A&W ECOLOGISCH ONDERZOEK

Towards a further extension of the OPIDIN tool

A&W-report 1514

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Towards a further extension of the OPIDIN tool

A&W rapport 1514

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Photo front
Diafarabé, Inner Delta, november 2009

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1 Introduction

OPIDIN[1] is a predictive model to forecast the flooding of the Inner Niger Delta when the water starts to raise. A first version of OPIDIN[2] was developed in 2009 within a study carried out by Royal Haskoning (lead), Altenburg & Wymenga Ecological Consultants and Wetland International. This study was financed by “Partners for Water”, a joint initiative of six departments of the Government of the Netherlands.

Wetlands International (Sévéré) took the initiative to explore the possibilities to extend the model and asked A&W to investigate how OPIDIN may be extended and improved.

The work was done in the framework of the Wetland & Livelihoods Project: *GIRE (Gestion integrée de resources naturelles) dans le basin du Niger en amont de Taoussa*. Given the changes to be expected in the Inner Niger Delta due to the ongoing climate change, predicting the flood will become more important. Moreover, OPIDIN may function as an early warning system and thus be an essential tool for the people, being either fishermen or farmers, to achieve food security.

[1] Acronym for **O**util de **P**rediction des **I**nondations dans le **D**elta **I**ntérieur du **N**iger
[2] Zwarts, L. (2009). - Predicting the annual peak flood level in the Inner Niger Delta. A&W-rapport 1254. Altenburg & Wymenga, ecological consultants, Feanwâlden. 18 pp.

2 The present model

In a year with a high peak flood level in the Inner Delta, the flood lasts four months longer than in a year with a low flood. As shown in Fig. 1, the wave comes in a wet year one month earlier and continues for an additional three months. To construct this figure, all daily measurements in Mopti (southern Delta) since 1944 were subdivided into six categories on the basis of the highest water level in that particular year. There are three years with a maximum flood between 450 and 500 cm (1984/5, 1987/8, 1993/4). For these three years the average water level per date is calculated. The same is done for the other categories: 500 – 550 cm (n = 6), 550 – 600 cm (n = 9), 600 – 650 cm (n = 7), 600 – 650 cm (n = 20) and 650 – 700 cm (n = 12). Besides the fact that the flood wave lasts longer with a higher flood, Fig. 1 shows that the peak level is reached more than a month later if the flood is high.

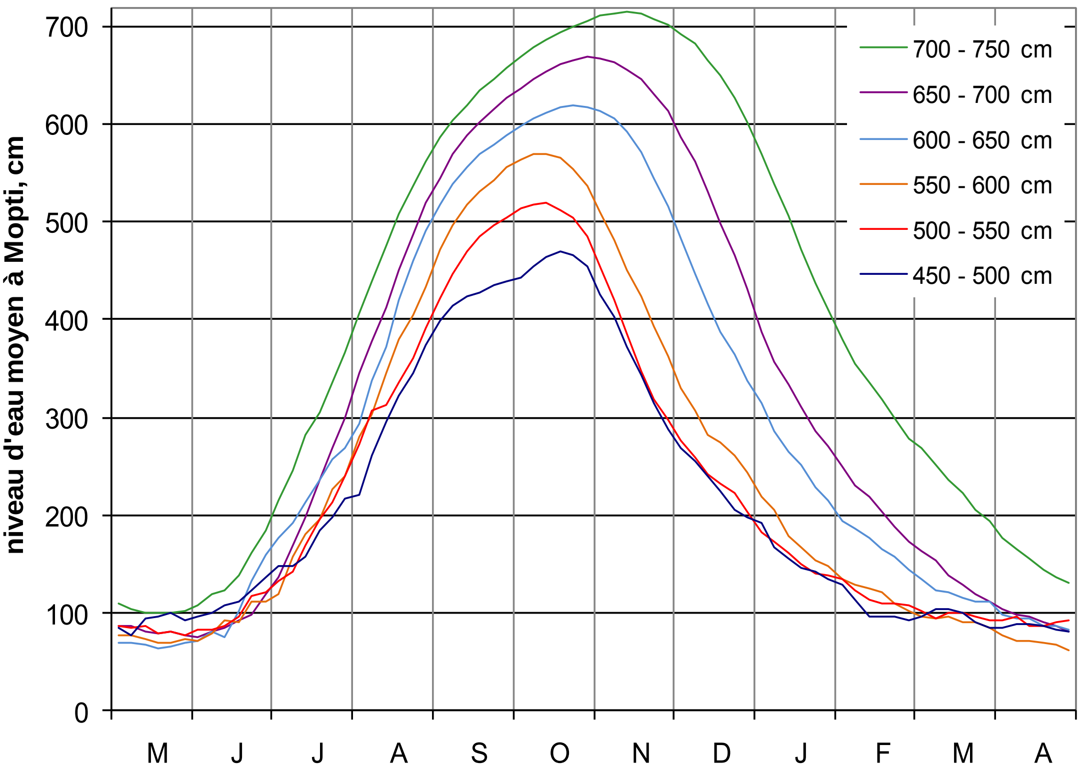


***Figure 1**. Average daily water level in Mopti during the hydrological year (1 May – 31 April) for six different flood levels. The daily water level in Mopti has been measured since 1922 and made available to us by DNH. The data since 1944 were split up in six categories: years during which the maximal flood level varied between 450 and 500 cm, 500 and 550 cm, etc. From: Zwarts, L. and Grigoras, I. 2005. Flooding of the Inner Niger Delta. - In: Zwarts, L., Beukering van, P., Kone, B. and Wymenga, E. (eds.), The Niger, a lifeline. RIZA/Wetlands International/IVM/A&W, pp. 43-77.*

Fig. 1 shows six flood curves, based on readings of the scale at Mopti. The water level in Mopti is in May-June, on average, 100 cm on the local scale. In dry years, the flood level rises 380 cm above this level, but in wet years more than 600 cm. Fig. 1 shows that, again on average, the water level in June, and even in July, cannot be used to foretell the peak flood level. However, when the water level in August is still low, one can be rather sure that also the maximum flood level will be low too, while a high flood may be foreseen if the water level in August is high.

The existing model is based on the daily measurements of the water level in Mopti and in Akka (central part of the Inner Niger Delta) since 1956. The data were made available by DNH in Bamako and in Sévaré. For each year the maximal water level, and the data at which this level was reached, was related to the water level such as measured in the same year on 10 July, 20 July, 30 July, 10 August, 20 August, 30 August, 10 September, 20 September and 30 September. The functions could be described with linear regressions.

These analyses were performed for three data sets:

- Measured water level in July-September in *Mopti* to predict the timing and the level of the peak flooding also in *Mopti.*
- Measured water level in July-September in *Akka* to predict the timing and the level of the peak flooding also in *Akka,*
- Measured water level in July-September in *Mopti* to predict the timing and the level of the peak flooding in *Akka*.

The analyses clearly showed that there is no relationship between the peak flood and the water level such as measured in July. The first OPIDIN report gives tables with the predicted peak flooding (date and level), being usually in November, as a function of the measured water level in August and September. The predictions appeared to be not precise in August, but rather accurate in September.

3 Possible further extensions of OPIDIN

3.1 Longer time series

The existing model is based on the time series 1956-2007; recent years may be added to increase the reliability of the predictions. As a consequence, all existing regression equations will change and have to be re-entered again into the model. Also all tables will change.

3.2 Indicate reliability interval

The existing model gives the predicted flooding and refers to the scatterplots where peak flooding was regressed against the water level in July-September(also given in the first OPIDIN-report) as an indication of reliability of the predictions. It would be an important improvement to give beside the predicted flooding also the lower and higher limit of the estimate, the confidence interval.

3.3 Investigate the impact of the water consumption upstream

The regression equations used in OPIDIN are based on the hydrological data from 1956 onwards. The implicit assumption of the model is that the curve for the flooding and the deflooding varies according to the river discharge (Fig. 1) and to nothing else. This might not be true, however, since we know that the reservoir of Sélingué is filled in August and September (Fig. 2). As a consequence the flood curve in the Inner Niger Delta may have been altered since Sélingué came into existence.

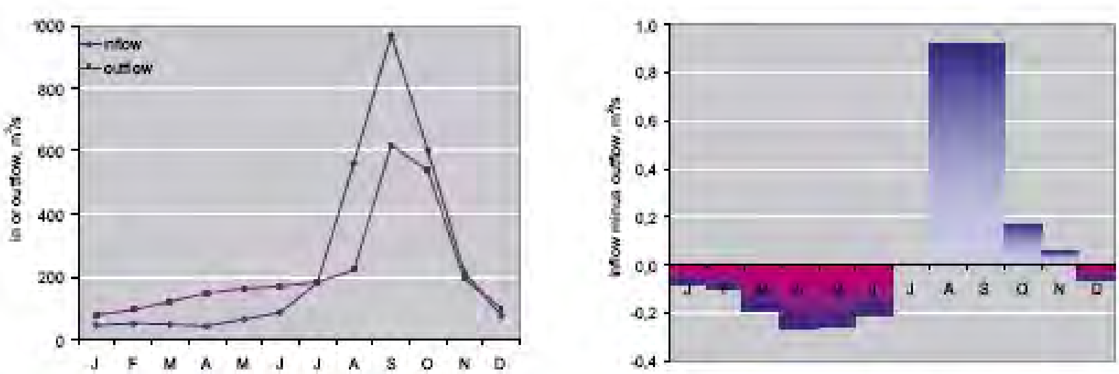


***Figure 2**. LEFT: The monthly inflow and outflow of the Selingué reservoir (m^3/s), averaged over the period 1982-2003; source: EDM. RIGHT: Using the same data, the difference as m^3/s between monthly inflow and outflow in the Sélingué reservoir. FromZwarts, I., Cissé, N. & Diallo, M (2007) Hydrology of the Upper Niger- In: Zwarts, L., Beukering van, P., Kone, B. and Wymenga, E. (eds.), The Niger, a lifeline. RIZA/Wetlands International/IVM/A&W, pp. 15-42.*

The OPIDIN model might be recalculated solely for 1982 onwards. However, by doing so, all years with a high flood are lost for the model (see appendix 1). This reduces the statistical power of the regression equations on which the model is built. Nevertheless, it is worthwhile to investigate in detail whether the predictions might be improved when it is taken into account that the flood curves before and after 1982 may be different.

3.4 More hydrological stations

Predictions regarding the Niger between Markala dam and Mopti may be based on the water levels measured in Kirango just downstream of the Markala dam. Downstream of Akka, regular measurements of the water level are available for Niafunké, Diré and Korioumé. The peak flooding in these stations may be related to the water level measurements in the months before, such as measured in these stations themselves, but also compared to the stations in the southern Inner Niger Delta.

3.5 Predictions for the deflooding

The existing model compares the measurements of the water level in July-August to the peak flooding (timing as well as level). In the same way, the data at which the water level has declined to a certain level during the deflooded may be regressed against the water level in July-August. This analysis may be done for all hydrological stations for which sufficient data are available. Appendix 2 gives already an example: the prediction of the day at which the water level had declined during the deflooding to 200 cm relative to the scale of Akka as a function of the water level measured.

3.6 Predictions of the inundation

Zwarts & Grigoras (2005) converted satellite images of the Inner Niger Delta available for 24 different dates into maps showing the actual coverage by the flood at a certain moment. The water levels in Mopti, Akka and Diré have been measured on those days, so the relation between the actual flooding and the measured water level could be ascertained. These water maps could be combined to construct a composite water map, which may be considered as a digital flooding model. This was done separately for incoming and receding water. For receding water it was even necessary to make a separate flooding model for years with a high and a low peak level since there were more temporary, isolated water bodies after the peak water level had been high.

The disadvantage of the given composite water maps was that the intervals between the different water levels were unequal. To make a water map with equal intervals, the water line was interpolated at a water level of each additional 10 cm (i.e. 10, 20, 30 cm, etc.), using a pycnophylactic interpolation technique (for details see Zwarts & Grigoras 2005).

OPIDIN predicts the water level within the same flooding cycle. These predictions may be converted into water maps, using the just described digital flooding model. The digital flooding model was based on Landsat satellite images with a resolution of 30 x 30 m. This appeared to be accurate enough to describe, even at a very local level, the flooding and deflooding process.

The digital flooding model was extensively used during the field work between 2003 and 2010. The water maps appeared to be surprisingly precise, given the fact that the selected satellite images (being used to construct the water maps) refer to the period 1984 – 2003. Apparently, there have been amply spatial changes in the flooding process during the last 20-30 years.

4 Further possibilities to improve the OPIDIN?

4.1 Use data of hydrological stations further upstream

The annual variation in flooding of the Inner Niger Delta may be attributed to the annual variation in the river flow of Niger and Bani Rivers. The hydrological station of Mopti measured the combined flow of Bani and Niger. When hydrological stations further upstream are used to predict the flood level in the Inner Niger Delta, they have to be combined for both rivers to describe the flooding downstream of Mopti. Kirango, however, may be used for the floodplains along the Niger upstream of Mopti, whereas the data of Douna or Sofara may be used to predict the flooding of the floodplains along the lower Bani.

Hydrological station upstream of Kirango may only be used in OPIDIN if the water consumption by Office du Niger at the Markala dam is taken into account. However, this makes the analysis so complex, that this has no sense to do so. The same is true for Douna since the Talo dam has an impact on the river flow of the Bani.

In conclusion, Mopti, Akka and Diré may be well used in OPIDIN for the southern, central and northern Delta, respectively. The use of other hydrological stations have no, or only a local, function.

4.2 Use rainfall in the Upper Niger

In theory, it would be possible to predict the flooding of the Inner Niger Delta in an early stage using the meteorological data of the Upper Niger since rainfall precedes the runoff of the river. However, this would only have sense if it would be possible to get for each year the rainfall data of the same 20-30 rainfall stations in the Upper Bani and Upper Niger. In practice, this might give a large retardation.

There is, however, an alternative since satellite technology allows an alternative method of monitoring rainfall. Daily estimates have been combined by NASA per ten-day-period from July 1995 onwards and may be consulted instantaneously at internet. However, from earlier research we know already that the flooding of the Inner Delta is only partly due to the rainfall in the Upper Niger and Upper Bani during the months before. The river flow not only depends on the rainfall in preceding months, but also on rainfall in the preceding years. This system is complicated by irrigation schemes and water reservoirs that, by extracting and diverting water from the rivers, interfere with the natural timing of the flow.

In conclusion, we gain nothing by adding the rainfall in the Upper Niger and Bani in the OPIDIN model.

5 Application of OPIDIN

5.1 An early warning system

The life of (rural) people is Inner Niger Delta is governed by the flooding. It might help them in several ways when they know some months before what would be the peak flood level, when this peak will be reached, at what time the flood level will have been declined to a certain level, etc.

The main problem is to find a way to convert technical information, such as "peak flood will be 511 cm (confidence limit: +/-23 cm) at the scale of Akka" such that people really knows what this means.

The first possibility is to categorize the flooding into a five-point scale (very high, high, normal, low and very low; see Appendix 1) and use systematically these five classes in the transfer of information. Fortunately, people have a „collective memory' regarding to the flood levels in the past and, for instance, know very well that there were high flood in 1994 and 1999 and a very low one in 1984. This will certainly facilitate the transfer of information, e.g. "the flood level this year will be *faible*, - about as high as in 2002, 2004 and 2005" (see Fig. A3).

When people know in August what kind of flood they may expect, they can make their own decisions:

- people having built a house on the lower part of the river bank will know themselves that their house may be flooded if the forecast of the flood is *fort*, being as high as in 1994 or 1999.
- people showing a temporary migration (leaving the Inner Niger Delta in years with a poor flood to work elsewhere in Mali or even abroad), may plan to leave their village when they know already in August that the flood will be *faible*.
- fishermen buy more new nets and more often a new pirogue when they know that the flood will be high and thus they will catch more fish. The catch is highly dependent on the flood and at present they start to do new investments when the flood is clearly at a high level. OPIDIN may help the fishermen to plan their investments earlier.
- The access of the lower floodplains during the deflooding for grazing (see appendix 3, for an example).

These four examples show that OPIDIN must be carefully used and that all must be done to prevent that the model give a wrong prediction. One strategy might be to spread the news (by phone calls to key persons and by messages at local radio stations) about the fore coming flood at several moments:

- at 20 July: a very global prediction, based on the calculated confidence interval to state that the flood will be " most likely *faible* or *normal*, but likely not *fort*" or "most likely not higher than *normal* during the last 5 years"
- at 1 August: a prediction being a more specific, if this may be derived from the measurements on the scale of Mopti on this day.
- at 10 August, idem.
- at 20 August, idem.

Beside this global information about the peak flooding, OPIDIN may be used to give specific predations, e.g.:

- when will a lake of a depression during the deflooding get isolated from the flooding system?
- when will a floodplain during the deflooding become accessible for grazing cattle, or for recession farming?
- when will the Niger during the declining water be too shallow for transport of large pinasses?

OPIDIN may be able to predict the date in the given three examples some months before, but need to know from earlier years when this event took place. The data base of the daily water levels must be checked to know to what level the flood in a nearby hydrological station has declined. If the water levels for this event do not differ too much for the different years, the average water level may then be entered into OPIDIN to calculate the predictive equations as shown in Appendix 2 (Fig. A4). OPIDIN, however, will not be able to predict the date of this event if the water level in the nearby hydrological station differs from year to year. This is to be expected if the water body in the area concerned is already disconnected from the river system in an earlier stage and thus not the actual deflooding but the evaporation determines the local water level; appendix 3 extensively deals with this problem.

5.2 A spatial planning tool

When OPIDIN is combined with the digital flooding model or the digital vegetation map (both given in the book *The Niger, a lifeline*), a spatial planning model may be developed. Three example may illustrate how such a model may look like.

Water birds are annually counted during the northern winter in many thousands of wetlands all over the world. The Inner Niger Delta is too large to count all birds in the entire region, so a selection was made of the central lakes Korientze, Debo and Walado. An analysis of the counts (started in 1992) showed that these counts have to be done before 1 March (when the northern migrants start to return to their breeding grounds), but also when the water level at Akka is below 200 cm and floodplains elsewhere in the Inner Niger Delta are dry. OPIDIN is now used to determine when the annual counts of the water birds has to be done (Fig. A4 in Appendix A2).

Different heron species (large, wading fish-eating birds) breeding in the flooded forests Akkagoun and Dentaka feed at a distance of 10, 15 or 20 km from these breeding colonies. Most feeding birds are found in bourgou fields being flooded by 10, 20 or 30 cm of water. A GIS system was used to plot the potential feeding areas for different flood levels. In combination with OPIDIN, the change in the potential feeding area during the breeding season may be indicated. This may help us to understand the factors limiting the size of the breeding colonies in the different forests in years with a different flooding.

Appendix 3 shows how OPIDIN might be combined with water maps in the analysis of the date at which cattle are allowed to enter the bourgou fields near Diafarabé.

Appendix 1: A classification of the peak flood level in the Inner Niger Delta

The water level on the gauge of Akka has been measured since 1-1-1956, thus now since 54 years. The annual peak flood level has varied in those years between 336 cm in 1984 and 625 cm in 1957 (Fig. A1).

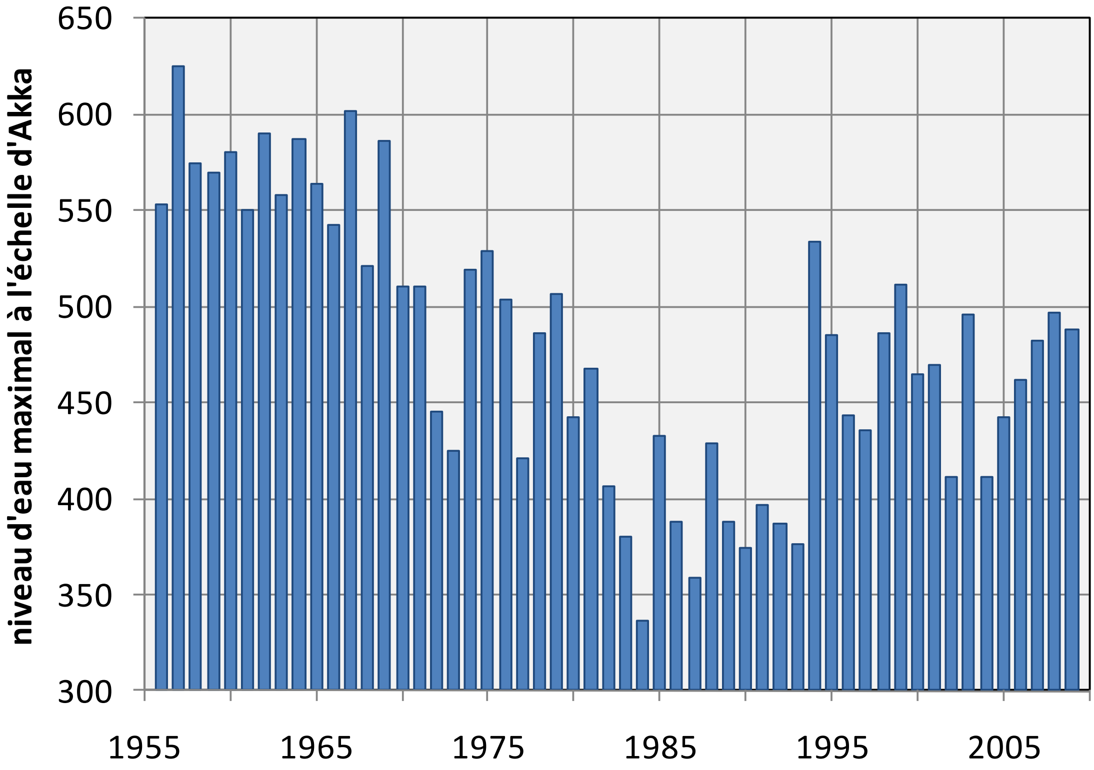


***Figure A1**. The annual peak flood level in Akka between 1956 and 2009.*

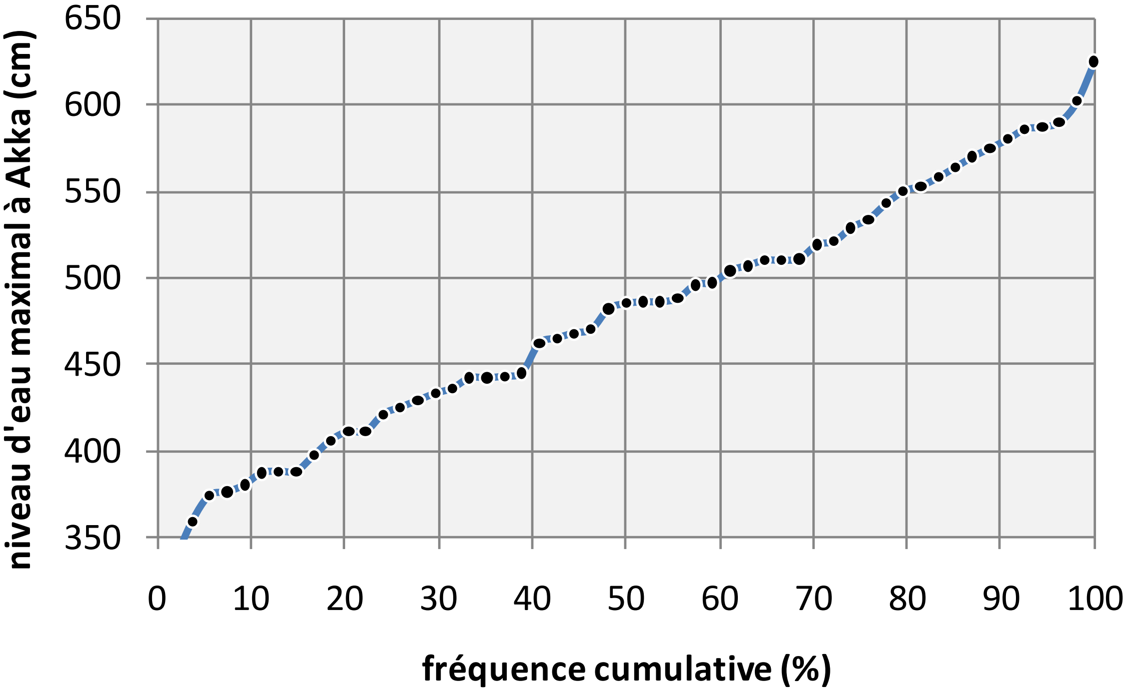


***Figure A2**. The cumulative frequency distribution of the peak water level in Akka, calculated for 54 years (1956-2009); same data as Figure A1.*

The data have been ranked according to peak level to construct a cumulative frequency distribution (Fig. A2). Afterwards the years were split up in five 20%-classes. The limits between these classes are shown in Table A2.

Akka, cm	crue	fréquence
330-410	très faible	10x
411-450	faible	11x
451-500	normal	11x
501-550	fort	11x
551-625	très fort	11x

Table A1. A classification of the peak flood levels in five different classes, based on data given in Fig. A2.

Using the classification given in Table A1, the data from Fig. A1 may be replotted showing the five different classes. It is evident that all years classified as „très fort' were all before 1970, all years being „très faible' between 1982 and 1993 and that the most recent years have been „normal'.

It should be noted that the classification depends on the span of period over which the frequency distribution has been calculated. The flood levels reached in 1994 and 1999 have now been classified as „fort', but were the classification based on the 40 (instead of the 54) most recent years, both years would have been ranked evidently as „très fort'.

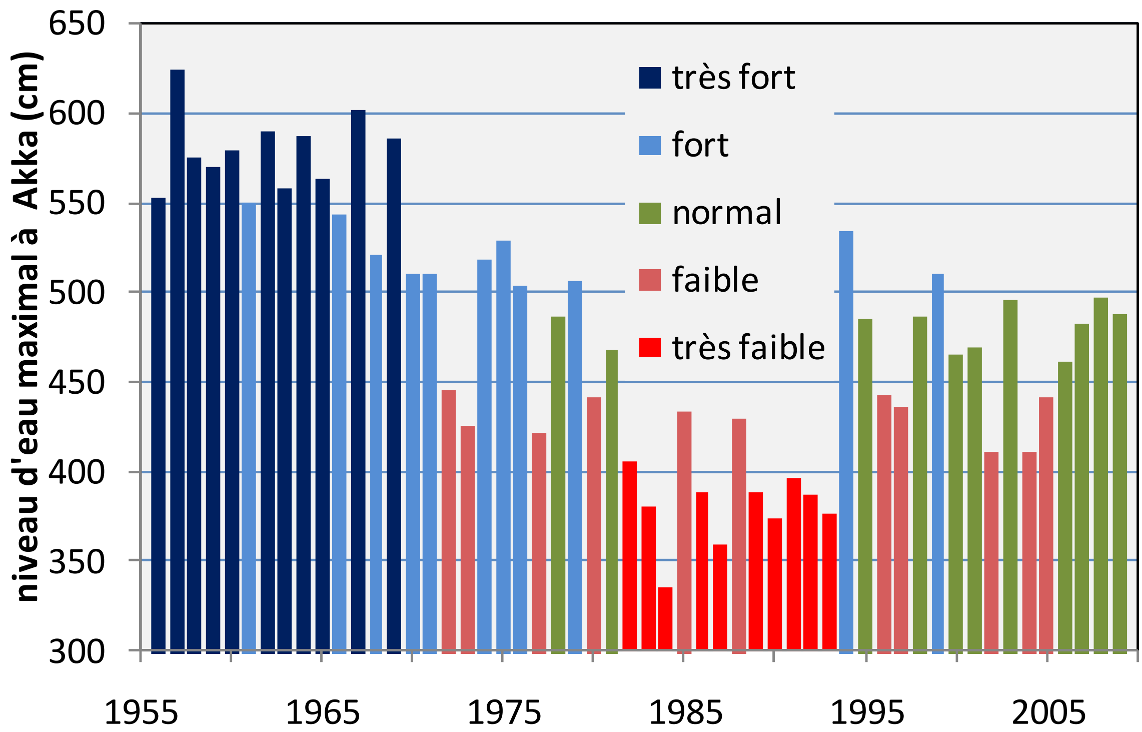
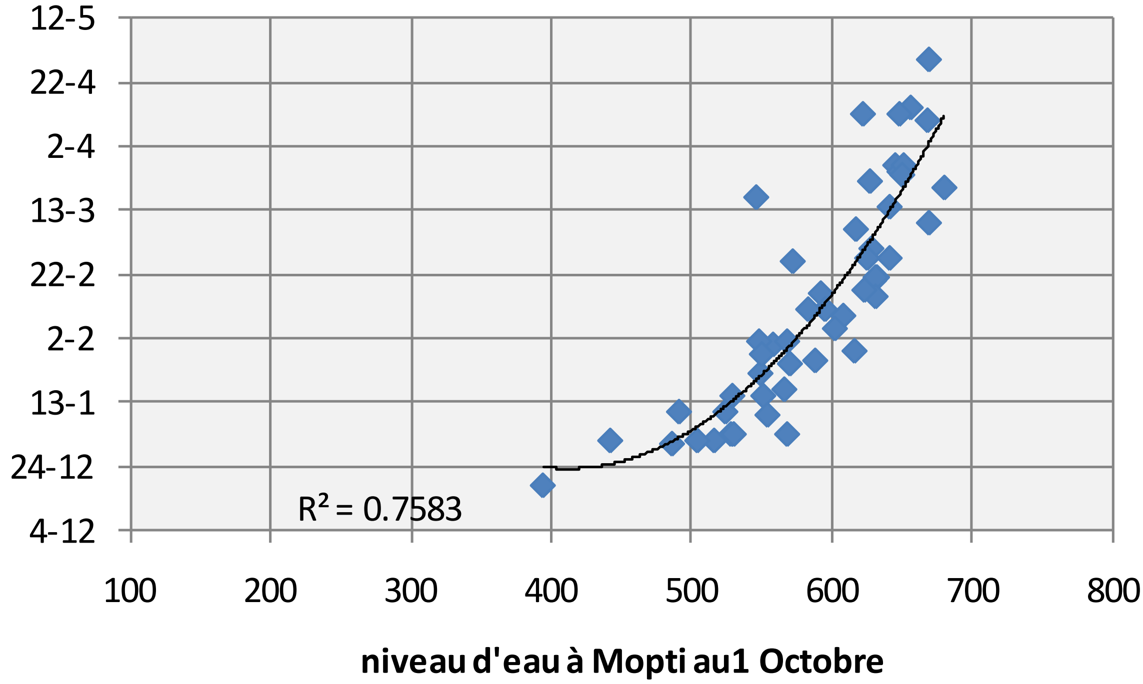
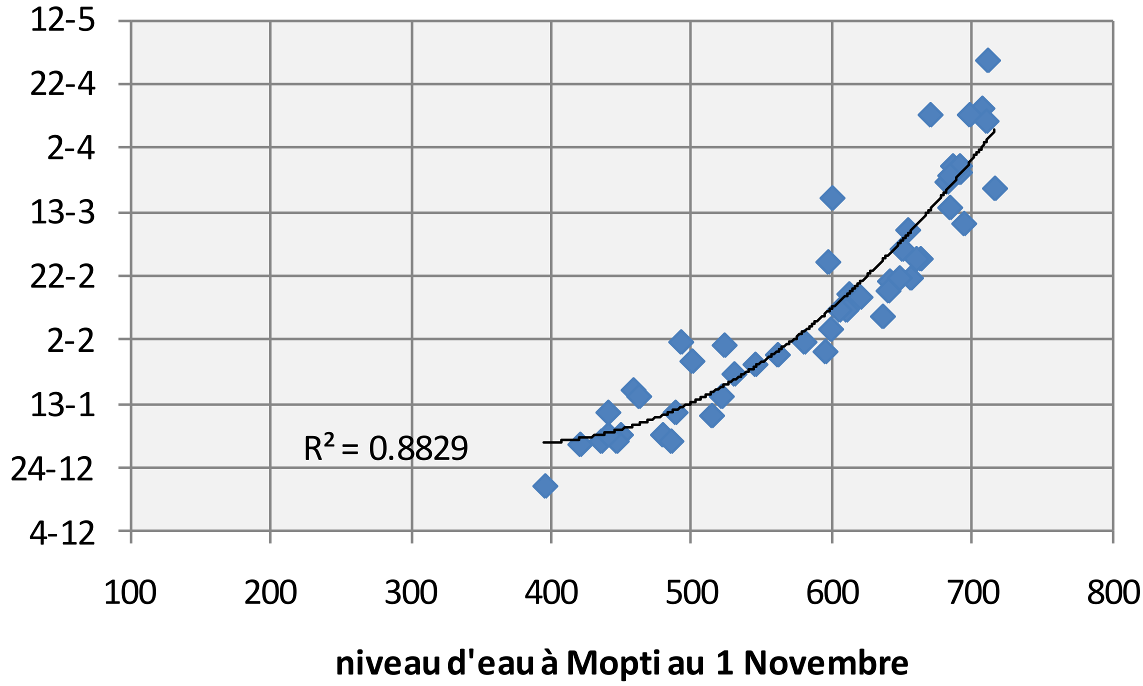


Figure A3. *The annual peak flood levels in Akka since 1956; same data as Fig. A1, but now using different colors regarding to the five distinguished categories (see Table A1).*

Appendix 2: An example: prediction of the timing of deflooding

The *peak* flood level may be predicted some months in advance. Using the same methodology, it is also possible to predict the curve during the deflooding, and thus also to predict when floodplains will become accessible for grazing cattle during receding water, etc. As Fig. 1 clearly shows, the flood curve does not differ much before the peak level is reached, but the difference is much larger during the deflooding. As a consequence, the flood level during the deflooding may be predicted already remarkably accurate when the water is still coming up. Fig. A4 shows the relationship between the water level in Mopti and the date at which the water level in Akka has declined to a level of 200 cm.





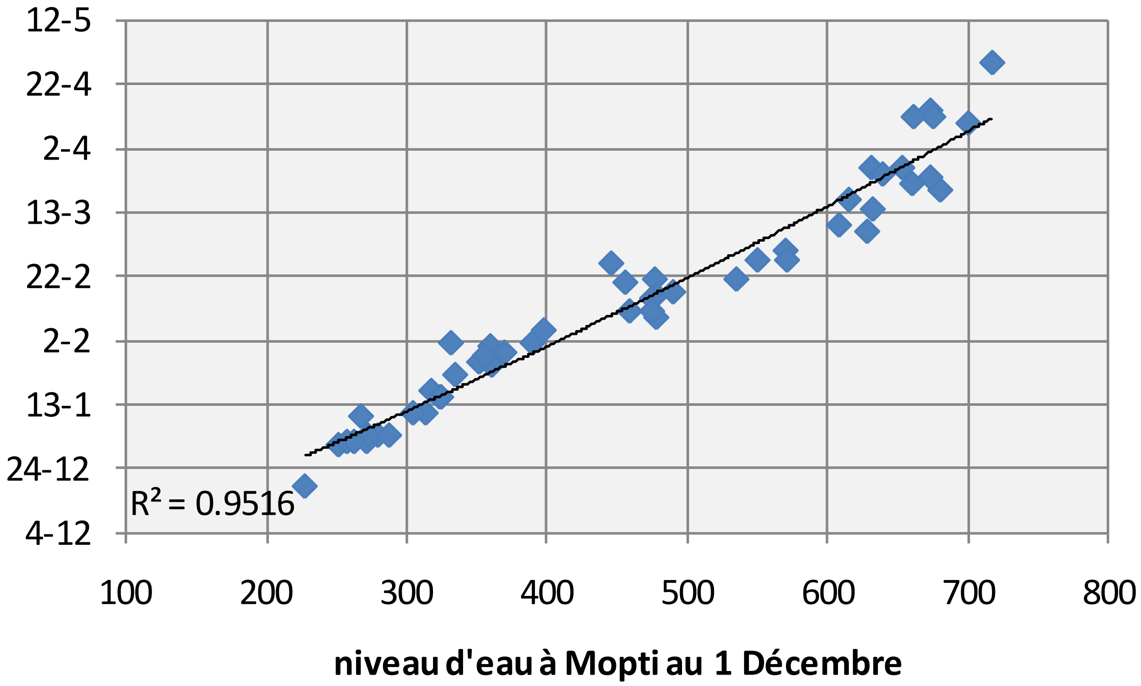


Figure A4. *The relationship between the water in Mopti on 1 October, 1 November and 1 December and the data at which the water within the same flooding cycle has declined enough to reach a level of 200 cm on the gauge of Akka.*

Fig. A4 shows the relationship between the date at which the water level has declined to 200 cm on the gauge of Akka whereby nearly all floodplains are exposed. This important moment in the flood cycle may be predicted accurate up to a fortnight on 1 October, being late December in a dry year and early May in a very wet year. Comparing the three graphs in Fig. A4 reveals that the prediction becomes more precise later in the season.

Note that the relationships based on the water levels October and November are not linear but curvilinear, since the data of deflooding cannot be predicted accurately if the water level in early October or early November are low.

In conclusion: data as shown in Fig. A4 may be used to make tables showing the predicted dates at which the water as fallen to a certain level as a function of the observed water level many months before.

Appendix 3: An example: prediction of access to the grazing grounds at Diafarabé during the deflooding

This section investigates the possibilities to predict the *date de traversé*, the access date, at Diafarabé, using the daily water level measurements at Kirango, 135 km upstream of Diafarabé. The analysis is based on a still incomplete (and uncorrected) data base, but large enough to get a first impression about the possibility of an implementation into OPIDIN.

Prediction of the access date

Fig. A5 shows the daily variation in water level in Kirango for 25 years. Despite there were many gaps in the series, it was possible to determine the maximal level of the peak flood for all these years (Table A2). The lowest peak flood was measured in 1984 (348 cm on the local scale) and the highest peak in 1979 (604 cm).

The floods reached their peak mostly in the second half of September. The lowest peak flood ever measured was already reached, however, on 20 August. On average, a high flood reached its peak level, 3 weeks later than a low flood, but the variation is very large (see column 2 & 3 in Table A2).

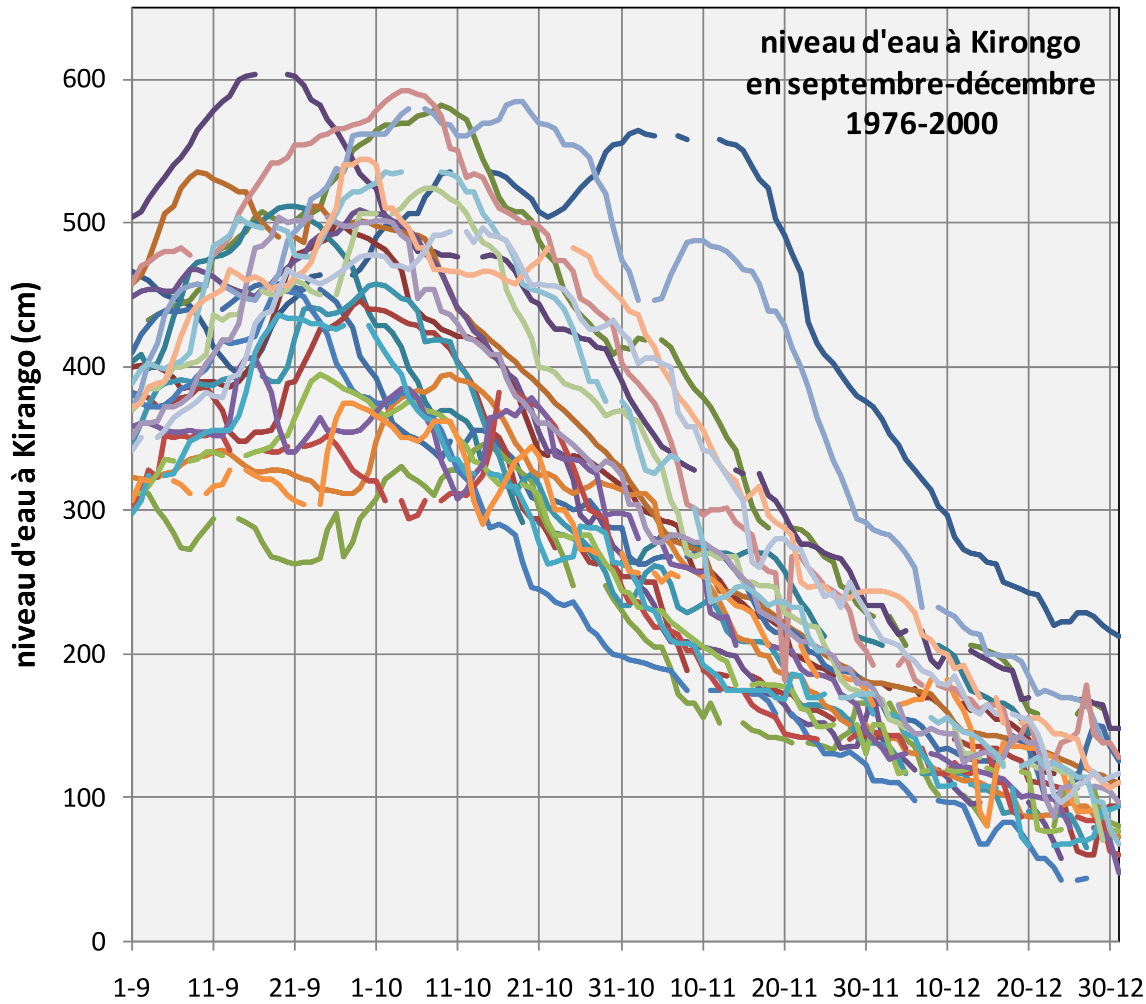


Figure A5*. Water level at Kirango, just downstream of the Markala dam, such as measured between 1-1-1976 and 31-12-2000. The graph shows the daily measurements for the period 1 September – 31 December. Data from DNH.*

an	niveau d'eau max.		niveau d'eau baissé jusqu'à			acces à Diafarabe		
	cm	date	3.0 m	2.5 m	2.0 m	date	cm	jours
1976	564	2-11	9-12	17-12	3-1			
1977	500	26-9	2-11	12-11	20-11			
1978	582	9-10	16-11	26-11	15-12			
1979	604	16-9	19-11	28-11	13-12			
1980	512	20-9	18-10	20-11	10-12	22-11	236	63
1981	536	9-9	3-11	11-11	25-11	21-11	217	73
1982	458	17-9	28-10	15-11	23-11	13-11	265	57
1983	446	29-9	19-10	3-11	7-11	5-11	232	37
1984	348	20-8	21-10	24-10	5-11	11-10	328	52
1985	509	29-9	25-10	2-11	12-11	30-11	155	62
1986	457	1-10	22-10	5-11	18-11	22-11	163	52
1987	395	10-10	4-11	10-11	16-11	14-11	212	35
1988	453	19-9	14-10	19-10	29-10	26-11	130	68
1989	382	11-9	26-10	30-10	9-11	25-11	140	75
1990	394	24-9	20-10	30-10	11-11	24-11	149	61
1991	406	15-9	28-10	10-11	21-10	23-11	186	69
1992	436	19-9	19-10	1-11	9-11	14-11	174	56
1993	374	13-9	22-10	11-11	22-11	14-11	234	62
1994	584	9-9	28-11	6-12	14-12	17-12	198	99
1995	592	4-10	11-11	23-11	30-11	9-12	176	66
1996	524	21-9	6-11	15-11	25-11	30-11	172	70
1997	504	23-9	2-11	15-11	25-11	17-11	230	55
1998	536	4-10	9-11	15-11	25-11	25-11	202	52
1999	544	29-9	17-11	22-11	9-12	4-12	240	66
2000	496	14-10	15-11	24-11	4-12	25-11	240	42
moyen	485	24-9	2-11	13-11	23-11	21-11	204	59

Table A2. *The peak water level and the date at which this peak is reached in Kirango in 1976-2000, based on the graphs shown in Fig. A5. The yearly date at which the water level during the deflooding has declined to 3.0, 2.5 and 2.0 m is derived from the same graph. The access date refers to the date at which the cattle are allowed to cross the Niger River. The last two columns give the corresponding water level at this date and the time span since the peak flooding in Kirango, respectively (given in column 3).*

To predict the accessibility of the grazing grounds, it is necessary first to investigate whether the selected date of access is related to a fixed water level. That seems to be the case, but only to a certain amount (upper graph in Fig. A6). The water level was at the access date about 200 cm and apparently not related to the flood level. The only exception was the disaster year 1984 when the water level at the access date amounted to 328 cm.

The access date was usually in the second half of November, but earlier in the extremely dry 1984 and later in the wet 1994 and 1995 (lower graph in Fig. A6). The access date was, on average, 2 months after the peak flood level has been reached (see last column in Table A2).

In the further analysis, the water level of 200 cm at Kirango is taken as the moment at which the bourgou fields are accessible for grazing. The relationship between the water level at 1 September and the date at which the water level has declined to 200 cm as rather weak. The prediction was hardly better when the water level of 10 September was taken. The best fit was obtained when the peak flood level was regressed against the date at which the water level during the deflooding was 200 cm (Fig. A7). The red lines are drawn at 10 cm from the calculated regression line. In 4 of the 16 years, the deviation between the observed and predicted access data is more than 10 days.

In conclusion, using the available data set OPIDIN, one may predict the access date at Diafarabé when the peak flood level is known in Kirango, being about 2 months earlier. However, the prediction of the access date appeared not to be very accurate. To improve the prediction, it would be necessary to add the measured daily water level since 2000 into the date base. Moreover, the measured daily water levels in Kirango should be carefully compared to the daily series of Mopti (245 km downstream of Kirango), to check for errors.

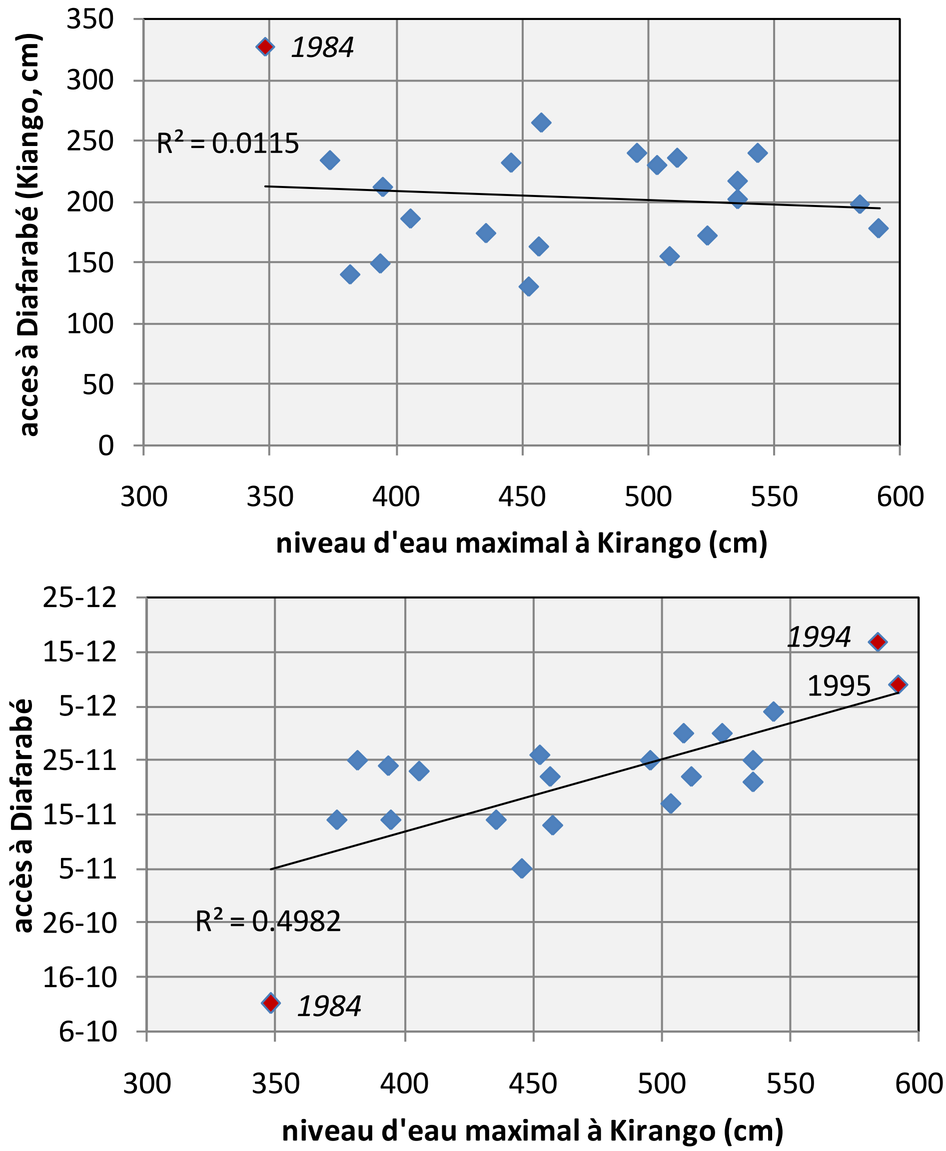


Figure A6. *The water level at the date of access at Diafarabé as a function of the peak flood level in Kirango (upper graph). The lower graph gives the access date as a function of the peak flood level. All data are from Table A2 (column 2 and 8 for upper graph and column 2 and 7 for the lower graph).*

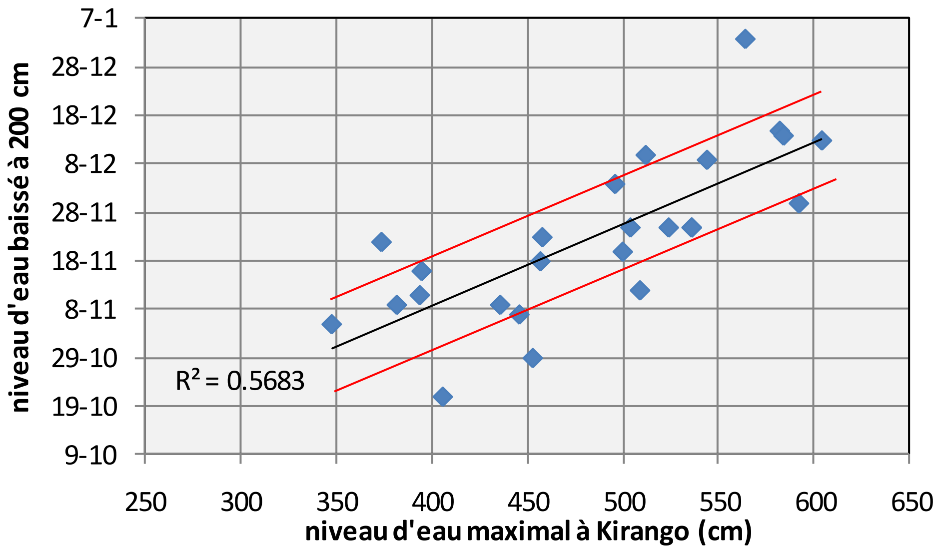


***Figure A7**. The date at which the declining water level in Kirango was 200 cm as a function of the maximal water level at Kirango at the same flooding cycle. The red lines are 10 days above and below the calculated regression line. It shows that most of the years, the predicted date at which the water level was 200 cm may usually deviate up to 10 days from the actual date at which the water has fallen to this level, but in some years the error may even be greater.*

An alternative might be to analyse the access date at Diafarabé as a function of the flood levels in Mopti (110 km downstream of use of Diafarabé). Although this is illogical from an hydrological point of view, Mopti might be selected if it appeared to give a better fit than Kirango regarding the data of access at Diafarabé.

Access date and flooding

The digital flooding model described by Zwarts & Grigoras (2005) in The Niger, a lifeline may be used to show the actual flood extent at the average access date at Diafarabé. This model, however, refers to the entire Inner Niger Delta. That is why the water level measured in the central Delta (at Akka) is taken as point of reference. This makes the model less applicable for the actual flooding in the SW part of the Inner Niger Delta, since the predicted access date at Diafarabé refers the water level measured in Kirango, some 370 km upstream of Akka. That is why the actual inundation in the surroundings of Diafarabé were compared to the measured water level on the same day in Kirango.

The digital flooding model is based on 24 water maps. The water level at Kirango is presently known for 19 dates of which 7 refer to October-November, one from 1999 (Fig. A8), one from 1986 (Fig. A9), two from 1987 (Fig. A10) and three from 1984 (of which two are shown in Fig. A11).

The maps show a region of 60 km from west to east (between Diafarabé and Ouro-Modi) and 50 km from north to south. Fig. 8 refers to a year when the peak flood has been relatively high. The image was taken 61 days after the peak flood, and, although the water level at Kirango had declined already by more than 3 meter, still much water has left behind on the floodplains.

The water level on Fig A9 (209 cm) was only somewhat lower than on the map shown in Fig. A8 (238 cm). The difference in flood extent is very large, however. This has all to do with the peak flood: Fig. A9 is from 1986, a relatively dry year (peak flood 457 cm, thus 87 cm lower than in 1999).

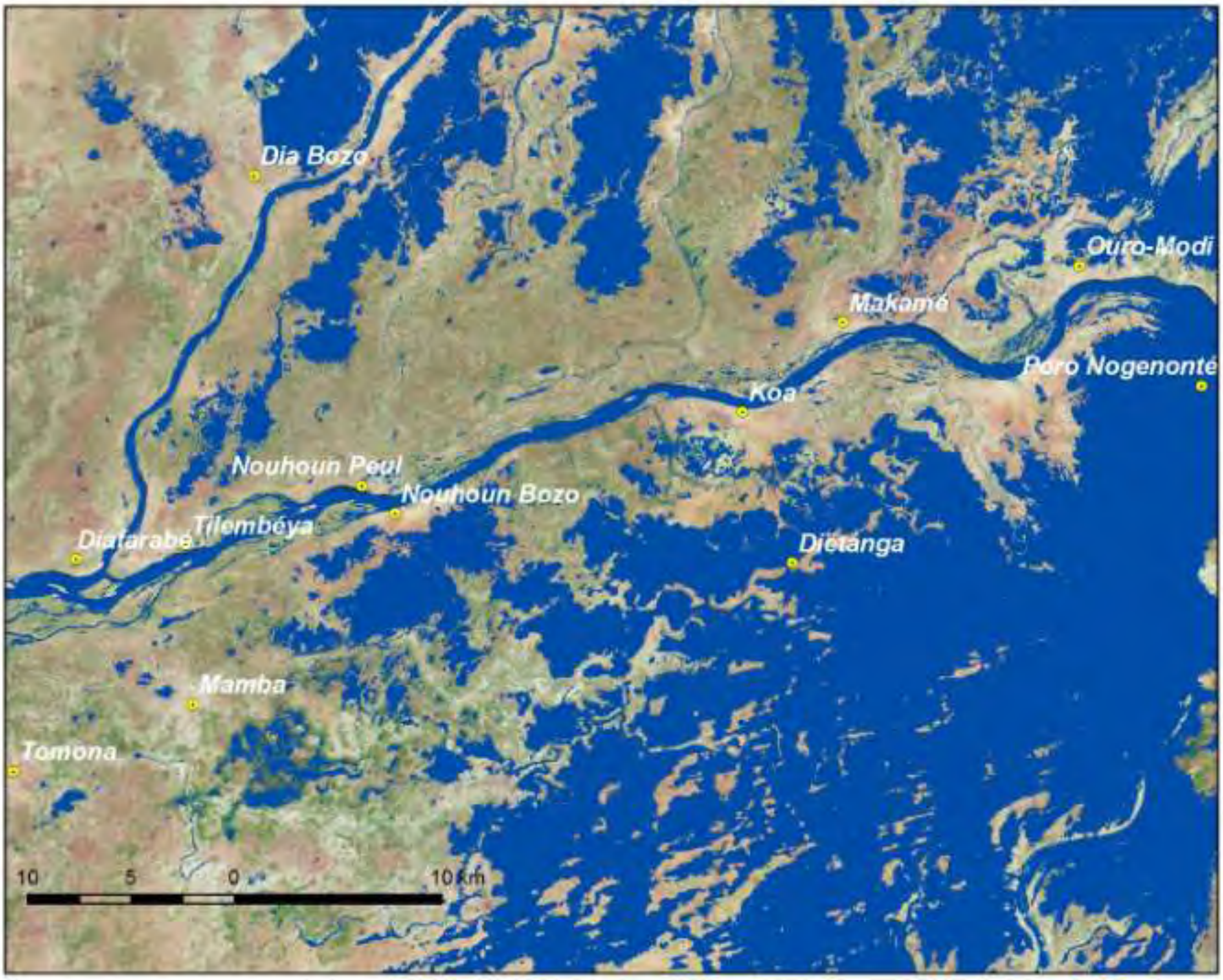


***Figure A8**. The flood extent on 28 November 1999, shown in blue, when the water level in Kirango was 238 cm, three days before the water level would have declined to 200 cm. The peak level in Kirango was reached that year on 29 September (544 cm). Hence the flood extent is shown 61 days after the peak flood has been reached and the water level in Kirango has declined already by 306 cm.*

The flood extent in Fig. A10 (showing the flood extent in 1987) is similar to those of Fig. A9 (showing the flood extent in 1986). The flood extent in Fig. A10 is even a bit lower than in Fig.A9, which is surprising since the water level in Fig. A9 amounts to 209 cm in Kirango and to 364 and 347 cm in Fig. A10, thus about 1.5 meter higher! The explanation of this apparently odd result is that the peak flood in 1986 amounted to 457 cm (Fig. A9) and to only 348 cm in 1987 (Fig. A10). This shows again that the observed flood extent during the deflooding highly depends on the peak flooding.

The same conclusion may be drawn from Fig. 11, showing the small flood extent in 1984. Although the water level was not low when the image was made (248 cm), the peak flood level was extremely low (348 cm).

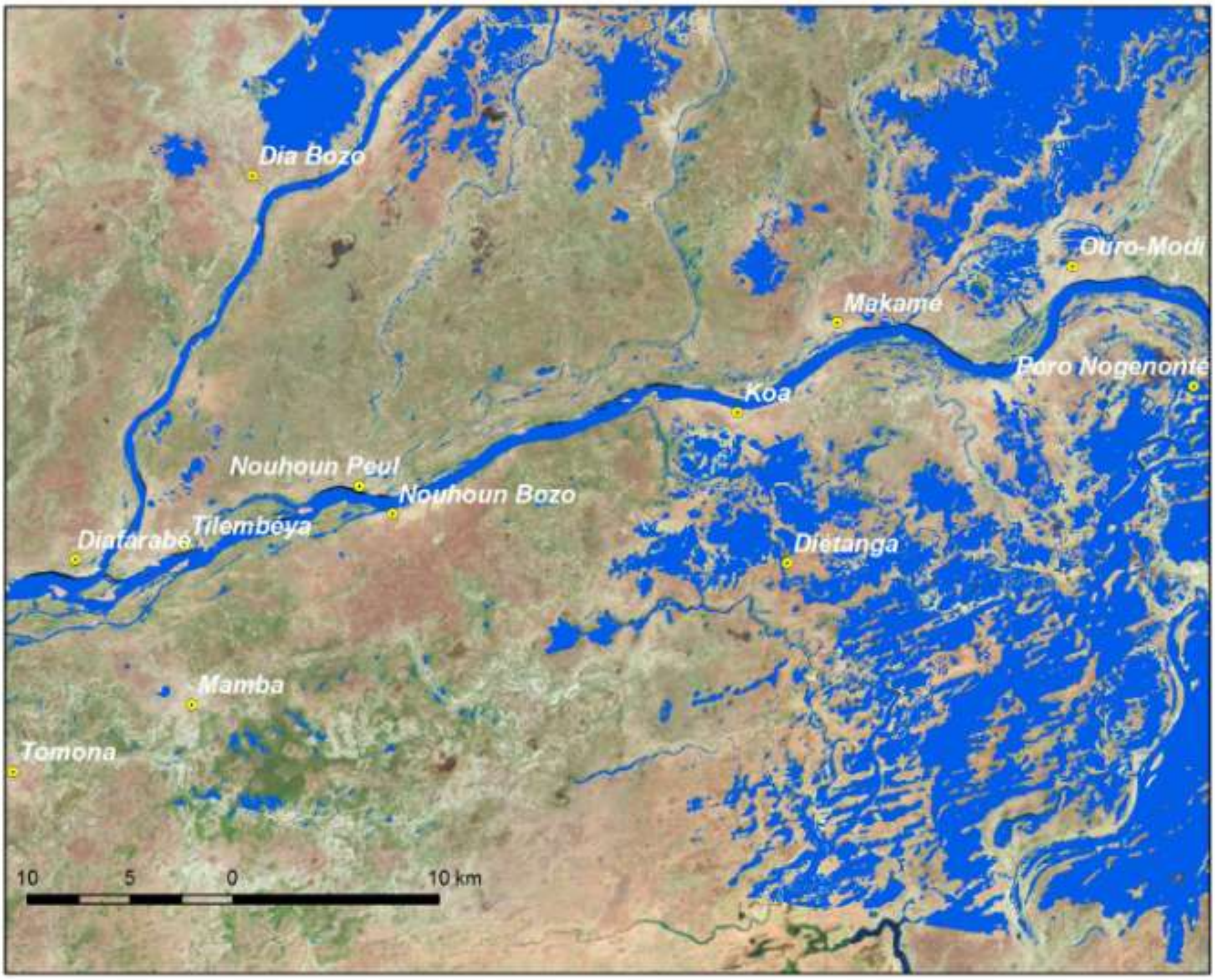


***Figure A9**. The flood extent on 16 November 1986, shown in blue, when the water level in Kirango was 209 cm, three days before the water level would have declined to 200 cm. The peak level in Kirango was reached that year on 1 October (457 cm). Hence the flood extent is shown 46 days after the peak flood has been reached and the water level in Kirango has declined already by 248 cm.*

Fig. A12 shows a composite water map, based on Fig. A8, A9 and A11. A selection was made of three water maps with about the same water level (209-248 cm), but from different years where the peak flood level varied between 348 and 544 cm.

The main conclusion from this exercise is that it is not easy to predict the flood extent during the deflooding, since the flood extent is not only depends on the water level itself, but also on the maximal water level reached in the preceding months. The explanation is that the river water fills isolated lakes if the peak flood exceeds a certain level. Hence the higher the peak flood level, the more lakes and depressions are being filled.

Thus, the complication in modelling the deflooding is caused by the shallow lakes and depressions which are no longer connected to the flood system. In other words, the model needs to account for the period between the moment that a lake lost connection with the hydrological system and its disappearance due

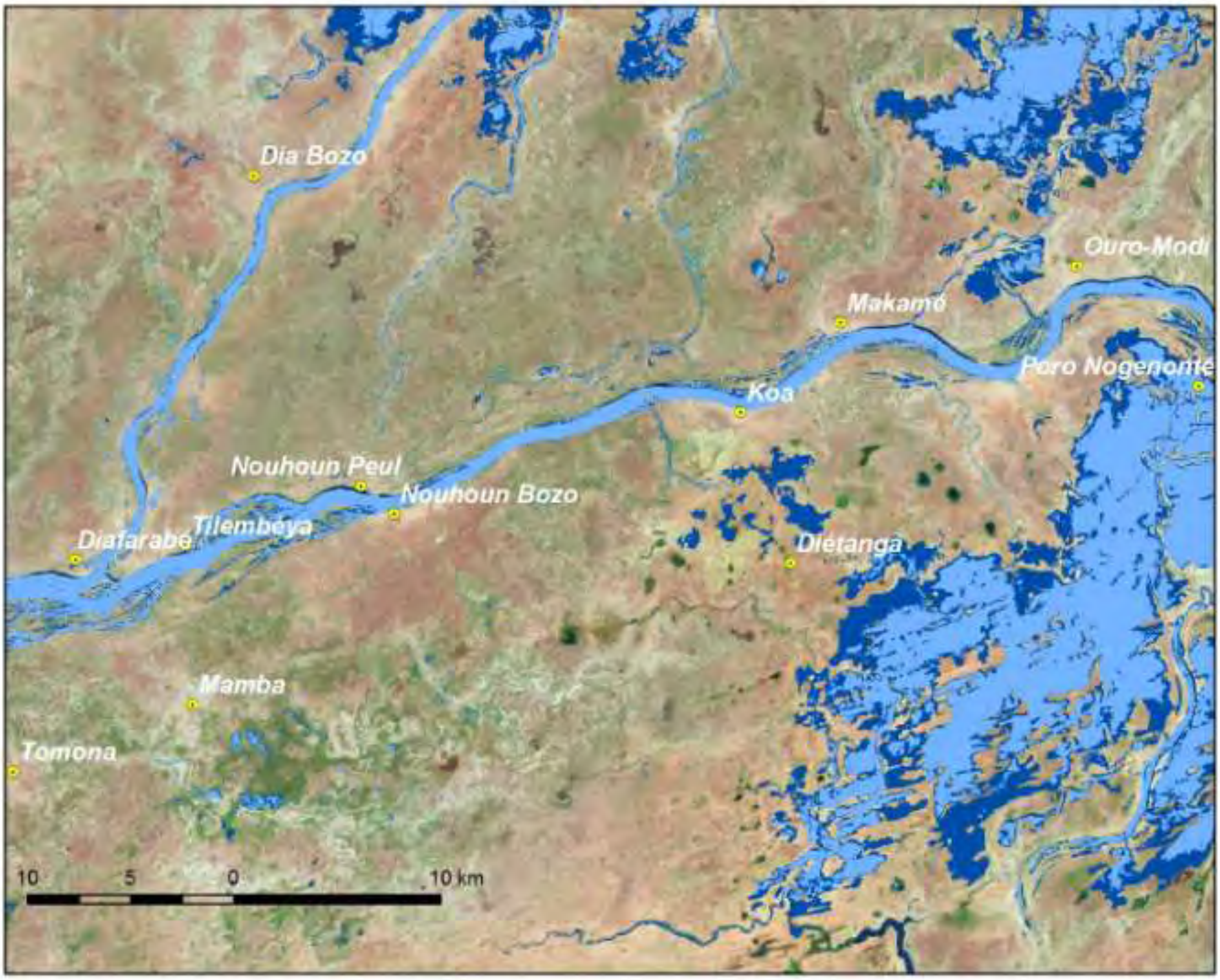


***Figure A10**. The flood extent on 2 October 1987 (364 cm at Kirango), shown in either dark or light blue, and on 18 October 1987 (347 cm at Kirango), shown in light blue. The water level in Kirango reached its peak on 20 August 1987 (348 cm). The combined dark+light blue colour shows the flood extent 8 days before the peak flooding, whereas the light blue colour shows the flood extent 8 days after the peak flood. Hence the flood extent is shown for 8 before and 10 days after the peak flood has been reached. The difference in flood extent on both days amounts to 364 – 347 = 17 cm. Although this difference is small, the first flood plains south of Diétanga became dry already (shown as dark blue).*

to evaporation. The decline of the water level being in open connection with the river system is 3-5 cm per day, but only 0.7 cm (due to evaporation) as soon as it becomes disconnected from the flooding system.

Many more areas remained covered by water if the water level has been high in the months before. Zwarts et al. (2003)[3] determined the surface area being connected and disconnected to the river system for each satellite image. Their analysis shows that during the deflooding about 50% of the inundated area is disconnected to the river by the time the water declined to a level between 100 and 300 cm at Akka. In a dry year, with a low maximum water level, such as in 1984, most of these areas remained dry all year round.

[3] Zwarts, L., Grigoras & W. Dubbeldam. 2003. A digital flooding model of the Inner Niger Delta: a first analysis of remote sensing data. Mali-PIN 03-01.

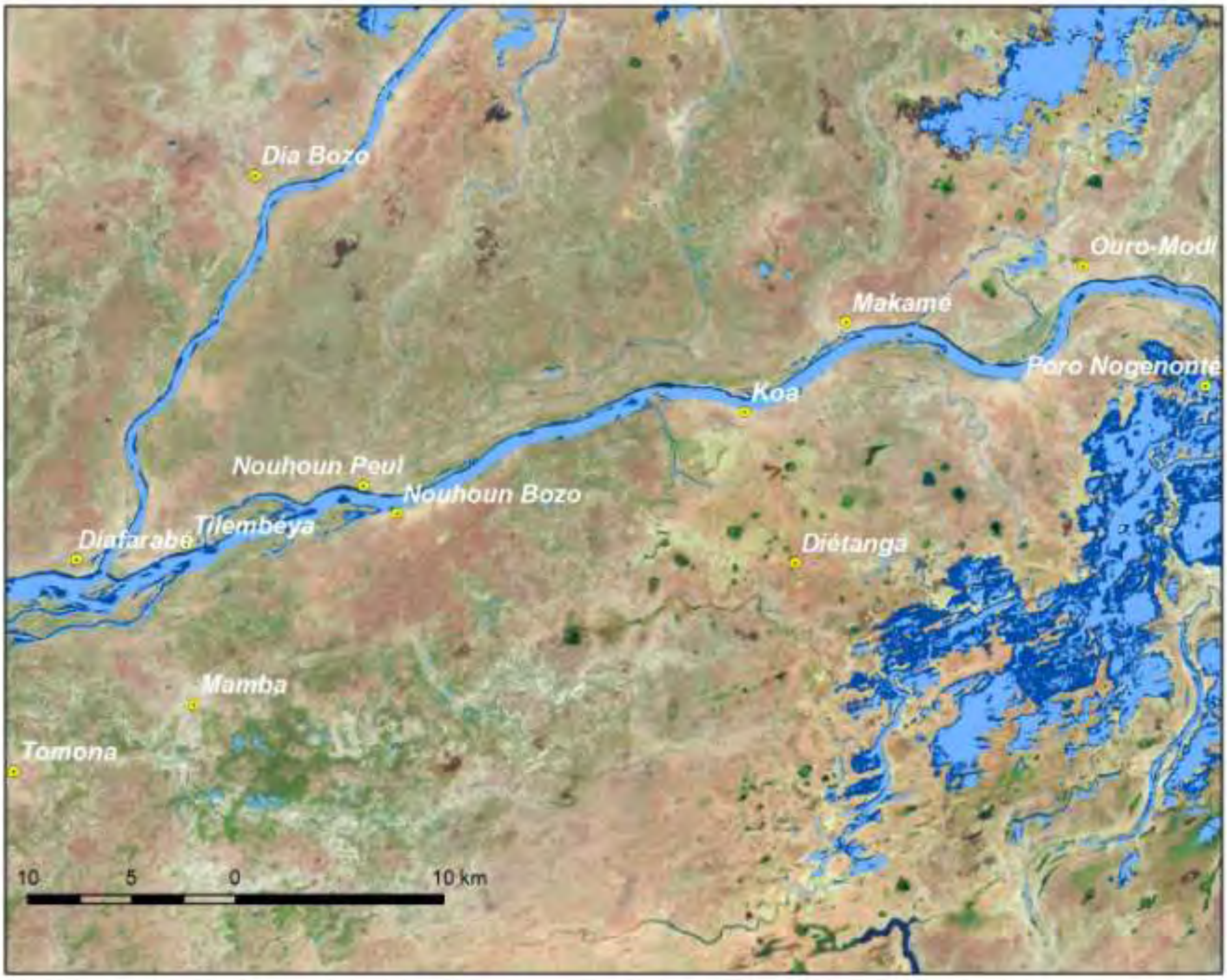


***Figure A11**. The flood extent on 25 October 1984 (water level 248 cm in Kirango), shown in either dark or light blue, and on 10 November 1984 (water level 156 cm at Kirango), shown in light blue. The water level in Kirango reached its peak that year on 20 August 1987 (348 cm). Hence the flood extent is shown for 43 and 59 days after the peak flood has been reached. The difference in flood level on both days amounts to 248 – 156 = 92 cm. In this fortnight a large part of floodplains southeast of Diétanga and south of Pora became dry (shown as dark blue).*

Zwarts & Grigoras (2005) met, of course, the same problem when they constructed their digital flooding model. That was also why they made two digital flooding models for the deflooding, - an inclusive and an exclusive model. However, when the water level at deflooding is getting lower, it becomes more difficult to compare images from different years. In such conditions, the maximal water level as well as the time passed since the water level has reached its peak, determine where isolated and temporary lakes with water can be found.

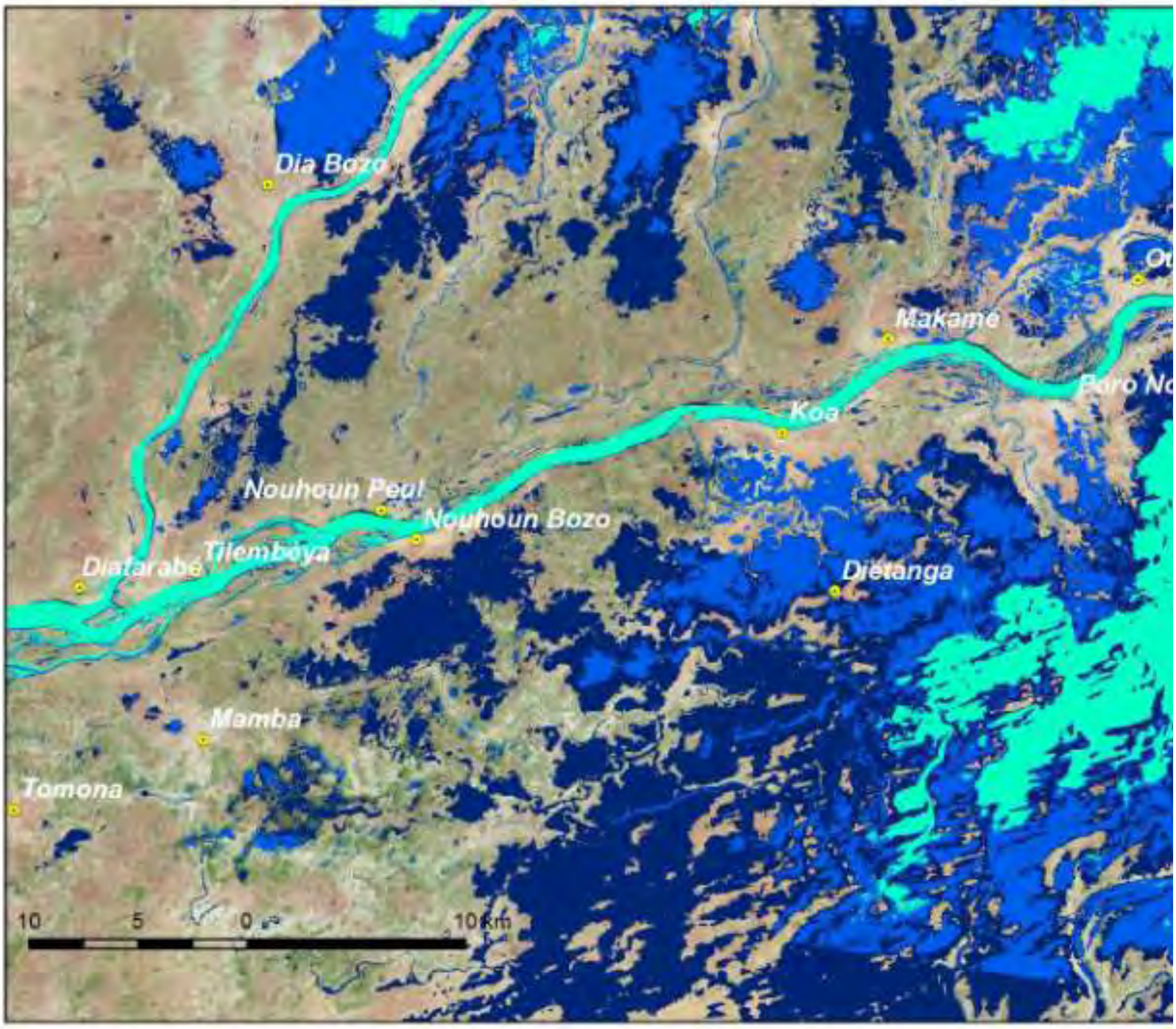


***Figure A12**. The flood extent on three different days:*

colour	*date*	*Water level*	*Peak flood level*	*Days since peak*	*Map*
Dark blue	*28-11-1999*	*238 cm*	*544 cm on 29-9*	*61 days*	*Fig. A8*
Light blue	*16-11-1986*	*209cm*	*457 cm on 1-10*	*46 days*	*Fig. A9*
Green blue	*20-8-1984*	*248cm*	*348 cm on 20-8*	*45 days*	*Fig. A11*

Note that the water map of 28-11-1999 extend further south than the other two maps by which no flooding could be shown for the southwest corner of the map for 16-11-1986 and 20-8-1984

From this, one may conclude that the flooding during incoming water may be derived rather well from the water level measured at different hydrological stations. The same might be done for the deflooding but several problems are met and have to be solved. Beside the problems discussed above, there is still another problem when the digital flooding model would be used regarding to the grazing cattle. The water maps in Fig. A9-A12 show the flood extent independent whether the water depth is 1 or 600 cm. Cows may graze in bourgou being flooded by 0.5 m of water, or even more, but also in dry bourgou fields (although the food stock will be depleted after the bourgou has became available for grazing). It would be possible, to combine different water maps with a digital vegetation map, to construct a map showing the available grazing area (water depth less than 0.5 m) and show with different colours which part of the available bourgou fields are available for grazing) over different periods. It would be worthwhile to make such a map

The overall conclusion is that OPIDIN may be used to predict the water level during the deflooding in water bodies remaining connected to the river system. As soon as lakes and depressions become disconnected during the deflooding, the decline of the local water level becomes more difficult to predict.