment of Geometry of the Inner Delta

The most difficult tasks in the assessment of input data for the RIBASIM model are the geometry of the Inner Delta and the derivation of the inflow hydrographs.

5.1 Lakes in the Inner Delta

The assessment of the geometry of the Inner Delta is necessary to be able to model the hydrological behaviour of the delta with the RIBASIM model. In order to simulate the inundation process and the volume storage of water in the delta, a relationship has to be derived for the water levels – volumes – surface areas of the delta. It is important to realize that the inundation process of the delta occurs over a period of several months, starting in the upstream region passed Ké-Macina and slowly moving downstream towards Akka and finally Diré. For this reason it is necessary to distinguish between various zones in the delta, preferably zones in which the inundation process occurs about simultaneously. On a map of the Inner Delta, various main zones can be distinguished (Figure 25).

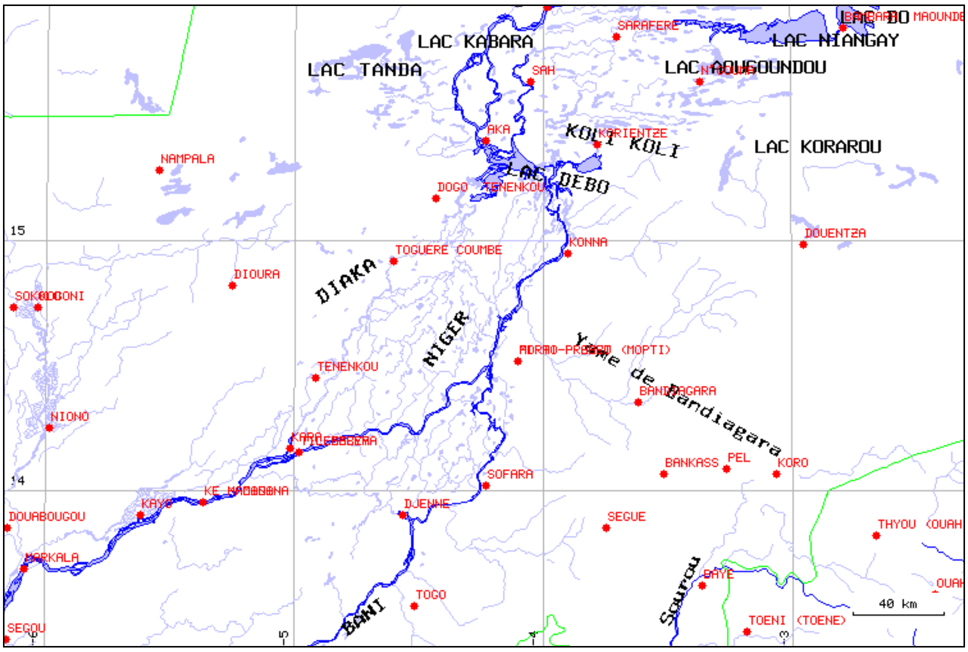


Figure 25 Map of the Inner Delta

On this map it is clear that the Niger River already branches into two major channels downstream of Ke-Macina: the Diaka and the Niger. The Niger is joined further downstream by the Bani river. It is in the region of Lac Debo (Akka) where the two branches meet again. This will need to be modelled as such in RIBASIM, but it is also important to notice that this distinction between branches gets obliterated in the later stage of the inundation process.

In order to derive the geometry and thus the required relationship between water levels and volume / surface area of the various parts of the delta, it is necessary to make use of satellite images as there are no reliable bathymetric surveys of the region. The topographic maps of the regions, available on a scale of 1:50,000 are relatively old (from the 1950es). Although the general outlines of the lakes seem to have changed only little, there is no depth information on them and it is also not clear to which water level the outlines refer. Given the major change in inundated area during the wet season, this makes the use of topographic maps for the geometry of the delta only valid for general reference purposes.

5.2 Schematisation of the Inner Delta

The fact that several different regions can be distinguished within the Inner Delta implies that it is useless, e.g. to derive such a relationship water level-volume for the total region between Mopti and Akka as this part of the delta is not homogeneous, i.e. they do not inundate at the same time. Therefore a number of zones have been distinguished in the delta.

The schematisation of the Inland Delta is based on satellite images which show the inundation of the area at different times during the year. Table 5-1 shows which satellite images (resolution approximately 30 m) were available for the project for respectively the rising (crue) and the lowering part (décrue) of the flood hydrograph in the Delta. In Table 5-2 the various images that were available per month are summarized.

Table 5-1 Dates of the various satellite images available for the Inner Delta

RISING WATER (CRUE)	RECEDING WATER (DÉCRUE)
06-08-1984	10-11-1984
25-10-1984	26-11-1984
08-07-1985	13-01-1985
13-09-1986	14-02-1985
02-10-1987	16-01-1986
18-10-1987	16-11-1986
28-11-1999	03-01-1987
26-08-2000	19-01-1987
27-09-2000	20-02-1987
10-06-2001	19-03-2000
28-07-2001	28-11-1999
16-10-2001	02-02-2001

Table 5-2 Available satellite images per month (décrue in red and cursive)

MONTH	DATE OF THE IMAGE			
January	*13-01-1985*	*16-01-1986*	*03-01-1987*	*19-01-1987*
February	*14-02-1985*	*20-02-1987*	*02-02-2001*	
March	*19-03-2000*			
April	-	-	-	-
May	-	-	-	-
June	10-06-2001			
July	08-07-1985	28-07-2001		
August	06-08-1984	26-08-2000		
September	13-09-1986	27-09-2000		
October	25-10-1984	02-10-1987	18-10-1987	16-10-2001
November	*28-11-1999*	*10-11-1984*	*26-11-1984*	*16-11-1986*
December	-	-	-	-

From this table it is clear that the rise of the flood occurs in the months June – October and the lowering of the flood (décrue) in the months November – February. The latter months and dates are indicated in Table 5-2 in red cursive.

Analysis of these satellite images revealed eight zones which are inundated separately. Therefore, the Inland Delta is schematised using eight distinct nodes (See Figure 26 and Figure 27).

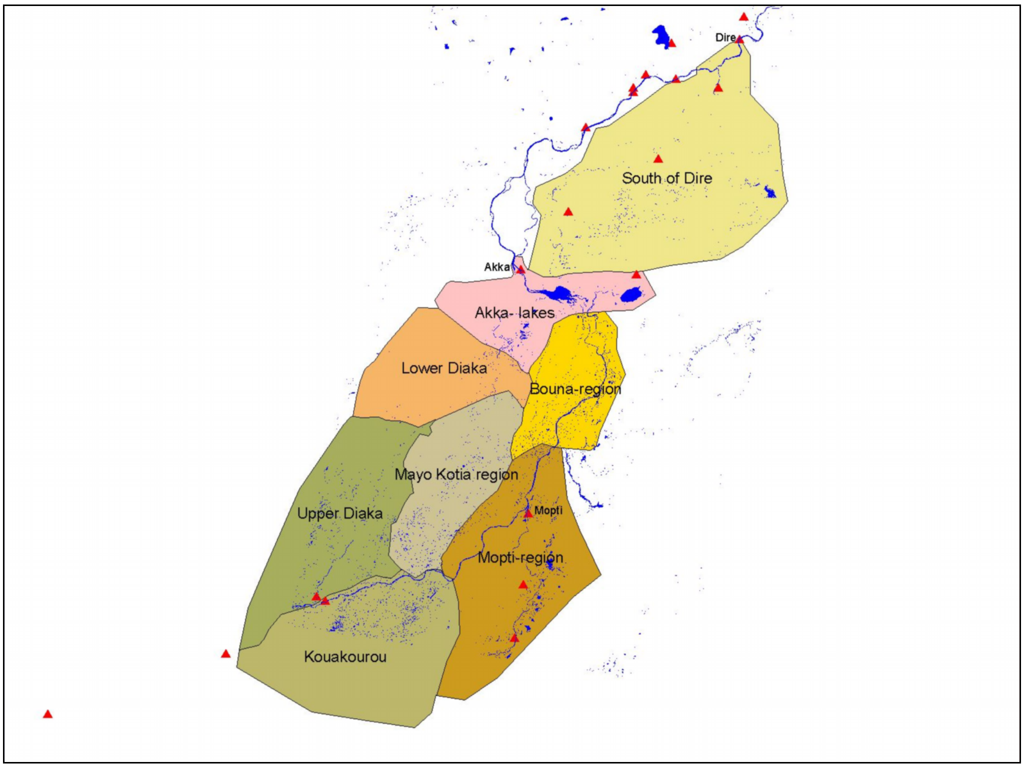


Figure 26 Regions distinguished for the derivation of the geometry of the Inner Delta

Now that the Inner Delta has been subdivided into eight zones, this scheme can be used in the setup of the final schematization of the RIBASIM model, which is shown in Figure 15. In Figure 28 the details of the schematization of the Inner Delta are given.

It is evident from the maps of the Inner Delta that there are extensive volumes downstream from Diré which are not included in the present model. The most important example is the Lac Faguibine at the far downstream end of the Inner Delta, which is connected nowadays by a canal to the Niger River. Due to its location the impact on the Inner Delta flooding is only noticeable in the region of Diré, but it is important when the Tossaye dam is included in the analysis as the two lakes will mutually influence each other. The Lac Faguibine, located at about 150 km from Tombouctou, has a surface area of 650 km², and is very important as a source of fishery.

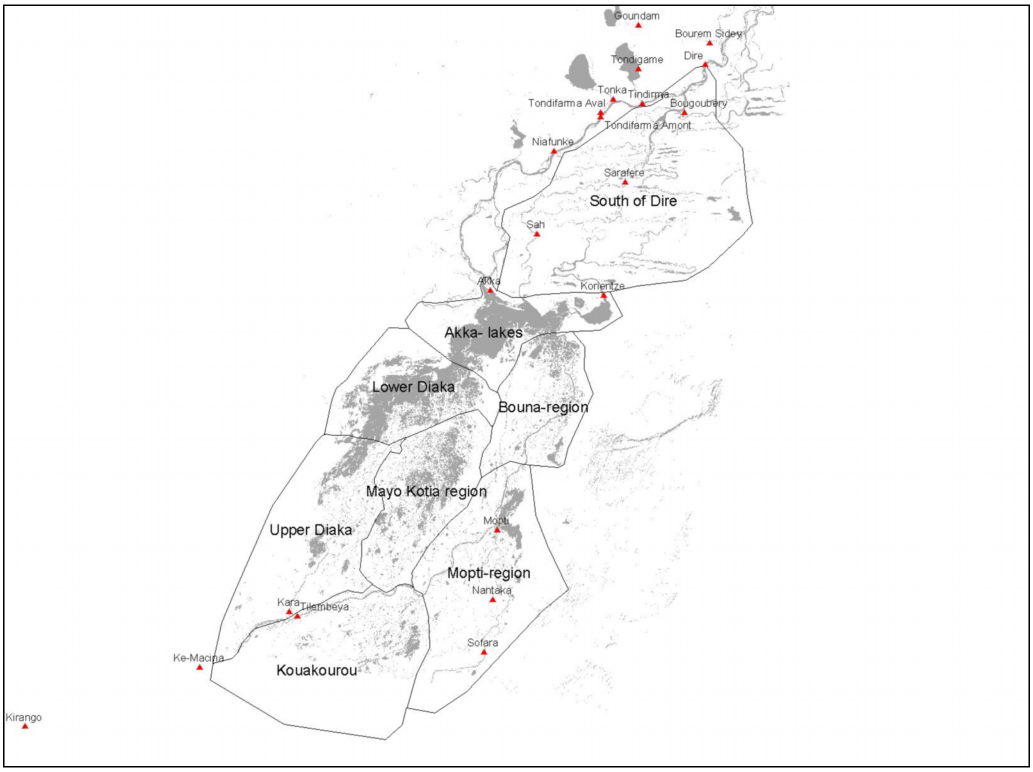


Figure 27 The eight zones of the Inner Delta with an example of inundation area

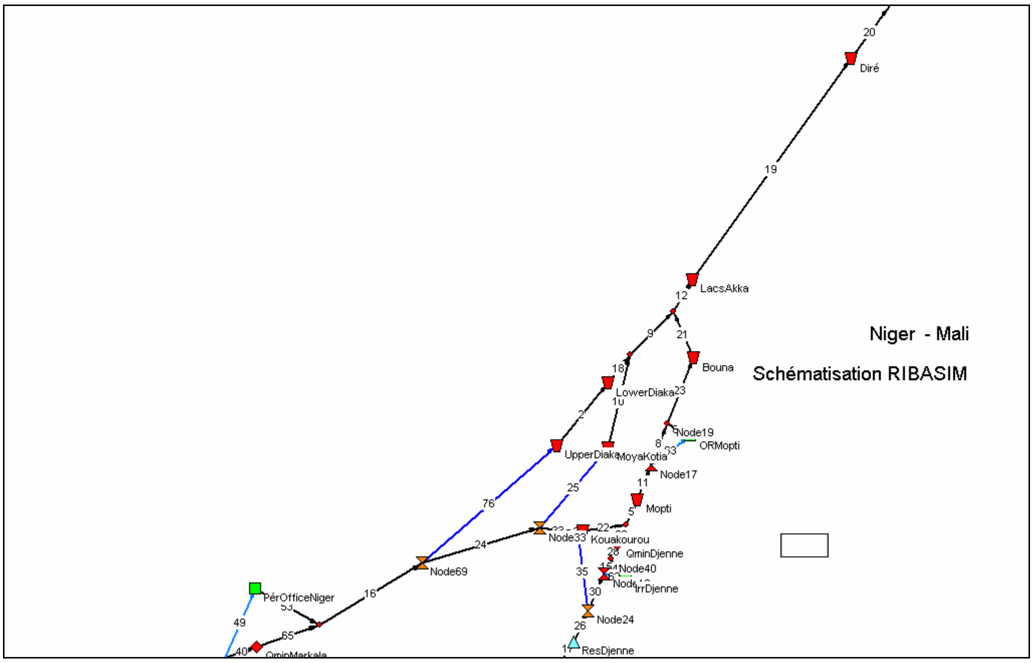


Figure 28 Detail of the RIBASIM schematization showing the Inner delta

For each of these inundation zones link storage nodes are used in the RIBASIM schematization. Although RIBASIM is a “0-D” model, link storage nodes provide the possibility to store water in a link. This way the relationship between depth, width and discharge of the different inundation zones can be taken into account. In the project the eight zones have the following names (in downstream direction):

- Kouakourou
- Upper Diaka
- Mopti
- Mayo Kotia
- Lower Diaka
- Bouna
- Akka Lakes
- South of Diré

There are two off-takes of the Niger: the Diaka and the Mayo Kotia. The Diaka and the Mayo Kotia join before reaching the Akka Lakes. The Niger itself confluences with the Bani after the bifurcations, and joins again the Diaka and Mayo Kotia at the Akka Lakes, while one branch of the water of the Niger and Bani continues to Diré and out of the Delta. Based on the satellite images one extra bifurcation is included at the Bani shortly before entering the Delta. Water flows to the Kouakourou inundation zone after which it flows into the Niger.

In the derivation of the hydrology of the Inner Delta, a number of hydrological stations have been used, summarized in Table 5-3. Most stations have only water level data as they are located at lake sides where discharges are very difficult to assess.

Table 5-3 Measuring stations of water level in the Inner Delta

Measuring station	**Reference level (m)**
Akka	258.38
Mopti	260.12
Diré	256.85
Tilembeya	266.32
Kara	267.16
Sofara	262.76
Niafunké	257.66
Saraféré	259.00

The inundation zones that are used in the RIBASIM model are given in Table 8 (in downstream order). This table also shows the discharge stations with daily water levels that were used to determine the corresponding water level in each of the satellite images. However, for some of the stations, the date in the chosen time period of simulation (1980 – 2000) is lacking.

Table 5-4 Summary of the inundation zones and their representation in RIBASIM

Name	Reference level (m)	Water level station used in the analysis
Kouakourou	266.32	Tilembaya, Kara
Diaka Haut	267.16	Tilembaya, Kara
Mopti	260.12	Mopti, Sofara
Mayo Kotia	260.12	Mopti
Diaka Bas	258.38	Akka, Mopti
Bouna	258.38	Akka, Mopti
Lacs Akka	258.38	Akka
Diré Sud	256.85	Niafunké, Saraféré, Korientze, Akka, Diré

This distinction in regions has been used for the derivation of the level – area relationships using the GIS files. The results for the eight regions are shown in Figure 29. For the region of Diré Sud not all the images are complete and some missing values occur. This is, however, only a minor part of the total inundated area.

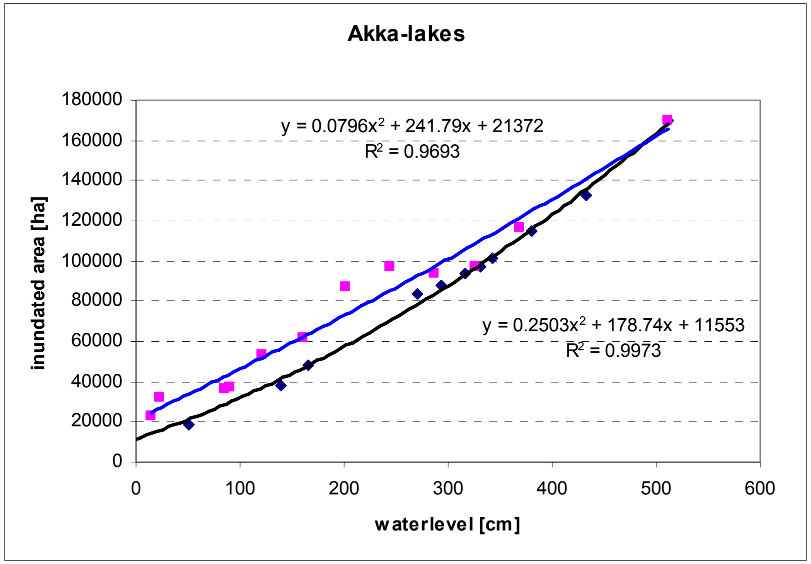
It is evident that for some of the regions, such as Akka, the relationship between water levels and surface area is very good. The coefficients of regression vary between 0.85 and 0.97.

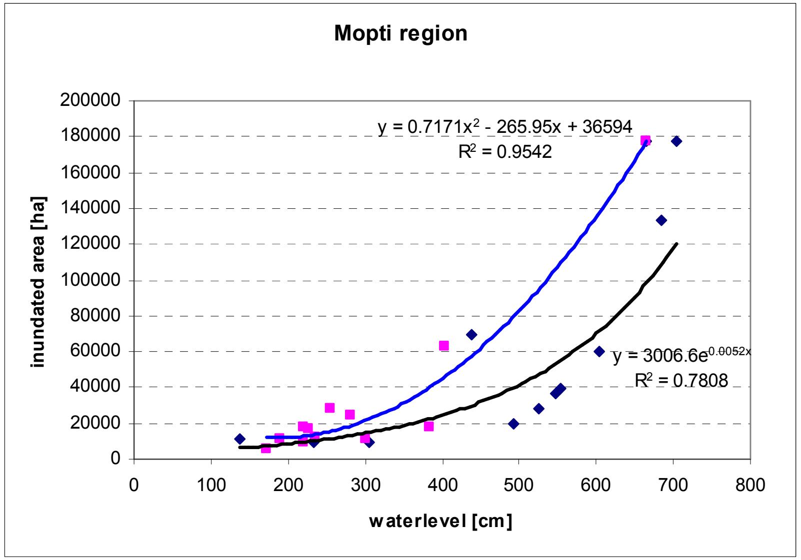
Using the information on the water level – surface area relationship, it is easy to derive a similar relationship for the water levels – volumes in each of the regions.

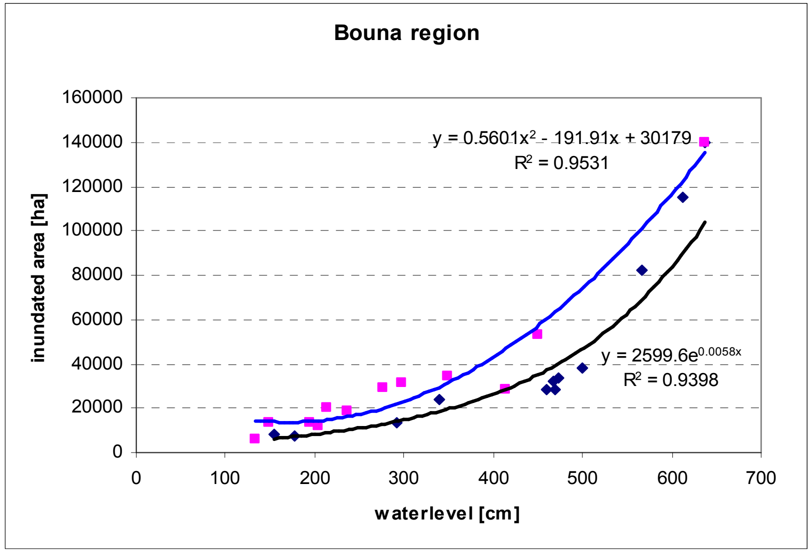
For all the regions, there is a relationship for the rising and falling limb of the hydrographs (crue et décrue). In the present project, the rising limb (crue) is the most important as this represents the relationship that is valid when the Inner Delta is being filled. As has been remarked earlier, it is very important to establish the impact of the initial filling of the existing (Sélingué) and newly planned (Talo and Fomi) reservoirs on the onset of the flood wave entering the Inner Delta. Therefore the relationships for the rising limb have been used in the RIBASIM model.

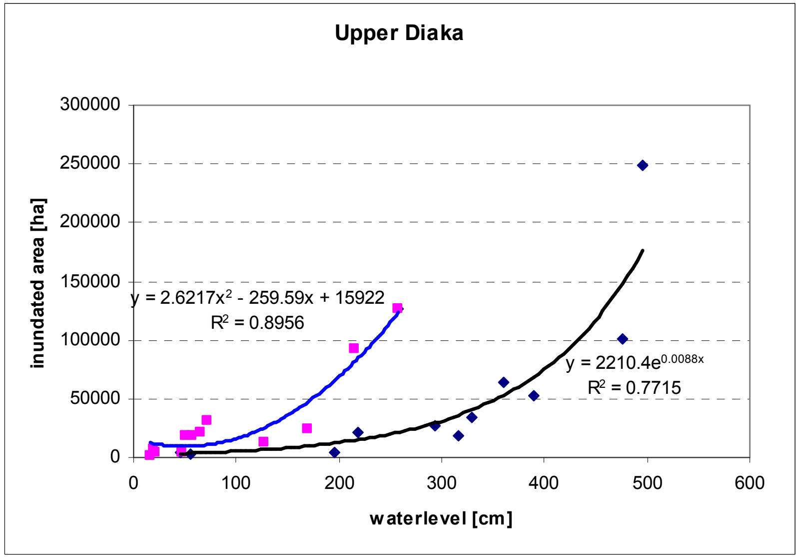
5.3 Interconnections between the lakes

As has been mentioned earlier, several branches can be distinguished in the Inner Delta. This is an important issue as this determines the actual flow pattern between the eight regions distinguished in the Inner Delta. It is evident that the actual flow process is very complicated and is often of a diffuse character through the extensive vegetation plains. However, some major channels can be distinguished. The level at which the channels start to function can also be derived from the satellite images and this information will be used to make approximate relationships of water level – discharge capacity for each of the connections.


Akka-lakes
y = 0.0796x2 + 241.79x + 21372
R2 = 0.9693
y = 0.2503x2 + 178.74x + 11553
R2 = 0.9973
inundated area [ha]
waterlevel [cm]


Mopti region
y = 0.7171x2 - 265.95x + 36594
R2 = 0.9542
y = 3006.6e0.0052x
R2 = 0.7808
inundated area [ha]
waterlevel [cm]


Bouna region
y = 0.5601x2 - 191.91x + 30179
R2 = 0.9531
y = 2599.6e0.0058x
R2 = 0.9398
inundated area [ha]
waterlevel [cm]


Upper Diaka
y = 2.6217x2 - 259.59x + 15922
R2 = 0.8956
y = 2210.4e0.0088x
R2 = 0.7715
inundated area [ha]
waterlevel [cm]

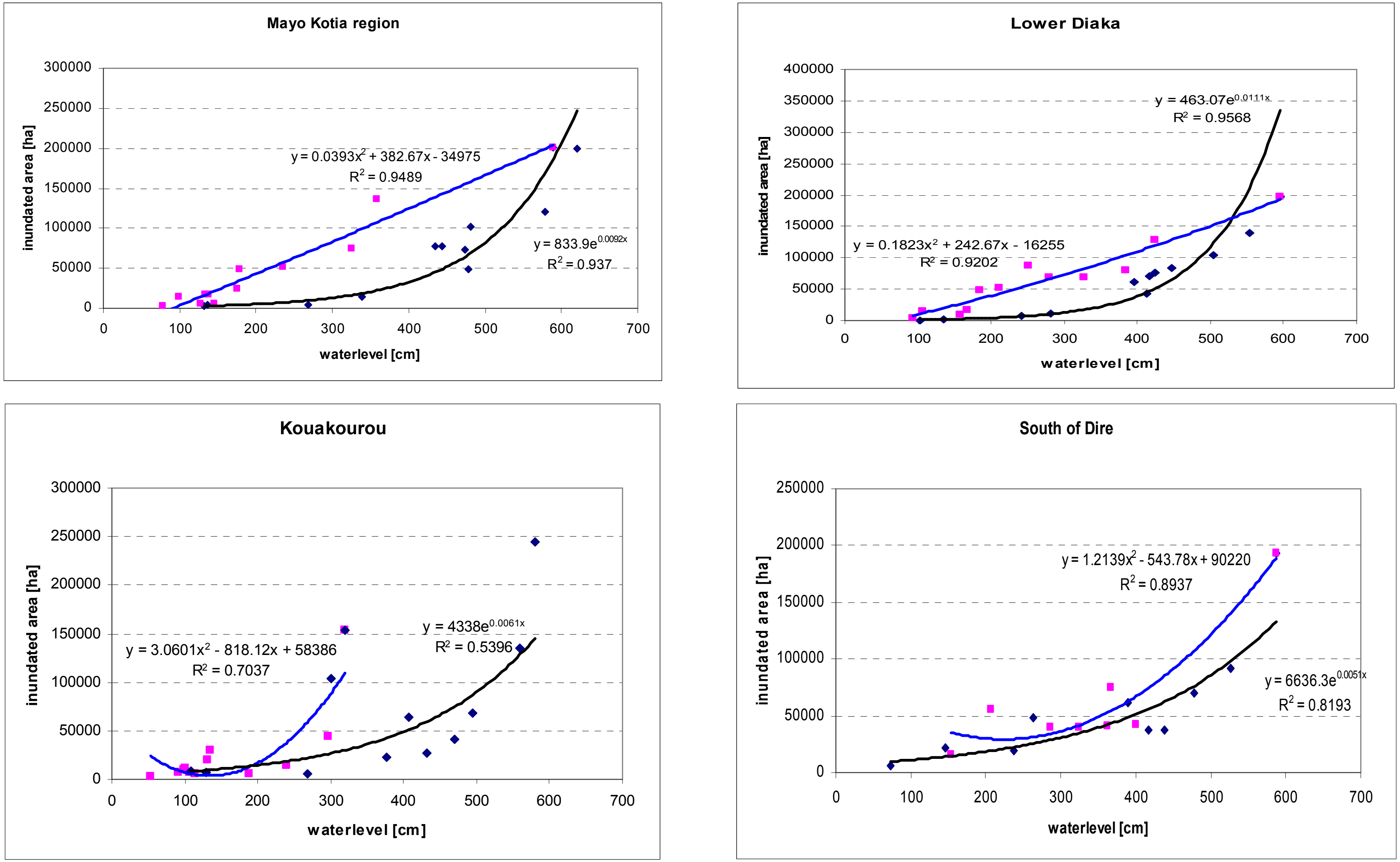


Figure 29 Water level-inundated area relationships for the eight regions distinguished in the Inner Delta based on satellite images.

6 Calibration of the model

The calibration of RIBASIM has been accomplished in two steps:
1. delay of high water wave through delta
2. inundated surface of regions in delta

6.1 Delay

Comparison of total inflow and outflow discharge data revealed a delay of the flood wave of approximately 2 months. Literature mentioned a delay between Ké-Macina and Diré of 2-3 months in a wet period (1962-1966) and 1-2 months during a dry period (1982-1986) (Quensière, 1994).

To obtain the correct delay the model was calibrated by varying the discharge through each of the link storage nodes. The discharge was calculated by multiplying a fixed cross section by varying average flow velocities. Finally an average flow velocity of 0.08 m/s resulted in a delay of ca. 1.5 months. Such a low flow velocity is reasonable given the large flow cross-sections of the lakes.

6.2 Inundated surface of regions in delta

Inflow from the Niger is diverted to the Diaka and later to Moya Kotia, after which the remaining flow confluences to the Bani. From the satellite images it is not completely clear from where the water inundating the Kouakourou areas comes. Finally it was decided to let part of the flow derive from the Bani tributary. After Kouakourou this water flows again into the Bani.
The first step was to find the optimal bifurcation ratios. The final bifurcation ratios are given in Table 6-1.

Table 6-1 Bifurcation ratios for the different river reaches

RIVER REACH	PERCENTAGE OF FLOW BIFURCATED
Upper Diaka	25 %
Moya Kotia	30 %
From Bani to Kouakourou	20 %

The next step was to change the relationship between depth and width of the river stretches. This was done without changing the total cross section (i.e. the total discharge), and hence the delay through the delta, would remain the same.

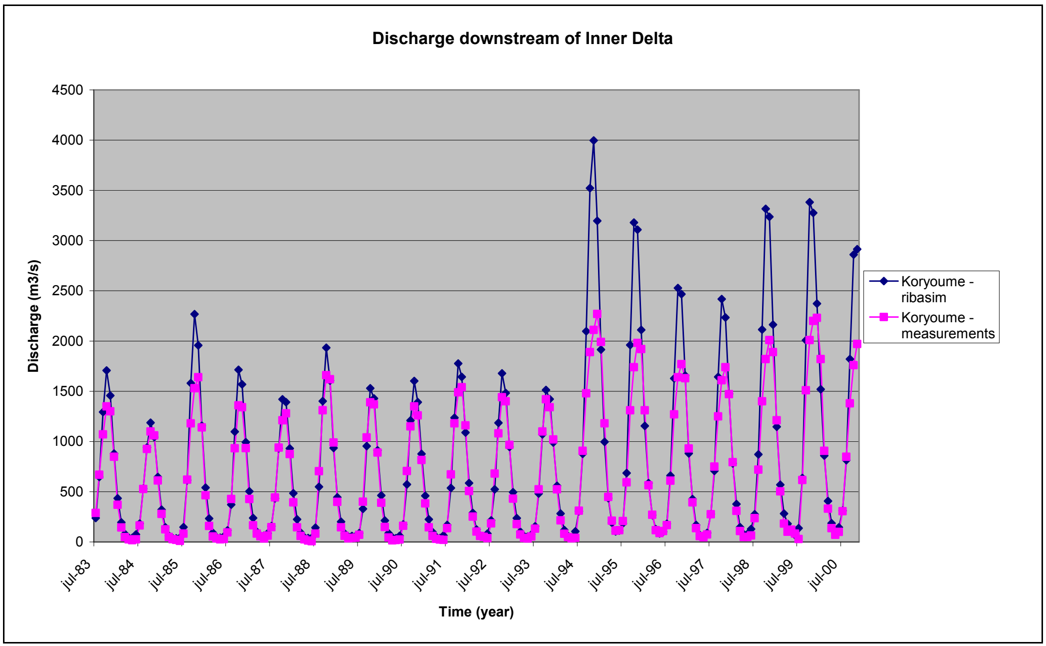
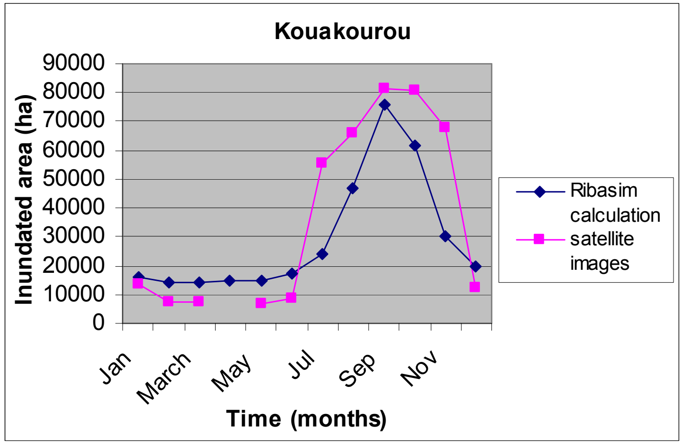


Figure 30 Inflow hydrographs at Koyoume

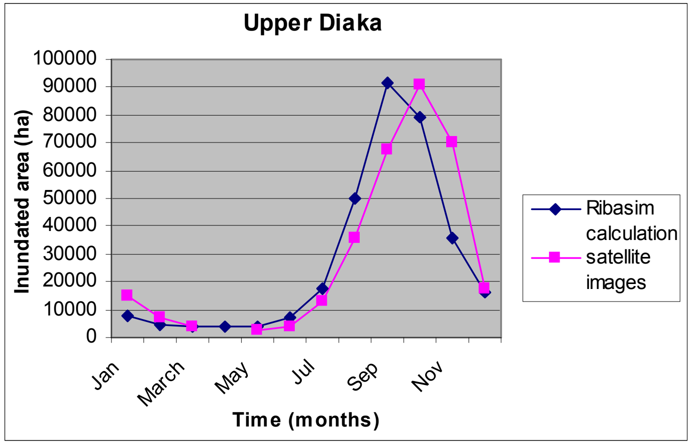
Finally the inundated area of the inundation zones was used for the calibration. To obtain the correct inundated area the relationship between water level (H) and width (W) was altered. This was done by dividing the water levels used in the first calculation by a certain factor, after which the width was calculated. The total cross section area remained the same by these calculations in order not to change Q, and thus delay. The final factors and input data can be found in Appendix II.

Two types of comparisons of inundated areas were made for calibration:

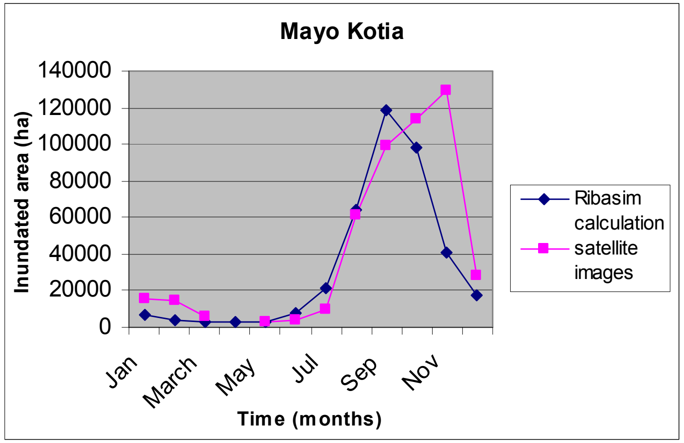
1. the absolute difference was determined between the calculated value in RIBASIM and the satellite image of the same date. RIBASIM gives only 1 value per month at the end of the time step, what is taken into account in the comparison. The sum of the absolute difference of different simulations was compared to find the best simulation.
2. the average inundation per month over the entire period of simulation was compared with average measured inundation in the satellite images. Since RIBASIM gives values at the end of the month, the average inundation of the satellite images of the period from the 15th of that month till the 14th of the next month were used for comparison. For the period between 15th of April and 14th of May no data are available. The result of this step is shown in Figure 31.



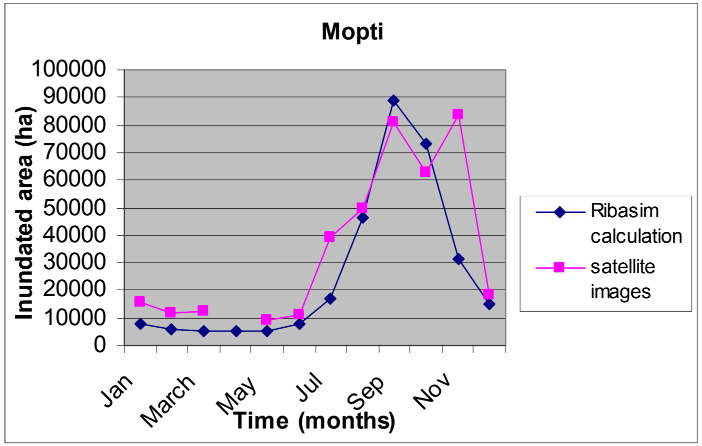
. *Calibration result Kouakouro*



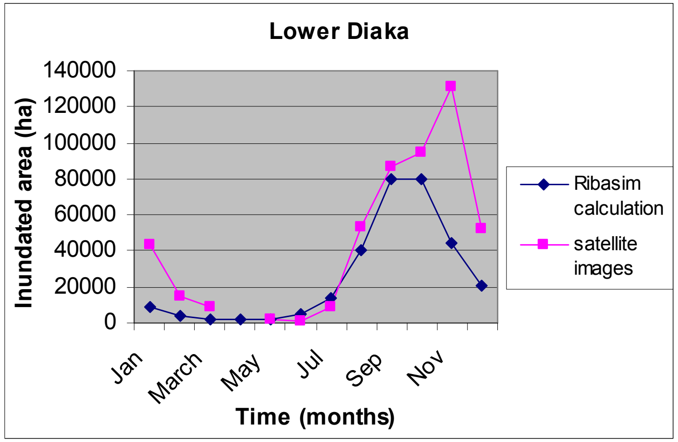
. *Calibration result Upper Diaka*



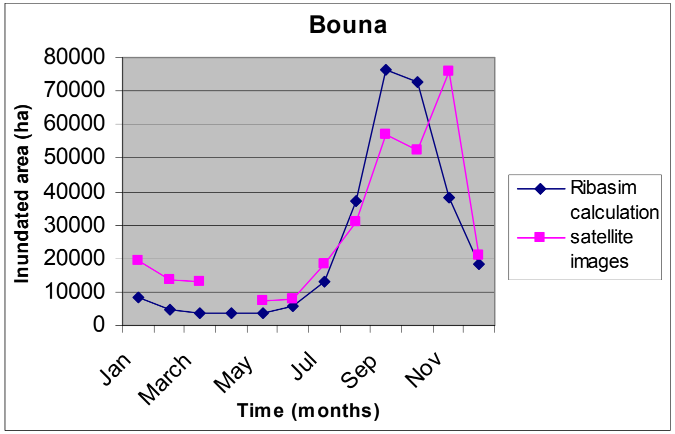
. *Calibration result Mayo Kotia*



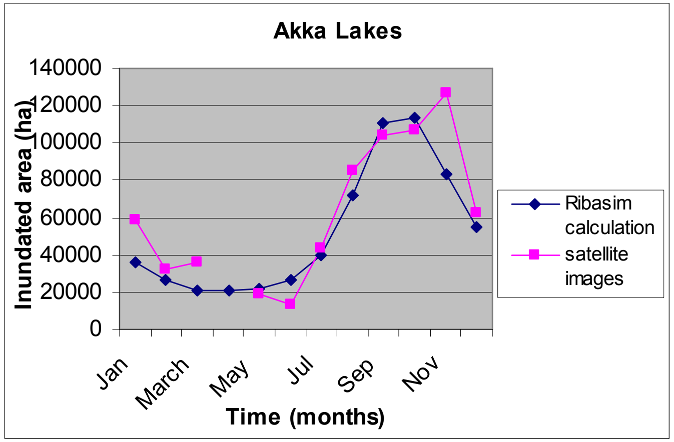
. *Calibration result Mopti*



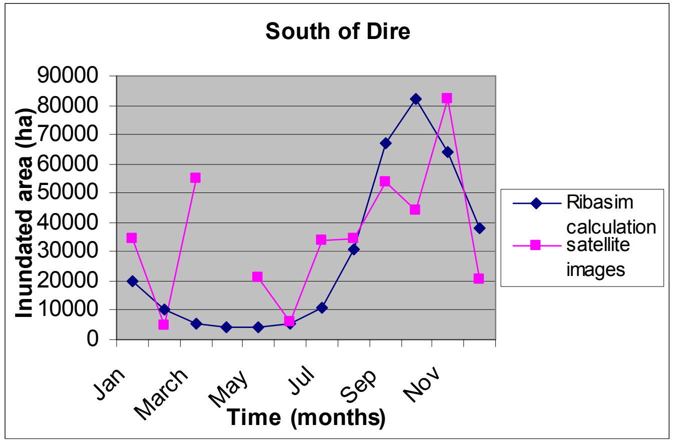
. *Calibration result Lower Diaka*



. *Calibration result Bouna*



. *Calibration result Akka Lakes*



. *Calibration result South of Diré*

Figure 31 Results of the calibration activities for inundated areas in the eight regions in the Inner Delta

7 Model simulations

7.1 Definition of the simulations

The basic question by ecologists and economists to the RIBASIM simulation model is: what is the influence of existing and planned reservoirs on the water levels and inundated areas in the Inland Delta, and specifically on the locations Mopti and Akka.

The simulation model is capable to answer this question. However, some matters should be kept in mind. The validity of the answer depends first of all on the exactitude of the model, which is necessarily imperfect, given its discrete schematisation of the complicated reality in a network of nodes and links, a time step of 1 month, and hydrological time series that are partly ‘constructed’ due to lack of measured data. Further there is the management of the water resources system and the hydraulic infrastructure. The question on the influence of the reservoirs on the Inner Delta cannot be seen loose from the main purpose for which the reservoirs are built: supply of water to irrigation and generation of hydropower. In what way are the reservoirs (existing or planned) operated: is the operation dictated by firm power generation? Is the water demand of the irrigation at Office du Niger at Markala transferred upstream to corresponding releases from Sélingué and Fomi, or does the Office du Niger only take from the Niger ‘what is available’, so without or with minor influence on the operation of the upstream reservoirs? It seems that in the past the latter has been the case for many years.

The simulation model can only work with clearly specified management options for a whole simulation period: Office du Niger asks water from Sélingué or it does not, a specified quantity of power generation at Sélingué is firm and for the rest secondary (that is by using water releases for irrigation or other users) or it is not.

In consultation with RIZA the number of simulation runs was determined. As explained in Chapter 4.4 Markala is not a reservoir, so there is no situation with or without. Office du Niger and Baguinéda have for long times been operational, and take water from the Niger which does not reach the delta any more. So it is included in nearly all the runs, however, *without direct demand* to the upstream reservoirs, i.e. they simply receive water if there is sufficient discharge at the intake point. The périmètres Sélingué and Talo are active when the corresponding reservoirs are active. There is no specific irrigation area coupled to the future Fomi reservoir. This reservoir will primarily be used for power generation. Neither are minimum flow requirements activated.

The Table 7-1 below shows the specific conditions for the six runs. All runs were made with the hydrological time series for the years 1980 - 2001 (see Annex C).

Table 7-1 Overview of simulations made with the RIBASIM model

	No Dams	Sélingué	Sélingué 18 Gwh/month	Sélingué + Fomi	Sélingué + Talo	Sélingué + Fomi + Talo	No dams, no users
Run nr	**1**	**2**	**2A**	**3**	**4**	**5**	**8**
Reservoirs							
Sélingué	-	x	x	x	x	x	-
Talo	-	-	-	-	x	x	-
Fomi	-	-	-	x	-	x	-
Firm power							
Sélingué	-	-	x	-	-	-	-
Fomi	-	-	-	-	-	-	-
Irrigation							
Irr. Sélingué	-	x	x	x	x	x	-
Irr. Office du Niger	x	x	x	x	x	x	x
Irr. Baguinéda	x	x	x	x	x	x	x
Irr. Talo	-	-	-	-	x	x	-
Irr. Mopti	-	x	x	x	x	x	-
Irr. Djenné	-	-	-	-	-	-	-
Irr. Ségou 1	-	-	-	-	-	-	-
Irr. Ségou 2	-	-	-	-	-	-	-
Minimum flows							
Exit Mali	-	-	-	-	-	-	-
Markala	-	-	-	-	-	-	-
Djenné	-	-	-	-	-	-	-
Talo	-	-	-	-	-	-	-

x = active
- = inactive

Run nr. 3 can be regarded as the present situation.

Some typical results of the simulations are shown below. For the lakes the inundated area is shown for Mopti and Akka for the dry year 1984, for Run 2 (only Sélingué is operational) and Run 5 (Sélingué, Fomi and Talo operational). To get an idea of the magnitude of the net evaporation of the reservoirs and the supply to irrigation some graphs on these items are presented. Their magnitude, and their influence in the Niger basin, can be compared with the flows in Ké-Macina and Koryoume, located respectively upstream and downstream of the delta.

One special run was made with none of the structures or water demands operational (Run 8).

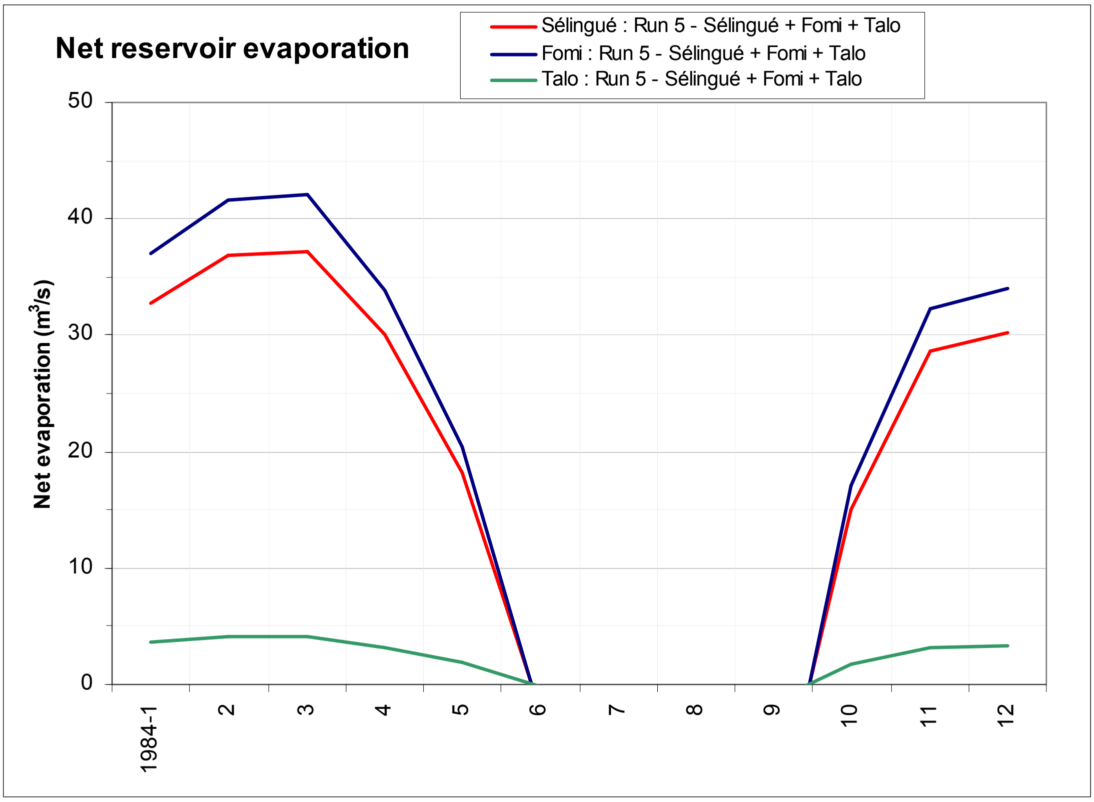


Figure 32 Net reservoir evaporation for run nr. 5 (all reservoirs active)

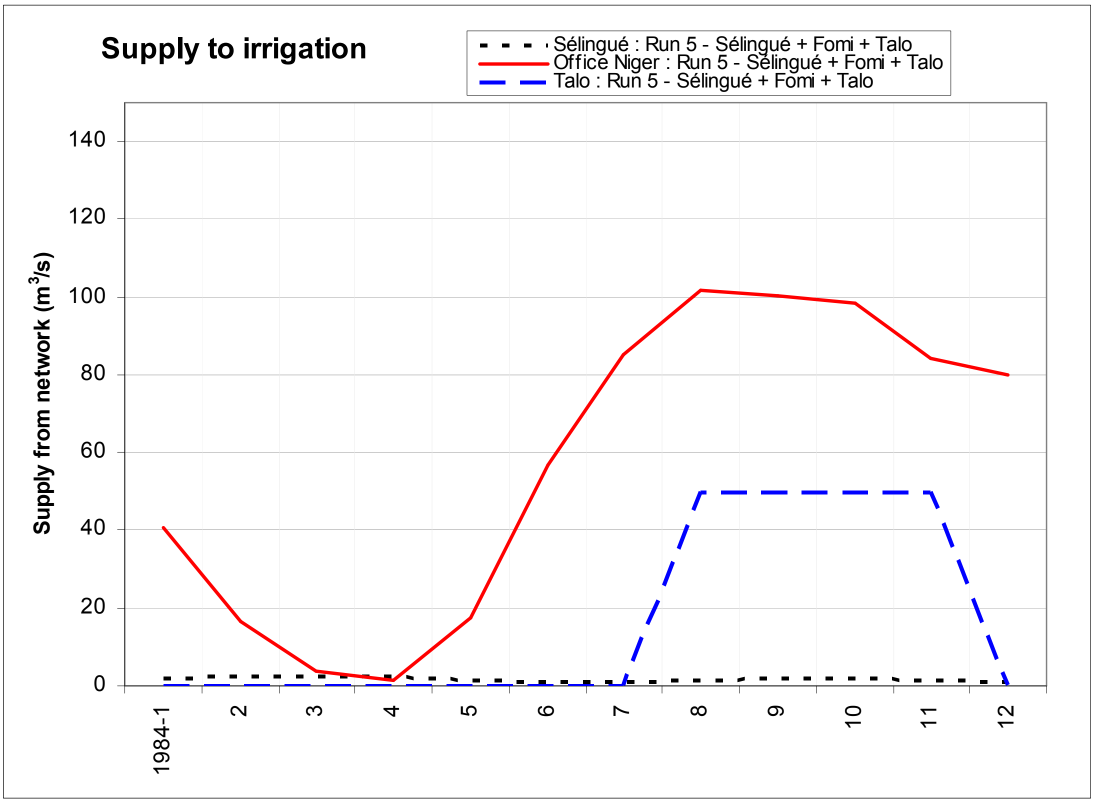


Figure 33 Water supply to irrigation for run nr. 5 (all reservoirs active)

From Figure 32 it is evident that the reservoir evaporation from the newly planned Talo reservoir is rather small. However, the values for the reservoirs Sélingué and Fomi reach maxima of resp. 38 and 42 m^3/s, i.e. a total loss of about 80 m^3/s. These are significant losses, comparable to the irrigation water shown in Figure 33, although unavoidable if the reservoirs need to be filled in order to maximize the power generation (which is in general the main objective). In the flood season, such losses can be neglected, though, as the inflow to the reservoirs is in the order of 2000 m^3/s.

7.2 Simulations of the impact of the Fomi reservoir

The Fomi reservoir is probably the most important structure in the Upper Niger River that will be build in the near future. For this reason it is important to assess the possible impact of this reservoir on the hydrology of the Inner Delta. Therefore simulations were made with RIBASIM for situations with and without the new reservoir (run 2 and run 3). The results are shown in the following figures (Figure 35 - Figure 38).

This difference in inflow is shown in Table 7-2 for the river station at Ké-Macina were the difference in flow is evident in the month of July when the reservoirs are still filling, but afterwards in the months of August and during autumn the difference in flow is negligible.
In the dry months, especially February to April, the existence of the Fomi reservoir results in a significantly increased flow, which implies that the Fomi reservoir can be used for low-flow enhancement if required. It should be stressed, though, that the actual outflow from Fomi will probably be determined by the power generation and any positive or negative effect on the flow regime in this part of the Niger river is only accidental. It would be required to design a fully integrated water resources management plan of the Niger river system to optimize the use of the available resources, not just for power generation, but for all the other water users, including the ecology of the Inner Delta.

Table 7-2 River flow at Ké-Macina (m3/s) for situation with and without Fomi reservoir

River flow at Ké-Macina (m^3/s)		
	Sélingué + Fomi	Sélingué only
1984-1	15	28
2	6	19
3	1	6
4	1	2
5	34	48
6	97	139
7	534	574
8	2198	2161
9	2161	2146
10	1665	1682
11	413	445
12	68	102

In Figure 34 both the inflow (station Ké-Macina – red line) and outflow (station Koryouma – blue line) from the Inner Delta are shown for the situations with and without the Fomi reservoir. It is clear from this figure that the effect of the Fomi reservoir is very small for the outflow at Koryoume and only noticeable at the start of the inundation period (increased low flow) and at the end of the wet season (later start of the lowering of the water levels by about 2 weeks). It is important to stress that the timing of the peak of the inundation, and therefore the travelling time of the flood wave through the Inner Delta, is not affected by the Fomi reservoir.

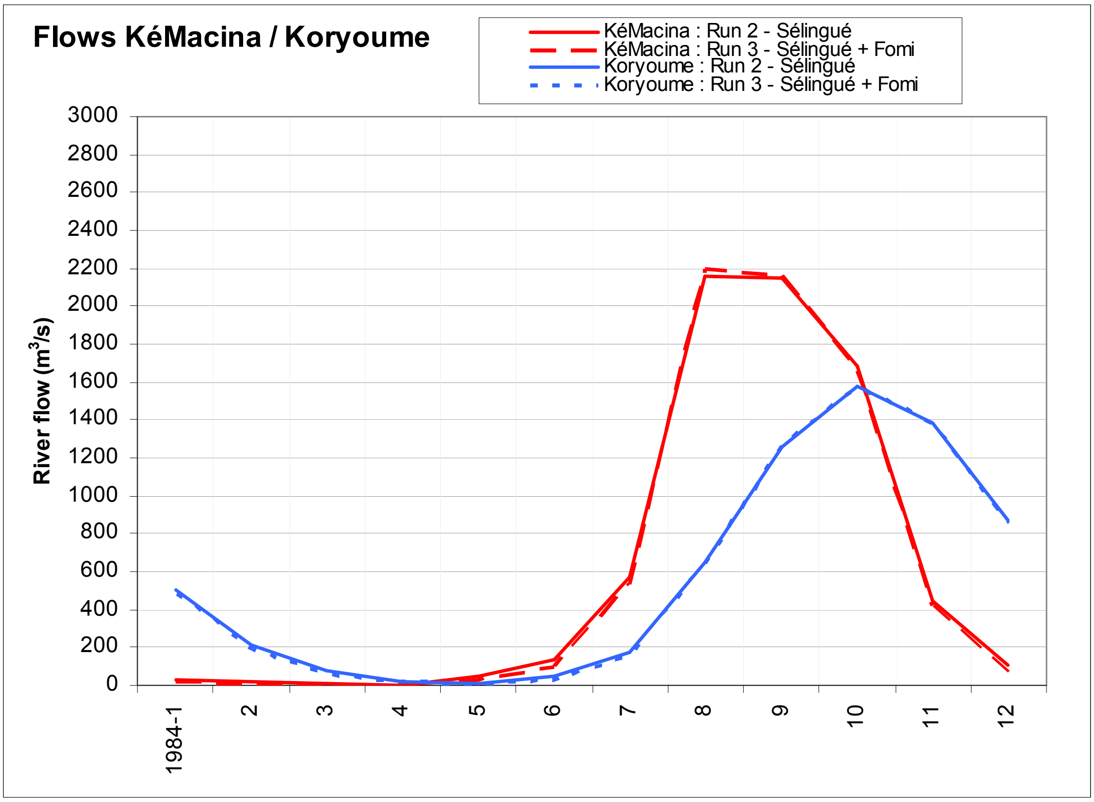


Figure 34 River flow (discharge) at Ké-Macina and Koryoume with and without Fomi reservoir

In Figure 35 and Figure 36 the inundated area is shown for respectively the sections of the Inner Delta at Mopti and Akka for the situations with Sélingué reservoir only and with both Sélingué and the newly planned Fomi reservoir. It is evident that the impact of Fomi on the Inner Delta is negligible. The inundated area is nearly the same for the situation with and without the Fomi reservoir. It is not possible yet to make any assumptions regarding the possible effect of changes in operation of the Fomi reservoir as the information of the dam, which is in design stage, does not contain any data on future operation strategies.

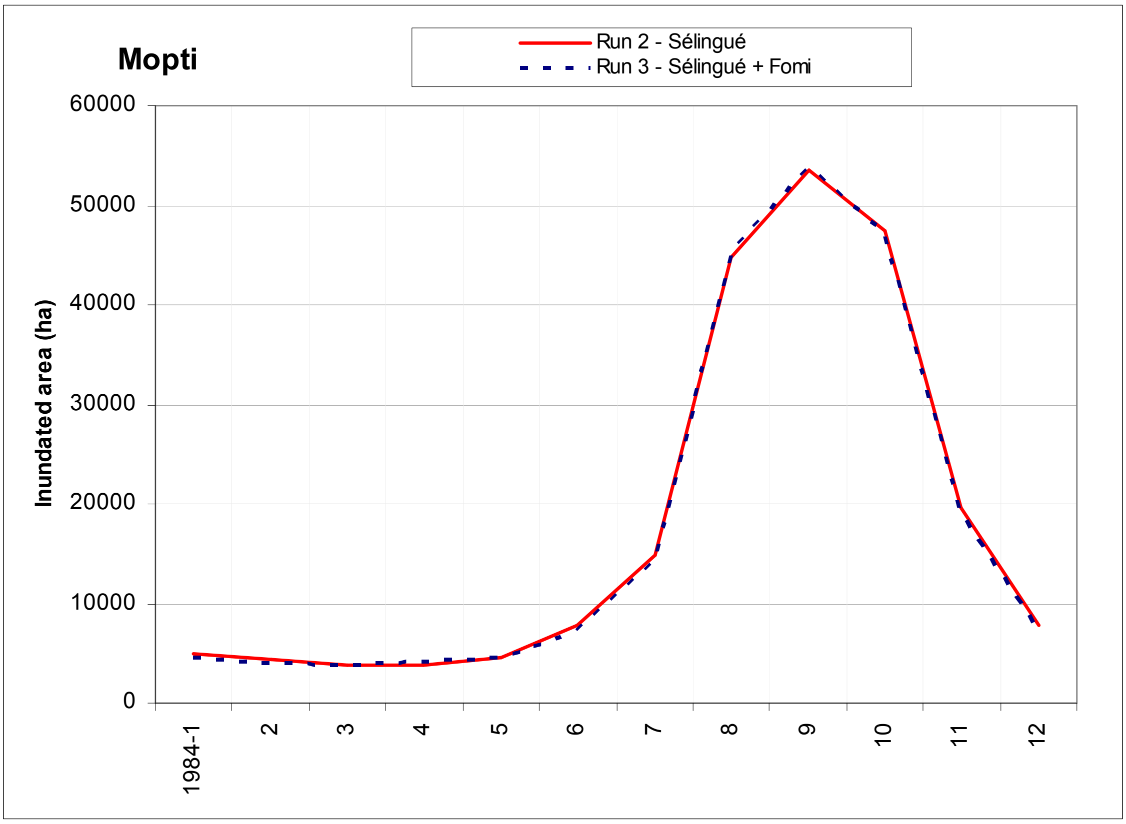


Figure 35 Inundated area of the Inner Delta at Mopti for situation with and without Fomi reservoir

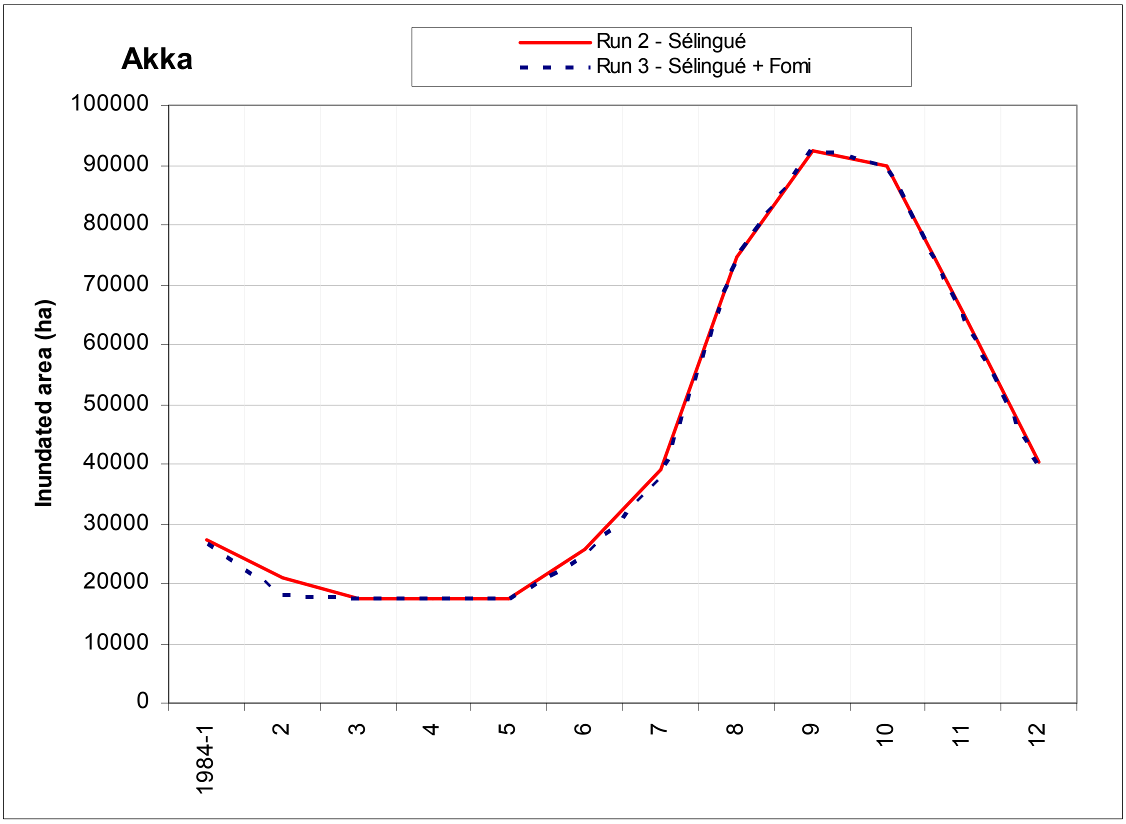


Figure 36 Inundated area of the Inner Delta at Akka for situation with and without Fomi reservoir

7.3 Simulations of the impact of the combined new reservoirs

Apart from the Fomi reservoir, another reservoir, the Talo, is planned on the Bani river, one of the main tributaries of the Niger River that joins the Niger at Mopti. This reservoir has been included in the analysis together with the newly planned Fomi reservoir, because the latter is already in an advanced state of development and its implementation is very likely. In Table 7-1 these are run 2 and run 5.
In Figure 37 and Figure 38 the results are shown of the analysis for the locations of Mopti and Akka.

As can be seen in these figures, there is a slight delay in the start of the inundation of also about two weeks at the onset of the wet period, but once the inundation increases the difference becomes negligible. This is due to the relatively small volume of both the Fomi and the Talo reservoirs compared to the vast inundation volume of the Inner Delta as well as the large flow discharges of the Niger and Bani rivers during the wet season.

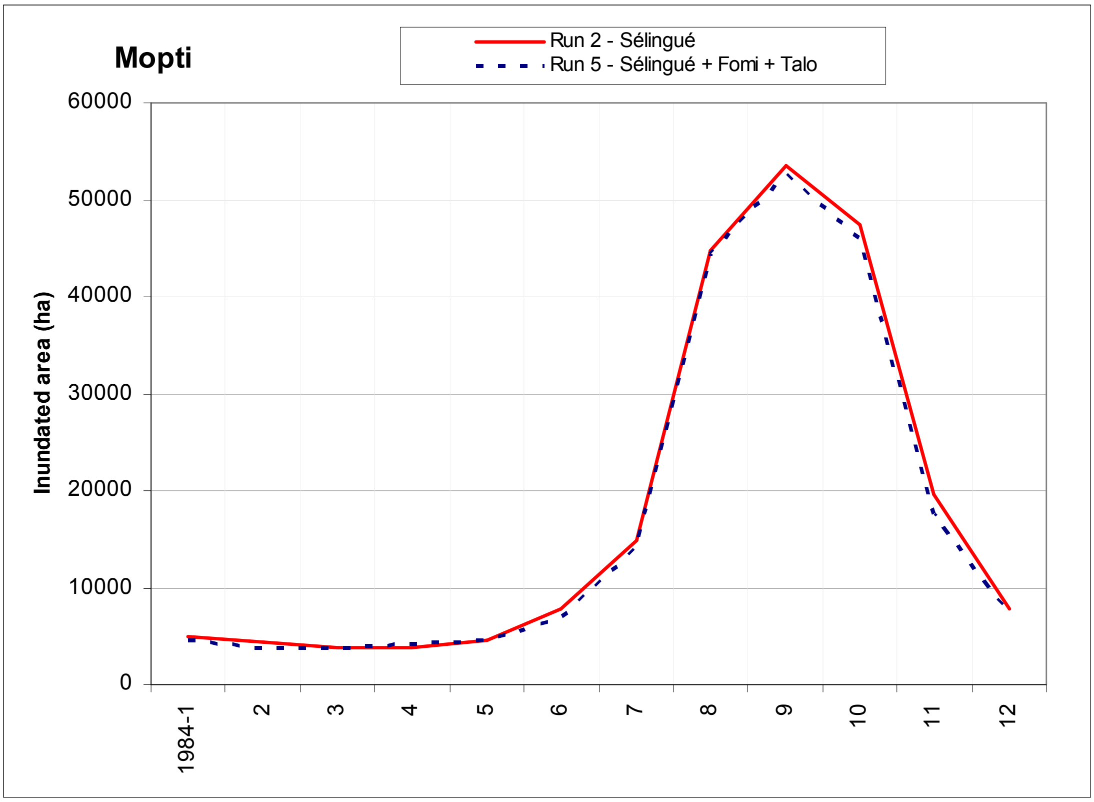


Figure 37 Inundated area at Mopti for situation with and without the Fomi and Talo reservoirs.

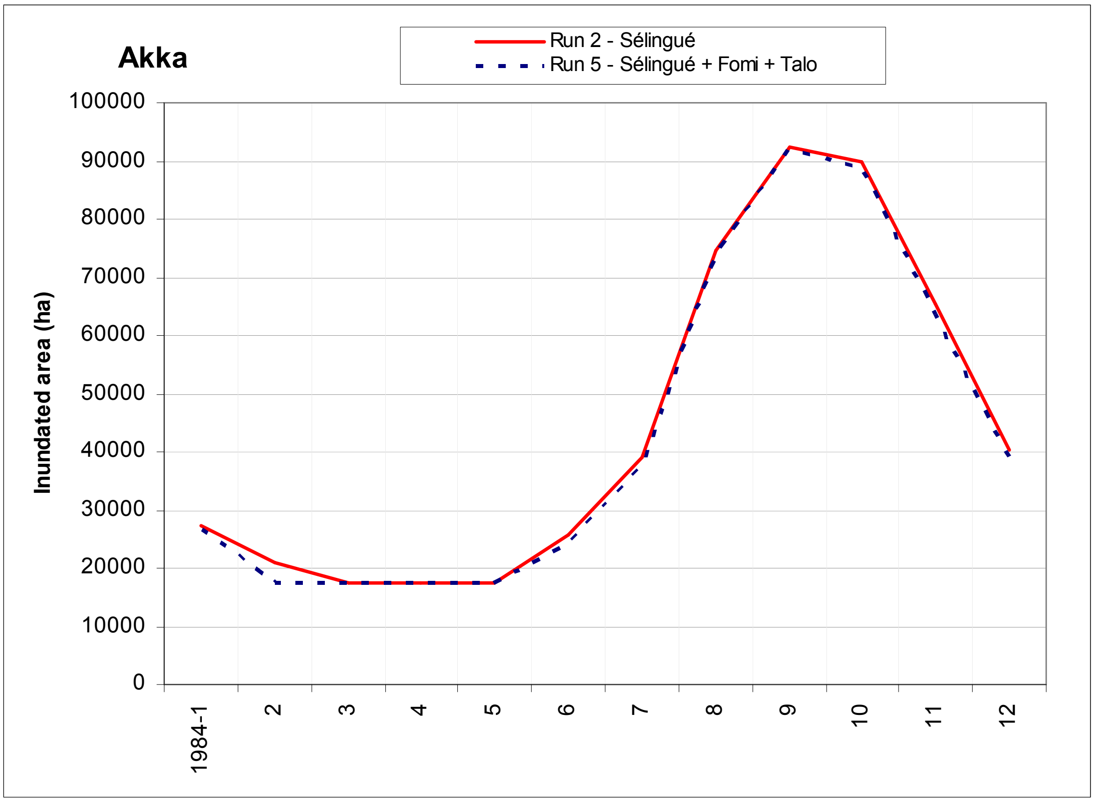


Figure 38 Inundated area at Akka for situation with and without the Fomi and Talo reservoirs

7.4 Sélingué with Firm Power

As there is hardly any information on the actual operation rules of the Sélingué reservoir, most of the model runs have been made with rules, i.e. the reservoir is left to fill according to the natural inflow minus the evaporation losses and outflow only occurs once the water level has reached the spillway levels. However, a visit to the Sélingué reservoir made it clear that in general power generation is given absolute priority over any other water user (in fact downstream users are hardly taken into account) and therefore it is interesting to make a simulation for a situation in which an operation rule is used for which the power generation is optimized using a firm power rule in the model. This has been included as run nr. 2A. The results, expressed as inundated area in the Inner Delta at Mopti and Akka, are shown in Figure 39 and Figure 40. The figures show that the application of an operation rule that assumes power generation at Sélingué results in change of the form of the yearly curve, with a higher inundation area in the dry season because the reservoir continues to spill water for power generation, despite the fact that it is still filling up. In the flood season, the total inundated area is smaller, because the flood water volume available from Sélingué would be smaller as part of the water was already spilled earlier. The difference in operation of the reservoir has no influence on the timing and the duration of the flooding in the Inner Delta. This conclusion applies for both the locations Mopti and Akka.

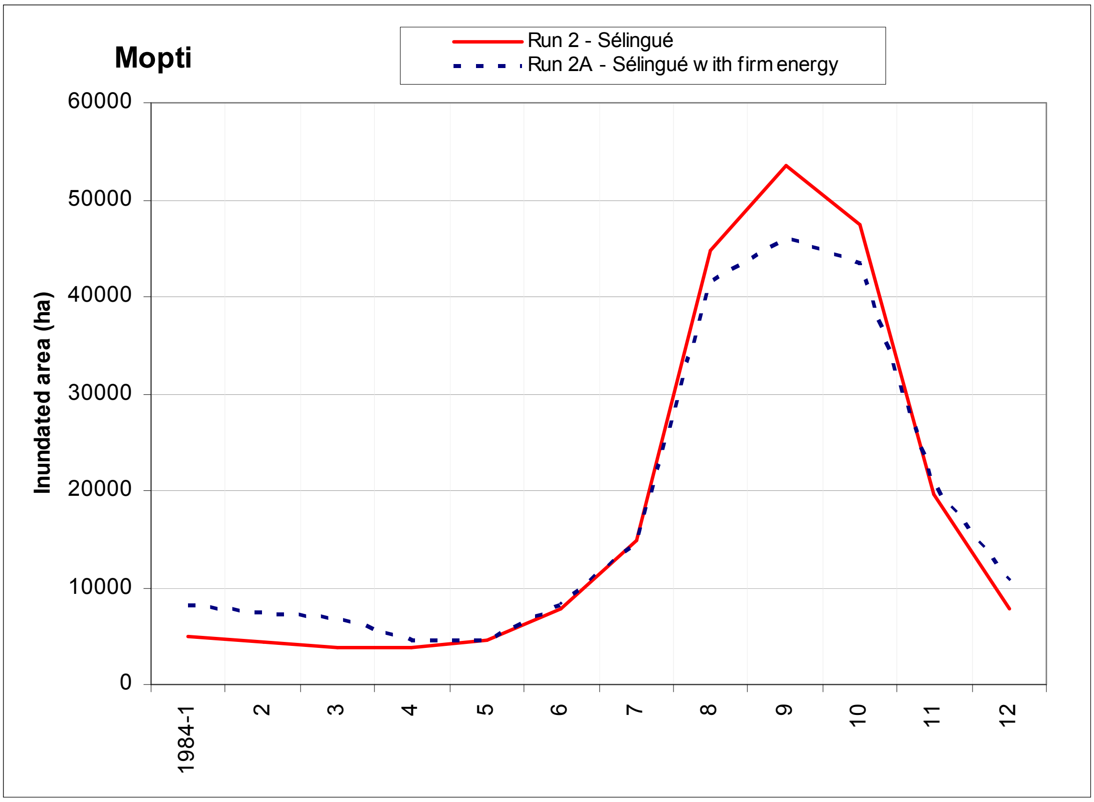


Figure 39 Inundation area at Mopti for runs with Sélingué reservoir with and without firm energy operation rule

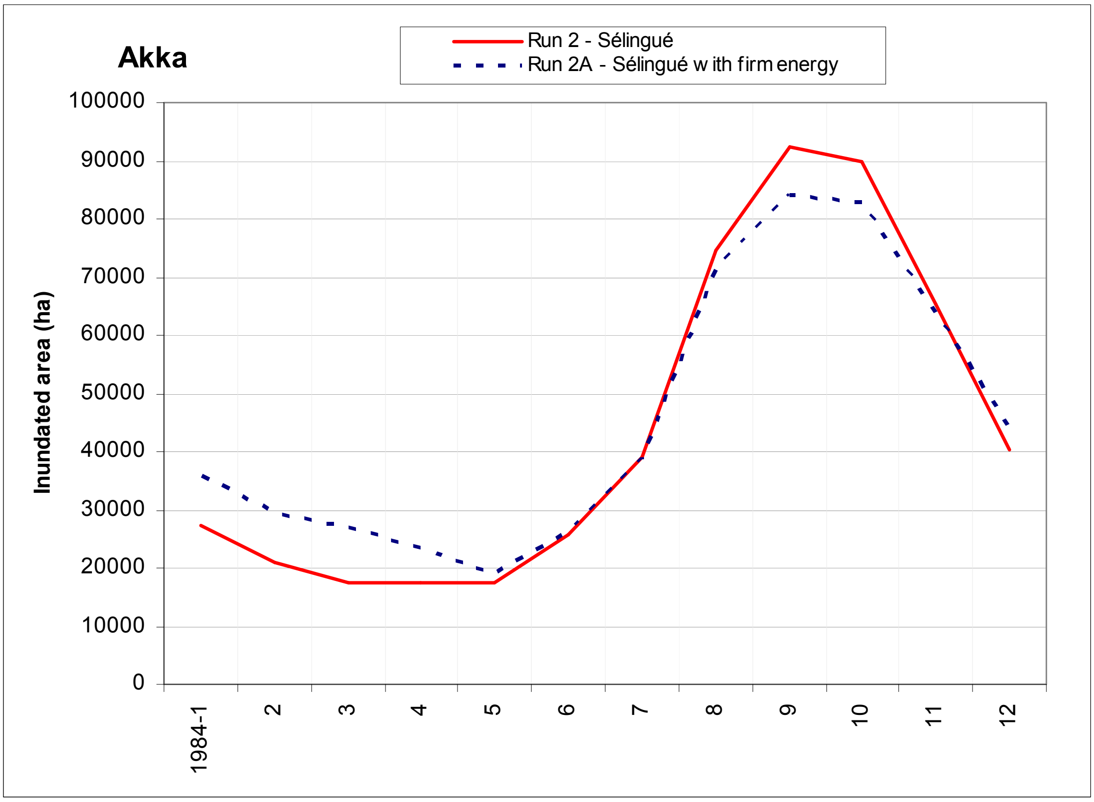


Figure 40 Inundation area at Akka for runs with Sélingué reservoir with and without firm energy operation rule

7.5 No reservoirs and Sélingué with Firm Power

The simulation for the situation described in the foregoing Chapter on Sélingué with firm power can be compared to the situation without reservoirs. In Figure 41 and Figure 42 the results are shown of the inundated area at respectively Mopti and Akka.
It is evident from these figures that the existence of the Sélingué dam using an operation rule that would guarantee power generation will result in a smaller inundated area, because part of the water available for inundation of the Delta is released earlier, resulting in an increase in storage area at the beginning of the flood season and thus smaller release during that period. The decrease in inundated area would be in the order of 10-15% in comparison with the situation without reservoirs.

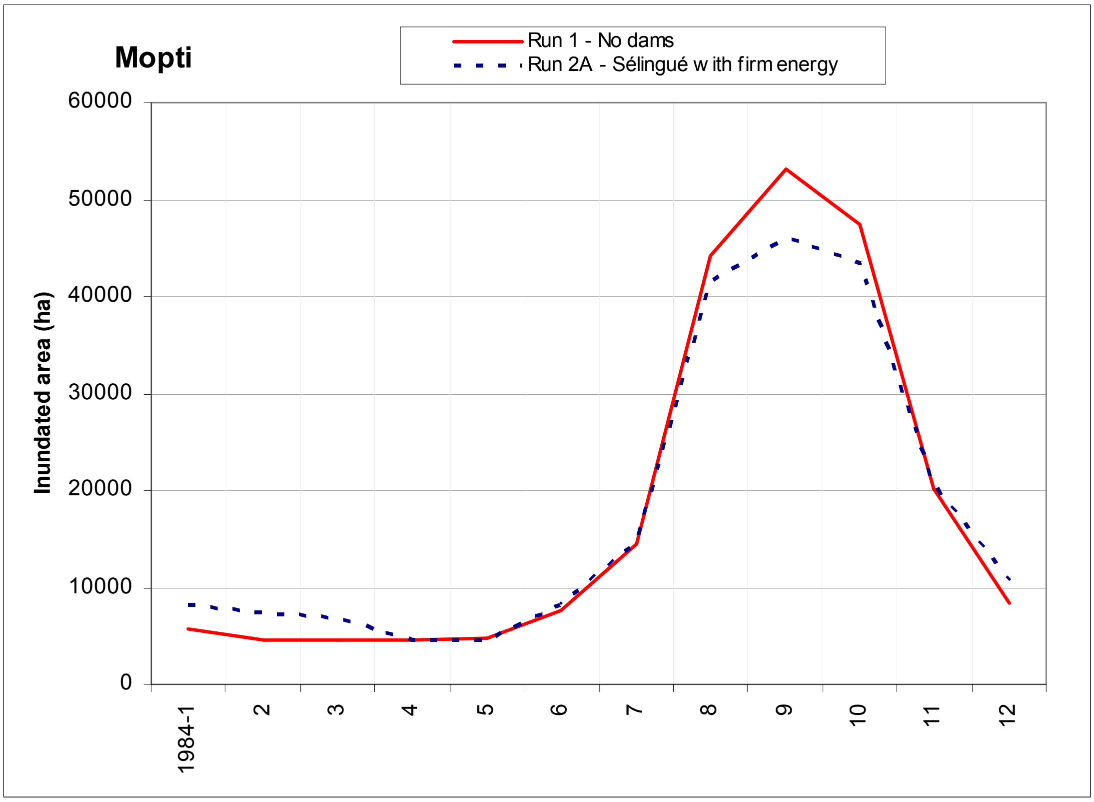


Figure 41 Comparison situation without dams and with Sélingué operated on fim power energy for Mopti

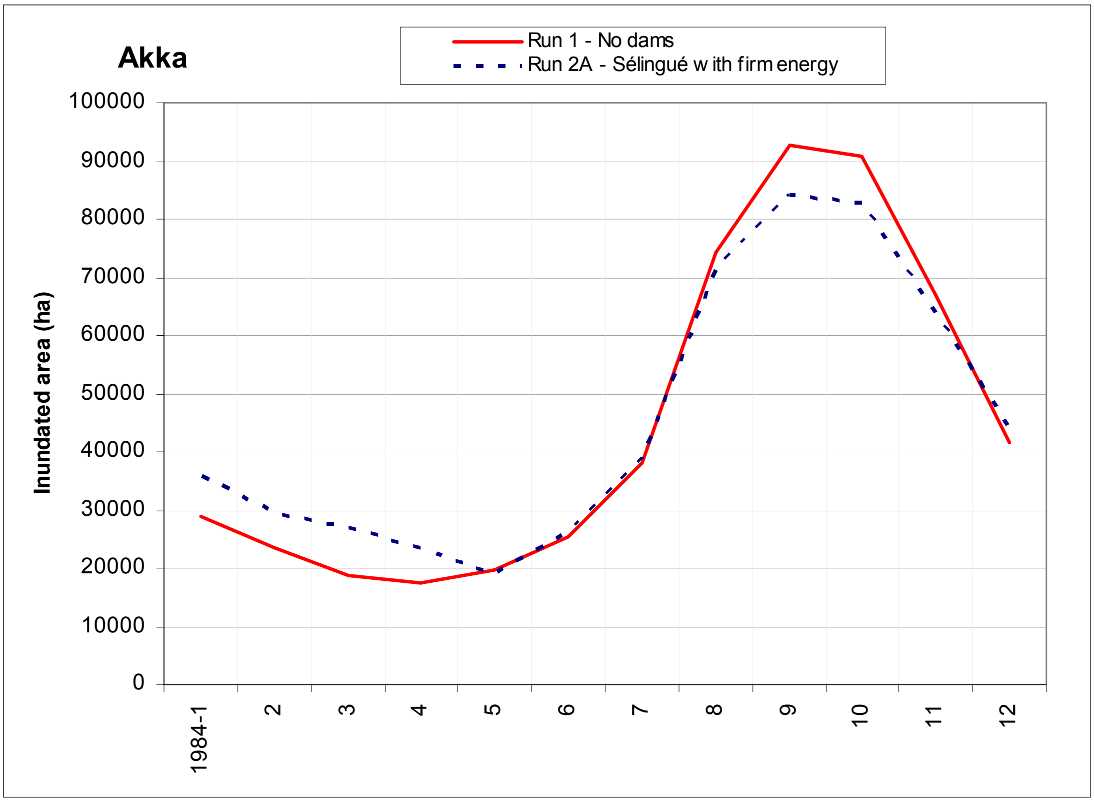


Figure 42 Comparison situation without dams and with Sélingué operated on fim power energy for Akka

7.6 Situation without water extraction by Office du Niger

In order to allow for a comparison of the effects of the reservoirs on the hydrology of the Inner Delta, a final analysis was made of the situation without any reservoirs, i.e. even without the existing Sélingué reservoir and also without any water extractions at the Office du Niger ('no dams, no users', run 8). This is compared with the situation with the reservoirs, but no water extraction. The results are shown for the water levels at Mopti, Akka and for the flows at Ké Macina and Koyoume. The results are shown respectively in Figure 43, Figure 44 and Figure 45.

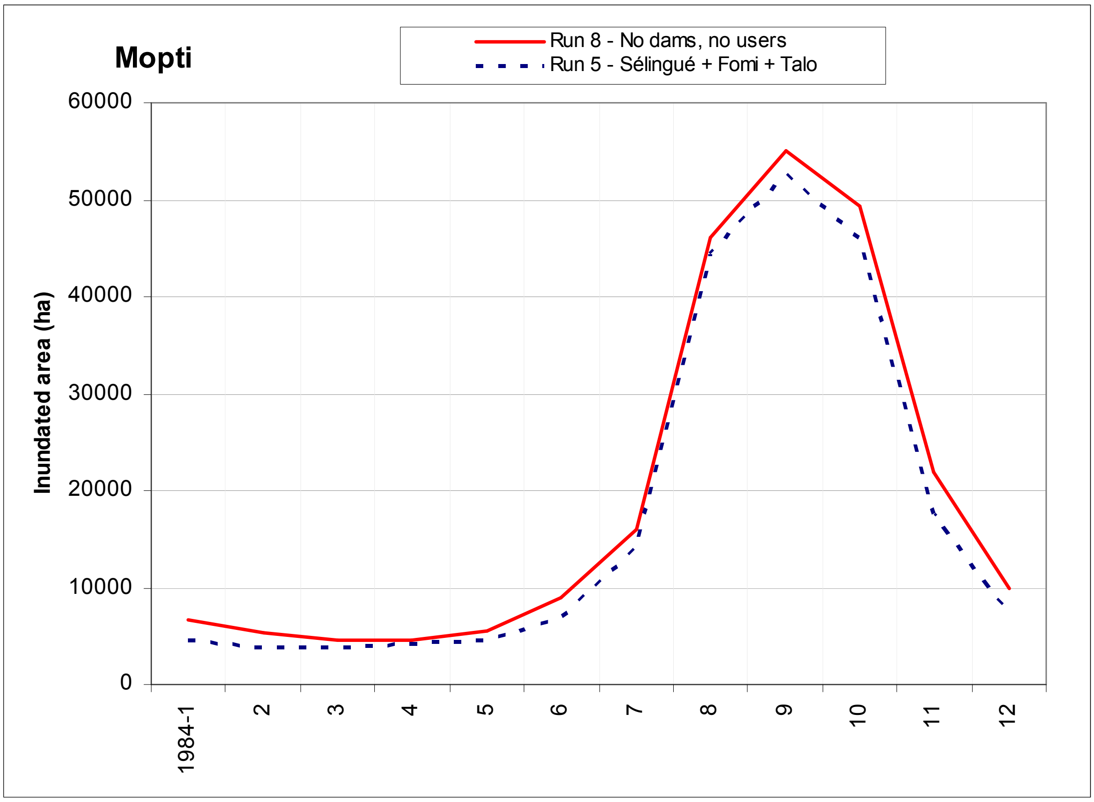


Figure 43 Results of simulations without water extraction (with and without dams) at Mopti

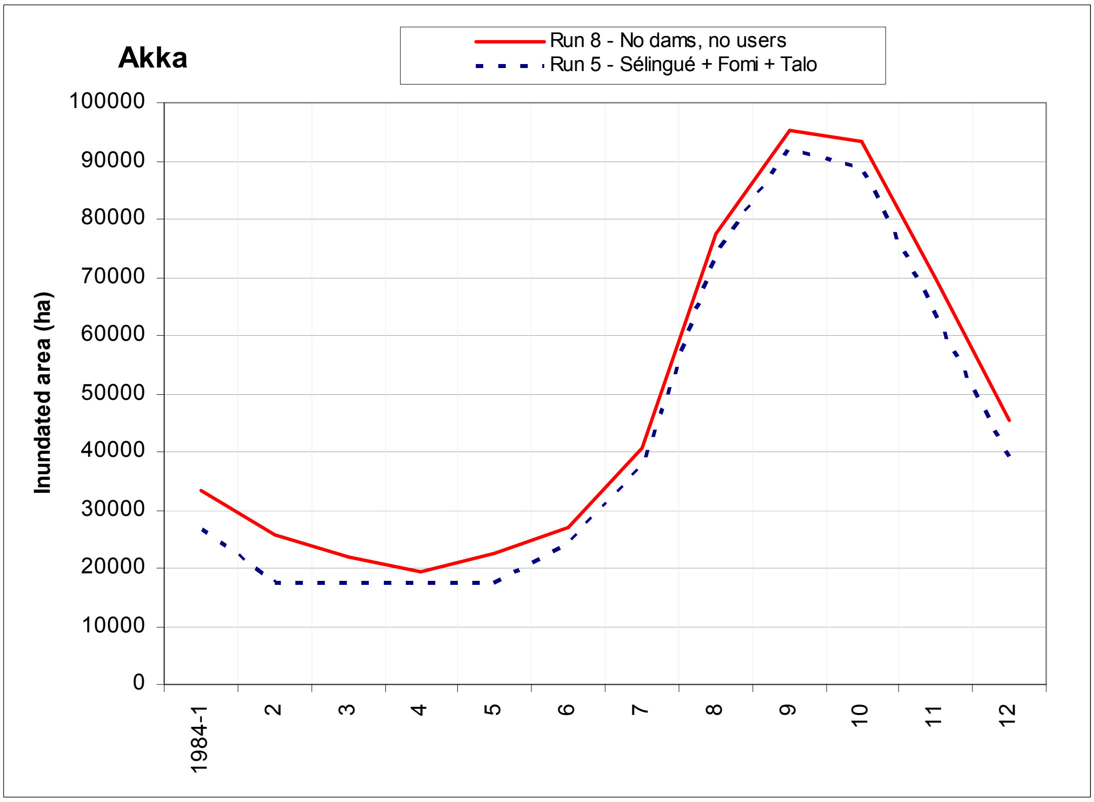


Figure 44 Results of simulations without water extraction (with and without dams) at Akka

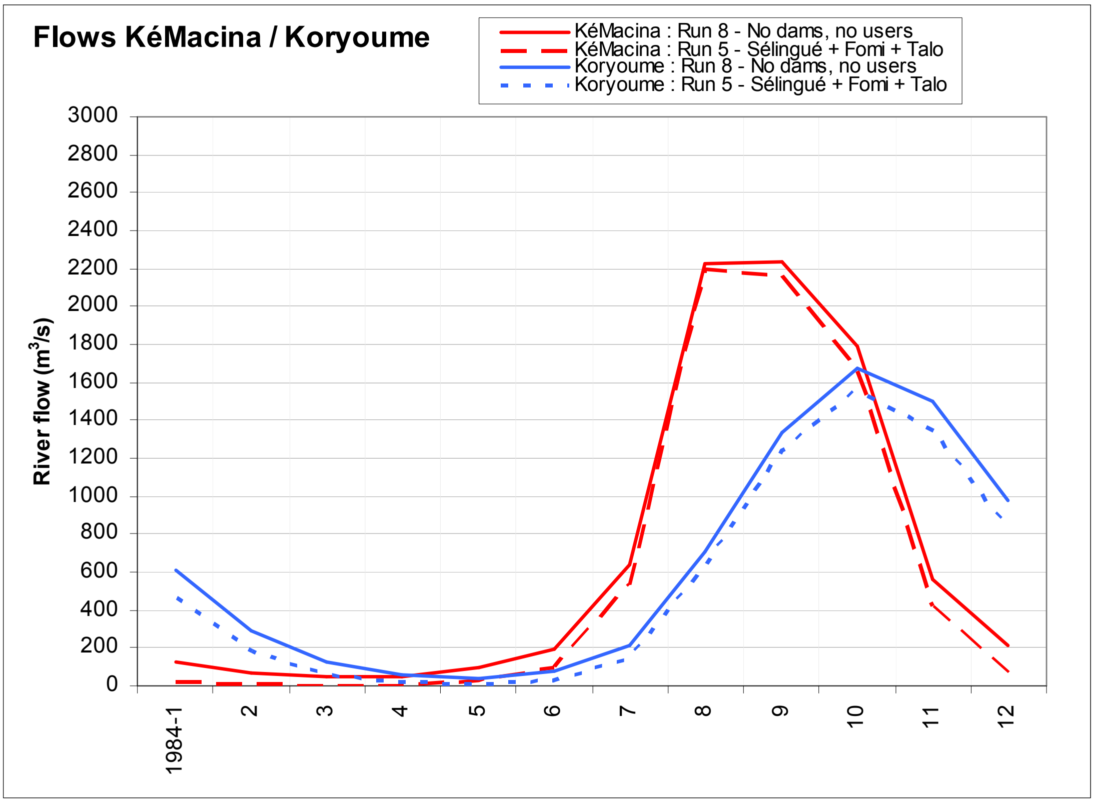


Figure 45 Results of simulations without water extraction (with and without dams) at Ké Macina and Koryoume

From the results, especially for the water levels at Mopti and Akka, it is clear that the impact of the reservoirs on the water levels is small, both in absolute values and in time of occurrence. The flows at Koryoume are also only marginally affected, with a small decrease in the peak flow and total volume and hardly any change in timing of the flood wave.

As a conclusion to these analyses the tentative conclusion can be made that the newly planned reservoirs will have no major impact on the hydrology of the Inner Delta of the Niger River. However, this important and far-reaching conclusion should be further studied by improving especially the representation of the geometry of the Inner Delta in the model and the inflow series of the Niger and Bani rivers using more detailed rainfall data in the upper basins.
Another important issue is the intake of irrigation water from the Office du Niger area.

7.7 Other changes with possible impact on the Inner Delta

There are yet no reliable data on possible increases of the water intake of the Office du Niger at Markala, but it is expected that major increases in the water demand of the irrigation areas will have a more important impact on the hydrology of the Inner Delta than the newly planned reservoirs.
There are some results on this issue already available from the GHENIS project. In Figure 46 the impact the results are shown for a simulation for the situations with and without the newly planned Fomi reservoir.

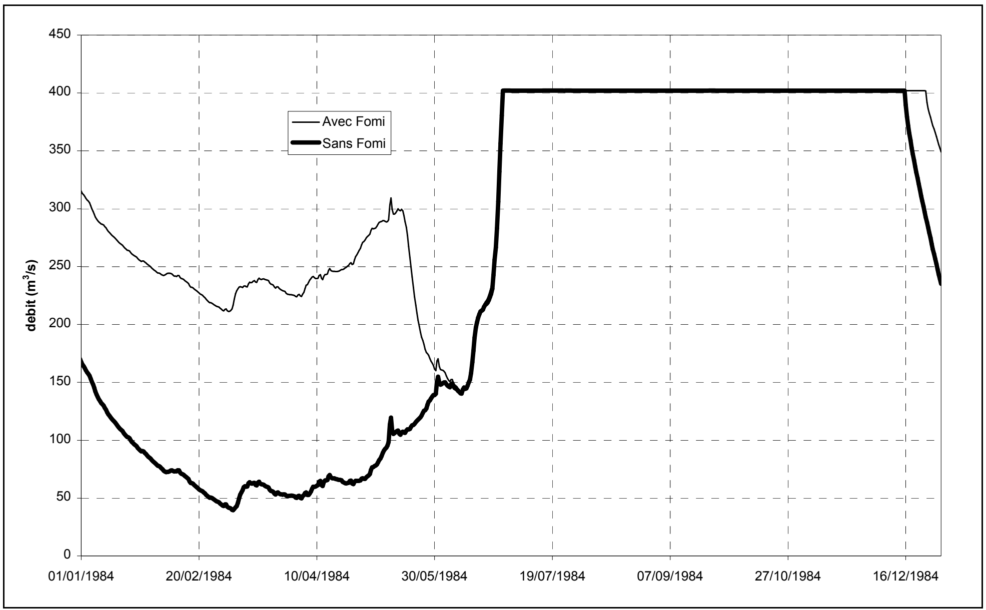


Figure 46 Intake of water at Markala in a dry year for situation with and without new Fomi reservoir in case irrigation area is increased to 230.000 ha.

The importance of the new Fomi reservoir for the development of additional irrigation area in the Delta Mort region (Markala) is evident: in the dry season the Fomi reservoir is able to sustain a much higher minimum flow than in the situation with only the Sélingué reservoir. During the flood season the maximum intake (here: 400 m^3/s instead of the present day 100 m^3/s) can always be reached, also without the new Fomi reservoir.

It is recommended to make impact studies of possible scenarios of irrigation area development to assess both the impact of such increases as well as the feasibility of such changes. With such a study the sustainable maximum intake at Markala can be determined and subsequently the maximum sustainable irrigated area for the Office du Niger, both for the present situation and for the situation with the new Fomi reservoir.

7.8 Improvements over existing models

As has been described in the Annex to the Inception Report, another detailed model is available for the Inner Delta. This model MIDIN was built as part of an IRD project. It is interesting to compare the newly developed RIBASIM model and the existing MIDIN model, which is still accessible on the internet. As has been remarked in the description of the model, the MIDIN model focuses on the socio-economic aspects of the delta and the hydrology of the delta system is included a very simple way and without the possibility to calculate the hydrological situation over a number of years. The construction of dams at upstream or downstream sites is included in the model, but only a few scenario's are possible, based on which water levels are determined through calculation rules without a real effort to model the behaviour of the reservoirs under different conditions and operation rules. The latter cannot be included in the simulation, which severely restrict the possibilities to make future studies of changes in the structures and their operation.

For the hydrological inflow, the model makes use of three historical years which are considered representative:

1993 – 1994: bad flood year
1994 – 1995: good flood year
1995 – 1996: average flood year

It is not clear whether these years are chosen according to a certain probability or whether they simply function as an example of relatively dry and wet years.
The time step of the MIDIN model is the same as for RIBASIM (15 days), as both models are essentially balance models. However, from the description of the MIDIN model it becomes clear that the model is not really a water balance model, but should be considered a type of 'behaviour model', i.e. it produces the expected output according to pre-defined rules. In fact it is doubtful whether the MIDIN model does really maintain a water balance of the region over a certain period of time. According to the description water can be allocated and water levels produced without a physical relationship to the actual availability of the water. This is illustrated by the treatment of storage and corresponding water levels in the Inner Delta. In case of storage in the upstream part of the Delta, inundation is supposed to occur in the total Delta with the exception of the Bani River and the Upper and Lower Djenné regions. The calculation of the water levels in the Inner Delta is corrected according to empirical formulas:

VOLUME OF UPSTREAM STORAGE ($*10^9$ M^3)	CORRECTION OF CALCULATED LEVELS
5	10%
10	30%
15	40%

Similar corrections are applied to two separately distinguished lakes:

VOLUME OF UPSTREAM STORAGE ($*10^9$ M^3)	CORRECTION OF CALCULATED LEVELS	
	Lac Debo	Lac Faguibine
5	0.5 m	-
10	1.25 m	0.38 m
15	2.0 m	1.25 m

It is evident that such fixed rules cannot be used in all situations as the exact water levels in each location depend on the form of the flood wave entering the Inner Delta and the interaction between the various lakes and their connections.

In summary it can be concluded that the MIDIN model is very strong in the socio-economic aspects of the total system of the Inner Delta. These aspects are not included in the RIBASIM model, which is essentially a hydrologic water balance model, and need to be assessed by other means / agents on the basis of the outcomes of the RIBASIM simulations. On the other hand the basis of the results of the MIDIN model, the hydrology of the Inner Delta with especially the extension of the inundation area and the corresponding water levels, seem to be lacking in physical correct treatment of the water balance of the total region of study. This implies that the results of the socio-economic module should be handled with care. Further details on the MIDIN model have been given in Annex 3 of the Inception Report.

8 Conclusion and Recommendations

The following conclusions and recommendations can be made on the basis of the outcome of this study.

Conclusions

- the use of satellite images in combination with information on the water levels at the time the images are an excellent source for the 'decipherment' of the hydrological system of the Inner Delta which consists of a large number of interconnected lakes, marshy areas and channels
- the use of time series of such images and water levels makes it possible to derive water level-area-volume relationships for various zones of the Inner Delta with sufficient detail for a reliable simulation with a water resources model such as RIBASIM
- calibration of the model is hampered by the lack of reliable flow data in the upper basin of the Niger River in Guinea and lack of information on water intakes along the river and in the Inner Delta itself
- the simulations with RIBASIM of the full Niger / Bani system down to Gao indicate that an implementation of new reservoirs at both Fomi on the Niger in Guinea and Talo on the Bani river will have a small impact on the hydrology of the Inner Delta. At the discharge station of Koryoume the flow is only marginally affected, with a small decrease in the peak values and total volume and hardly any change in timing of the flood wave
- there is a clear impact of the new reservoirs in the timing of the inundation of the Inner Delta, with a delay in the order of two weeks. There is a small impact on the final extension of the inundation area and volume in the Inner Delta in case of unconditional release of water at the Sélingué dam
- in case it is assumed that the Sélingué dam will try to maximize power generation (firm energy condition), there is a much higher impact on the maximum inundated area in the Inner Delta (in the order of 10 - 15% decrease) compared to the situation without reservoirs

Recommendations

- in order to arrive at a better founded conclusion on the impact of the new reservoirs it is necessary to improve the information on the inflow hydrographs and on the water demand / intake by other water users both along the Niger/Bani rivers as well as in the Inner Delta itself
- it is also required to extend the modelling work to the downstream part of the Inner Delta (i.e. passed Diré, including the lakes between Diré and Tombouctou) in order to come to a better assessment of the hydrology of the Inner Delta. This is essential in case the Tossaye dam is included in the study
- it is expected that the possible increase in water demand for irrigation requirements of the Office du Niger will have a more important impact on the hydrology of the Inner Delta than the new reservoirs

- it is recommended to extend the present study to simulations of scenarios of possible extensions of the present water demand of the Office du Niger intake at Markala
- at the same time it may prove interesting to study the feasibility of such extensions of the irrigated area of the Office du Niger by compensating the increased water demand with improved operation of the existing Sélingué reservoir and/or the newly planned reservoirs at Fomi and Talo.
- in order to study the effect of changes in the control structures on the water quality of the Niger river system, it may prove very useful to include in a future study the concept of 'fraction calculations', i.e. the study of the source of the water in each location in the system.
- it is advisable to include in a future study the groundwater storage. This can be combined with the 'fraction calculations' in order to find the percentage of water in the Inner Delta that comes from groundwater outflow.
- any negative impact of the hydrology of the Inner Delta, such as possible decrease in inundated area, may possibly be mitigated by the implementation of the Tossaye reservoir. This reservoir, although downstream from the Delta, may be used to meet the minimum flow requirement at the Mali/Niger border at Gao and allowing a nearly zero outflow at the downstream end of the Inner Delta (depending on ecological minimum flows and water quality aspects).

9 References

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A Input data link storage nodes

node	ID	length	reference level	relationship from satellite images	factor
Kouakourou	16	15000	266.32	y = 4338e0.0061 * x	3.4
Upper Diaka	73	100000	267.16	y = 2210.4e0.0088 * x	1.2
Lower Diaka	12	50000	258.38	y = 463.07e0.0111 * x	2.5
Mayo Kotia	29	84000	260.12	y = 833.9e0.0092 * x	2
Mopti	28	50000	260.12	y = 3006.6e0.0052 * x	1.2
Bouna	15	70000	258.38	y = 2599.6e0.0058 * x	0.8
Akka Lakes	13	40000	258.38	y = 0.2503x2 + 178.74x + 11553	1.3
South of Diré	14	175000	256.85	y = 6636.3e0.0051 * x	0.3

Kouakourou

Q	H	W
0.0	266.3	9832.8
23.9	266.3	10451.3
135.8	266.5	13339.4
320.7	266.6	18096.6
571.6	266.8	24550.3
911.9	266.9	33305.5
2024.9	267.2	61296.6
4073.2	267.5	112812.1
7843.1	267.8	207623.0
14781.2	268.1	382115.8
27550.3	268.4	703257.9
51050.9	268.7	1294298.0

Upper Diaka

Q	H	W
0.0	267.2	265.2
1.8	267.2	289.6
11.2	267.6	411.9
28.7	268.0	639.5
55.9	268.4	992.9
98.2	268.8	1541.7
273.5	269.7	3717.0
696.1	270.5	8961.3
1714.9	271.3	21604.7
4171.3	272.2	52086.7
10093.4	273.0	125575.8
24371.0	273.8	302750.8

Lower Diaka

Q	H	W
0.0	258.4	231.5
0.8	258.4	258.7
5.0	258.6	403.3
13.9	258.8	702.6
29.3	259.0	1223.8
56.1	259.2	2131.8
193.7	259.6	6468.7
611.3	260.0	19628.4
1878.3	260.4	59559.5
5722.8	260.8	180724.9
17388.6	261.2	548384.0
52786.6	261.6	1663994.0

Mayo Kotia

Q	H	W
0.0	260.1	198.5
0.8	260.2	217.7
5.1	260.4	314.5
13.2	260.6	498.2
26.1	260.9	789.2
46.5	261.1	1250.2
134.2	261.6	3137.0
354.4	262.1	7871.7
906.9	262.6	19752.4
2293.2	263.1	49564.4
5771.9	263.6	124371.6
14501.1	264.1	312084.4

Mopti

Q	H	W
0.0	260.1	721.6
4.9	260.2	760.1
27.6	260.5	935.8
63.4	261.0	1213.7
109.8	261.4	1574.1
170.1	261.8	2041.5
352.6	262.6	3433.9
659.6	263.5	5775.9
1176.0	264.3	9715.2
2044.5	265.1	16341.3
3505.5	266.0	27486.5
5962.8	266.8	46233.0

Bouna

Q	H	W
0.0	258.4	297.1
3.1	258.5	314.8
17.3	259.0	397.0
40.5	259.6	530.6
71.5	260.3	709.1
112.9	260.9	947.7
244.9	262.1	1692.7
480.7	263.4	3023.2
901.8	264.6	5399.5
1654.0	265.9	9643.7
2997.4	267.1	17224.0
5396.7	268.4	30762.7

Akka Lakes

Q	H	W
0.0	258.4	3754.7
24.9	258.5	4343.8
162.8	258.8	6862.6
428.1	259.1	10377.3
807.7	259.5	14298.6
1314.2	259.9	18626.7
2764.4	260.7	28503.2
4872.4	261.5	40006.5
7738.3	262.2	53136.9
11462.4	263.0	67894.1
16144.6	263.8	84278.4
21885.1	264.5	102289.5

South of Diré

Q	H	W
0.0	256.9	113.8
3.1	257.2	119.7
17.3	258.5	146.8
39.7	260.2	189.5
68.7	261.9	244.5
106.0	263.5	315.5
218.1	266.9	525.4
404.8	270.2	874.9
715.8	273.5	1457.0
1233.5	276.9	2426.3
2095.8	280.2	4040.6
3531.7	283.5	6728.7

B Hydrological stations

Hydrological Stations Guinee						
OHRAOC	HYDROM3	Nom de la station	Rivière	Bassin	Altitude en (m)	Surf bassin en Km²
GN0175	1171200105	Kounsi	Gambie	Gambie		5015
GN0001	1171200205	Nianou	Dimma	Gambie		776
GN0176	1171200206	Téliré	Dimma	Gambie		127
GN0177	1171200207	N'Dossa	Litti	Gambie		136
GN0002	1171201805	Koulountou	Koulountou	Gambie		2 538
GN0003	1171202105	Oundou Bac	Oundou	Gambie		1 415
GN0004	1171202505	Matakaou	Silamé	Gambie	517	380
GN0008	1171500110	Dialakoro	Niger	Niger		71 000
GN0013	1171500115	Faranah	Niger	Niger	417	3 180
GN0014	1171500120	Kouroussa	Niger	Niger	355	18 000
GN0016	1171500130	Tiguibéry	Niger	Niger	337	70 000
GN0017	1171501510	Serekoroba Nouveau	Mafou	Niger		
GN0019	1171501512	Dialoua	Mafou	Niger		
GN0020	1171501524	Sérékoroba	Mafou	Niger		3 705
GN0014	1171500120	Balan	Milo	Niger		9 030
GN0016	1171500130	Kankan	Milo	Niger	361	9 900
GN0017	1171501510	Kérouané	Milo	Niger		1 695
GN0027	1171501710	Konsankoro	Milo	Niger	510	1 000
GN0028	1171501805	Baro	Niandan	Niger	416	12 600
GN0030	1171501807	Yarakoura	Niandan	Niger		
GN0031	1171501808	Sansambaya	Niandan	Niger		
GN0032	1171501810	Kissidougou	Niandan	Niger	478	1 260
GN0034	1171502005	Mandiana	Sankarani	Niger	354	21 900
GN0035	1171502006	Morissanako	Sankarani	Niger		
GN0036	1171502007	Sanankoro	Sankarani	Niger		
GN0037	1171502105	Koundiana-koura	Sankarani	Niger		
GN0043	1171502405	Sansambaya	Balé	Niger		
GN0044	1171502406	Amont-sansambaya	Balé	Niger		
GN0045	1171502502	Dabola	Tinkisso	Niger		1 260
GN0048	1171502507	Fifa	Tinkisso	Niger		
GN0049	1171502510	Tinkisso	Tinkisso	Niger	369	6 400
GN0052	1171502805	Koundeboun	Balé	Niger		
GN0057	1171503506	Baranama	Dion	Niger		590
GN0059	1171503508	Kolédougou	Dion	Niger		
GN0060	1171503509	Diamaradou	Dion	Niger		
GN0061	1171503605	Kodiana	Kouraé	Niger		
GN0062	1171503705	Gbeleba	Gbébon	Niger		
GN0068	1172600120	Pont Km 17	Bafing	Bafing		18
GN0070	1172600125	Sokotoro 2	Bafing	Bafing		
GN0072	1172601515	Salouma	Kioma	Bafing		775
GN0073	1172601519	Téliko	Kioma	Bafing		360
GN0075	1172602006	Bébélé	Téné	Bafing		3 470
GN0079	1172605005	Douréko	Samenta	Bafing		225
GN0081	1173200430	Nimba	Cavaly	Cavaly		244
GN0082	1173500110	Cogon Bac	Cogon	Cogon		2 845
GN0084	1173700105	Bac Diani	Diani	Diani		4 095
GN0086	1173702010	Kérémenzou	Oulé	Diani		1 029
GN0087	1173702015	Koliplita	Oulé	Diani		2 782
GN0088	1173702750	Sérédou	Véré	Diani		19,4
GN0089	1174000103	Bindan	Fatala	Fatala		5 107
GN0093	1174400115	Kromaya	Kaba	Kaba		1 128
GN0095	1174401921	Marela	Mongo	Kaba		671
GN0096	1174500105	Badera	Kolenté	Kolenté		2 747
GN0097	1174500106	Madina Oula	Kolenté	Kolenté		1 455
GN0099	1174500130	Tassin	Kolenté	Kolenté		6 609
GN0178	1174500141	Pont Kolenté	Kolenté	Kolenté		541
GN0108	1175000102	Yekemato	Konkouré	Konkouré	10	16 230
GN0109	1175000103	Friguia Pompage	Konkouré	Konkouré		
GN0110	1175000105	Pont Télimélé	Konkouré	Konkouré	154	10 250
GN0112	1175000108	Garafiri	Konkouré	Konkouré	287	2 480
GN0113	1175000109	Pont De Linsan	Konkouré	Konkouré		385
GN0114	1175000110	Kaleta Bac	Konkouré	Konkouré		10 886
GN0116	1175000112	Kaleta Crique	Konkouré	Konkouré		11 380
GN0120	1175001201	Bac De Badi	Badi	Konkouré	44	3 240
GN0122	1175002206	Kondonboufou	Kakrima	Konkouré		5 800
GN0123	1175002207	Kaba	Kakrima	Konkouré	272	2 730
GN0125	1175004002	Diawla	Kokoulo	Konkouré		401
GN0126	1175004003	Nianso	Kokoulo	Konkouré	228	2 260
GN0128	1175004903	Diambata	Sala	Konkouré		
GN0129	1175004905	Pont De Pellel	Sala	Konkouré		284
GN0133	1175006310	Kellico	Garambé	Konkouré		90
GN0147	1175400170	Yalenzou	Mani	Mani		179
GN0148	1175501913	Gueckédou	Makona	Makona		2 960
GN0149	1175501921	Nongoa	Makona	Makona		7 148
GN0150	1175504015	Nongoa	Mafissa	Makona		1 494
GN0152	1175504515	Gueckédougou	Ouaou	Makona		2 280
GN0155	1176500113	Gaoual	Tominé	Tominé		3 348
GN0159	1176501610	Gaoual	Koliba	Tominé		9 749
GN0162	1176503716	Komba Bac	Komba	Tominé		2 027
GN0179	1176503717	Komba Pont	Komba	Tominé		2 027
GN0166	1176504012	Komba	Ouességuélé	Tominé		820
GN0167	1176506305	Bantala Bac	Bantala	Tominé		1 568
GN0170	1177500150	Tan,ne	Tinguilinta	Tinguilinta		1 891
GN0174	1178001805	Fandié	Killy	Killy		240

C Details of the model input

Inflow series RIBASIM model

Inflows of Sélingué reservoir

Sélingué

m3/s	1	2	3	4	5	6	7	8	9	10	11	12
1980	98.6	60.4	39.9	19.6	39.8	68.0	57.5	424.0	1100.0	565.0	275.0	151.0
1981	46.3	27.0	17.3	11.0	42.7	89.3	314.5	824.5	1003.8	651.8	236.3	90.3
1982	41.8	39.1	36.2	56.9	78.7	142.3	269.2	620.4	1083.6	534.8	227.4	93.0
1983	44.7	42.4	33.7	41.9	53.3	137.9	232.1	614.5	691.9	408.5	128.8	54.6
1984	35.6	28.7	37.8	38.1	53.8	76.0	118.8	448.0	612.5	374.8	110.9	45.2
1985	26.5	24.4	33.0	36.5	46.2	59.1	182.7	746.9	1082.6	596.3	161.8	47.2
1986	27.6	30.2	34.4	52.2	59.3	68.3	91.0	367.7	906.0	451.2	184.9	38.5
1987	34.9	63.4	26.9	37.5	47.8	52.8	92.0	335.0	608.7	414.6	143.1	25.9
1988	30.6	53.9	19.7	21.8	34.6	51.1	119.0	350.2	656.0	303.7	50.6	20.5
1989	45.7	31.0	26.9	36.1	44.3	38.4	94.9	422.2	606.3	355.4	99.3	33.5
1990	23.0	42.6	29.2	28.0	86.9	88.6	213.2	609.1	634.9	423.0	134.3	40.1
1991	37.3	51.9	28.3	26.4	56.2	80.4	249.5	651.4	778.9	490.9	210.5	73.5
1992	31.2	58.9	52.3	25.7	47.7	91.2	207.9	566.9	1106.9	522.3	167.0	79.0
1993	26.5	45.1	69.1	37.3	70.3	78.9	138.5	485.6	864.9	544.5	196.8	81.0
1994	27.1	46.4	67.0	26.3	61.1	97.7	222.0	419.1	1004.3	1145.2	676.7	191.1
1995	81.8	86.4	47.6	51.1	68.7	69.7	78.5	701.7	1135.1	859.9	267.1	82.1
1996	81.2	74.1	71.1	72.0	94.4	77.2	88.5	432.9	913.6	711.9	216.4	77.3
1997	51.2	61.4	59.4	48.2	76.2	97.7	266.9	687.0	1191.3	631.0	211.0	87.3
1998	54.3	53.0	71.8	47.2	69.3	110.2	233.7	1021.8	1216.1	992.5	264.7	98.0
1999	64.5	72.7	69.9	76.2	77.3	36.1	118.6	429.6	1094.0	764.5	297.4	97.8
2000	83.3	42.6	68.3	50.3	77.2	154.3	209.4	679.8	972.4	768.3	287.0	104.0
2001	53.9	38.8	51.0	75.7	66.2	95.0	237.0	735.5	2369.5	787.0	251.5	113.0

Inflows of Fomi reservoir from Niandan

Niandan

m3/s	1	2	3	4	5	6	7	8	9	10	11	12
1980	62.3	36.2	20.4	9.4	13.7	35.9	108.3	546.7	947.1	396.9	297.7	148.0
1981	49.4	28.8	18.5	11.8	45.6	95.4	336.0	880.9	1072.4	696.4	252.4	96.4
1982	38.6	20.9	11.3	8.4	28.0	107.2	257.3	581.5	842.6	539.7	265.7	82.5
1983	33.5	18.7	11.4	6.1	8.9	83.6	238.9	543.2	877.4	598.9	188.7	74.9
1984	29.9	13.5	5.0	2.9	14.4	41.8	180.7	619.8	564.1	494.4	155.6	58.1
1985	23.1	9.9	3.4	2.1	2.5	6.7	161.9	696.4	1041.1	685.9	177.6	59.9
1986	21.4	8.3	2.3	1.4	2.6	10.0	79.0	445.7	981.9	633.7	226.0	67.2
1987	25.5	11.1	2.5	1.0	1.8	64.8	159.8	497.9	759.1	731.2	252.1	78.3
1988	28.3	11.7	3.6	1.6	1.1	10.6	114.9	567.5	1009.7	431.8	148.7	48.1
1989	18.2	7.8	3.5	2.3	2.5	19.6	80.8	383.0	748.6	602.4	183.8	73.8
1990	26.0	9.6	3.2	1.4	9.5	21.8	134.4	515.3	783.4	543.2	199.2	73.8
1991	27.8	9.6	3.7	2.3	3.0	24.9	145.5	501.4	724.2	605.8	250.0	81.1
1992	31.7	14.3	4.8	1.7	2.8	38.6	192.2	473.5	779.9	511.8	204.0	71.7
1993	27.3	11.6	6.5	3.9	6.7	26.2	104.1	536.2	675.5	536.2	284.8	102.7
1994	37.6	15.5	7.9	3.8	4.8	77.6	252.4	679.0	1424.1	1319.6	797.4	192.2
1995	78.0	35.2	16.8	15.6	22.0	48.7	149.4	828.7	1518.1	1239.6	435.2	141.7
1996	64.1	39.0	16.4	10.9	21.5	59.5	179.3	647.6	1239.6	1058.5	372.6	114.6
1997	49.8	24.4	9.9	5.3	13.9	61.6	244.8	543.2	1062.0	814.8	348.2	117.7
1998	48.4	22.5	12.3	5.2	9.4	67.5	207.9	807.8	1173.4	1058.5	317.5	98.9
1999	42.5	16.5	43.6	17.9	4.3	15.3	127.1	480.5	1229.1	1068.9	194.6	504.9
2000	69.3	31.9	14.8	9.1	18.0	82.5	227.7	623.3	1086.4	1149.0	487.5	156.0
2001	64.1	26.0	13.4	9.1	12.8	25.8	254.5	877.4	1535.5	846.1	317.2	161.6

Inflows of Niger tributaries upstream of Banankoro, exclusive Niandan

Niger

m3/s	1	2	3	4	5	6	7	8	9	10	11	12
1980	116.7	67.8	38.3	17.5	25.7	67.1	202.7	1023.3	1772.9	743.1	557.3	277.0
1981	92.6	53.9	34.6	22.1	85.4	178.6	629.0	1649.1	2007.6	1303.6	472.6	180.6
1982	72.4	39.0	21.2	15.7	52.3	200.8	481.7	1088.5	1577.4	1010.3	497.3	154.5
1983	62.6	34.9	21.2	11.5	16.7	156.4	447.1	1016.8	1642.6	1121.1	353.3	140.1
1984	56.0	25.4	9.3	5.4	27.0	78.2	338.3	1160.2	1055.9	925.6	291.4	108.9
1985	43.2	18.5	6.3	3.9	4.8	12.4	303.1	1303.6	1948.9	1284.1	332.4	112.1
1986	40.0	15.4	4.3	2.5	4.8	18.8	148.0	834.3	1838.1	1186.3	423.0	125.8
1987	47.8	20.7	4.8	2.0	3.3	121.2	299.2	932.1	1420.9	1368.8	471.9	146.7
1988	53.1	22.0	6.6	3.0	2.2	19.7	215.1	1062.5	1890.3	808.2	278.3	89.9
1989	34.0	14.6	6.5	4.3	4.8	36.6	151.2	717.0	1401.4	1127.6	344.2	138.2
1990	48.8	18.1	5.9	2.7	17.8	40.7	251.6	964.7	1466.6	1016.8	372.8	138.2
1991	52.0	17.9	7.0	4.3	5.6	46.5	272.5	938.6	1355.8	1134.2	468.0	151.9
1992	59.3	26.9	9.1	3.3	5.3	72.4	359.8	886.5	1460.1	958.2	382.0	134.3
1993	51.2	21.6	12.3	7.4	12.4	49.0	194.9	1003.8	1264.5	1003.8	533.2	192.3
1994	70.4	29.0	14.8	7.0	9.1	145.4	472.6	1271.0	2665.9	2470.4	1492.6	359.8
1995	146.0	65.8	31.5	29.1	41.3	91.3	279.6	1551.3	2841.9	2320.4	814.8	265.3
1996	119.9	73.0	30.7	20.5	40.3	111.5	335.7	1212.4	2320.4	1981.5	697.4	214.4
1997	93.2	45.6	18.6	10.0	26.0	115.4	458.2	1016.8	1988.0	1525.2	651.8	220.3
1998	90.6	42.1	23.0	9.6	17.5	126.5	389.1	1512.2	2196.6	1981.5	594.5	185.1
1999	79.5	31.0	81.5	33.5	8.0	28.5	237.9	899.5	2300.9	2001.1	364.4	945.1
2000	129.7	59.6	27.8	16.9	33.7	154.5	426.3	1166.7	2033.6	2151.0	912.5	292.0
2001	119.9	48.6	25.0	16.9	24.0	48.2	476.5	1642.6	2874.5	1583.9	593.8	302.4

Inflows of Talo reservoir from Bani river

Bani

m3/s	1	2	3	4	5	6	7	8	9	10	11	12
1980	37.4	17.2	6.4	2.4	2.7	18.2	50.9	341.6	896.0	491.2	145.6	58.0
1981	33.8	20.7	5.4	1.9	11.4	16.9	69.7	638.4	1136.0	658.4	182.4	67.8
1982	30.4	14.3	5.5	2.8	5.8	29.0	67.1	295.2	601.6	332.8	140.0	56.0
1983	23.3	8.4	2.9	1.3	2.9	16.7	37.9	112.0	231.2	191.2	53.8	18.3
1984	5.8	2.1	0.7	0.2	0.0	43.4	19.4	80.0	203.2	230.4	67.4	19.5
1985	5.9	1.8	0.6	0.1	0.0	6.4	84.0	249.6	527.2	412.8	104.0	32.4
1986	8.7	3.0	1.0	0.3	0.2	11.7	49.1	174.4	472.8	312.8	91.2	30.3
1987	8.6	3.1	1.0	0.2	0.0	6.6	17.8	120.8	268.8	270.4	91.2	23.5
1988	5.6	2.2	0.7	0.2	0.0	5.0	136.8	403.2	952.0	645.6	179.2	49.9
1989	16.1	6.8	2.8	1.0	0.4	1.1	28.6	300.0	808.0	459.2	120.0	37.2
1990	13.2	5.8	1.6	0.4	0.1	2.6	100.0	512.8	441.6	303.2	94.4	34.6
1991	11.2	3.3	0.8	0.2	0.1	32.7	48.3	433.6	699.2	396.0	179.2	60.5
1992	26.0	10.9	2.9	0.8	0.4	23.2	47.5	180.8	563.2	362.4	120.8	46.6
1993	18.0	6.2	1.4	0.4	0.1	0.2	75.8	184.0	551.2	336.0	118.4	44.8
1994	19.1	6.0	1.3	0.3	0.2	19.8	101.6	736.8	1176.0	1288.0	872.0	264.8
1995	76.4	41.0	19.1	8.2	8.8	32.2	41.9	362.4	713.6	656.8	282.4	87.2
1996	38.6	14.7	4.2	1.4	1.0	27.8	51.2	410.4	654.4	536.0	190.4	63.7
1997	27.0	7.7	1.7	0.6	5.0	33.3	67.8	404.0	793.6	456.0	167.2	61.0
1998	25.0	7.4	3.4	5.4	14.2	61.6	82.4	645.6	1248.0	1200.0	446.4	96.8
1999	44.6	17.6	46.3	19.0	4.6	8.4	122.4	1040.0	1696.0	1272.0	524.8	164.8
2000	69.7	38.9	14.1	4.6	2.7	29.0	94.4	653.6	1008.0	764.8	337.6	108.0
2001	50.2	20.1	5.6	1.4	0.7	10.2	158.4	493.6	928.0	628.8	176.8	66.0

Inflows downstream of Talo reservoir

Bani downstream Talo

m3/s	1	2	3	4	5	6	7	8	9	10	11	12
1980	9.3	4.3	1.6	0.6	0.7	4.6	12.7	85.4	224.0	122.8	36.4	14.5
1981	8.5	5.2	1.4	0.5	2.9	4.2	17.4	159.6	284.0	164.6	45.6	17.0
1982	7.6	3.6	1.4	0.7	1.5	7.3	16.8	73.8	150.4	83.2	35.0	14.0
1983	5.8	2.1	0.7	0.3	0.7	4.2	9.5	28.0	57.8	47.8	13.5	4.6
1984	1.5	0.5	0.2	0.1	0.0	10.8	4.8	20.0	50.8	57.6	16.9	4.9
1985	1.5	0.5	0.2	0.0	0.0	1.6	21.0	62.4	131.8	103.2	26.0	8.1
1986	2.2	0.7	0.3	0.1	0.1	2.9	12.3	43.6	118.2	78.2	22.8	7.6
1987	2.2	0.8	0.2	0.1	0.0	1.7	4.5	30.2	67.2	67.6	22.8	5.9
1988	1.4	0.6	0.2	0.0	0.0	1.3	34.2	100.8	238.0	161.4	44.8	12.5
1989	4.0	1.7	0.7	0.2	0.1	0.3	7.2	75.0	202.0	114.8	30.0	9.3
1990	3.3	1.5	0.4	0.1	0.0	0.6	25.0	128.2	110.4	75.8	23.6	8.7
1991	2.8	0.8	0.2	0.1	0.0	8.2	12.1	108.4	174.8	99.0	44.8	15.1
1992	6.5	2.7	0.7	0.2	0.1	5.8	11.9	45.2	140.8	90.6	30.2	11.6
1993	4.5	1.5	0.4	0.1	0.0	0.0	18.9	46.0	137.8	84.0	29.6	11.2
1994	4.8	1.5	0.3	0.1	0.0	5.0	25.4	184.2	294.0	322.0	218.0	66.2
1995	19.1	10.3	4.8	2.0	2.2	8.0	10.5	90.6	178.4	164.2	70.6	21.8
1996	9.7	3.7	1.1	0.3	0.2	7.0	12.8	102.6	163.6	134.0	47.6	15.9
1997	6.7	1.9	0.4	0.2	1.3	8.3	17.0	101.0	198.4	114.0	41.8	15.2
1998	6.3	1.8	0.9	1.4	3.5	15.4	20.6	161.4	312.0	300.0	111.6	24.2
1999	11.2	4.4	11.6	4.8	1.1	2.1	30.6	260.0	424.0	318.0	131.2	41.2
2000	17.4	9.7	3.5	1.1	0.7	7.3	23.6	163.4	252.0	191.2	84.4	27.0
2001	12.6	5.0	1.4	0.3	0.2	2.6	39.6	123.4	232.0	157.2	44.2	16.5

Reservoir Characteristics

Sélingué reservoir (existing)

Level (m)	Area (ha)	Volume (Mm^3)
338.0	0	0.00
341.0	11000	83.60
342.0	13200	203.72
343.0	16500	360.38
344.0	20100	546.52
345.0	25000	762.00
346.0	30000	1049.00
347.0	34000	1383.41
348.0	39000	1670.95
349.0	45000	2135.40

Full reservoir level = +349.00 m
Dead storage level (lowest gate level) = +338.5 m
Initial level at start of simulation = +349 m

Fomi reservoir (planned)

Level (m)	Area (ha)	Volume (Mm^3)
351.0	0	0.00
360.0	10000	1000.00
370.0	20000	1800.00
380.0	45000	2460.00
390.5	50700	6160.00

Full reservoir level = +390.5 m
Dead storage level (lowest gate level) = + 380 m
Initial level at start of simulation = +390 m

Talo reservoir (planned)

Level (m)	Area (ha)	Volume (Mm^3)
268.3	0	0.00
269.3	2000	20.00
270.3	3000	50.00
271.3	3500	78.00
272.3	4000	108.00
273.3	4500	138.00
274.3	5000	175.60

Full reservoir level = +274.3 m
Dead storage level (lowest gate level) = + 269 m
Initial level at start of simulation = +274 m

Evaporation, precipitation and net evaporation from the reservoirs

Month	Evaporation (mm/day)	Precipitation (mm/day	Net evaporation (mm/day)
Jan	6.3	0.0	6.3
Feb	7.1	0.0	7.1
Mar	7.2	0.1	7.2
Apr	6.4	0.7	5.8
May	5.3	1.8	3.5
Jun	4.0	4.4	-0.4
Jul	3.3	7.4	-4.1
Aug	3.4	9.6	-6.3
Sep	4.1	6.6	-2.5
Oct	5.1	2.1	2.9
Nov	5.7	0.2	5.5
Dec	5.8	0.0	5.8

Total annual evaporation
1932 mm

Total annual precipitation
1009 mm

Total annual net evaporation
1932 - 1009 = 923 mm

Hydropower generation (more details in Annex D)

Sélingué power plant (existing)

Net head (m)	Power capacity (MW)
0	0
8	26.0
14	43.0
16	47.6
18	47.6

Max. capacity at full head = 4 * 11.9 = 47.6 MW
Intake level = +339 m
Tail race level = +331 m (assumed to apply for all turbine discharges)
Generating efficiency is assumed to be 85 % for all heads (including head losses)

Fomi power plant (planned)

Net head (m)	Power capacity (MW)
0	0
17.0	53.5
18.6	58.5
20.6	64.8
22.6	71.1
24.6	77.4
26.6	83.7
28.6	90.0

Max. capacity at full head = 90 MW
Intake level = + 380.4 m
Tail race level = +363.4 m (assumed to apply for all turbine discharges)
Generating efficiency is assumed to be 85 % for all heads (including head losses)

Irrigation

Périmètre Sélingué

Month	Area (ha)	Water demand (mm/day)	Irrigation efficiency (%)	Water demand to river (m^3/s)
Jan	1500	5.8	50	2.0
Feb	1500	7.2	50	2.5
Mar	1500	7.2	50	2.5
Apr	1500	7.2	50	2.5
May	1500	4.3	50	1.5
Jun	1500	2.9	50	1.0
Jul	1500	2.9	50	1.0
Aug	1500	4.3	50	1.5
Sep	1500	5.8	50	2.0
Oct	1500	5.8	50	2.0
Nov	1500	4.3	50	1.5
Dec	1500	2.9	50	1.0

The surface water return flow from the périmètre Sélingué is assumed to be 30 % of the abstraction from the Sélingué reservoir.

Périmètre Office du Niger

Month	Area (ha)	Water demand (mm/day)	Irrigation efficiency (%)	Water demand to river (m^3/s)
Jan	15000	17.3	50	60.0
Feb	15000	20.2	50	70.0
Mar	15000	23.0	50	80.0
Apr	15000	23.0	50	80.0
May	60000	7.2	50	100.0
Jun	60000	7.2	50	100.0
Jul	60000	8.6	50	120.0
Aug	60000	8.6	50	120.0
Sep	60000	9.4	50	130.0
Oct	60000	9.4	50	130.0
Nov	60000	7.9	50	110.0
Dec	60000	7.2	50	100.0

The surface water return flow from the Office du Niger is assumed to be 10 % of the abstraction via the inlet from the Markala weir. The mm/day demands in Jan - Apr seem high and probably need correction (or the areas c.q. water demands need some correction).

Périmètre Baguinéda

Month	Area (ha)	Water demand (mm/day)	Irrigation efficiency (%)	Water demand to river (m^3/s)
Jan	2500	10.4	50	6.0
Feb	2500	10.4	50	6.0
Mar	2500	10.4	50	6.0
Apr	2500	10.4	50	6.0
May	2500	10.4	50	6.0
Jun	3500	11.1	50	9.0
Jul	3500	11.1	50	9.0
Aug	3500	11.1	50	9.0
Sep	3500	11.1	50	9.0
Oct	3500	11.1	50	9.0
Nov	3500	11.1	50	9.0
Dec	3500	11.1	50	9.0

The surface water return flow from the Périmètre Baguinéda is assumed to be 30 % of the abstraction from the diversion at Sotuba.

Périmètre Talo

Month	Area (ha)	Water demand (mm/day)	Irrigation efficiency (%)	Water demand to river (m^3/s)
Jan	0	0.0	50	0.0
Feb	0	0.0	50	0.0
Mar	0	0.0	50	0.0
Apr	0	0.0	50	0.0
May	0	0.0	50	0.0
Jun	0	0.0	50	0.0
Jul	0	0.0	50	0.0
Aug[3]	20320	10.6	50	50.0
Sep	20320	10.6	50	50.0
Oct	20320	10.6	50	50.0
Nov	20320	10.6	50	50.0
Dec	0	0.0	50	0.0

The return flow from the périmètre Talo is assumed to be 30 % of the abstraction from the diversion of the Talo.

Périmètre Office du Riz Mopti

Month	Area (ha)	Water demand (mm/day)	Irrigation efficiency (%)	Water demand to river (m^3/s)
Jan	0	0.0	50	0.0
Feb	0	0.0	50	0.0
Mar	0	0.0	50	0.0
Apr	0	0.0	50	0.0
May	0	0.0	50	0.0
Jun	0	0.0	50	0.0
Jul	0	0.0	50	0.0
Aug	30000	8.0	50	9.0
Sep	30000	8.0	50	9.0
Oct	30000	8.0	50	9.0
Nov	30000	8.0	50	9.0
Dec	0	0.0	50	0.0

The return flow from the périmètre Office du Riz Mopti is assumed to be 40 % of the abstraction from the Mopti lake.

[3] *Irrigation at Talo starts at 20 August and ends at 20 November*

Périmètre Djenné

Month	Area (ha)	Water demand (mm/day)	Irrigation efficiency (%)	Water demand to river (m^3/s)
Jan	0	0.0	50	0.0
Feb	0	0.0	50	0.0
Mar	0	0.0	50	0.0
Apr	0	0.0	50	0.0
May	0	0.0	50	0.0
Jun	0	0.0	50	0.0
Jul	0	0.0	50	0.0
Aug[4]	85000	10.6	50	208.6
Sep	85000	10.6	50	208.6
Oct	85000	10.6	50	208.6
Nov	85000	10.6	50	208.6
Dec	0	0.0	50	0.0

The return flow from the périmètre Djenné is assumed to be 40 % of the abstraction from Bani.

Périmètre Ségou-1

Month	Area (ha)	Water demand (mm/day)	Irrigation efficiency (%)	Water demand to river (m^3/s)
Jan	0	0.0	50	0.0
Feb	0	0.0	50	0.0
Mar	0	0.0	50	0.0
Apr	0	0.0	50	0.0
May	0	0.0	50	0.0
Jun	0	0.0	50	0.0
Jul	0	0.0	50	0.0
Aug	30000	7.0	50	48.6
Sep	30000	7.0	50	48.6
Oct	30000	7.0	50	48.6
Nov	30000	7.0	50	48.6
Dec	0	0.0	50	0.0

The return flow from the périmètre Ségou-1 is assumed to be 30 % of the abstraction from the Niger.

[4] *Irrigation at Djenné starts at 25 August and ends at 1 December*

Périmètre Ségou-2

Month	Area (ha)	Water demand (mm/day)	Irrigation efficiency (%)	Water demand to river (m^3/s)
Jan	0	0.0	50	0.0
Feb	0	0.0	50	0.0
Mar	0	0.0	50	0.0
Apr	0	0.0	50	0.0
May	0	0.0	50	0.0
Jun	0	0.0	50	0.0
Jul	0	0.0	50	0.0
Aug	30000	7.0	50	48.6
Sep	30000	7.0	50	48.6
Oct	30000	7.0	50	48.6
Nov	30000	7.0	50	48.6
Dec	0	0.0	50	0.0

The return flow from the périmètre Ségou-2 is assumed to be 30 % of the abstraction from the Niger.

D Hydropower generation Selingue

DNHE provided time series of hydropower generation at Sélingué for Jan 1982 - Jul 2003. This provides insight into the actually generated energy compared with firm energy and theoretical power capacity.

The first figure below shows the relation between the average monthly turbine flows and the average monthly reservoir level. Apparently the turbines operate up to a reservoir level of +349m, although in some publications the normal maximum water level of the reservoir is stated as +348.5 m.

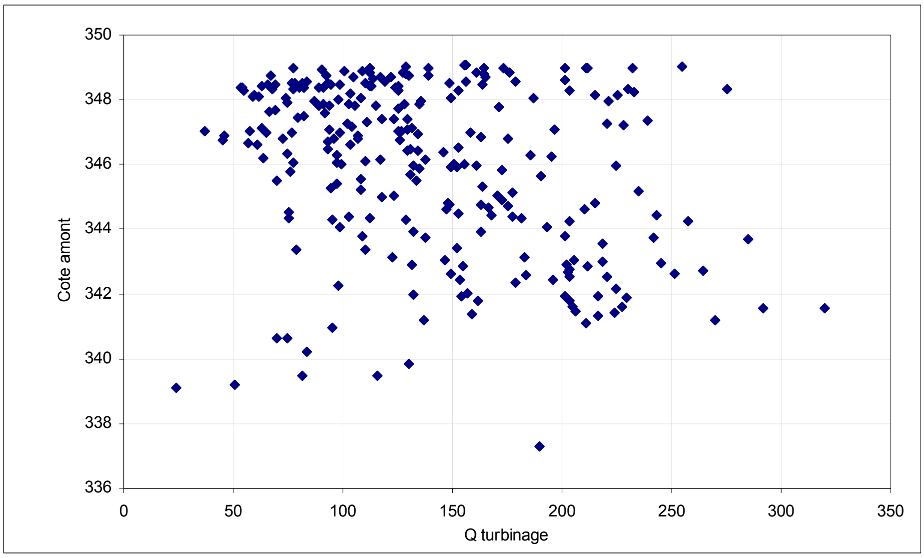

Figure D.1 - Sélingué: turbine flow versus reservoir level

The second figure shows the relation between the turbine flows and the monthly generated energy.

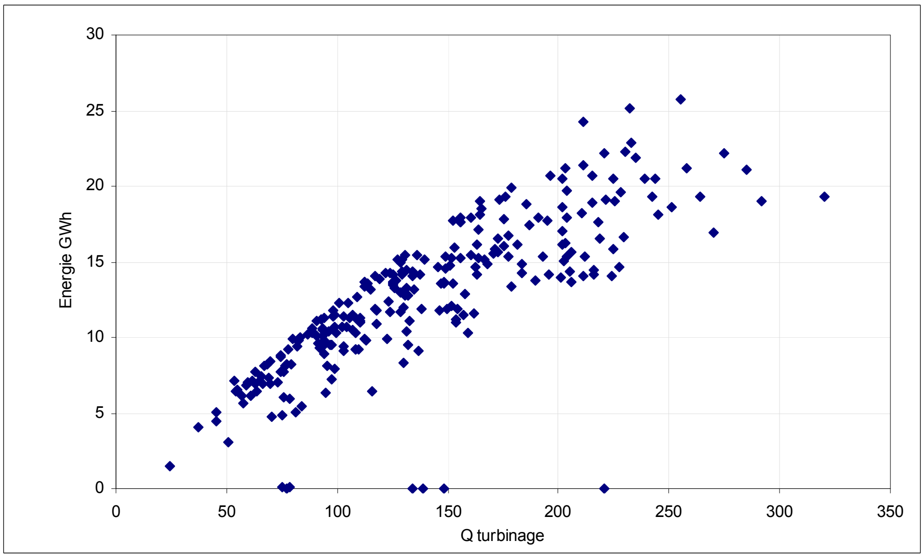

Figure D.2 - Sélingué: average turbine flow versus monthly generated energy.

Theoretically the installed capacity of 47.6 MW could produce 34.8 GWh per month under the condition that all four turbines are available and the available head is maximum, or in other words: the reservoir is full. The figure shows that the maximum generated energy was around 25 Gwh/month, so around 70 % of the theoretical value. The specified firm energy of 18 MW corresponds to about 13 GWh/month. In about 50% of the months the firm energy is generated or exceeded.

The last figure shows the reservoir level versus the monthly generated energy.

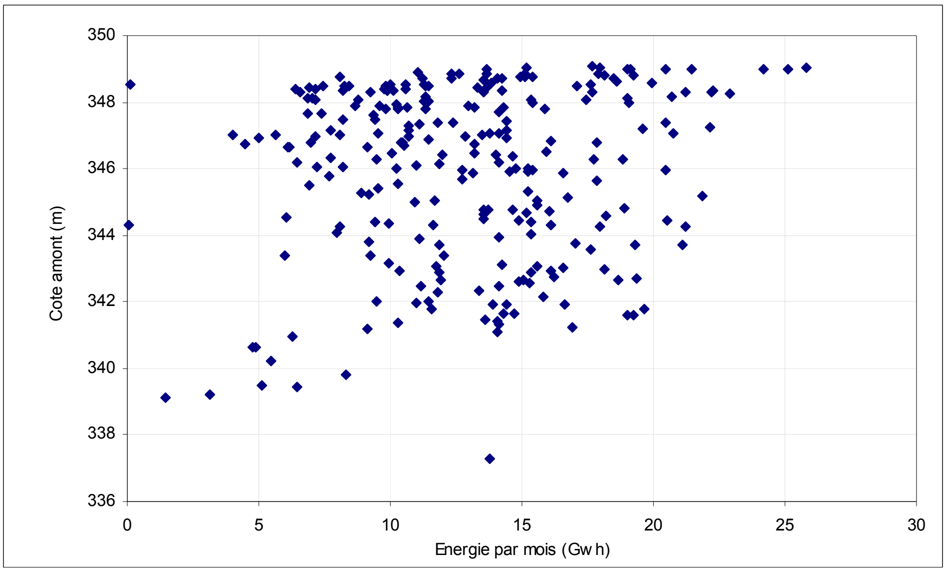

Figure D.3 - Sélingué: reservoir level versus monthly generated energy.

E Course in the application of RIBASIM

In February 2004 a Course was given at the Office of DNHE in Bamako in the application of RIBASIM in water resources management. The Course was given by Mr Rob Maaten of WL | Delft Hydraulics and took 3 days. A summary of the Course is given in the following Memo.

From 7 till 15 February 2004 a mission was undertaken to Mali, as part of the project 'Integrated Water Resources Modelling of the Upper Niger River (Mali)'. The aim of the mission was to give personnel of the Diréction Nationale de l'Hydraulique (DNHE) in Bamako an introduction and first training in the use of the WL | Delft Hydraulics' software package RIBASIM (RIver BAsin SIMulation). RIBASIM will be used to determine the possible impacts of developments in the upstream part of the Niger on the Delta Intérieur of this river.

As part of the Course, an official CD with the RIBASIM program was given to DNHE, together with three hardcopies of the manual.

Activities per day

Saturday 7 February 2004
Travel to Bamako via Paris with Air France. Arrival at Bamako at 20h30. I meet Leo Zwarts of RIZA, who is also in the plane, who is on its way to meetings with Wetlands International in Mopti. We are both picked up by Navon Cissé and the project driver. Leo is taken by the project driver, and Navon Cissé brings me to the Kempinski Hotel, which is close to DNH office.

Sunday 8 February 2004
Discover Bamako and prepare my presentation to the DNH team.

Monday 9 February 2004
Picked up by DNH car for first visit to DNH. It appears that DNH is at only 10 minutes walking distance from the hotel, so for the rest of the week no further transport needed.
Discussion with Navon Cissé about the project and my programme for this week. Course hours set to 9 – 12:30 and 14 – 16 hours. Introduced to the DNH team members in the computer room. Courtesy visit to Mr Sidi Touré, the Chef de la Division Inventaire des Ressources Hydrauliques. Installation of RIBASIM (version 6.32) on two DNH computers. Handover of 3 sets of the RIBASIM manuals (2 volumes).

Tuesday 10 February 2004
Start of the RIBASIM course. Four DNH staff members participate:
- Mr Navon Cissé
- Mr Bréhima Coulibaly
- Mr Dounanké Coulibaly
- Mr Tamba Kanouté

Start with a PowerPoint presentation on RIBASIM: introduction, field of application, principles.
The presentation is followed by a demonstration of RIBASIM on one pc (example Nile basin): how to build a network, fill it with input data, make a simulation and analyse results.

In the afternoon the DNH team starts exercising with RIBASIM on the two DNH computers.

Wednesday 11 February 2004
The team starts to construct a RIBASIM network of the Niger in Mali, which should comprise all necessary elements of the basin: reservoirs, irrigation areas, minimum flow sections, etc. Discussions on how to represent the reality with the standard tools of RIBASIM.

Thursday 12 February 2004
Refining of the RIBASIM schematisation. Concentration on the input data needed by each element in the network (reservoir volumes, irrigated areas, flows, etc). Further data to be sent later to Delft.

Friday 13 February 2004
Courtesy visit to Mr Amadou Guindo, Dirécteur national adjoint of DNH.
Make the French Midin model of the Delta Intérieur operational at a DNH PC.

Fieldtrip in the Bamako region with Navon Cissé and Tamba Kanouté:

- Prises d'eau upstream of Bamako (north-bank), visit to the facilities with a staff member of Mali Energie.
- Weir at Sotuba, Bamako (south-bank), inlet to the canal to the irrigation area Baguineda (3000 ha) and the run-of-river hydroelectric power plant. As it is dry season now, the river can be crossed here over the dam (which is submerged in the wet season). Visit to the north-side of the weir (barrage Damanda 1928).

Last discussions in the DNH office with the team. Explanation on how to produce hydrological time series for RIBASIM. Copy of the most detailed RIBASIM schematisation to the other DNH pc and to my laptop, for further completion in Delft.

Saturday 14 February 2004
Further discovery of Bamako. Picked up around 21h by Navon Cissé for transfer to airport. Departure to Paris with about half an hour delay.

Sunday 15 February 2004
Arrival in Paris at 6:30h (on time). Transfer and arrival in Amsterdam at 9.00h. End of mission.

F Final Course RIBASIM and Integrated Water Resources Management

From 16 till 24 October 2004 Mr Rob Maaten of WL | Delft Hydraulics undertook a second mission to Mali, as part of the project 'Integrated Water Resources Modelling of the Upper Niger River (Mali)'. The aim of the mission was:

- To give personnel of the Direction Nationale de l'Hydraulique (DNH) in Bamako further training in the use of the WL | Delft Hydraulics' software package RIBASIM (RIver BAsin SIMulation). Ribasim was used to determine the possible impacts of developments in the upstream part of the Niger on the Delta Intérieur of this river.
- To discuss the results of the study as described in Delft's final report. Comments of DNH, the Dutch embassy and Wetland International are still welcome before Delft will produce the final edition of the report.
- To give presentations on the study results and on integrated water resources management in general to DNH staff of the Bamako office, to regional staff in Ségou and Mopti, and to a representative of Wetland International.

Activities per day

Saturday 16 October 2004
Travel to Bamako via Paris with Air France. Arrival at Bamako at 20h20. Navon Cissé welcomes me at the airport. In spite of having taken an earlier flight AMS-CDG my luggage does not appear on the belt. Air France says that it will surely come with tomorrow's flight.

Sunday 17 October 2004
Walking through Bamako and preparing things for the rest of the week. At 19h Air France informs that my luggage is in this day's flight. After midnight it finally arrives in the hotel.

Monday 18 October 2004
Discussion with Navon Cissé about the last developments in the project after his visit to Delft in June, and on my programme for this week. It is the first week of Ramadan, Navon warns that attention of the DNH staff will fall back in the afternoon hours. I give Navon a copy of our final report and invite him to give comments before we make the final edition.
After this I continue with the installation of RIBASIM (version 6.33) and the last version of the Niger basin schematisation on two DNH computers. Handover of a new set of the RIBASIM manuals (2 volumes, now for 6.32 with an addendum for 6.33).
In February all effort was in preparing a network, now I explain the DNH staff (Navon already knows from his mission to Delft) how to make calculations and analyse the results. We make test runs to explain how priorities and sources in RIBASIM can be applied.
Mr Al Moustapha Fofana attends the whole day. He is very interested. Unfortunately for the rest of the week he will continue with his current task: the yearly current measurements in the Upper Niger to check the rating curves.
During the many test runs Mr Coulibaly becomes aware that you should work with clear run identifications and make also notes on paper to keep track of 'what is in what run'.

Tuesday 19 October 2004

Courtesy visit to Mr Sidi Touré, the Chef de la Division Inventaire des Ressources Hydrauliques. Continuation with the RIBASIM exercises. Two DNH staff members participate:

- Mr Navon Cissé
- Mr Bréhima Coulibaly

Two members of the February course do not participate now: Mr Dounanké Coulibaly cannot attend because his father has died, Mr Tamba Kanouté has other tasks at this moment.

More runs with RIBASIM: extension of Office du Niger simulated, while demanding yes or no to upstream reservoirs. Also explanation of RIBASIM's CAT (Case Analysis Tool) and how to export RIBASIM results to Excel (via csv- or dbf-files). In the afternoon I install the last RIBASIM version on the two DNH laptops.

Wednesday 20 October 2004

A DNH car takes me to the Dutch embassy for a meeting with Peter de Vries (Chef de Mission Adjoint) and Jaap van der Velden (Premier Sécrétaire, Développement Rural). I explain the results of our study and handover the final report to de Vries, with a request that any comment is welcome (via Leo Zwarts of RIZA) before we make the final edition.

Back at DNH I continue working with Coulibaly and Navon on RIBASIM options: firm energy, the different outlets of a reservoir, and rule curves.

Thursday 21 October 2004

From 9-13 hr the GIRE course (Gestion Intégrée des Ressources en Eau). For programme: see Annex 1. List of attendants as below:

1. Mr Navon Cissé, DNH, Bamako
2. Mr Modibi Sidibe, Hydrologist DRHE in Ségou
3. Mr Ibrahim Sidibe, Hydrologist DRHE in Mopti
4. Mr Mory Diallo, Wetland International in Mopti (I give him Delft's report for Mr Kone)
5. Mr N'Tjiè Coulibaly, Hydrologist at DNH, Bamako
6. Mr Bréhima Coulibaly, Hydrologist at DNH, Bamako
7. Mr Tamba Kanouté, Hydrologist at DNH, Bamako
8. Mr Seydou Maiga, Hydrogéologue, DNH, Bamako

Mr Sidi Touré, Chef de la Division Inventaire des Ressources Hydrauliques opens the course. The first presentation is held by Mr Housseini Amadou Maiga, chef de la Cellule GIRE at DNH. He is the key person on GIRE at DNH and has frequent contacts with the GWP (Global Water Partnership) and the donors. World Bank and CIDA (Canada) seem to be the main funding agencies for GIRE activities in Mali. There is a Code de l'Eau 2002 in which GIRE already got some place.

Up till now the efforts are concentrated on organisational aspects and the 'process'. Mr Maiga gets many questions from DNH, in particular from the region. There is a lively discussion. Everybody is quite interested. This continues after my presentations. Apparently the course also serves as a place for regional and Bamako DNH to meet.

My presentation on RIBASIM is also attended by Mr Touré. It seems that he now realises what RIBASIM is and what we are doing.

Friday 22 October 2004

From 9 – 12 the second part of the GIRE course. Presentation of the results of the now finished study by Delft. My second presentation treats the GIRE analytical and computational framework. Examples of other RIBASIM studies shown and shown what other Delft software is used in GIRE studies: HYMOS, SOBEK. The session ends with a discussion on items that should get attention in a follow-up of the present study (see Annex at end of this summary for the suggestions). The geohydrologist strongly advises that groundwater must also get a place then.
After a photo is taken of the participants, everybody leaves for Ramadan obligations, departure to the region, etc.
In the afternoon I get a phone call from Jaap van der Velden of the Dutch Embassy. He is in a meeting with people from CDP and Ecorys on the Office du Niger. He would like me to show something on the Delft study. With a taxi I go to the embassy and explain some results of our study and show something of RIBASIM. The main subject of the meeting is institutional aspects of OffNiger, so I do not further participate and go back to the hotel.

Saturday 23 October 2004

Long walk in Bamako. Visit the zoo on the hill north of Bamako. Prepare this mission report. Departure to Paris at 23:00 with AF791.

Sunday 24 October 2004

Arrival in Paris at 6:30 (on time). Transfer and arrival in Amsterdam at 11:00h. End of mission.

Programme for 21-22 October 2004

WL | delft hydraulics

Gestion Intégrée des Ressources en Eau
Bamako, 21-22 octobre 2004

Programme

Jeudi

- Gestion Intégrée des Ressources en Eau: Cas du Mali (Maiga)
- Présentation des principes généraux de la GIRE (Maaten)
- Le logiciel RIBASIM (Maaten)

Vendredi

- Résultats de l'étude sur le Niger au Mali avec RIBASIM (Maaten)
- Cadre d'analyse et informatique, autres projets et logiciel (Maaten)
- Suivi de la présente étude ....? Désirs, recommandations, …..

Suggestions for follow-up study

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Suggestions pour suivi du projet

- Eau souterraine
- Modélisation plus détaillée de l'irrigation (prendre en compte la pluie)
- Modélisation du système interne de l'ON
- Qualité de l'eau
- Prévision des crues, système d'alerte
- Hymos? Equipement pour backup
- Langue française
- Hauteurs d'eau dans les lacs du delta à inclure en Ribasim
- ……