A&W ECOLOGICAL CONSULTANTS

OPIDIN: predicting the flood in the Inner Niger Delta

A&W-rapport 1927

commissioned by

WETLANDS INTERNATIONAL

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L. Zwarts

Cover photograph

The southern Inner Niger Delta at a relatively high flood (October 2012). Photo: Leo Zwarts

L. Zwarts 2013

OPIDIN: predicting the flood in the Inner Niger Delta. A&W-report 1927

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Project number	Project leader	Status
2025opi	E. Wymenga	Final version

Authorisation	Autograph	Date
Approved	E. Wymenga	25th of July 2013

Contents

1 Introduction

In the Inner Niger Delta, flood height may reach six metres, but in many years it is less and in most recent years even much less. The year-to-year variation in the flood peak is precisely known since the seasonal rise and retreat of the flood has been measured daily by the DNH at several hydrological stations over many decades (Fig. 1).

The water level is low from April to June, and begins to rise in July. In years of low river flow, the water reaches a height of about 3.5 m, peaking in late October in Mopti. At high river flows, although the water level rises at the same daily rate, it does so over a longer period, peaking at 6 m by late December in Mopti. Usually, lower-level floods cover floodplains for four months only (October-February), but high floods inundate them for twice as long (September-April).

During the flooding and the deflooding the water level rises and declines 3-5 cm per day. This gives the opportunity to predict the flood level for the next week or fortnight. OPIDIN (***O***util de ***P***rédiction des ***I***nondations dans la ***D***elta ***I***ntérieur du ***N***iger) is a tool to predict the flooding of the Inner Niger Delta when the water starts to rise. As such it functions as an early warning system for the people living in the Inner Niger Delta.

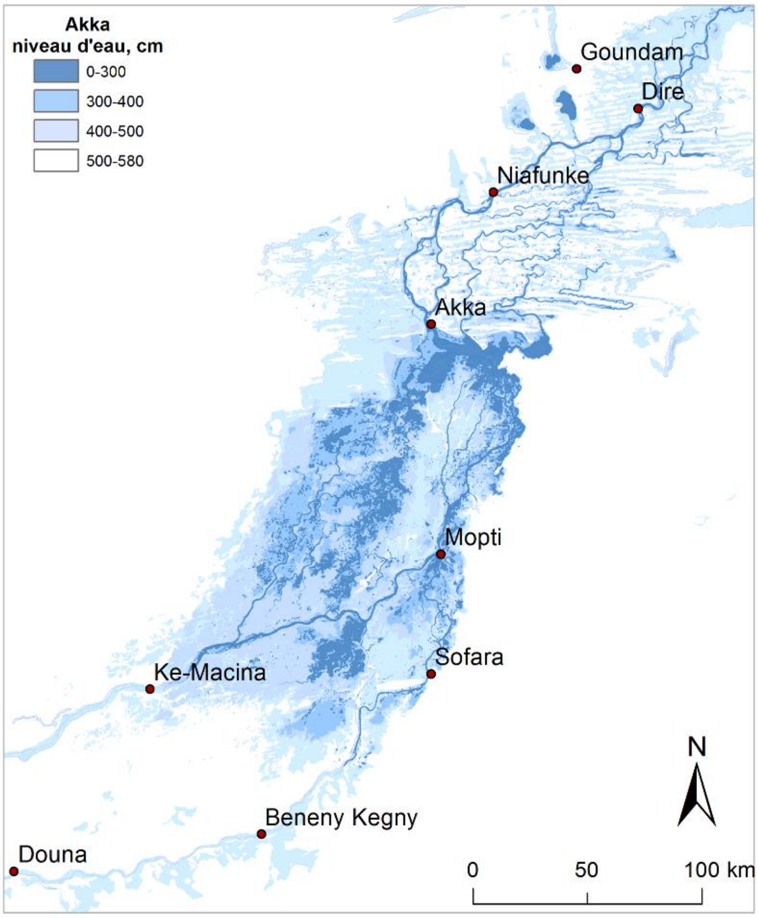


Fig. 1. The nine hydrometric stations used in OPIDIN. The four colours blue show the flood extent in the Inner Niger Delta at different flood levels in Akka.

OPIDIN predicts the maximum flood level and the date at which the flood peak is reached, but it may also be used to predict the water level during different stages of the flooding curve, e.g. the date at which the water level has declined to a certain level.

The flooding model, given in *The Niger, a lifeline* (Zwarts *et al*. 2005), allows to indicate precisely the flood extent related to a certain flood level. Thus, OPIDIN not only predict the peak flood but also the inundated areas.

The study could built upon earlier work. A preliminary version of OPIDIN was developed in 2009 in the framework of *Projet PvW 07012 (Mali): Gestion intégrée des ressources en eau dans le bassin du Niger en amont de Taoussa – Outil d'aide à la decision*, a study financed by 'Partners for Water', a joint initiative of six departments of the Government of the Netherlands. A first version of OPIDIN was described by Zwarts (2009a).

The study got a follow-up in the framework of *Wetland & Livelihoods Project: GIRE (Gestion integrée de resources naturelles) dans le basin du Niger en amont de Taoussa*, a project of Wetlands International. These results were summarized in Zwarts (2009b). A further improvement of OPIDIN could be realised in the framework of the EU-framework 7 project AFROMAISON; results which are incorporated in this report.

OPIDIN could be improved a lot in 2012-2013:

- The predictions are based on all data being collected since 1922;
- The predictions are improved by using curvilinear instead of linear regression equations;
- The change of the flooding curve due to the Sélingué reservoir was quantified and integrated in the improved flood predictions;
- The predictions are given for more stations (Mopti, Akka, Diré);
- The confidence interval are indicated for all predictions;
- The timing of the deflooding is given as well.

Moreover, an Atlas has been produced, showing in 52 maps (26 for the northern and 26 for the southern half of the Inner Niger Delta) the flood extent between 300 and 520 cm at the gauge of Akka. The Atlas is available as book (Zwarts & Hoekema 2013), but also as pdf.

OPIDIN is on line since August 2013 (see www.opidin.org). The flood viewer on the site gives the predicted peak flood level and flood extent based on the current water level measurements. The same information will be broadcasted frequently on the local radios in August - October.

This report is meant as technical background information. It explains the methodology and gives the essential statistics, such as the regression equations being used to predict the flooding and deflooding. For general information about OPIDIN we refer to earlier reports and to www.opidin.org.

Acknowledgement
The Dutch Embassy in Mali made it possible to improve and extend OPIDIN in 2013.

2 Results

2.1 Annual flooding curves

DNH measures every day the water level on hydrometric stations along the Niger since already a very long time and in Koulikoro even since 106 years.

This report uses all available data of nine stations (see Fig. 1):

- three along the Bani (Douna, Beneny-Kegny and Sofara),
- Ké-Macina in the Niger at the entrance of the Inner Niger Delta,
- five stations in the Inner Niger Delta itself (Mopti, Akka, Niafunké, Diré and Goundam).

Fig. 2 gives for the nine stations the daily measurements during the "hydraulic year" (1 June to 1 June the next year). The curves are shown for the years given in the title of the graph. The curves connect the daily measurements. Obviously, the daily increase during the flooding and daily decline during the deflooding are very regular. This is important to note since OPIDIN is based upon daily measurements and if they would vary a lot it would be a source of errors. The curves are less smooth for Ké-Macina (impact of the irregular releases at Sélingué and Markala dam), but these irregularities disappear further downstream. A part of the daily variation in the water level during the flooding appears to be due to variations in the daily rainfall in the Upper Niger and Upper Bani.

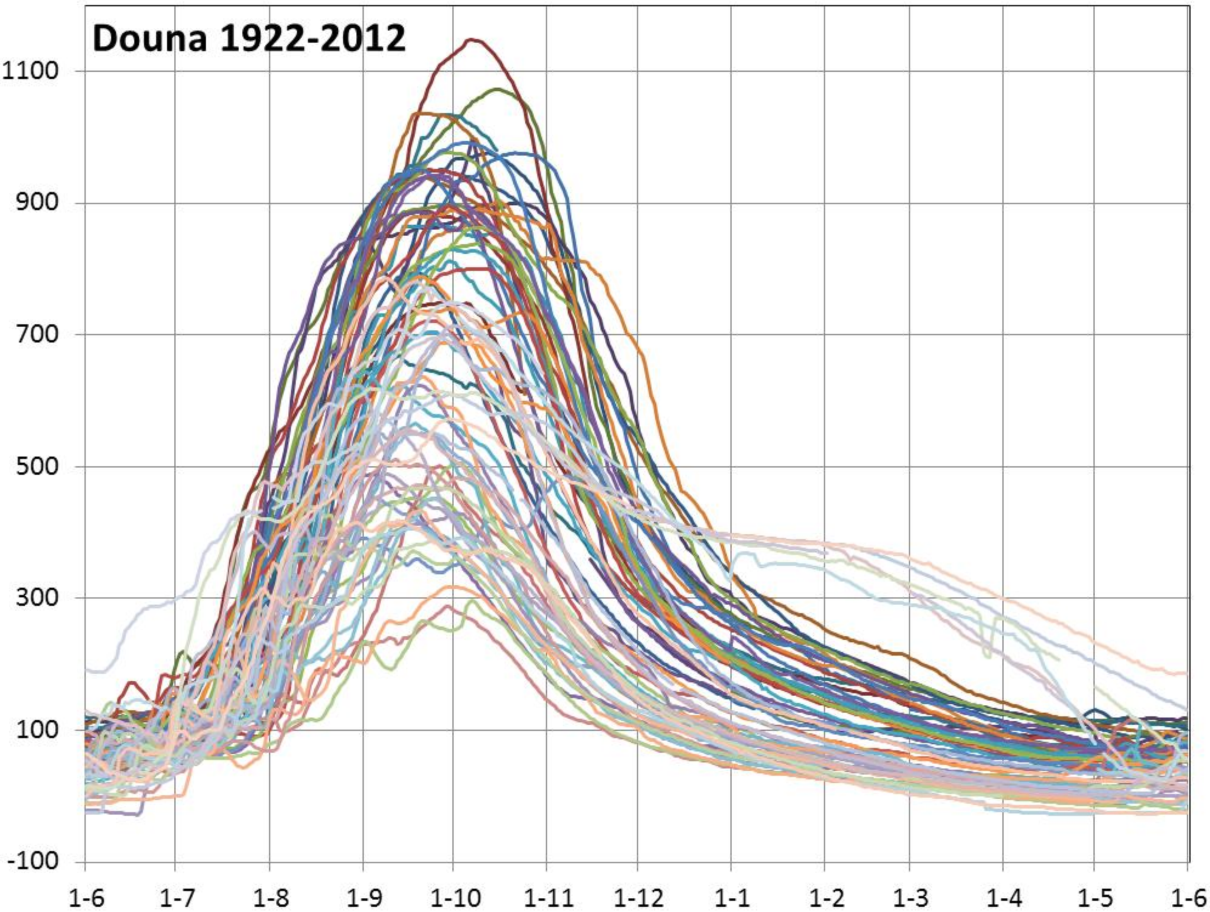


Fig. 2. Daily water level measurements (cm) between 1 June and 1 June the next year in Douna, given separately for all years available. Source: DNH. Note the six curves being 2 meters higher than all other years during the dry season. These curves are from the most recent years since the construction of the Talo reservoir in 2005.

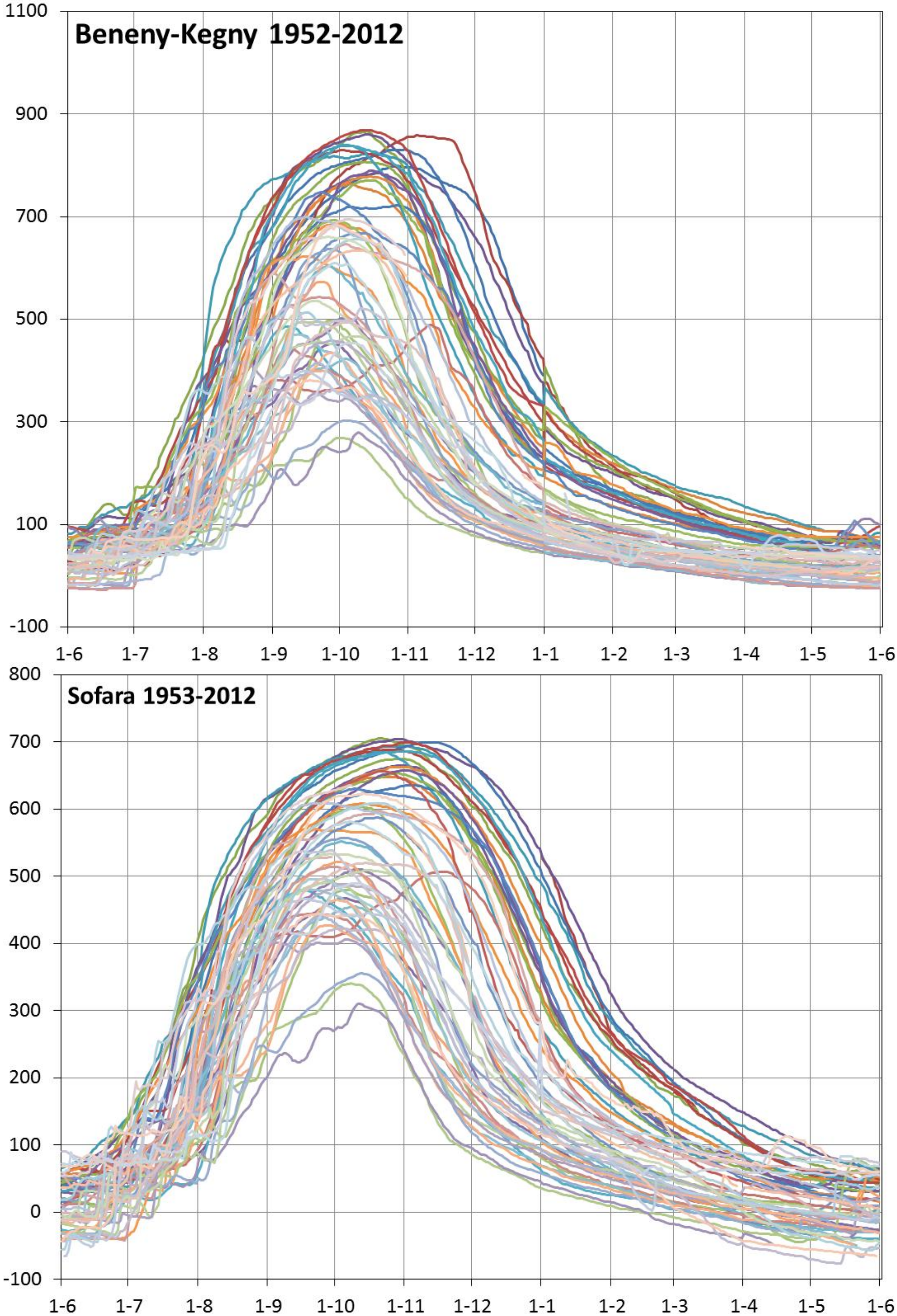


Fig. 2 (continued). Daily water level measurements (cm) between 1 June and 1 June the next year in Beneny-Kegny and Sofara, given separately for all years available. Source: DNH.

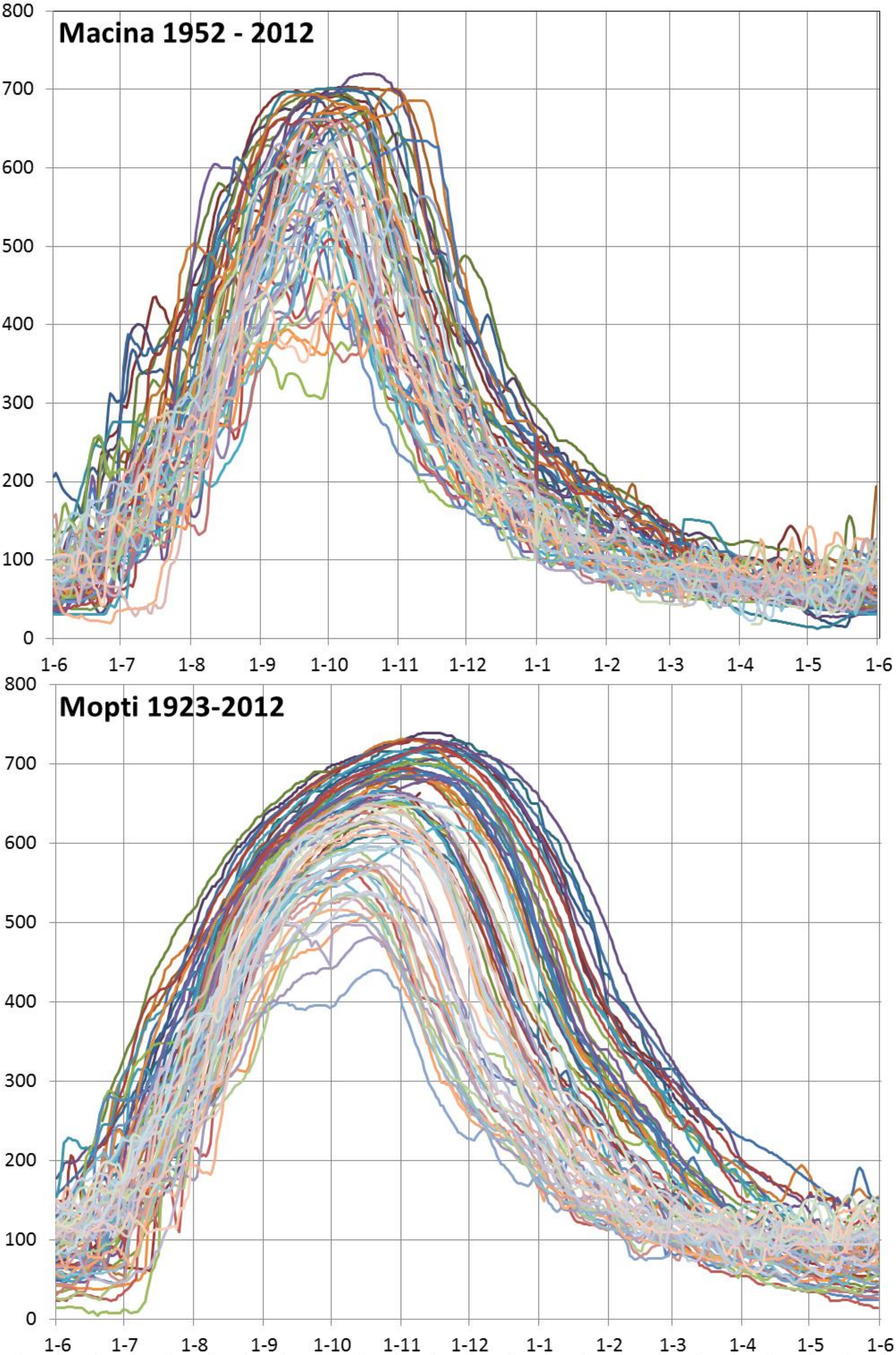


Fig. 2 (continued). Daily water level measurements (cm) between 1 June and 1 June the next year in Ké-Macina and Mopti, given separately for all years available. Source: DNH.

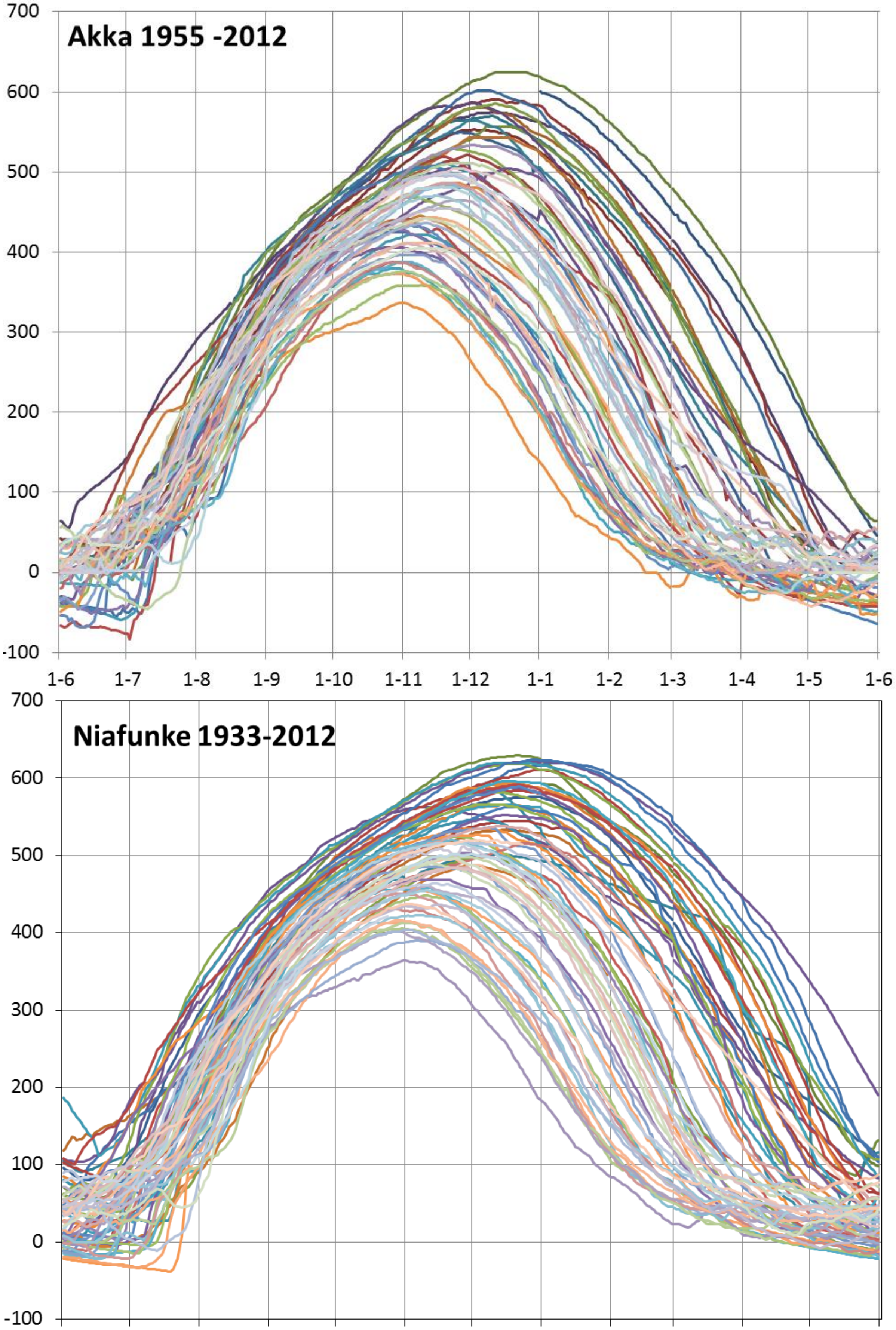


Fig. 2 (continued). Daily water level measurements (cm) between 1 June and 1 June the next year in Akka and Niafunké, given separately for all years available. Source: DNH.

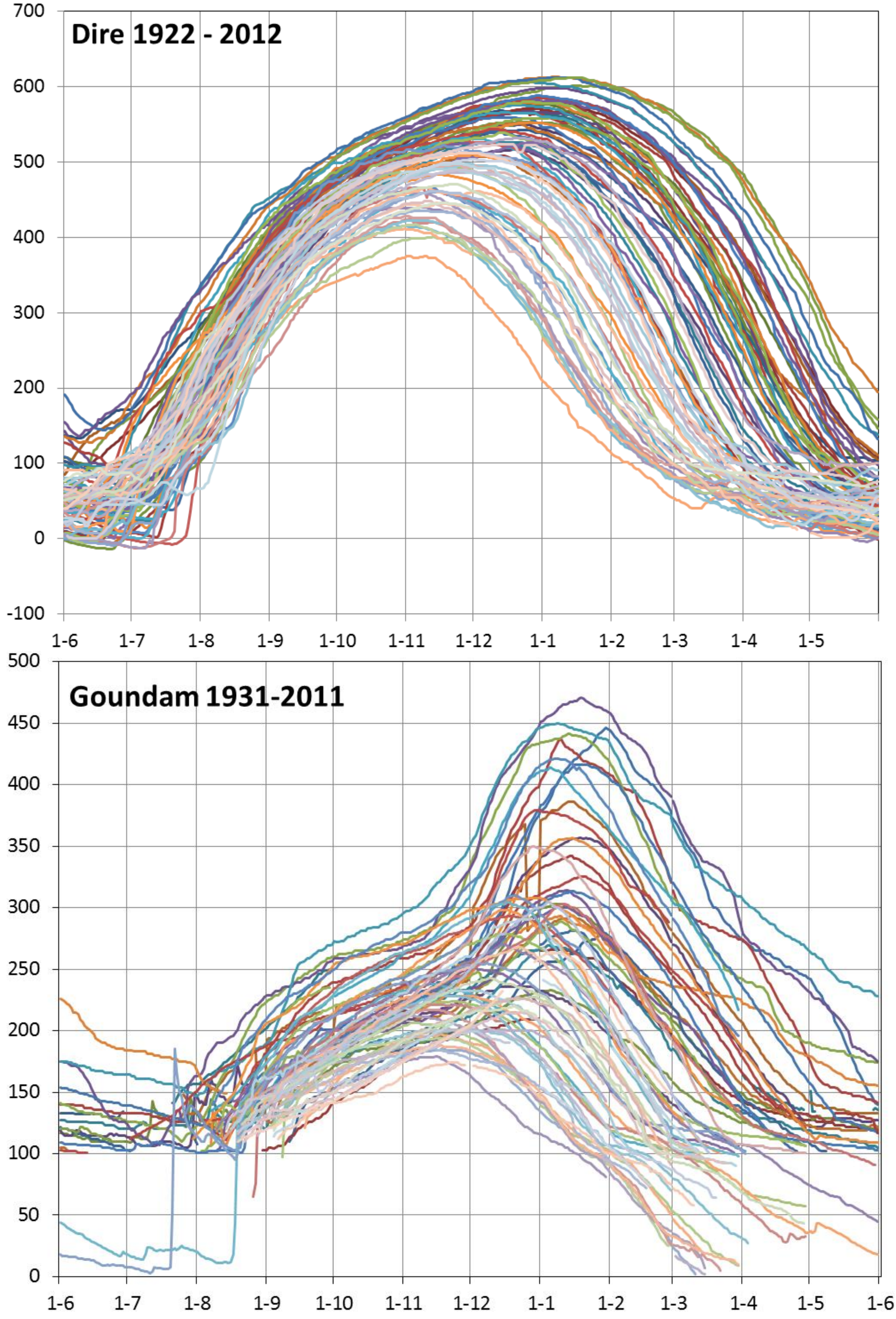
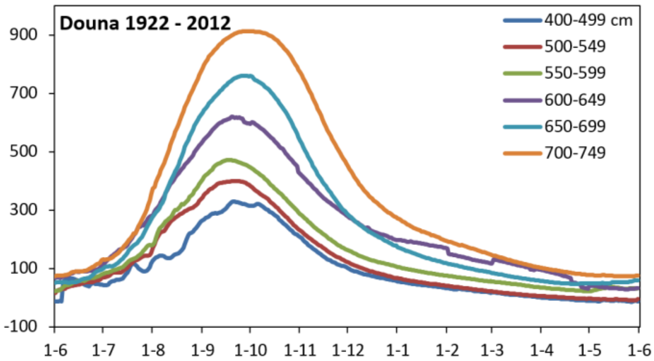
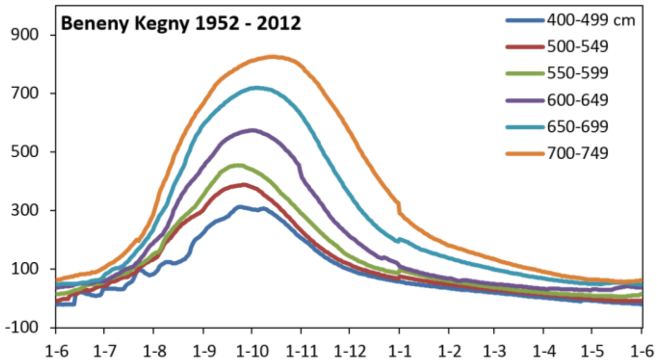


Fig. 2 (continued). Daily water level measurements (cm) between 1 June and 1 June the next year in Diré and Goundam, given separately for all years available. Source: DNH.

2.2 Average flooding curves

Fig. 2 clearly shows that the seasonal flooding curves are different in years with a high and low flood. To investigate the variation in the flood curve as a function of the flood height, all daily measurements were subdivided into six categories according to the height of the peak flood in Mopti. The results are given in Fig. 3 for the three Bani stations and in Fig. 4 for the six stations in the Inner Niger Delta.





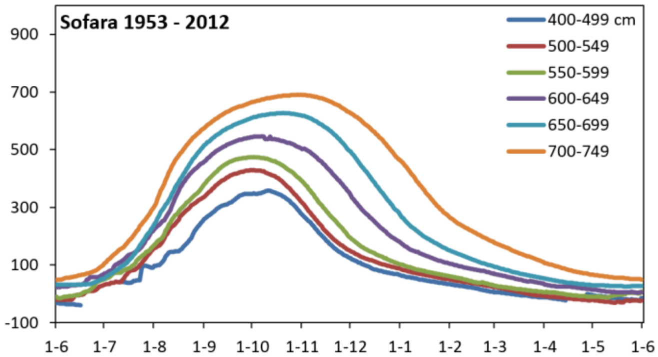


Fig. 3. The average flood curves (cm) during the year from June till June next year in Douna, Beneny-Kegny and Sofara, using the data from Fig. 2. The flood curves are given for six categories: the peak flood levels in Mopti below 5 m, between 5 and 5.5 m, etc. to between 7-7.5 m No corrections were made for lacking data, which explains the sudden, small shifts in some curves of Douna and Beneny-Kegny.

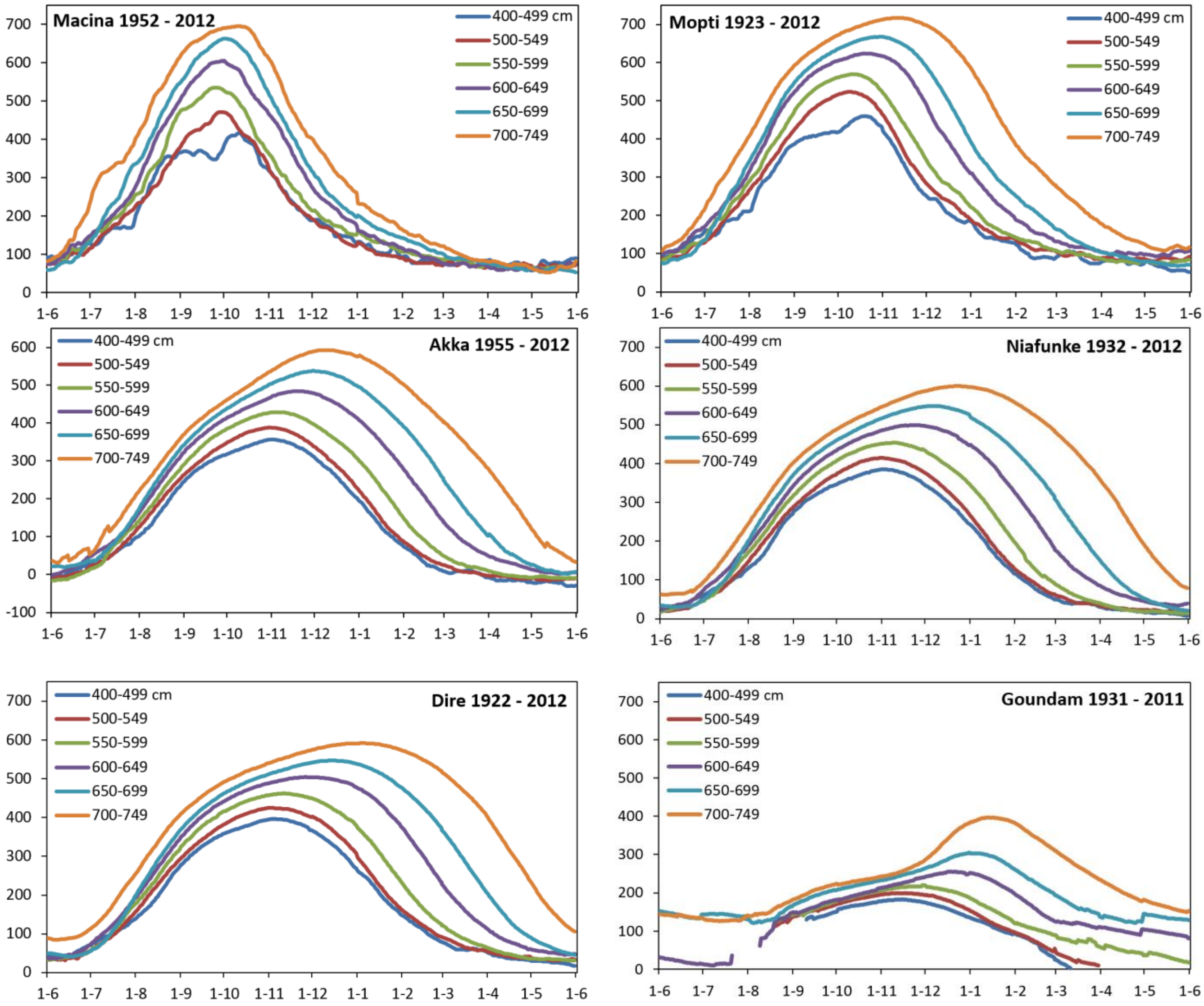


Fig. 4. The average flood curves (cm) during the year from June till June next year in six stations in the Inner Niger Delta, using the data from Fig. 2. The flood curves are given for six categories: the peak flood levels in Mopti below 5 m, between 5 and 5.5 m, etc. to between 7-7.5 m No corrections were made for the very few lacking data, which explains the few sudden, small shifts in some curves. The irregular curves for Ké-Macina have all to do with the large fluctuations in the daily water level (see Fig. 2).

2.3 Peak flood level in Mopti and hydrometric stations upstream

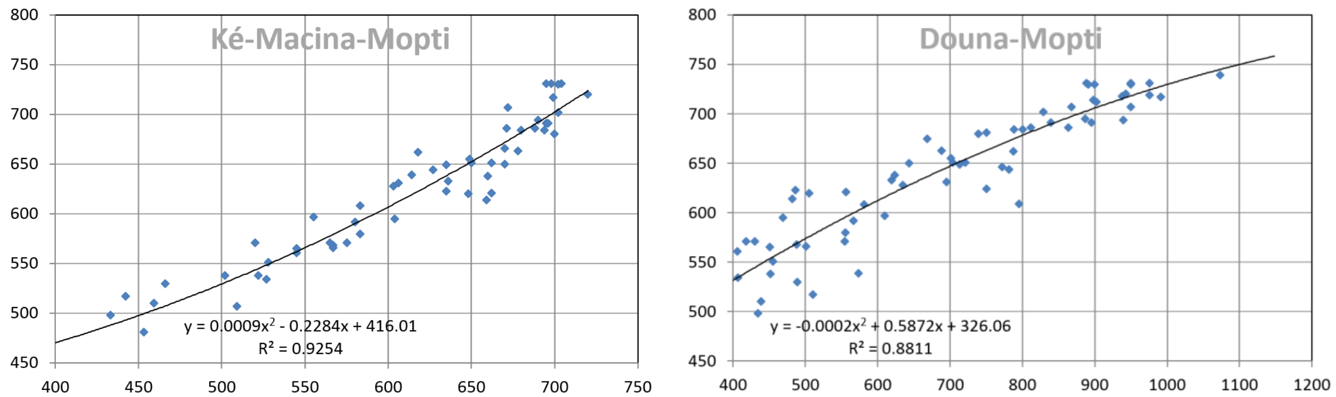


Fig. 5. The peak flood level in Mopti (cm) as a function of the peak (same year) in Ké-Macina (left) and Douna (right).

The annual peak flood level in Mopti had varied between 470 and 730 cm. The peak flood level in Mopti is determined not only by the flow of the Niger but also by the flow of the Bani. The correlation between the peak flood levels in Ké-Macina and Mopti is a little bit higher than between Douna and Mopti (Fig. 5). Unexpectedly, the peak flood level in Douna is only weekly related to the peak in Ké-Macina. (We would expect a higher correlation since the rainfall in Upper Niger and Upper Bani fluctuates concordantly, being high in relatively wet and low in relatively dry years).

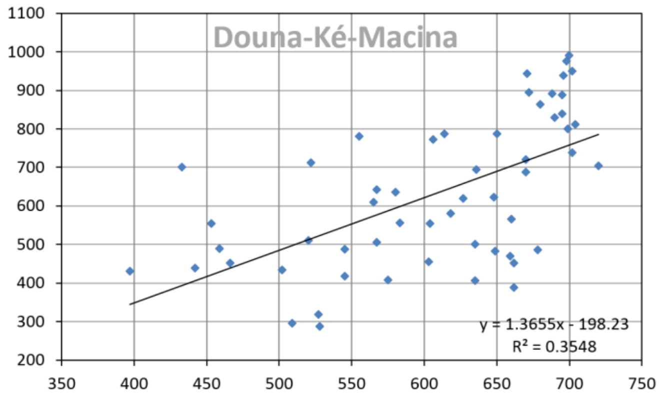


Fig. 6. The peak flood level in Douna (cm) as a function of the peak in Ké-Macina (cm), measured in the same year.

2.4 Peak flood level in Mopti and hydrometric stations downstream

The annual peak flood level in Mopti is highly correlated with the other hydrometric stations in the Inner Niger Delta (Fig. 7), but the relationships are clearly not linear.

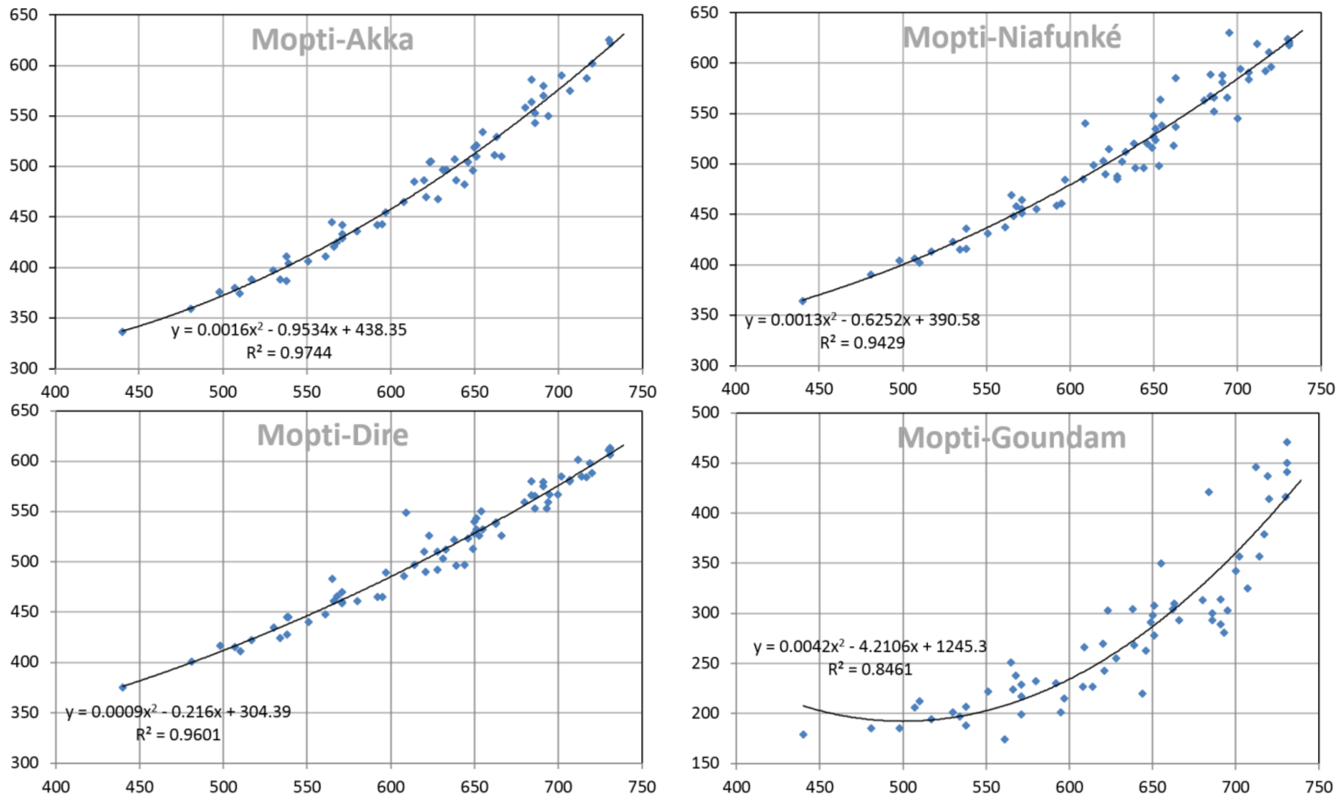


Fig. 7. The annual peak flood level in Akka, Niafunké, Diré and Goundam as a function of the peak in the same year in Mopti, all in cm; same data as shown in Fig. 2 and 3.

2.5 Timing of the peak flood level

There is hardly any relationship between the height of the peak water level in Douna and the date at which the peak is reached (Fig. 8). The highest water level in Douna is usually observed around 19 September, but this a week later, on average, when the peak water level is high. The peak flood level in Beneny-Kegny (120 km downstream of Douna) is, on average, 5 days later than in Douna, but in years with a high flood level, the retardation increases to 12 days. The peak water level in Sofara, being again 110 km further downstream, is about 20 days later than in Douna, during an average year. In an extremely dry or wet year, this time gaps amounts to 12 and 33 days.

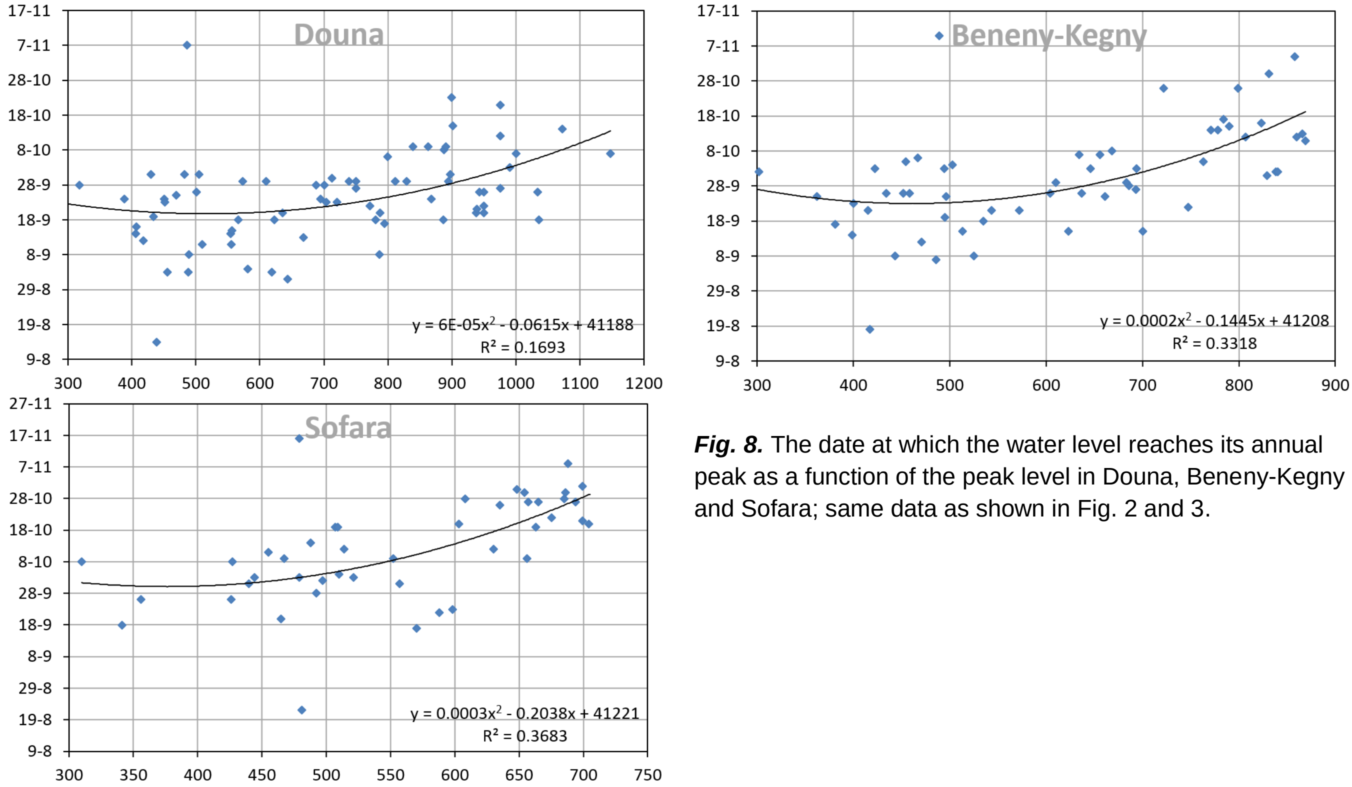


Fig. 8. The date at which the water level reaches its annual peak as a function of the peak level in Douna, Beneny-Kegny and Sofara; same data as shown in Fig. 2 and 3.

Fig. 9 shows the relationship between the height of the peak flood and the timing for the six station in the Inner Niger Delta. At the entrance of the Delta, there is hardly any relationship between the height and the timing of the peak, but the retardation is evident in Mopti and getting larger further downstream (Table 1). The delay is in wet years much larger than in dry years.

Table 1. The average date of the peak flood level at three flood levels: 500 cm (= <550), 600 cm (= 550-650 and 700 cm (= >650) at the gauge of Mopti. The same data as given in Fig. 9 are used. However, to make the data comparable, the average levels and dates for the flood levels in the six hydrometric stations were categorised for three flood categories in Mopti and not separately for the six stations (as done in Fig. 9).

	Average date of the peak			Average delay after 30/9		
	500 cm	600 cm	700 cm	500 cm	600 cm	700 cm
Ké-Macina	30-9	1-10	3-10	0	2	3
Mopti	19-10	29-10	22-11	19	29	53
Akka	3-11	18-11	15-12	35	49	76
Niafunké	8-11	29-11	3-1	39	60	95
Diré	14-11	4-12	13-1	45	65	105
Goundam	14-11	11-12	15-1	46	72	107

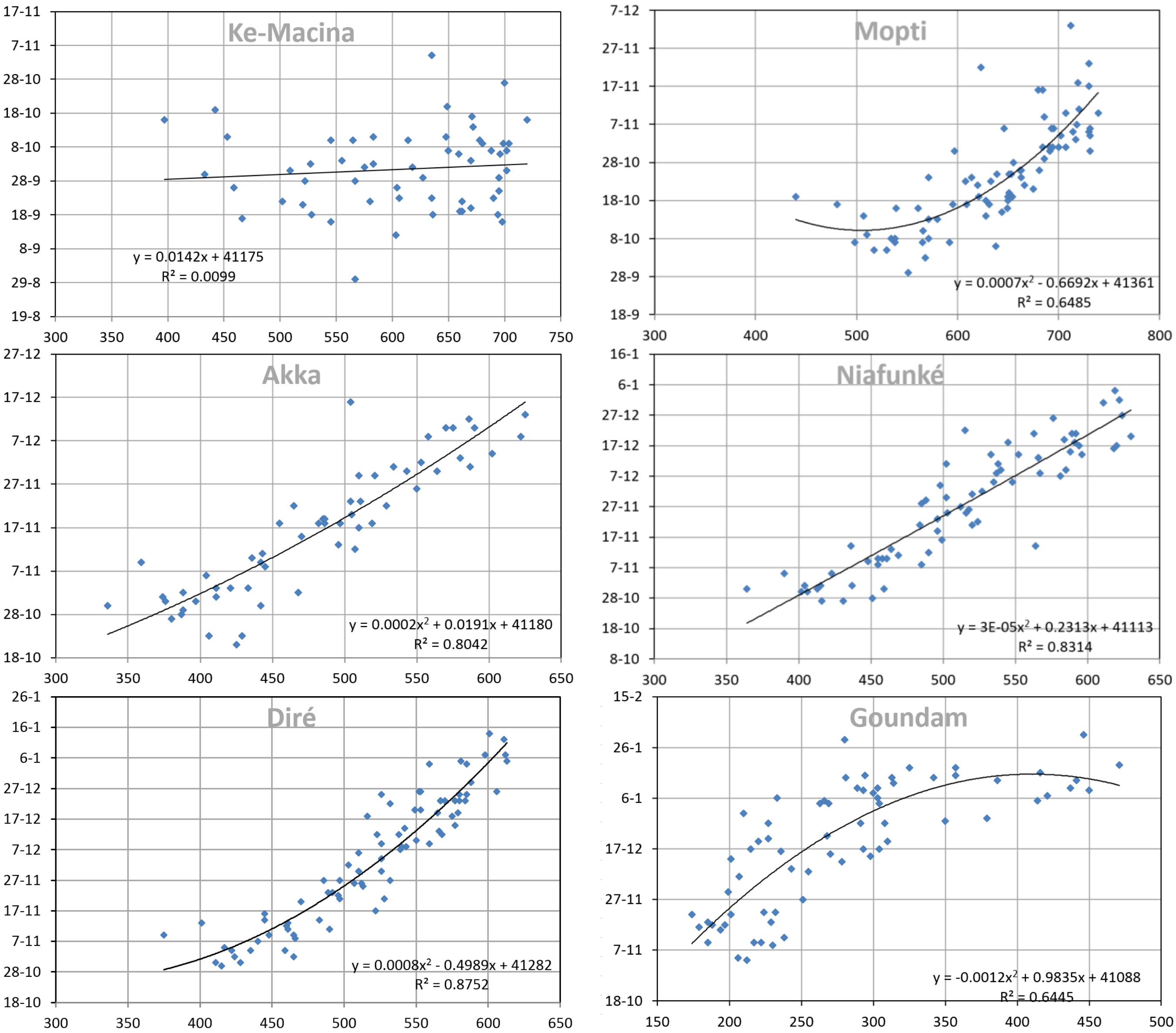


Fig. 9. The date at which the flood reaches its annual peak level as a function of the peak level (cm) in Ké-Macina, Mopti, Akka, Niafunké, Diré and Goundam.

2.6 Flood prediction: taking into account impact Sélingué

The Sélingué reservoir has changed the flooding curve. The peak level is reduced because the reservoir is filled in the early wet season and emptied in the dry season by which the river flow of the Niger became twice as high in April and May. As a consequence, the relationship between the water level in the early wet season and the peak flood level has changed. Fig. 10 gives two examples: the peak flood level as a function of the water level in Mopti on 1 and on 21 August. The water level observed on 1 August gives a rough indication of the expected flood peak, but it is obvious that the prediction with and without Sélingué differs an estimated 61 cm, on average. The relation with the peak flood level is much better on 21 August; the average impact of Sélingué is reduced to 37 cm. This large difference is due to a combined effect: (1) in years with a same peak flood level, the water level is, on average, higher in (early) August since the construction of Sélingué due to the water released during the dry season; (2) in years with a similar water level in (early) August, the peak flood level is lower since the construction of Sélingué due to the water being withhold.

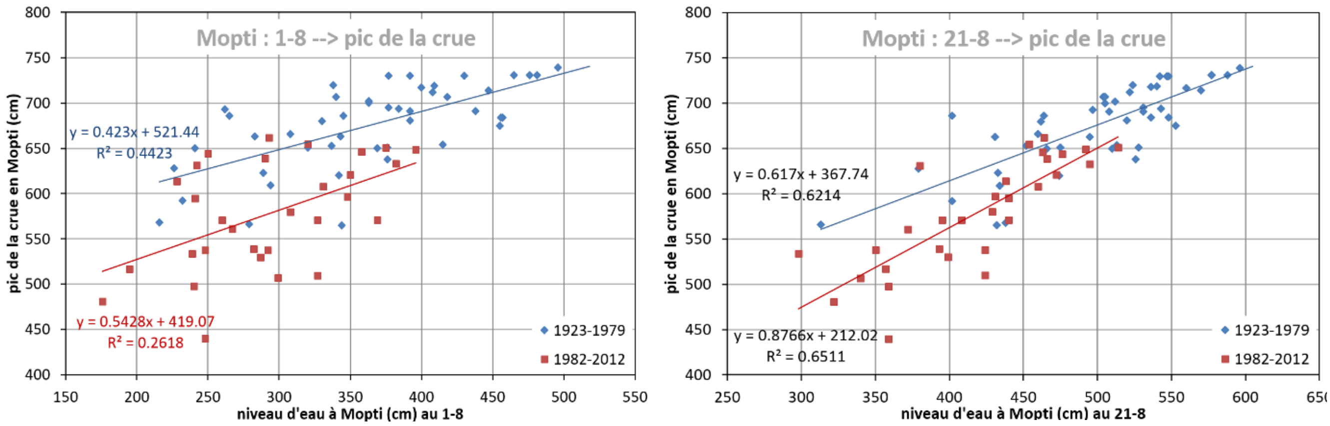


Fig. 10. The peak flood in Mopti as a function of the water level in Mopti on 1 August (left) and on 21 August (right), split up for the years with and without Sélingué.

It would be wrong to predict the peak flood level in the current situation (thus with Sélingué) using the regression equation calculated over all historical data. The problem is solved by only using the years after the construction of Sélingué. Instead, we decided to use all data and calculate a multiple regression equation with a common slope but a different intercept to take into account the difference before and after the construction of Sélingué. To illustrate the principle, Fig. 11 shows the result for one date, 1 August.

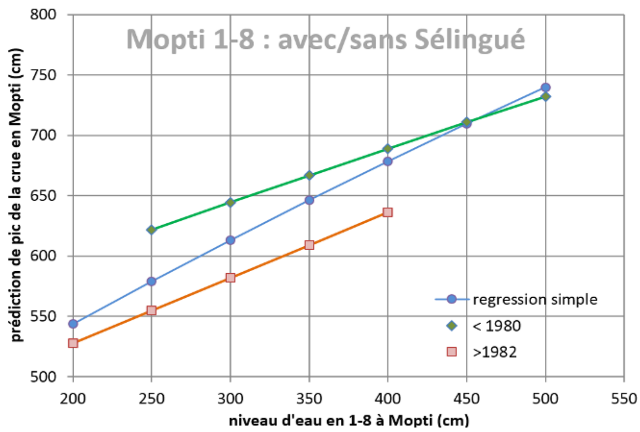


Fig. 11. The data from 1 August in Fig. 10 were used to calculate a regression equation for all data (blue line; “regression simple”) and a multiple regression equation where the data were split up before (green line) and after (red line) the construction of Sélingué. Note that the slopes of both regressions are equal and that only the intercept differs. The red line is used in OPIDIN to predict the peak flood level.

2.7 Prediction of the peak flood: a curvilinear relation

The relationships as shown in Fig. 10 are linear in August but later in the season they became curvilinear (Fig. 12). Hence we used in OPIDIN second degree polynomials to relate water level in August - October to the peak flood level.

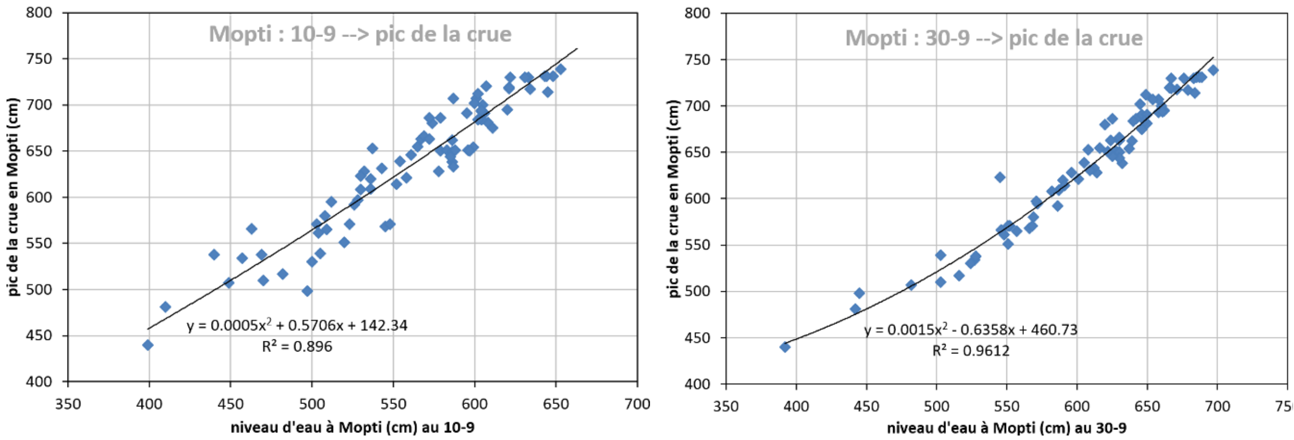


Fig. 12. The peak flood level in Mopti as a function of the water level measured in Mopti on 10 September (left) and on 30 September (right). The relationship is linear in early August, but becomes curvilinear in September.

2.8 Prediction of the peak flood level: confidence intervals

It is already evident in August whether the peak flood level in October will be high or low. For instance, if the water level on 20 August is 550 cm, we may predict that the peak flood level will be 700 cm, while if the water level is not more than 300 cm, the flood will be low too, about 500 cm (Fig. 13). The relationship is not perfect, as was already clear from Figs. 10 and 12, being even rather poor in July but becoming better later in the season.

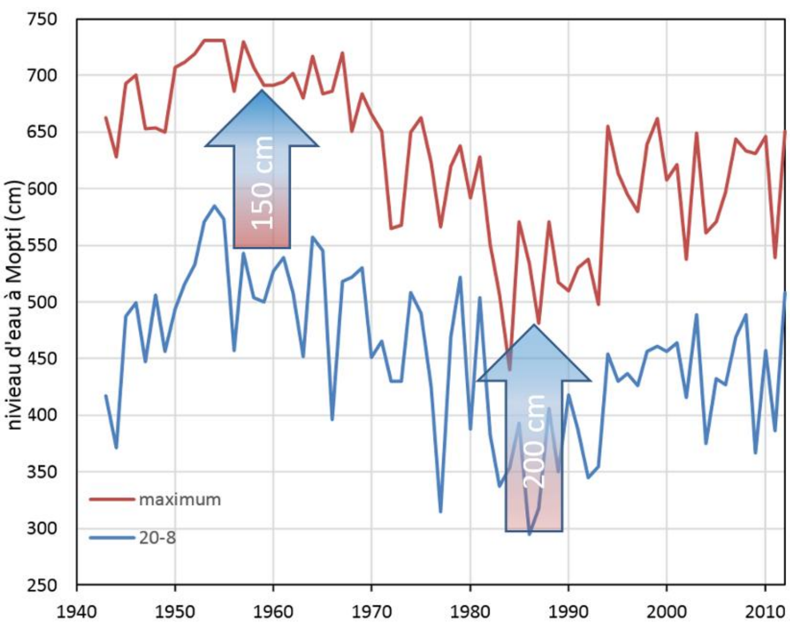


Fig. 13. The annual variation in the peak flood in Mopti (red line) and the water level in Mopti at 20 August for the last 70 years, to show that the peak flood in October-December may already be predicted in August.

We calculated the relationship between the peak flood level in Mopti as a function of the water level in Mopti on 21 July, 26 July, 1 August, 5 August etc. until 16 October, altogether for 18 dates. The next section gives the multiple regression equations, but first we pay attention here to the accuracy of the predicted flood level.

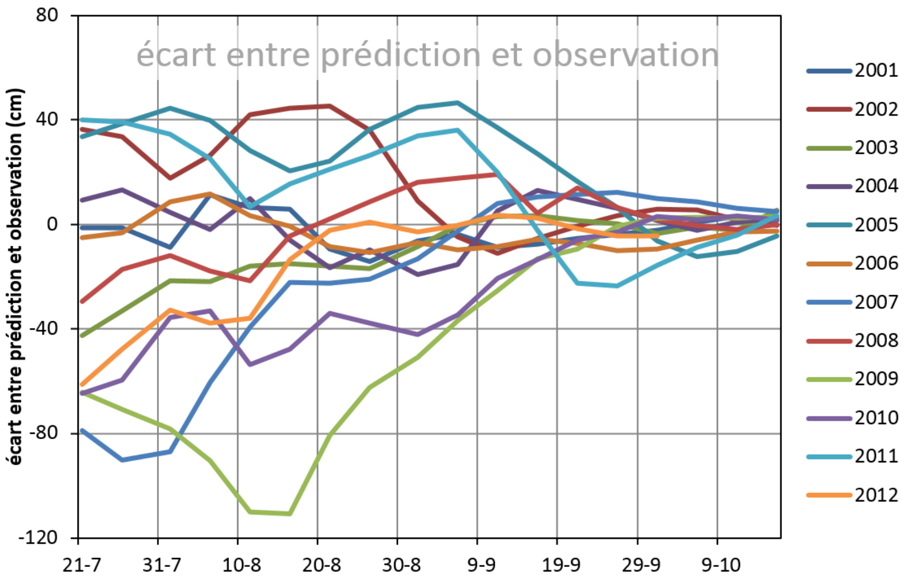


Fig. 14. The deviation between the actual and predicted flood level in Mopti between 21 July and 16 October. The error is shown for the last 12 years.

We calculated the predicted peak flood level in Mopti using the 18 equations from 21 July to 16 October and compared the predicted to the actual flood values measured in October. Fig. 14 shows for 12 years (2001-2012) the difference between the predicted and actual peak flood. Obviously, the error is small from mid-September onwards. The error is also small in most years in the preceding weeks, but there are some years during which the deviations are large. For instance, we predicted a very low peak flood in 2009, given the still very low water level in August (see the green line in Fig. 14). The rains came late that year, so the water level increased fast from mid-August onwards, by which also the predicted peak flood went up. A similar large underestimation of the peak flood occurred in 2007 until early August (see the dark blue line in Fig. 14). It is also obvious from Fig. 14 that the underestimation can be relatively large in July and August, but that the overestimations are limited. Apparently, if the water level is already high early in the season, this is always a clear indication of a high flood, but if the water level is still low, the peak flood will usually be low, but may sometimes become high.

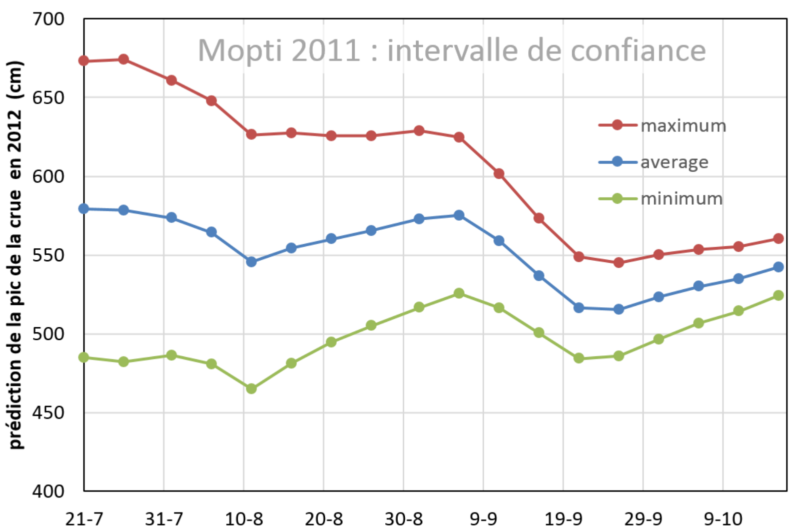


Fig. 15. The predicted peak flood level in Mopti in 2011 (blue line). The 95% calculated confidence interval (between the red and green line) is also given. The actual flood peak on 16 October 2011 was 539 cm, thus very close to the last predictions.

The equations give the predicted peak flood level, but also the 95% confidence interval, which means that there is a probability of 95% that the prediction will fall between certain limits. Fig. 15 shows for one year (2011) the predictions from 21 July onwards and their interval. In late July 2012, we could only say that the expected peak flood would be higher than 480 cm and lower than 670 cm. During the course of August, the accuracy gradually increased. Hence, it is always important to give the prediction not as a simple value, but as a range between an expected minimum and maximum value.

2.9 Prediction of the peak flood: regression equations

Table 2 gives the set of regression equations used to predict the peak flood level in Mopti. The function can be written as:

Peak-cm = a + cm + cm^2 +Sél,
where cm = the water level on a certain date,
Sél = 0 before 1982 and Sél = 1 since 1982.

To give an example, if the water level on 1 September is 500 cm, the predicted peak flood level (cm) becomes:

$246.1 + 0.58*500 - 0.00033*500^2 - 26.3 = 594$ cm.

The confidence interval (c.i.) for 1 September is 28 cm, so the predicted range is 594 ± 28 cm, or 566 - 622 cm.

The right table shows the formulae used to calculate at which date the peak flood level will be reached. To give an example, if the water level on 1 September is 500 cm, the predicted timing of the peak flood level (date) becomes:

$41226 - 0.22*500 - 0.00035*500^2 -2.2 = 41200$. This is the Julian Day Number, which may easily for converted (for instance in Excel) to the date: 18 October 2012. Year is irrelevant here, thus the prediction is 18-10. The confidence interval (c.i.) for 1 September is 20 days, so the predicted range for the peak is 18 October ± 20 days, thus between 28-9 and 7-11.

Table 2. The multiple regression equations used to predict the peak flood in Mopti using the measured water level in Mopti on 1, 6, 11 August, etc., until 16 October. Left table gives the equations to predict the peak flood level (cm) and the right table the equations to predict the date at which the peak flood is reached. c.i.= 95% confidence interval, R^2 = explained variance. Further explanation is given in the text.

CM	a	cm	cm^2	Sél	c.i.	R^2
1-8	467.3	0.68	-0.00031	-61.3	44	0.63
6-8	423.7	0.80	-0.00041	-58.4	42	0.65
11-8	383.4	0.85	-0.00041	-54.0	41	0.67
16-8	274.4	1.13	-0.00058	-45.3	37	0.73
21-8	266.4	0.93	-0.00023	-36.7	33	0.79
26-8	304.6	0.56	0.00026	-31.5	30	0.82
1-9	246.1	0.58	0.00033	-26.3	28	0.85
6-9	185.4	0.65	0.00035	-19.9	25	0.88
11-9	157.3	0.62	0.00042	-17.1	21	0.91
16-9	230.5	0.29	0.00073	-15.9	18	0.93
21-9	313.1	-0.03	0.00100	-13.3	16	0.95
26-9	381.9	-0.31	0.00122	-9.0	15	0.96
1-10	389.1	-0.35	0.00124	-7.1	13	0.97
6-10	335.7	-0.18	0.00109	-6.0	12	0.97
11-10	245.0	0.14	0.00078	-6.8	10	0.98
16-10	217.2	0.28	0.00062	-7.6	9	0.98

DATE	a	cm	cm^2	Sél	c.i.	R^2
1-8	41179	0.10	-0.00003	-6.8	22	0.34
6-8	41165	0.17	-0.00011	-6.5	22	0.37
11-8	41171	0.11	-0.00004	-6.3	23	0.35
16-8	41171	0.08	0.00001	-5.2	23	0.36
21-8	41177	0.02	0.00009	-3.5	21	0.41
26-8	41185	-0.04	0.00017	-2.4	23	0.44
1-9	41226	-0.22	0.00035	-2.2	20	0.44
6-9	41279	-0.43	0.00054	-1.4	20	0.46
11-9	41328	-0.61	0.00070	-1.4	20	0.47
16-9	41353	-0.69	0.00075	-1.6	20	0.47
21-9	41379	-0.77	0.00081	-1.5	20	0.48
26-9	41385	-0.78	0.00081	-1.0	20	0.48
1-10	41391	-0.80	0.00081	-0.4	19	0.50
6-10	41404	-0.84	0.00084	0.1	19	0.51
11-10	41398	-0.81	0.00081	0.4	19	0.53
16-10	41377	-0.74	0.00074	1.0	18	0.55

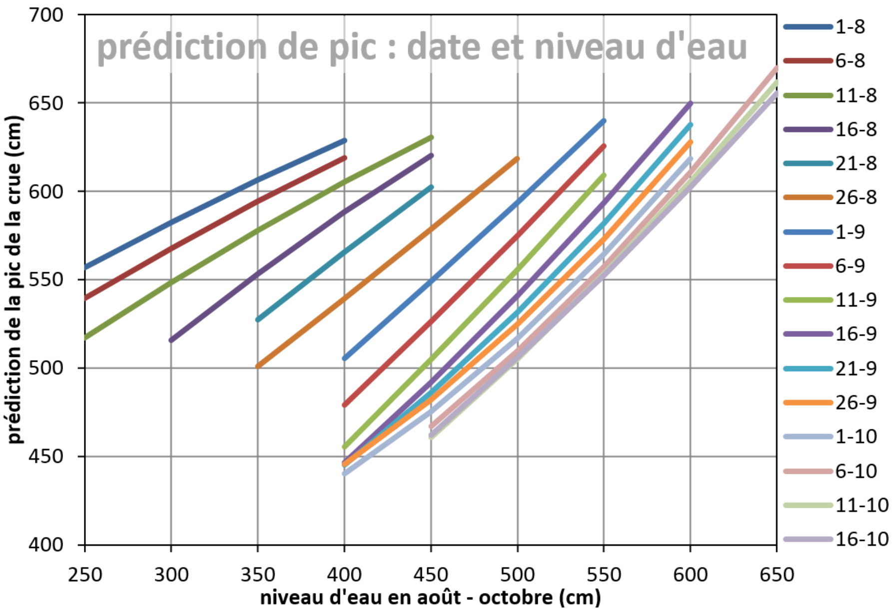


Fig. 16. The predicted flood peak in Mopti as a function of water level on 16 different dates. The lines are calculated using the regression equations given in Table 2.

The predicted peak flood levels as a function of the water level on different dates is shown in Fig. 16. The regression lines are shown for the range of values being ever observed. Fig. 17 shows the predicted peak levels at a certain water level on different dates. Fig. 16 and 17 are based on the regression equation calculated for 16 different dates.

For the intervening dates and intervening water levels the predicted peak flood level and the predicting date of the peak flood were calculated by interpolation. As a result we got a table with predicted peak flood levels given in 77 columns (per day between 1 August and 16 October) and 481 rows (per cm between 180 and 660 cm).

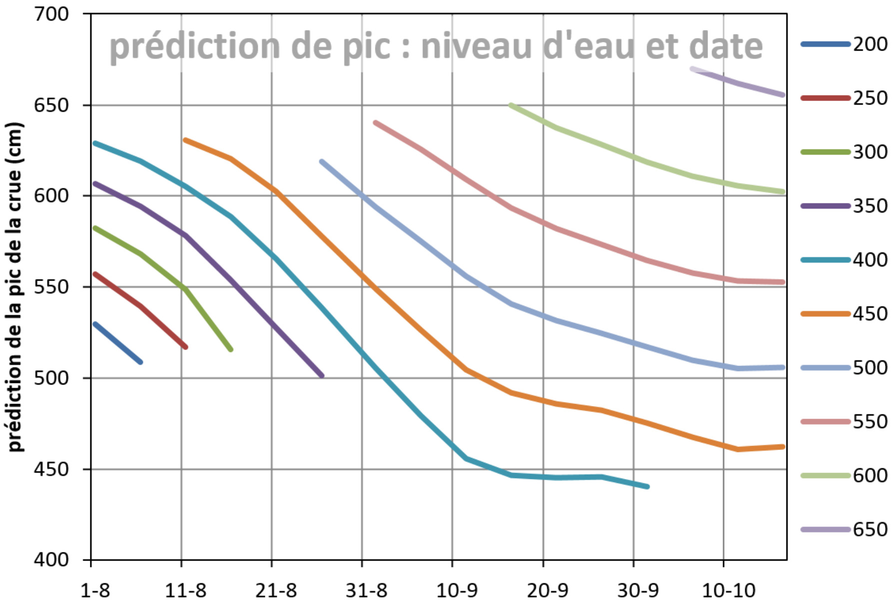


Fig. 17. The predicted flood peak in Mopti as a function of water level dates given separately for 10 different water levels. The lines are calculated using the regression equations given in Table 2.

2.10 Prediction of the peak flood in Akka and Diré

The measurements of the water in Augustus-October in Mopti were used to predict the peak flood in Mopti, but in the same way the measurements can be used to predict the flooding in Akka and in Diré. The regression equations are given in Table 3 (Akka) and Table 4 (Diré). The predictions for Akka are less accurate as for Mopti, but the difference in the confidence intervals is not large (Fig. 18). Unexpectedly, the predictions for Diré are even more accurate as those of

Mopti, at least before mid-September. It is also possible to use the water level in Akka in August-September (instead of those in Mopti) to predict the flood peak in Akka, but as shown in an earlier analysis, this gives for Akka less accurate predictions (Zwarts 2009a). Hence, we only use here the water levels in Mopti to predict the flood peaks at several stations in the Inner Niger Delta.

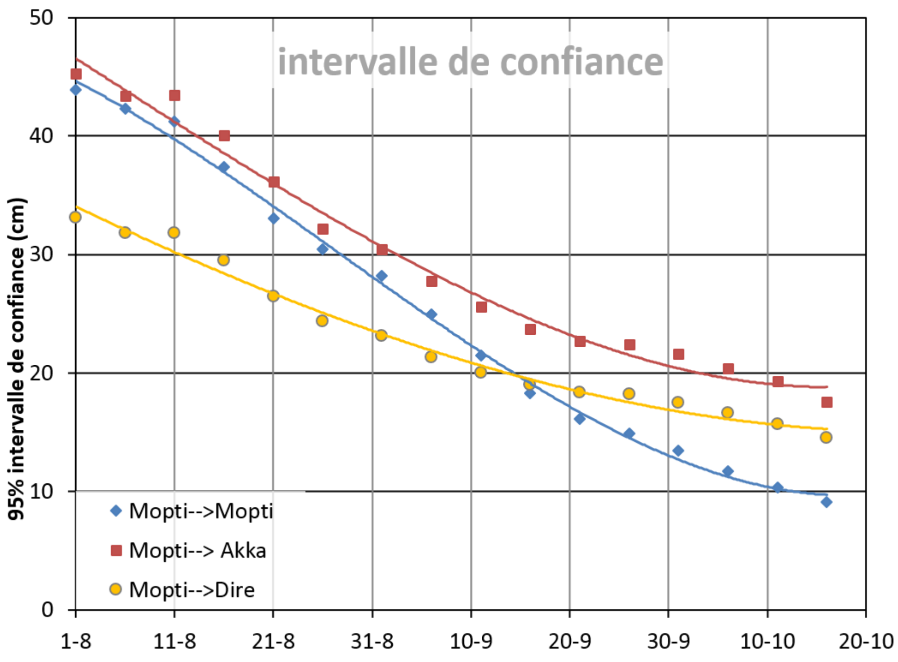


Fig 18. The confidence intervals of the 18 regression equations relating the water level at certain dates in Mopti to the flood peak in the same year in Mopti (blue symbols), in Akka (red symbols) and in Diré (yellow symbols).

Table 3. The multiple regression equations used to predict the peak flood in Akka using the measured water level in Mopti on 1, 6, 11 August, etc., until 16 October. Left table gives the equations to predict the peak flood level (cm) and the right table the equations to predict the date at which the peak flood is reached. c.i. = 95% confidence interval, R^2 = explained variance. Further explanation is given in the text.

cm	a	cm	cm²	Sél	c.i.	R²
1-8	407.0	0.02	0.00089	-51.7	45	0.63
6-8	396.1	-0.01	0.00089	-47.7	43	0.66
11-8	376.1	0.03	0.00078	-45.5	43	0.66
16-8	312.3	0.18	0.00064	-39.3	40	0.71
21-8	316.6	-0.01	0.00090	-33.2	36	0.77
26-8	457.9	-0.81	0.00182	-27.2	32	0.81
1-9	573.3	-1.39	0.00239	-24.9	30	0.83
6-9	632.3	-1.70	0.00267	-20.4	28	0.86
11-9	714.9	-2.05	0.00297	-20.0	26	0.88
16-9	743.9	-2.14	0.00298	-20.6	24	0.90
21-9	808.1	-2.33	0.00308	-19.6	23	0.91
26-9	832.2	-2.40	0.00308	-16.5	22	0.91
1-10	789.6	-2.23	0.00289	-15.1	22	0.92
6-10	782.6	-2.19	0.00282	-13.9	20	0.93
11-10	696.8	-1.85	0.00247	-15.5	19	0.93
16-10	627.2	-1.55	0.00215	-16.0	18	0.95

date	a	cm	cm²	Sél	c.i.	R²
1-8	41224	-0.05	0.00025	-7.6	23	0.43
6-8	41200	0.07	0.00006	-7.0	22	0.46
11-8	41200	0.06	0.00007	-6.8	23	0.44
16-8	41189	0.08	0.00005	-6.0	22	0.46
21-8	41188	0.06	0.00009	-4.9	21	0.51
26-8	41216	-0.10	0.00028	-3.7	21	0.55
1-9	41260	-0.30	0.00047	-3.3	20	0.55
6-9	41306	-0.49	0.00065	-2.5	20	0.56
11-9	41352	-0.67	0.00080	-2.6	20	0.57
16-9	41366	-0.70	0.00082	-2.8	20	0.58
21-9	41391	-0.78	0.00087	-2.6	19	0.59
26-9	41393	-0.78	0.00085	-2.0	19	0.60
1-10	41391	-0.77	0.00083	-1.6	19	0.61
6-10	41404	-0.81	0.00086	-1.0	19	0.64
11-10	41394	-0.77	0.00082	-0.9	18	0.66
16-10	41369	-0.68	0.00073	-0.4	17	0.70

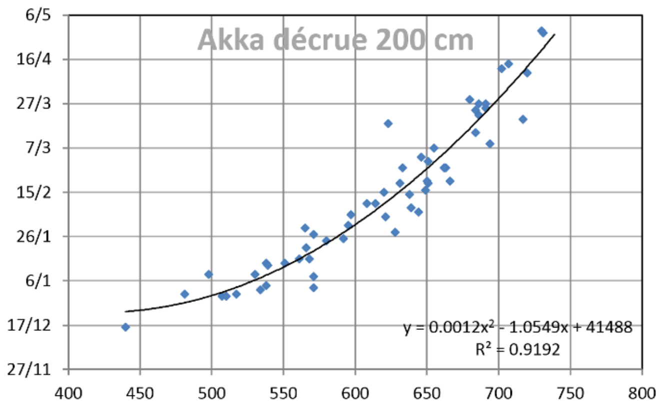
Table 4. The multiple regression equations used to predict the peak flood in Diré using the measured water level in Mopti on 1, 6, 11 August, etc., until 16 October. Left table gives the equations to predict the peak flood level (cm) and the right table the equations to predict the date at which the peak flood is reached. c.i. = 95% confidence interval, R^2 = explained variance. Further explanation is given in the text.

cm	a	cm	cm²	Sél	c.i.	R²
1-8	443.4	0.15	0.00040	-58.3	33	0.71
6-8	412.1	0.25	0.00026	-55.4	32	0.73
11-8	392.3	0.28	0.00021	-53.5	32	0.73
16-8	316.8	0.49	0.00004	-46.9	29	0.77
21-8	304.1	0.39	0.00022	-40.3	26	0.81
26-8	344.4	0.07	0.00061	-36.2	24	0.84
1-9	356.3	-0.11	0.00084	-33.1	23	0.86
6-9	362.5	-0.24	0.00099	-28.7	21	0.88
11-9	395.6	-0.43	0.00117	-27.4	20	0.89
16-9	452.2	-0.65	0.00135	-27.2	19	0.90
21-9	541.9	-0.97	0.00160	-25.8	18	0.91
26-9	586.6	-1.13	0.00171	-23.0	18	0.91
1-10	580.9	-1.12	0.00168	-21.4	18	0.92
6-10	554.6	-1.02	0.00158	-20.4	17	0.93
11-10	507.5	-0.84	0.00140	-20.7	16	0.93
16-10	471.2	-0.68	0.00122	-20.9	15	0.94

date	a	cm	cm²	Sél	c .i.	R²
1-8	41237	-0.03	0.00023	-18.5	31	0.51
6-8	41213	0.09	0.00006	-17.3	30	0.53
11-8	41220	0.03	0.00012	-17.3	30	0.51
16-8	41205	0.07	0.00010	-15.3	30	0.54
21-8	41196	0.06	0.00013	-13.0	28	0.58
26-8	41211	-0.05	0.00026	-11.3	27	0.61
1-9	41258	-0.28	0.00050	-10.2	26	0.63
6-9	41307	-0.49	0.00070	-8.8	26	0.65
11-9	41381	-0.77	0.00095	-8.4	25	0.67
16-9	41427	-0.94	0.00108	-8.2	25	0.68
21-9	41469	-1.07	0.00118	-7.8	24	0.69
26-9	41478	-1.10	0.00118	-6.9	24	0.69
1-10	41482	-1.10	0.00118	-6.1	24	0.71
6-10	41497	-1.15	0.00120	-5.4	23	0.72
11-10	41499	-1.14	0.00118	-5.2	22	0.74
16-10	41479	-1.07	0.00111	-4.6	21	0.76

2.11 Prediction of the timing of the deflooding

For many people in the Inner Delta, the date at which the water level has declined to a certain level is even more important than the flood itself. The timing of deflooding varies much between years. If the peak flood has been low, most of the floodplains are already dry in the second half of December, but if the flood has been high, this occurs in April, four months later (Fig. 19). The graphs show the timing of deflooding when the water level has declined to 200 and to 100 cm in Akka as a function of the peak flood in Mopti some months before. The same kind of relationships can easily be calculated for other stations and other water levels.



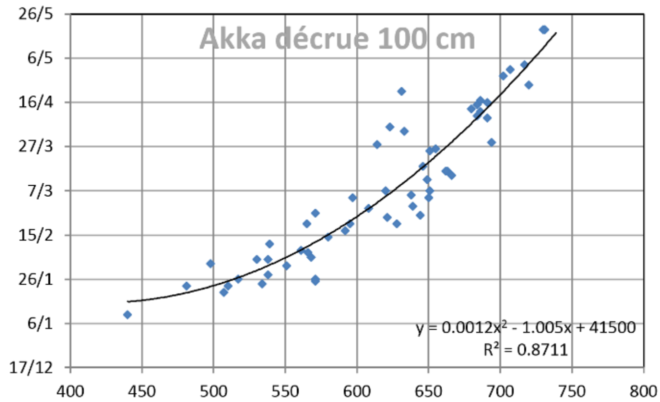


Fig. 19. The time at which the water level in Akka has declined to 200 cm (left) or 100 cm (right) as a function of the peak flood level in Mopti some months before.

2.12 OPIDIN and the *calendrier de traversées*

The herders and their cows need to cross the river during the deflooding. There are 32 frequently-used crossings. The date at which cows are allowed to cross the river differs for the various official crossing-points. Because the floodplain in the southeast becomes available in advance of the floodplain in the central Inner Delta, access is already permitted in November in Diafarabé. Between 90 to 110 days later, the area near Lac Walado-Debo is opened for grazing.

The annual meeting of stakeholders seeks to determine when cattle is allowed to enter the different zones in the Inner Delta. This meeting takes place in the second half of October, thus still during rising water or around high water. Hence the meeting arrives at a decision regarding the ‘calendrier de déplacement’, also known as ‘calendrier de traversées’ or ‘calendrier de la campagne des bourgoutières’ based on the expected date that the floodplain becomes available. Thus, an OPIDIN *avant la letter* using the observed water level in October (before or just around the peak flood in Mopti) to predict the timing of deflooding more than one month later.

The date of river crossing at Diafarabé in the period 1980-2009 varied between 5-11 and 17-12 (Fig. 20). The average date was 23 November, 30% of the annual dates were 1 or 2 days before or after this average and in 77% of the years it was up to 9 days earlier or later than 23 November.

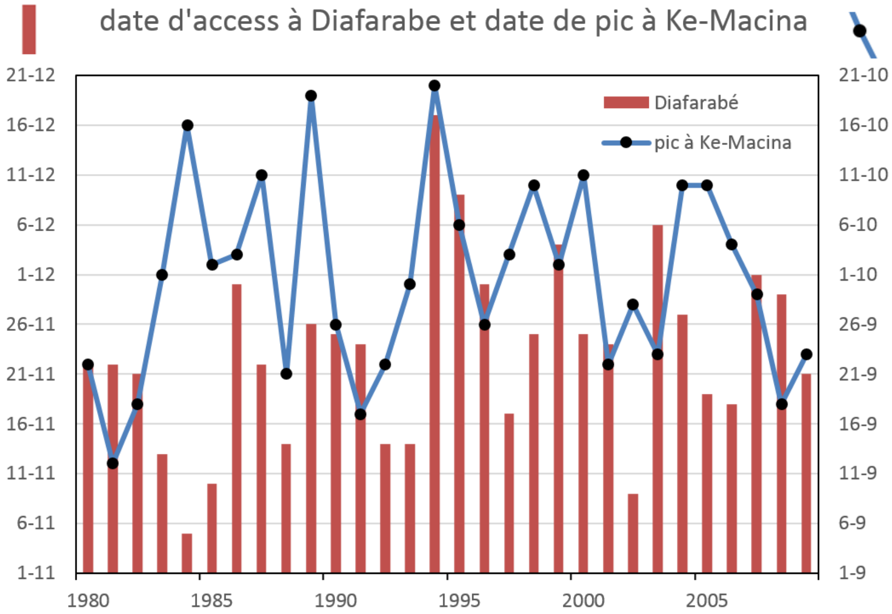


Fig. 20. The annual date between 1980 and 2009 when the cows are allowed to enter the Inner Niger Delta at Diafarabé (red bars; left axis), compared to the date at which the water level reached its peak in Ké-Macina (blue line; right axis). Ké-Macina is selected here since it is the hydrometric station being the most nearby.

The annual variation in the date of river crossing was related to the peak flood level in Ké-Macina (Fig. 21). Two regressions are given: the solid line shows the linear regression, the dotted line the curvilinear relationship. The data set is not large enough and the scattering is too large to decide which of the two gives the best fit. Which regression equation is used does not matter in years with an average peak flood of 450 - 650 cm, but the linear regression tends to arrive at an estimated date being too early in extremely dry as well as in extremely wet years.

The annual meeting with the stakeholders takes place in the second half of October, thus some weeks after the annual peak level at Ké-Macina is reached (see Fig. 2and 4). Hence Fig. 21 may be used as guideline at arrive at a reasonable date of river crossing.

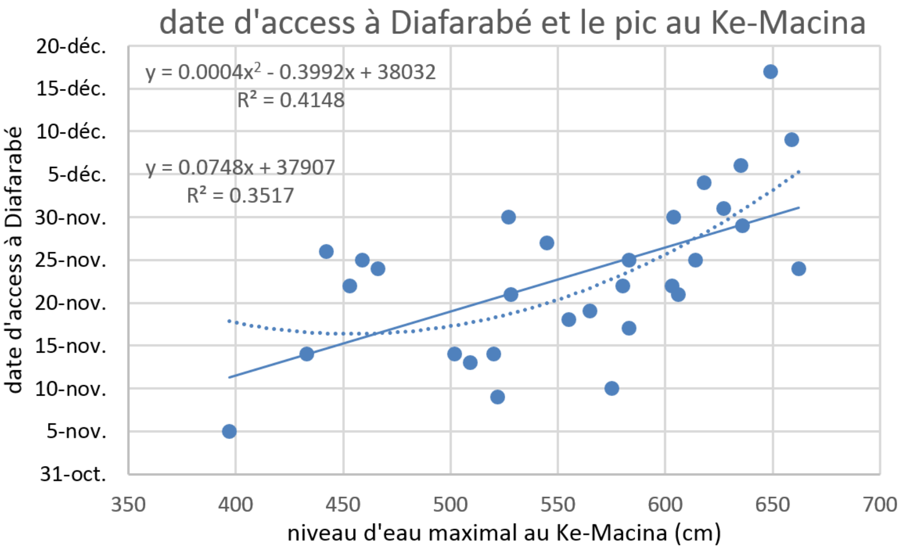


Fig. 21. The annual date when the cows are allowed to enter the Inner Niger Delta at Diafarabé as a function of peak flood level in Ké-Macina in the same year; same data as Fig. 20. A linear and a curvilinear regression are shown.

The *calandrier de traversées* is meant to indicate when the flooded bourgou fields becomes accessible for grazing. One way to check the predicted dates is to search in the data base of DNH for the water level at Ké-Macina on the annual dates of the river crossing at Diafarabé (Fig. 22). The average water level amounted to 254 cm, but the variation is large, varying between 180 and 340 cm in Ké-Macina (standard deviation is 41 cm). It is no improvement when the water level in Mopti is used instead. In that case the water level during the river crossing is, on average, 420 cm in Mopti, but the variation is twice as large (84 cm).

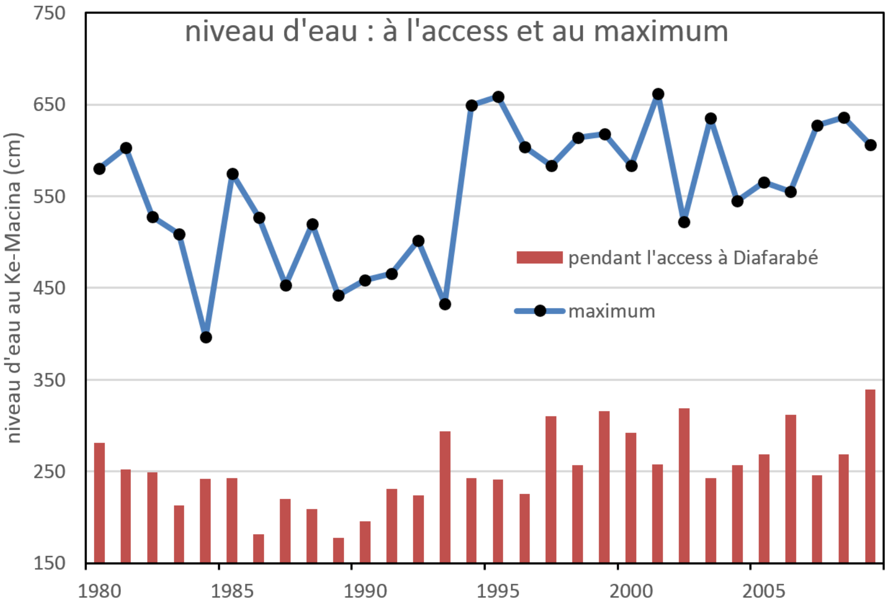


Fig. 22. The water level in Ké-Macina at the date when the cows are allowed to enter the Inner Niger Delta at Diafarabé (red bars), compared to the maximum water level in Ké-Macina in the same year (blue line).

A part of the variation in water level may be explained by the peak flood level (compare blue line and red bars in Fig, 22). In years with a low flood peak, the cows arrive earlier in the season (Fig. 21) when the water level is, on average, already lower than in a wet year. In contrast, in years with a high flood peak, the cows have to wait long until December when the water level is nevertheless still relatively high. The trend is clear, but the annual variation is large (Fig. 23).

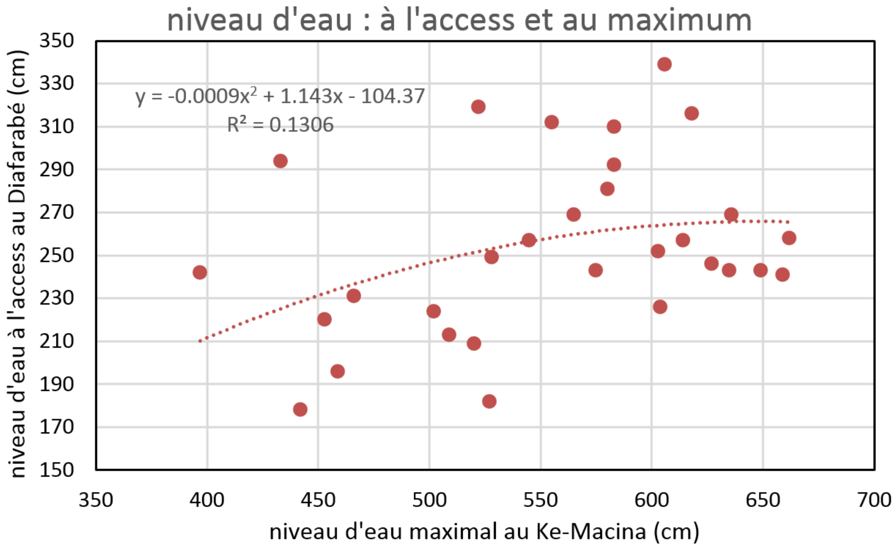


Fig. 23. The water level in Ké-Macina at the date when the cows are allowed to enter the Inner Niger Delta at Diafarabé as a function of the maximum water level in Ké-Macina in the same year. Same data as Fig. 22.

The date at which the cows get access to the Inner Niger Delta is a compromise between different interests. The river crossing at Diafarabé is, on average, 54 days after the peak flood in Ké-Macina (Fig. 20; standard deviation is 13 days). The peak flood is later in Mopti (Fig. 2 and 4), thus the time lag between the peak level in Mopti and the river crossing at Diafarabé is also less: 30 days, on average (standard deviation: 10 days).

The cows should not come too early to prevent problems with the rice farmer, but a time lag of 54 days after the peak flood should be enough. The pressure to enter the Inner Niger Delta is much larger in dry years. The fit between time lag and peak flood in Ké-Macina can be described with a linear function (R^2 = 0.33). At a peak flood of 400 cm in Ké-Macina, the river crossing in Diafarabé is already 40 days after the date of the peak flood in Ké-Macina. At a peak of 500 or 600 cm, the time lag increases to 50 or 60 days. Thus, a simple rule of thumb is: date of access in Diafarabé (days after date of peak flood in Ké-Macina) is peak flood level in Ké-Macina divided by 10. The date of access may also be derived from Fig. 22, as soon as the peak flood level in Ke/Macina is known.

An alternative is that OPIDIN is used to predict the date at which the water level has declined at a certain level. However, first it has to be clear whether the date should be fixed at a certain level, for instance the average water level of 254 cm in Ké-Macina, or that the predicted date should take into account the peak flood level, for instance, predict the date when the water level has declined to 250-250 cm if the peak flood has been normal or high (500 - 650 cm) and wait till the water has declined to 220 cm at an extremely low peak flood (Fig. 23).

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