Preliminary

Prepared for:

Mekong River Commission

Flood hazard assessment for Se Bangfai

Combined flood approach

Report

December 2009

Prepared for:

Mekong River Commission

Flood hazard assessment for Se Bangfai

Combined flood approach

Henk Ogink, Sopharith Tess and Ferdinand Diermanse

Report

December 2009

Contents

1 Introduction 1

2 Flood hazard assessment for combined floods 2

2.1 General 2

2.2 Outline of procedure 2

3 Basin description 4

3.1 General 4

3.2 Basin description 4

3.3 Problem description 6

3.4 Hydrological network and data availability 10

3.5 Hydrological characteristics 13

3.5.1 Rainfall 13

3.5.2 Evaporation 14

3.5.3 Runoff 15

4 Hydraulic model 18

4.1 General 18

4.2 Schematization 18

4.3 Boundary conditions 22

4.3.1 General 22

4.3.2 Discharge at Mahaxai 22

4.3.3 Lateral inflow 23

4.3.4 Discharge at Nakhon Phanom 25

4.3.5 Stage-discharge relation at Mukhdahan 28

4.4 Model performance test 30

5 Hydrological hazard assessment 36

5.1 General 36

5.2 Peak discharge and flood volume Se Bangfai at Mahaxai 36

5.3 Peak discharge and flood volume Mekong at Nakhon Phanom 39

5.4 Se Bangfai-Mekong correlation 43

6 Flood hazard assessment 45

6.1 General 45

6.2 Applied boundary conditions 45

6.3 Simulation results 46

6.3.1 Cases 46

6.3.2 Water levels in the Se Bangfai river 46

6.3.3 Water levels in the floodplains 52
6.4 Flood hazard determination 54
6.5 Bypass canal 60
6.5.1 Introduction 60
6.5.2 Simulations for the years 1995 until 2000 61
6.5.3 Probabilistic analysis for the diversion channel 67
6.6 Effects of varying bottom levels in the Mekong river 70
7 Conclusions and recommendations 73
7.1 Conclusions 73
7.2 Recommendations 75
8 Literature 77

1 Introduction

This Report deals with flood hazard assessment for combined floods in the Lower Se Bangfai. Combined floods refer to flooding in the downstream parts of tributaries in the vicinity of the Mekong caused by large discharges from the tributaries backed up by high water levels in the Mekong. The general procedure used in such cases is presented and its application to the Se Bangfai is discussed.

The set up of this Report is as follows. The procedure for flood hazard assessment for combined floods is outlined in Chapter 2. A description of the Se Bangfai basin, its hydraulic infrastructure, hydrological monitoring system and data availability is given in Chapter 3. The hydraulic model used for the simulation of the floods in the Se Bangfai basin, the river and flood plain schematization and applied boundary conditions are presented in Chapter 4. The hydrological hazard assessment is dealt with in Chapter 5, followed by the results of the simulations and of the flood hazard assessment in Chapter 6. Conclusions on the computations and analyses are drawn in Chapter 7 with recommendations on the application of this procedure for other areas.

2 Flood hazard assessment for combined floods

2.1 General

The procedure for flood hazard assessment in case of combined floods is discussed in this chapter. It deals with the creation of flood levels and flood extent of selected return periods as well as flooding depth and duration. Subsequently, flooding depth and duration are combined with land use information to determine the losses and benefits (social, environmental and economic) of the flooding, which is discussed in a separate volume.

2.2 Outline of procedure

The procedure applied to assess the flood hazard uses the Monte Carlo sampling technique to derive exceedance probabilities of water levels and damages. The procedure uses three random variables, representing the main causes for high water levels in the downstream part of the Se Bangfai catchment:

- the maximum discharge in the Mekong river at Nakhon Phanom, near the Se Bangfai river mouth at That Phanom;
- the total volume of the flow in the Mekong river at Nakhon Phanom, and
- the total volume of the flow in the Se Bangfai river at Mahaxai.

For each of the three random variables, samples are taken from their respective probability distribution functions. This procedure is repeated *N* times (with *N* sufficiently large) to obtain *N* combinations of possible realisations of the three random variables. This can be considered as a synthetic series of *N* years, where each sampled combination of random variables describes the main hydraulic features of the flood season in a single year.

For each combination/year the hydraulic model of the lower Se Bangfai based on ISIS is applied to derive the relevant hydraulic features like maximum water level at a number of locations in the Se Bangfai area. Formally, this means that the hydraulic model should run *N* times, but since *N* is generally quit large (100,000 in this case) that would require such a long computation time that the procedure would become unpractical. Instead, the hydraulic model is run for 90 different combinations of the three random variables that basically cover the whole spectre of possible outcomes. The results of the 90 simulations are stored in a database. Results of the *N* Monte Carlo runs are then determined by interpolation of the results of the 90 simulations. Since 3 random variables are involved, the interpolation is 3-dimensional.

The procedure above results in relevant hydraulic features at a number of locations in the Se Bangfai area. Based on economic analysis it is also possible to estimate the damage for each simulated year. The next step is to derive the probability of exceedance of threshold values

of the damage. For Monte Carlo techniques this is a relatively straightforward procedure. Suppose the threshold damage D^1 is exceeded in 100 out of N simulations, the estimated probability of exceedance of D^1 is equal to 100/N. Similarly, if another threshold value $D^2>D^1$ is exceeded in 10 out of N simulations, the estimated probability of exceedance of D^2 is equal to 10/N. Repeating this procedure for a range of threshold values provides a relation between damage on one hand and exceedance probability on the other hand. Figure 2.1 gives an example of what such a relation might look like.

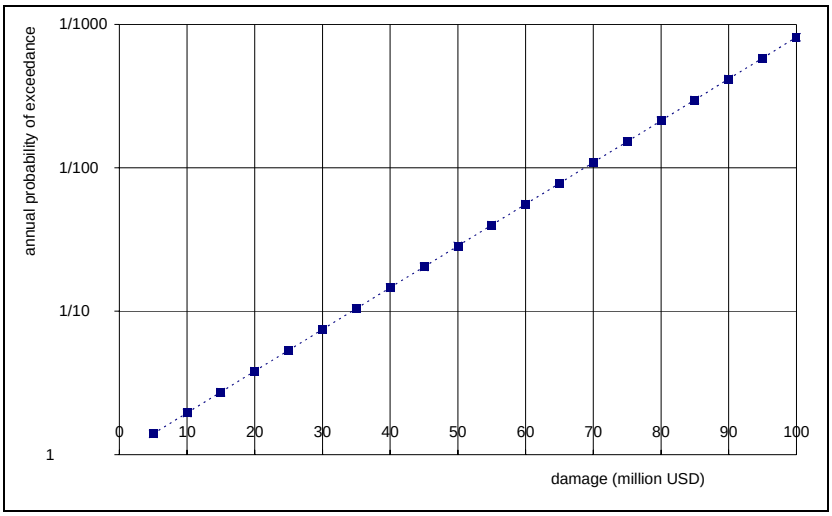

Figure 2.1 Hypothetic relation between damage and annual probability of exceedance

The last step in the procedure is to derive the T-year flood event. Using damage as the criterion, the T-year flood event is defined as:

"The threshold damage D_T which has a probability of exceedance of $p=1/T$ per year"

The availability of a relation as shown Figure 2.1 enables the determination of the T–year flood, i.e. the T-year damage. For example the 100-year damage D_{100} can simply be derived by checking were the dotted line crosses the horizontal threshold of p=1/100. In the example of Figure 2.1 this occurs at around 70 million USD, so D_{100} = 70 million USD.

Notes:

- Instead of damages also other criterions can be defined to derive the T-year flood, such as the maximum water level. In that case one needs to derive the water level that has an annual exceedance probability of 1/T. The same procedure as above can be applied, i.e. exceedance probabilities for a range of threshold water levels need to be derived.
- The procedure needs to be applied separately for each location in the area in which one is interested. This is because the relation between the three random variables on the one hand and the resulting maximum water level or damage on the other hand may vary significantly from one location to the other.

3 Basin description

3.1 General

The Se Bangfai has been selected by LNMC as focal area for IFRM (Integrated Flood Risk management) in areas with combined floods, i.e. flood levels in tributaries affected by backwater from Mekong.

3.2 Basin description

The Se Bangfai takes its rise in the Annamite mountain range near to the border with Vietnam west of Thakek and joins the Mekong at rkm 1,166, opposite of the city of That Phanom in Thailand. The river drains an area of 10,240 km^2. On its rise it is joined by the Nam Phanang, Nam Hue with major tributary Nam In, Nam Gnom or Nam Kathang, and just upstream of Mahaxai by Nam Phit. Downstream of Mahaxai the river Nam Oula and finally the largest tributary Se Noy, with its headwaters Nam Meng and Se Bay, discharges to the river. The Se Noy drains upstream of station Ban Se Bangfai/Highway Bridge 13S. The upper basin is steep, but below Mahaxai the river slopes are small and the reach from 10 km downstream of Mahaxai to the mouth is affected by backwater from the Mekong (Figure 3.1 and Figure 3.2). The strongly meandering Se Bangfai near the confluence opposite That Phanom is shown in Figure 3.3.

At Mahaxai the Se Bangfai drains an area of 4,520 km^2 or about 44% of the basin. At station Ban Se Bangfai or Highway Bridge 13S the upstream drainage area amounts 8,560 km^2, which is 84% of the basin.

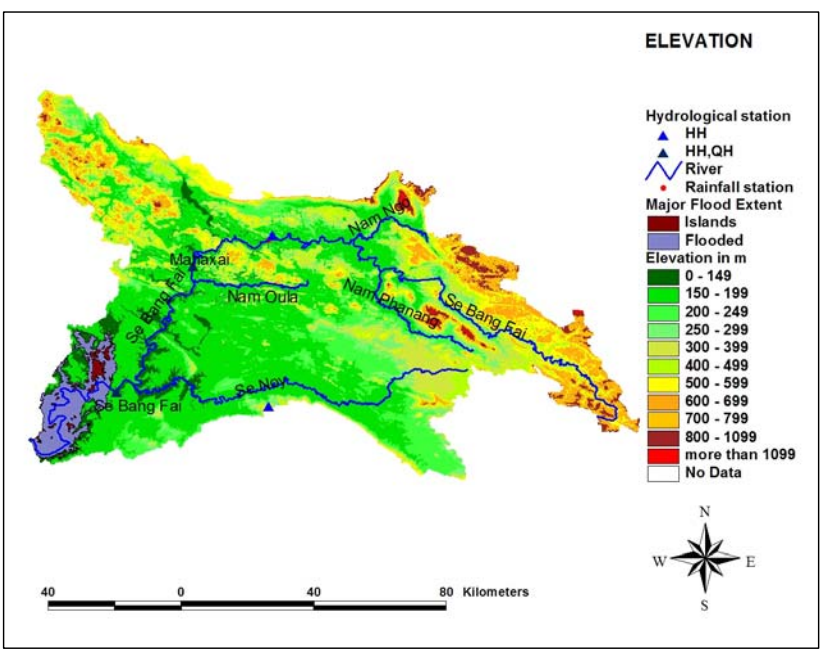

Figure 3.1 Elevation map of Se Bangfai basin

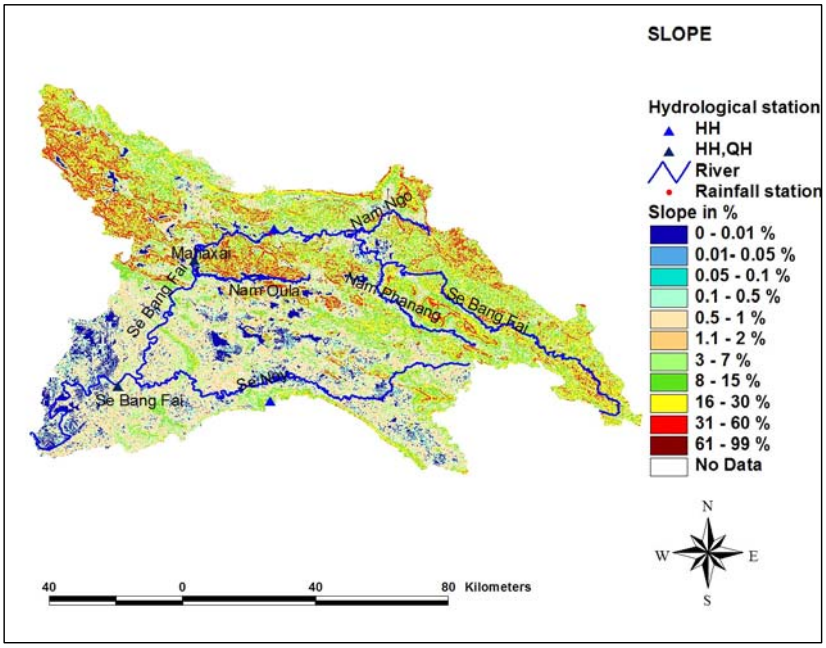

Figure 3.2 Se Bangfai slope map

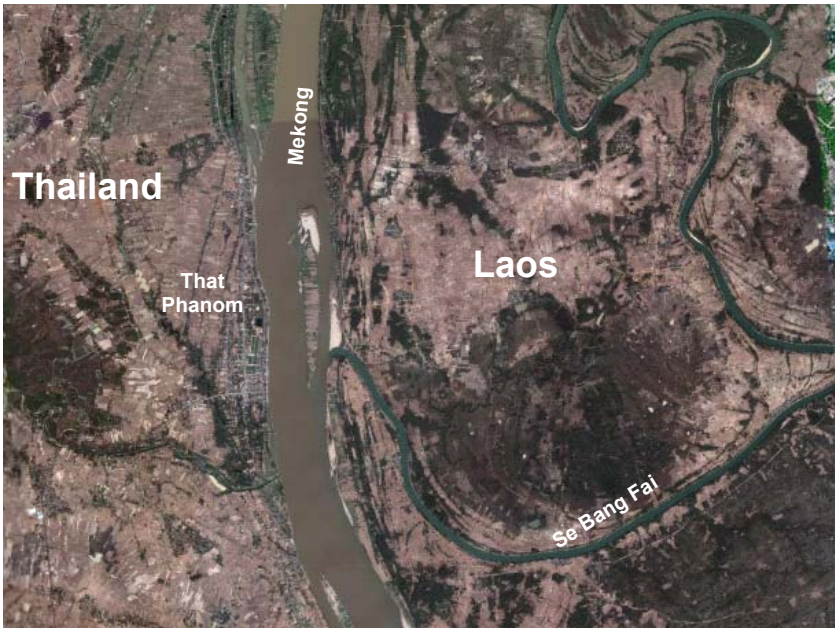

Figure 3.3 Confluence of Se Bangfai with Mekong opposite That Phanom

In December 2009 the Nam Theun 2 Hydro-electric Project will be put in operation (ADB, 2004). The Project will dam the Nam Theun near Ban Sop Hia in Khammouane Province and its average annual flow of 220 m^3/s will be diverted to the Se Bangfai. The Nam Theun water will be stored in the Nakai reservoir with a total capacity of 3.91 BCM. Water from the reservoir will drop about 350 m through a tunnel to a power station located at the base of the Nakai escarpment. From here the water will flow into an 8 MCM regulating pond controlled by the Regulating Dam (see Figure 3.4). From this dam water flows towards the Se Bangfai mainly via a 27 km Downstream Channel, which lower tail combines with the

Nam Pith, and a small part is discharged to the Nam Kathang at a rate equivalent to the current natural flow. The planned variation in the release from the Regulating Dam is between 315 and 60 m^3/s on week-days and a constant 60-75 m^3/s on Sundays. As can be observed from Figure 3.4, the inflows from Nam Theun take place upstream of Mahaxai.

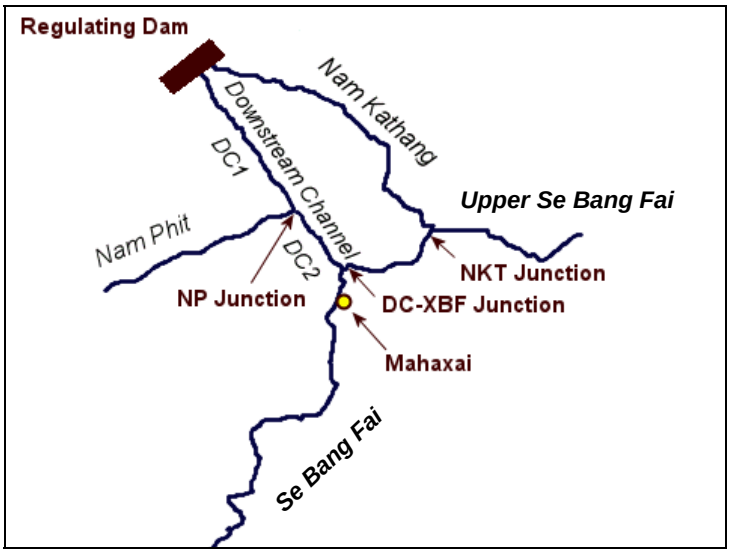

Figure 3.4 Schematic layout of trans-basin diversion from Nam Theun to Se Bangfai

3.3 Problem description

Se Bangfai river and flood plains near the confluence with Mekong are shown in Figure 3.5 and Figure 3.6. Flooding takes place in the districts Thakek, Nong Bok, Se Bangfai and Mahaxai. Major flooding takes place between the Mekong and Highway 13S, north of Se Bangfai river (see Figure 3.7). Lowest areas are 140 masl, whereas Nongbok village is flood free at an elevation of 150 masl. Flooding here lasts several months.

Figure 3.5 Se Bangfai at Nong Bok, looking upstream; left bank is in Savannakhet Province

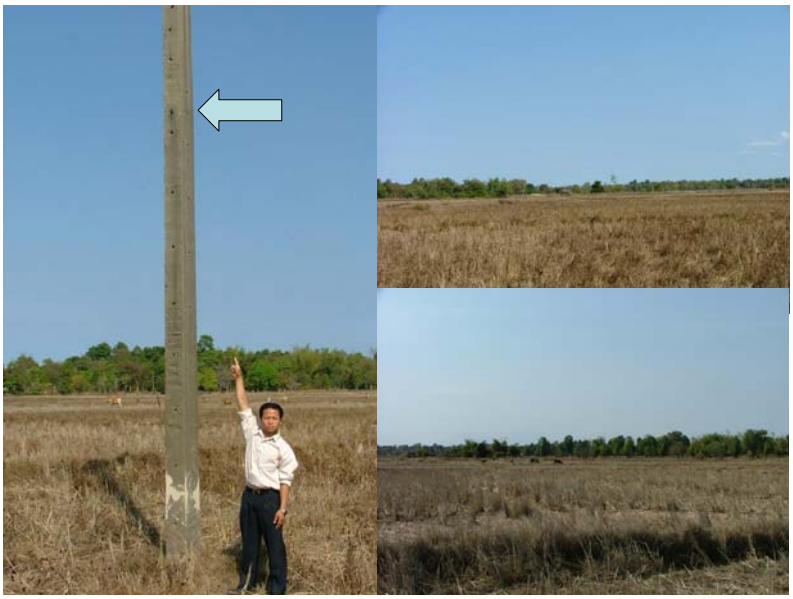

Figure 3.6 Areas east of Nong Bok severely flooded in wet season, with flood mark on concrete pile

Satelite Photo of Flood Extents on Sept 17, 2000 in Xe BangFai

Figure 3.7 Extend of flooding along lower Se Bangfai and Mekong in year 2000

Apart from the area along the lower Se Bangfai there is also one smaller area in Mahaxai District facing floods according to local information. This area is located near Road 1F between Mahaxai and Nam Oula, and is flooded each year during about one week.

To reduce the flood risk in Savannakhet Province, i.e. along the left bank of Se Bangfai, flood protection in the form of a dike is already in place. For Khammouane Province (along the right bank of Se Bangfai) the following options are being studied:

1. Construction of mini-polders and construction of dikes along Se Bangfai and Mekong
2. Construction of a bypass canal "Xelat" from Sokbo to Bungsan Nua in Nongbok District to the Mekong,
3. Construction of a regulating dam at the junction of the Se Noy with Se Bangfai.

For Option 1 a number of cases have been distinguished:

- Construction of mini-polders at 3 locations protecting in total 1,470 ha of land in Mahaxai and Se Banfai districts, involving dikes with a total length of 18.94 km (estimated cost USD 2.2 million)
- Step-wise construction of dikes along the lower Se Banfai and Mekong (estimated total cost USD 30.9 million) as follows (see Figure 3.8):
  - Step 1: 27 km long dike with crest at 148.0 m from Nongbone to Sokbo, protecting 9,700 ha of land including 26 villages
  - Step 2: 36 km long dike with crest at 146.0 m from Sokbo to Bungsanetha, protecting 4,000 ha of land and 17 villages, and
  - Step 3: 30 km long dike with crest at 145.7 m from Tantheung to Dannepakse, protecting 3,000 ha of land and 13 villages.
- One-step construction of a 65 km long dike along the right bank of Se Bangfai River only from Nongbone to Danpakse (estimated cost USD 20.6 million) (see Figure 3.9).

The bypass canal of Option 2 (see Figure 3.10) involves an 8 km long canal with bed width of 200 m at an elevation of 138 masl. The estimated cost is USD 9.6 million. Negative impacts of the option involve loss of 65 ha of land, no drainage when the Mekong levels exceed Se Bangfai and morphological effects in Se Bangfai.

The third option involves a 25 m high and 200 m long regulating dam with a reservoir capacity of 840 MCM operated at a level of 145 masl to provide irrigation water for 22,200 ha of land and flood protection to 92,910 ha along the right river bank. The estimated cost of this option is USD 138.7 million. The reservoir will flood 18 villages, adds dam break risks and requires construction of dikes along Se Banfai and Mekong. As an alternative a 30 m high and 450 m long dam with a reservoir capacity of 1,500 MCM has been mentioned. Costs of this alternative will be much higher and so will be its impacts.

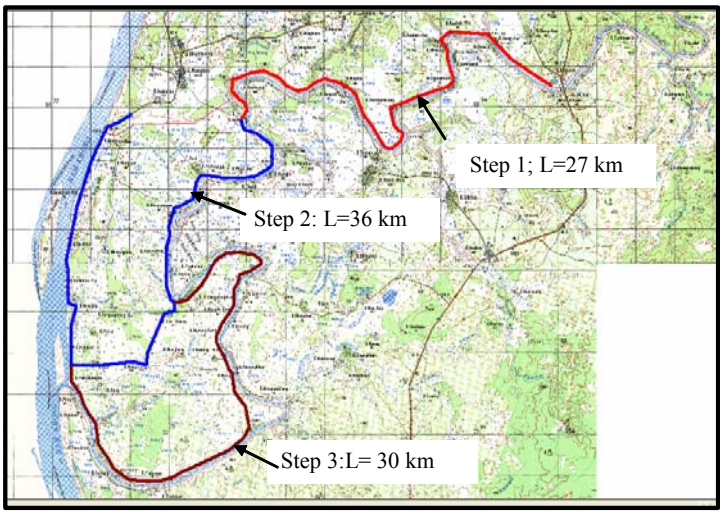

Figure 3.8 Step-wise construction of dikes along lower Se Bangfai

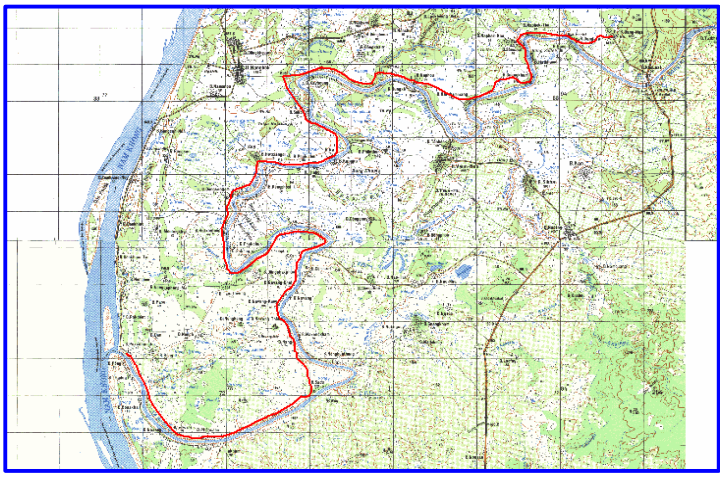

Figure 3.9 One-step construction of dike along right bank of Se Banfai

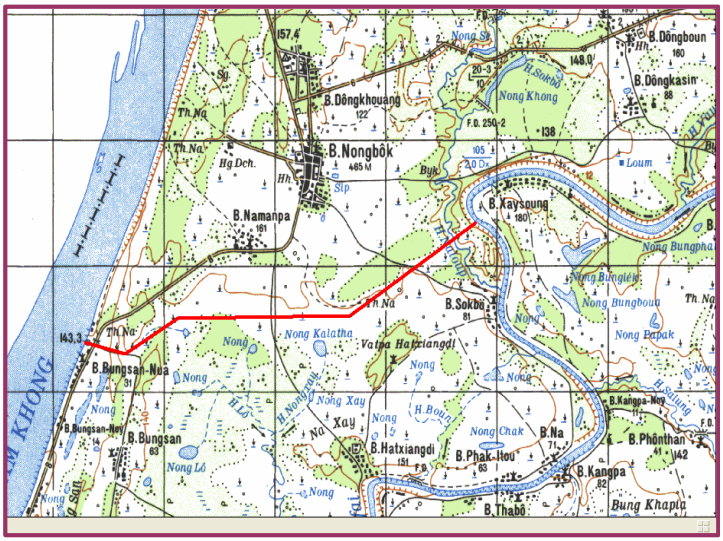

Figure 3.10 Canal “Xelat” from Sokbo to Bungsan Nua

3.4 Hydrological network and data availability

The upper boundary of the Se Bangfai to be included in the hydraulic model should be outside the backwater reach of the Mekong. An estimate of the distance over which the effect of the Mekong river is felt on the flood levels in the Se Bangfai can be derived from a first order backwater calculation (see also Figure 3.11 for a definition sketch):

$$\Delta h_L \approx \Delta h_0 \exp\left(\frac{-3S_0 L}{h_e(1-Fr^2)}\right) \approx \Delta h_0 \exp\left(\frac{-3S_0 L}{h_e}\right) \quad for\ Fr << 1$$

$$also,\ with\ \lambda = \frac{h_e}{3S_0}: \quad \Delta h_L \approx \Delta h_0 \exp\left(-\frac{L}{\lambda}\right) \tag{3.1}$$

$$because: \ln\left(\frac{\Delta h_L}{\Delta h_0}\right) \approx \frac{-3S_0 L}{h_e} = -\frac{L}{\lambda} \quad it\ follows:$$

$$at\ \Delta h_L = 5\%\ of\ \Delta h_0 \quad then \quad \ln\left(\frac{\Delta h_L}{\Delta h_0}\right) = -3, \quad so:$$

$$L_{5\%} \approx \frac{h_e}{S_0} = 3\lambda$$

with: Δh_0 = deviation from equilibrium depth at x=0
Δh_L = deviation from equilibrium depth at x = L
h_e = equilibrium depth
S_0 = bed slope
Fr = Froude number
λ = characteristic backwater length

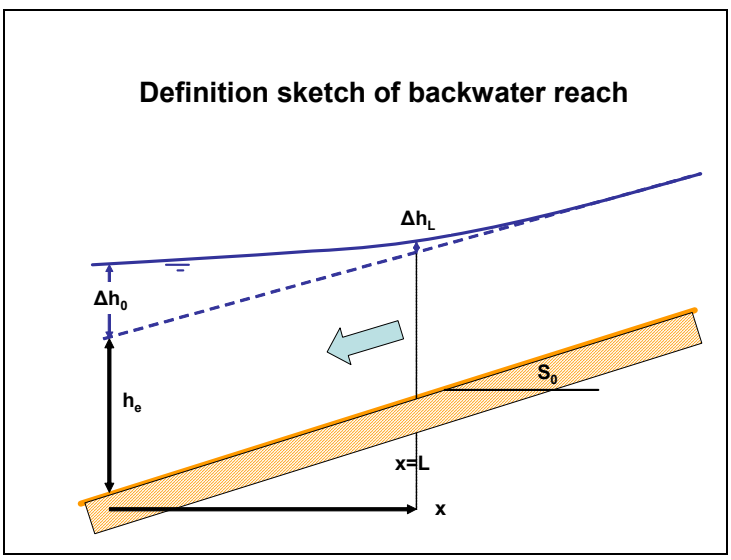

Figure 3.11 Definition sketch of extent of backwater reach

So, backwater of the Mekong on the Se Bangfai will be felt over a distance of:

$$L_{5\%} \approx \frac{h_e}{S_0} = \frac{15}{1.1x10^{-4}} \approx 134km \tag{3.2}$$

where the bed slope S_0 follows from the flood plain levels of 155.5 masl at Mahaxai and 139.5 masl along the Mekong at That Phanom, at a distance of about 143 km apart. The equilibrium depth h_e is taken as the maximum water level range at Mahaxai. It follows that the backwater effect from the Mekong exists till some 9 km d/s of Mahaxai. So, for simulation of the combined flooding in the lower Se Bangfai, basically, only the basin downstream of Mahaxai is of interest. The boundary conditions for this area comprise:

- the flow in the Se Bangfai at Mahaxai,
- lateral inflow to and outflow from the Se Bangfai between Mahaxai and the river mouth,
- water level in the Mekong at the junction with the Se Bangfai.

The key station on the Se Bangfai at Mahaxai is shown in Figure 3.12. This station controls apart from the runoff from the Se Bangfai basin in future also the trans-basin diversion from Nam Theun 2 Hydro-electric Project, which discharges upstream of Mahaxai via the Nam Pith and Nam Kathang,. The discharge record of Mahaxai starts in 1988.

Figure 3.12 Location of gauging station on Se Bangfai at Mahaxai

Regarding lateral inflow it is noted that no hydrometric stations are available on the tributaries Nam Oula and Se Noy downstream of Mahaxai. Only records from station Ban Se Bangfai at Highway 13S Bridge across the river is available. Basically, the lateral inflow can be derived from the discharge records at Highway Bridge 13S and Mahaxai. But the water levels at Highway Bridge 13S at 71.6 km from the river mouth are according to (3.2) affected by backwater from the Mekong. This complicates accurate assessment of the flow at the station and hence of the lateral inflow. Another way of deriving the lateral inflow and outflow downstream of Mahaxai would be through rainfall-runoff modelling provided that sufficient rainfall data is available.

The water level in the Mekong at the Se Bangfai junction is determined by the river discharge at the junction (That Phanom) and the conveyance capacity (with possible imposed water level conditions) downstream of the junction:

- The river discharge at the junction follows from the Mekong flow at Nakhon Phanom (Thailand) or Thakek (Laos) resp. 51 and 50 km upstream of the confluence and the runoff from the Se Bangfai. The combined flow (including also the runoff from the minor tributaries Nam Kam and Huai Bang Sai) is observed at Mukhdahan (Thailand)

and Savannakhet (Laos) resp. 43 and 46 km downstream of the confluence. Flow series for Nakhon Phanom and Thakek are available as from 1924 onward, whereas the discharge records of Mukhdahan and Savannakhet start in 1923 .

- The conveyance capacity of the Mekong downstream of the junction is determined by the river cross-section, bed slope and hydraulic roughness in the reach That Phanom-Mukhdahan/Savannakhet and beyond, covering a reach of approximately 150 km.
- For That Phanom at the junction a water level record is available as of 1972.

The rainfall, climatic and hydrometric stations and their data availability are presented in Table 3.1. From the table it is observed that daily rainfall data is available for a number of stations in the nineties and in the last decade. Prior to that only for two stations records are available. It follows that insufficient data on rainfall is available to create reliable long series of lateral inflow. Evaporation data is available for three stations from FAO's Climwat database.

Table 3.1 Overview of rainfall, climatic and hydrometric stations in and around Lower Se Bangfai with data availability

Variable	Stations	ID	Long	Lat	Availability
Rainfall	That Phanom	160403	104.7334	16.9500	1966-2005
	Phalan	160506	106.2333	16.7000	1991-94, 97, 01-06
	Thakek	170404	104.8000	17.4167	1961-64, 80-92, 94-06
	Signo	170501	105.0500	17.8333	1987, 90-06
	Muong Mahaxai	170502	105.2020	17.4133	1989-06
	Ban Kouanpho	170505	105.4167	17.4833	1995, 97-98, 00-06
	Ban Se Bangfai	320101	104.9850	17.0720	2004-06
Evaporation	Seno-FAO	160502	105.0000	16.6667	From Climwat database
	Mukdahan-FAO	160401	104.7367	16.5400	-do-
	Nakhon Phanom-FAO	170403	104.8034	17.3984	-do-
Water level	Ban Se Bangfai (HB13)	320101	104.9850	17.0720	1988, 1992, 1994-2006
	Mahaxai	320107	105.2020	17.4133	1988-2006
	That Phanom (rkm 1166)	013105	104.7334	16.9500	1966-2005
	Nakhon Phanom (rkm 1217)	013101	104.8034	17.3984	1972-2005
	Thakek (rkm 1216)	013102	104.8067	17.3933	1980-2006
	Keng Kabao (rkm 1151)	013301	104.7500	16.8133	1972-1999
	Mukdahan (rkm 1123)	013402	104.7367	16.5400	1960-2005
	Savannakhet (rkm 1126)	013401	104.7467	16.5617	1972-2006
Discharge	Ban Se Bangfai (HB13)	320101	104.9850	17.0720	1960-85, 88, 92, 94-04
	Mahaxai	320107	105.2020	17.4133	1988-2006
	Nakhon Phanom (rkm 1217)	013101	104.8034	17.3984	1924-2005
	Thakek (rkm 1216)	013102	104.8067	17.3933	1924-2006
	Mukdahan (rkm 1123)	013402	104.7367	16.5400	1923-2005
	Savannakhet (rkm 1126)	013401	104.7467	16.5617	1923-2006

Table 3.2 Gauge zero levels of water level gauging stations in and around Se Bangfai

Station	ID	River	Rkm	GZ (masl)
Ban Se Bangfai (HB13)	320101	SBF	-	125.00
Mahaxai	320107	SBF	-	139.56
That Phanom (rkm 1166)	013105	Mekong	1166	127.94
Nakhon Phanom (rkm 1217)	013101	Mekong	1217	130.961
Thakek (rkm 1216)	013102	Mekong	1216	129.629
Keng Kabao (rkm 1151)	013301	Mekong	1151	128.00
Mukdahan (rkm 1123)	013402	Mekong	1123	124.219
Savannakhet (rkm 1126)	013401	Mekong	1126	125.41

3.5 Hydrological characteristics

3.5.1 Rainfall

A long rainfall record in the neighbourhood of the lower Se Bangfai is available for station That Phanom, opposite the junction of the Se Bangfai with the Mekong. The long term annual rainfall for this station amounts 1,560 mm, varying from 890 to 1940 mm as can be observed from Table 3.3. About 87 % of the annual rainfall occurs during the South-West Monsoon from May to September, with highest rainfall on average in August, see also Figure 3.13. The annual rainfall, which is available for the years 1966-2005, does not show a distinct trend (Figure 3.14); the average rainfall in the period 1966-1987 of 1578 mm compares well with that in the period 1988-2005 of 1537 mm, the period for which also discharge data is available for the Se Bangfai at Mahaxai. Note that the average runoff depth at Mahaxai amounts about 1,650 mm per year. Compared to the rainfall value at That Phanom it indicates a strong orographic effect in the Se Bangfai rainfall from west to east.

Table 3.3 Monthly rainfall statistics and evaporation (ETo) in mm around Lower Se Bangfai

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average	3.1	20.7	43.4	79.1	200.3	274.8	276.6	350.6	250.3	54.7	4.8	1.2	1559.5
Stdev	8.3	31.6	40.9	46.7	88.1	95.8	108.1	151.9	129.8	53.5	10.0	4.7	267.9
Cv	2.69	1.53	0.94	0.59	0.44	0.35	0.39	0.43	0.52	0.98	2.11	3.96	0.17
Min	0.0	0.0	0.0	5.0	53.1	120.0	88.2	121.9	20.9	0.0	0.0	0.0	890.7
Max	31.3	161.7	150.9	226.4	377.1	516.8	542.8	758.8	538.1	257.9	58.3	27.6	1940.6
Evap.	122	122	156	162	150	124	127	120	112	129	128	121	1572

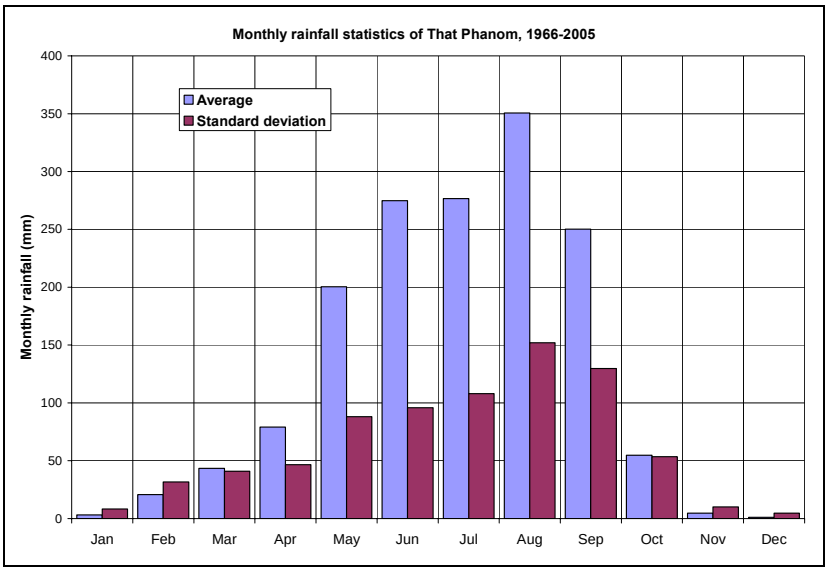

Figure 3.13 Monthly rainfall statistics of station That Phanom, Period 1966-2005

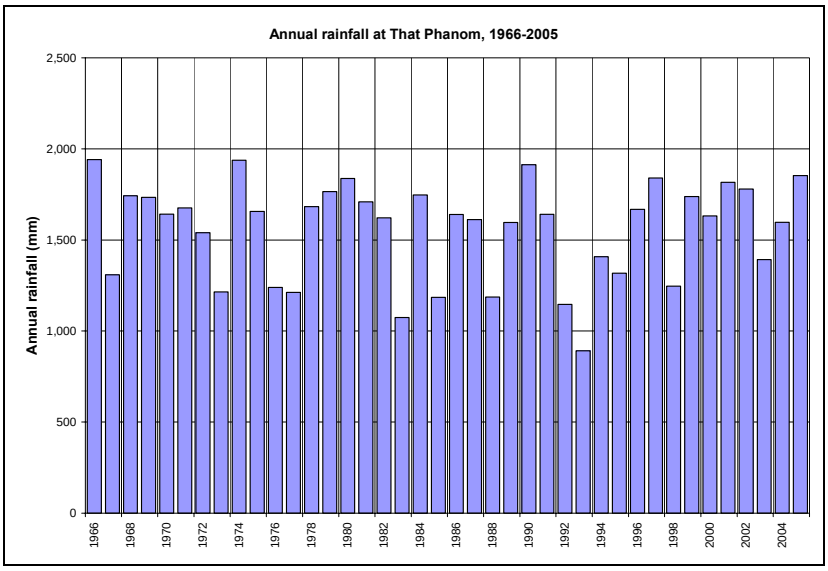

Figure 3.14 Annual rainfall at That Phanom, Period 1966-2005

3.5.2 Evaporation

Pan evaporation data is available for a few stations in the area, but the series showed unrealistic values for a number of years, and are therefore not presented. Below (Figure 3.15) monthly average daily reference evaporation rates (ETo) are shown for Seno/Savanakhet, Mukdahan and Nakhon Phanom, taken from the Climwat-database of FAO. During the flood season an average daily evaporation rate of about 4 mm/day or 120 mm per month is observed from the graph (see also Table 3.3). During these months the rainfall exceeds the evaporation by far, whereas from October to April there is water shortage as can be observed from Figure 3.16.

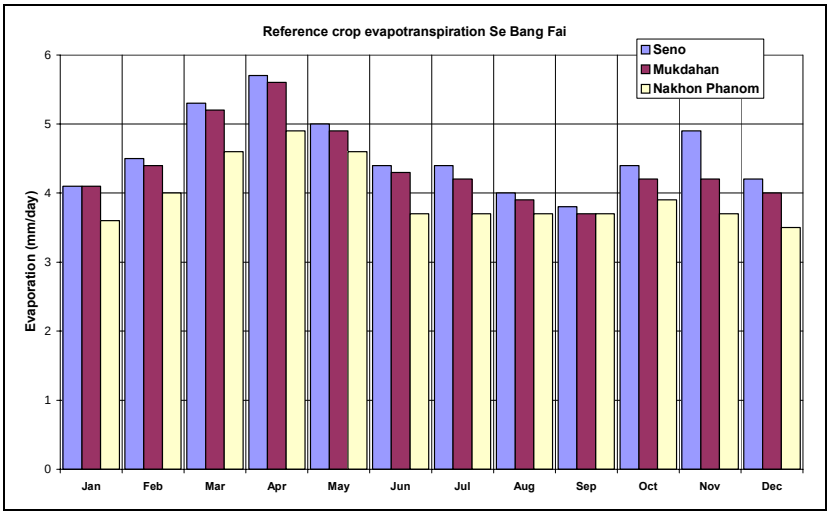

Figure 3.15 Monthly average daily evaporation (ETo) values for stations in the surrounding of the Lower Se Bangfai basin

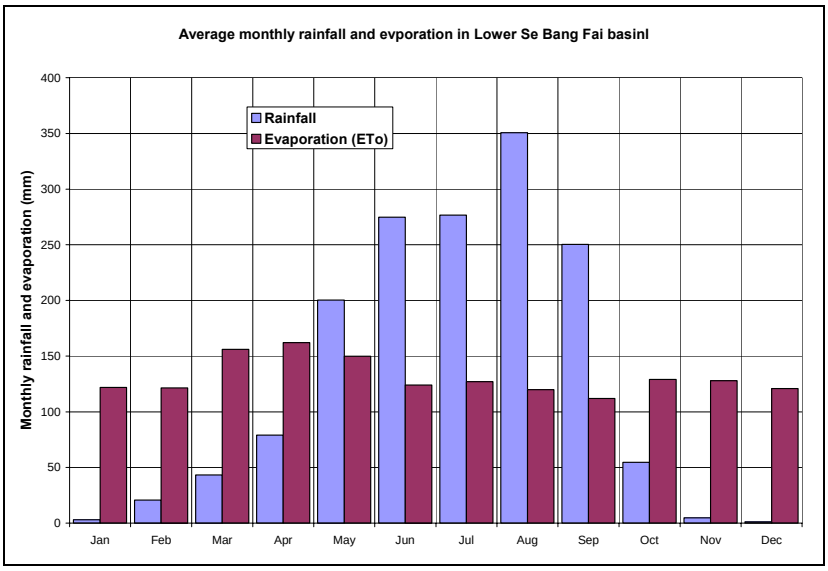

Figure 3.16 Average monthly rainfall and evaporation

3.5.3 Runoff

The monthly flow statistics of the Se Bangfai at Mahaxai is presented in Table 3.4 and Figure 3.17. Note that the average annual runoff depth at Mahaxai is larger than the annual rainfall at mouth. The frequency curves and extremes of the daily discharges of the Se Bangfai at Mahaxai are presented in Figure 3.18. The curves indicate that in the period from July till early October high discharges can be expected on the Se Bangfai. The hydrograph of a single year shows distinct sharply rising and falling limbs. From the frequency curves of the daily average water levels of the Mekong at That Phanom near the Se Bangfai river mouth (gauge zero = 127.94 masl and flood plain level 139.50 masl), shown in Figure 3.19, it is observed that these peaks are likely to coincide with high water levels on the Mekong.

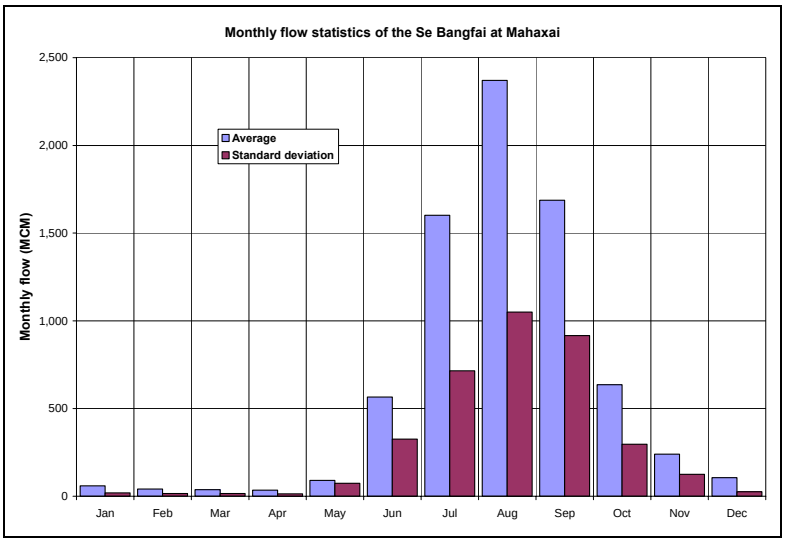

Figure 3.17 Monthly flow statistics of the Se Bangfai at Mahaxai

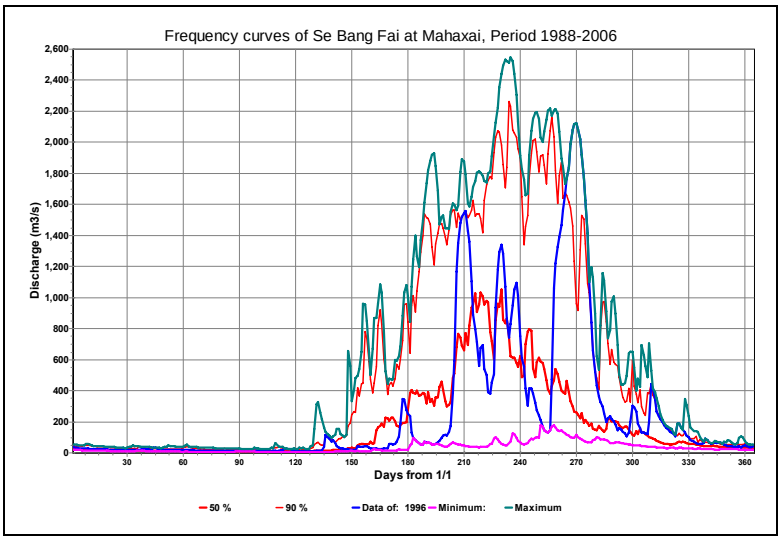

Figure 3.18 Frequency curves of daily average discharge of Se Bangfai at Mahaxai, Period 1988-2006

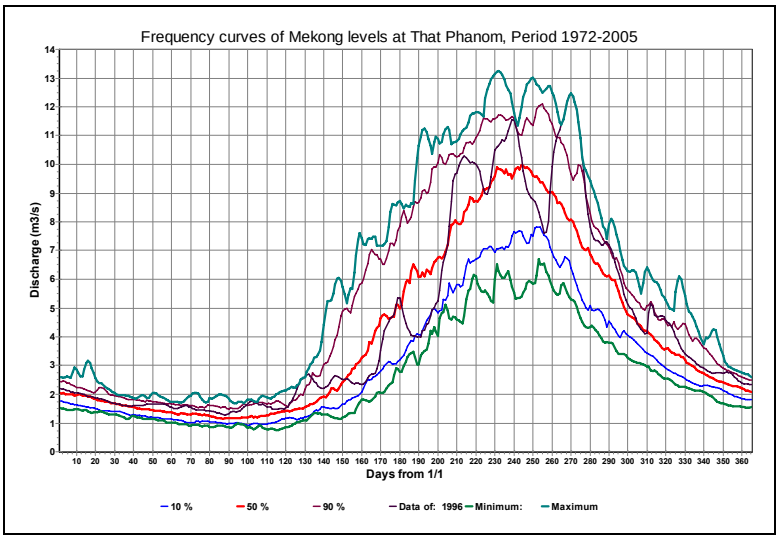

Figure 3.19 Frequency curves of daily average water levels of the Mekong at That Phanom, Period 1972-2005

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean (MCM)	60.0	41.5	37.2	34.7	90.8	565.6	1601.4	2370.7	1687.9	635.9	240.5	105.8	7504.4
St.dev (MCM)	19.6	15.4	15.5	14.0	73.4	325.8	714.9	1049.1	916.0	296.2	125.2	26.0	2155.4
Mean (mm)	13.3	9.2	8.2	7.7	20.1	125.1	354.3	524.5	373.4	140.7	53.2	23.4	1653.1
St.dev (mm)	4.3	3.4	3.4	3.1	16.2	72.1	158.2	232.1	202.7	65.5	27.7	5.7	476.9

Table 3.4 Monthly and annual statistics of runoff volume and depth of the Se Bangfai at Mahaxai

The statistics of the monthly flow of the Mekong at Nakhon Phanom and Mukhdahan are presented in Table 3.5 and Figure 3.20. It is observed that, generally, the peak flows in the Mekong at these locations occur in August similar to the Se Banfai. The lateral inflow to the Mekong between Nakhon Phanom and Mukhdahan is seen to be relatively small; the annual flow of the Se Bangfai is only some 3% of the annual total of the Mekong at Nakhon Phanom. Finally, in Figure 3.21 the frequency curves of the daily discharge at Nakhon Phanom is presented.

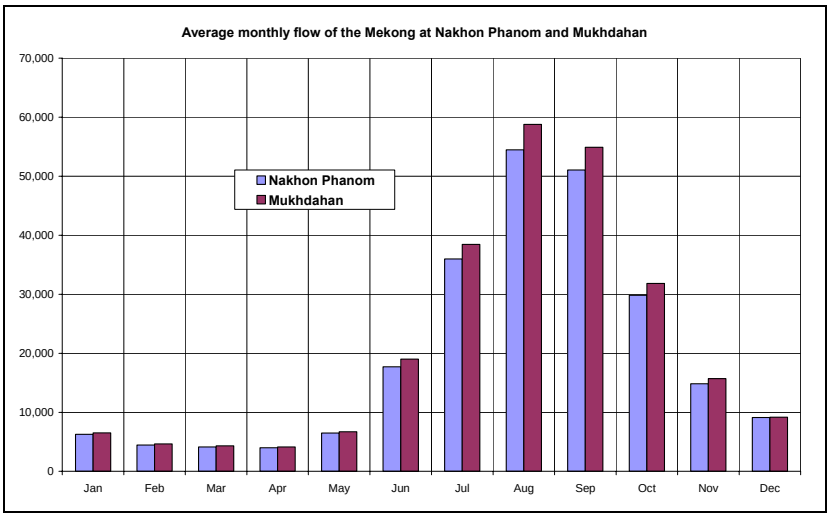

Figure 3.20 Average monthly flows in the Mekong at Nakhon Phanom and Mukhdahan

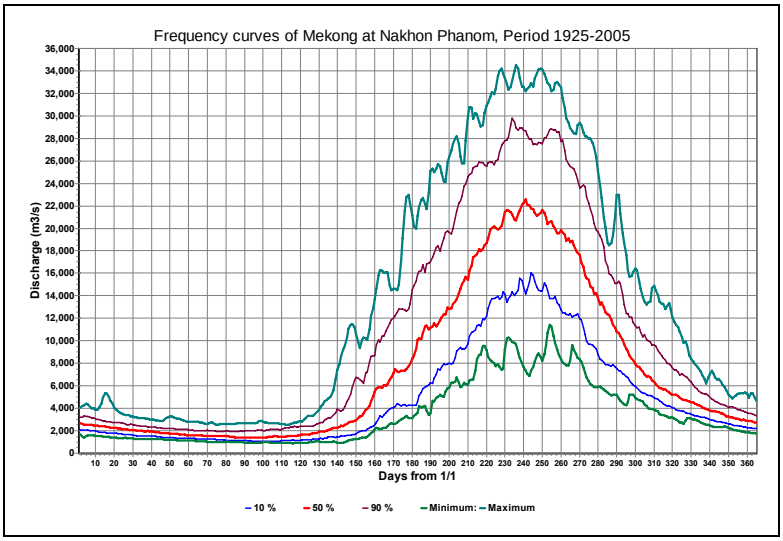

Figure 3.21 Frequency curves of daily average discharge of the Mekong at Nakhon Phanom, Period 1925-2005

Table 3.5 Monthly and annual statistics of the flow in the Mekong at Nakhon Phanom and Mukhdahan

N. Phanom	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean (MCM)	6,277	4,469	4,130	4,000	6,492	17,722	35,993	54,457	51,055	29,808	14,860	9,111	238,376
Stdev (MCM)	1,316	944	940	943	2,234	6,288	9,870	11,741	10,984	7,027	3,554	1,652	39,460
CV	0.21	0.21	0.23	0.24	0.34	0.35	0.27	0.22	0.22	0.24	0.24	0.18	0.17
Min	3,902	3,034	2,767	2,530	3,171	7,532	15,149	28,206	24,261	15,811	8,859	6,147	138,447
Max	10,864	7,371	7,106	6,729	17,503	33,849	62,865	81,324	70,290	45,702	27,322	13,504	340,084
Mukhdahan	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Mean (MCM)	6,522	4,651	4,317	4,134	6,703	19,029	38,441	58,772	54,893	31,841	15,686	9,183	253,875
Stdev (MCM)	1,030	690	686	733	2,102	6,810	9,788	12,203	11,021	7,576	3,634	1,613	36,214
CV	0.16	0.15	0.16	0.18	0.31	0.36	0.25	0.21	0.20	0.24	0.23	0.18	0.14
Min (MCM)	4,162	3,300	2,844	2,608	3,166	7,296	19,718	33,006	29,129	15,058	8,948	5,700	165,954
Max (MCM)	10,679	7,120	6,717	6,278	15,077	39,782	64,697	88,261	81,363	51,088	30,285	12,652	330,576

4 Hydraulic model

4.1 General

The flood levels in the Lower Se Bangfai are a function of the river discharge and the water levels in the Mekong. These flood levels are determined with a one-dimensional hydraulic model based on ISIS. This model has been developed by the LNMC and MRC. The schematization of river and flood plain, applied boundary conditions and calibration is discussed in this chapter.

4.2 Schematization

The hydraulic model of the Se Bangfai used for flood analysis in the lower Se Bangfai comprises the Se Bangfai river from Mahaxai to the river mouth at That Phanom and the Mekong between Nakhon Phanom upstream and Mukhdahan downstream of the confluence. The layout of the model is shown in Figure 4.1, with details in Figure 4.2. This model replaces the initial hydraulic model used for flood flow simulations and analysis during Stage 1 of FMMP-C2, which covered the Se Bangfai downstream of Mahaxai only.

Schematization of Se Bangfai

The Se Bangfai branch of the new model covers the lower 157.953 km of the river from the mouth of the Nam Khatang, at 14.916 km upstream of Mahaxai, to the confluence with the Mekong at That Phanom. The river bathymetry is represented by 38 surveyed cross-sections. In addition, the mouth of the Se Bangfai tributary Se Noy, which discharges about 10 km upstream of station Ban Se Bangfai/Highway 13S Bridge, is included in the model with 3 surveyed cross-sections. The remaining tributaries are modelled as lateral inflow points. The longitudinal profile and characteristic cross-sections at Mahaxai and Ban Se Bangfai are shown in Figure 4.3 to Figure 4.5.

The flood plains along the lower Se Bangfai are schematised by storage cells with a depth-volume relation. The storages are connected to the main stream via spillways/two way weirs. The schematisation of the storage cells has been derived from a digital elevation model (DEM), which in turn was based on topographic information in 1/10,000, 1/20,000 and 1/50,000 scale maps, updated by a sample survey in July 2008. The survey party consisted of the modelling teams of LNMC and MRC together with the irrigation engineer of the Dept. of Agriculture and Forestry of Khammouane Province. A high resolution DEM (15 x 15 m) was developed for the flood plain downstream of Highway 13, reproduced from 1/1,000 scale maps. To include the latest information on the elevation of the levees and layout of the flood protection structures in the model for reliable simulation of the spill to the flood plain, the levees and structures on either side of the lower Se Bangfai have been surveyed in October 2008.

The hydraulic roughness in the Se Bangfai branch of the model, expressed as Manning-n, ranges from 0.05-0.07 in the upper part of the model near Mahaxai to 0.045-0.036

downstream of the Se Noy confluence, see Figure 4.6. In comparison to the initial model used in Stage 1 the roughness values in the lower part have substantially increased.

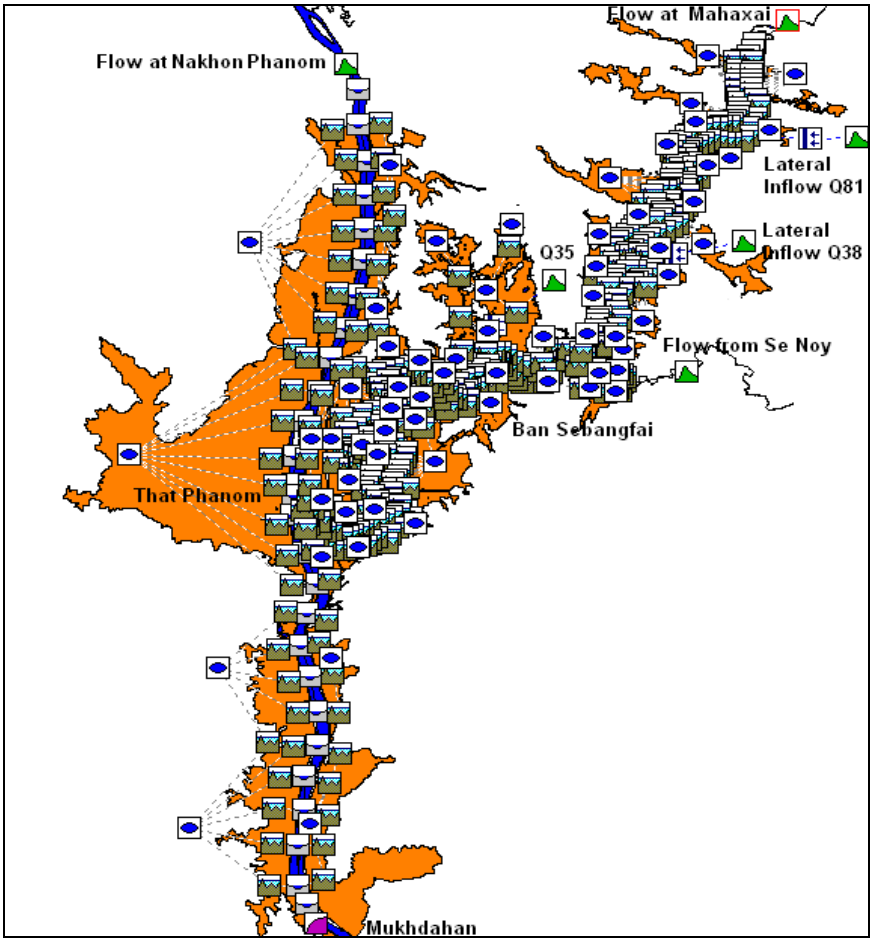

Figure 4.1 Schematization of Se Bangfai in ISIS-hydraulic model

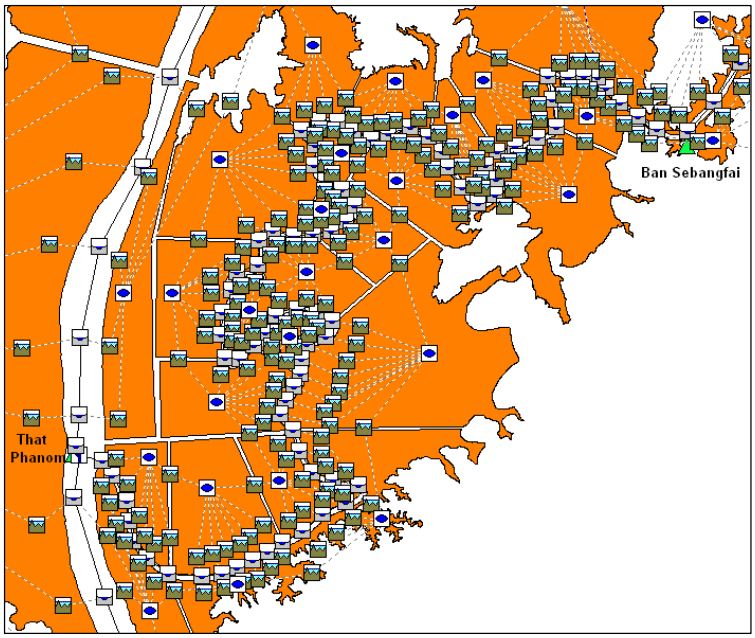

Figure 4.2 Detail of ISIS-hydraulic model of Se Bangfai near river mouth

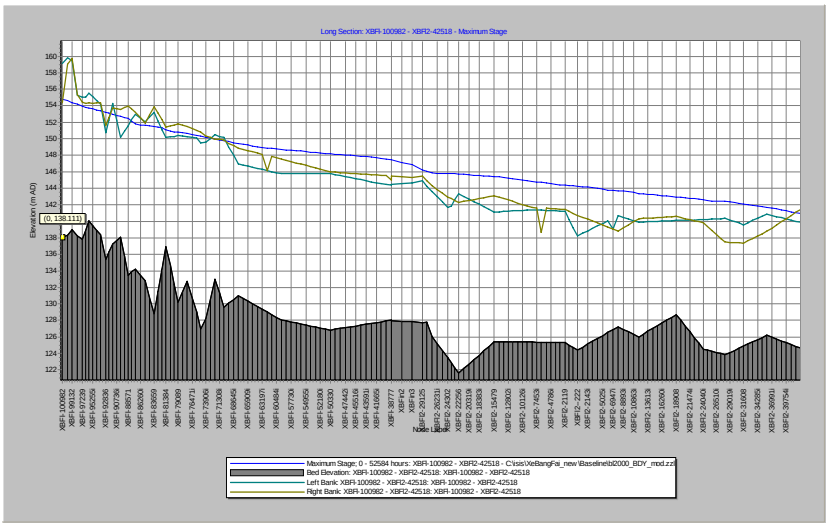

Figure 4.3 Longitudinal profile of Se Bangfai from 15 km u/s Mahaxai to river mouth

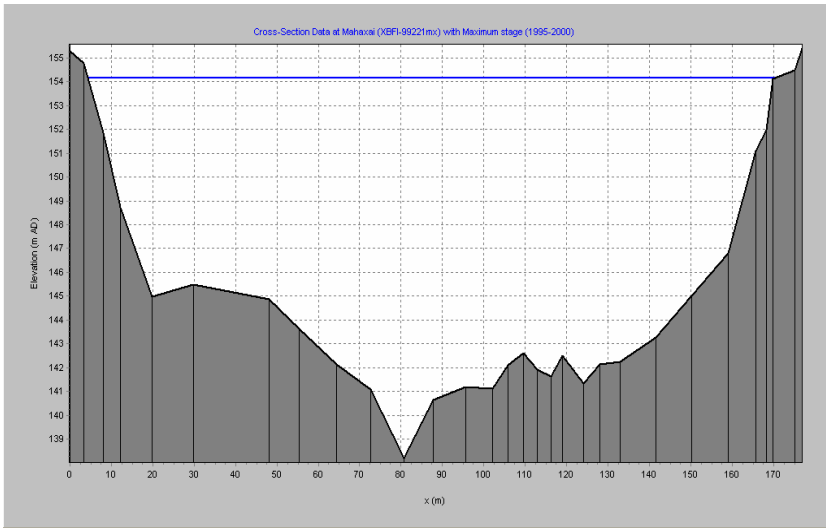

Figure 4.4 River cross-section at Mahaxai

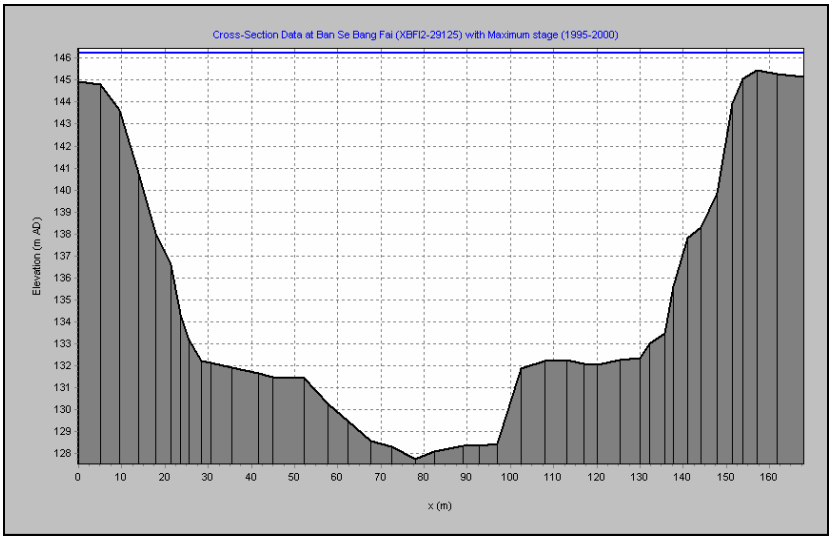

Figure 4.5 River cross-section at Ban Se Bangfai/Highway 13S Bridge

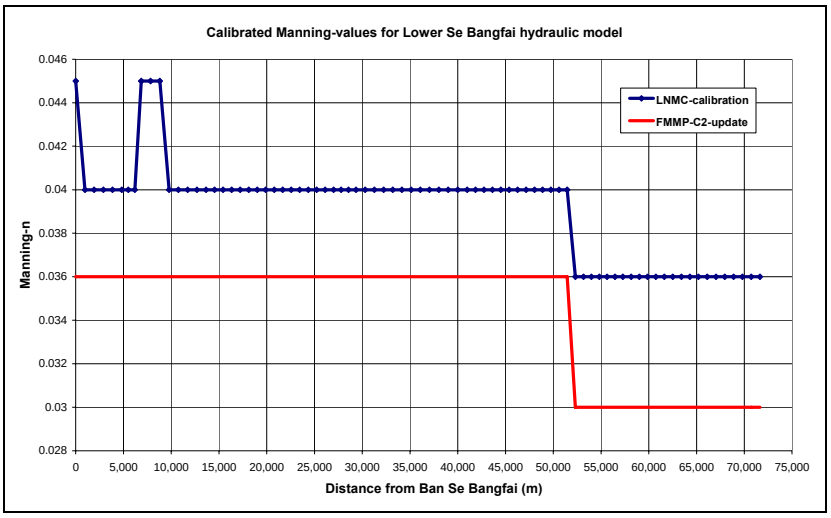

Figure 4.6 Hydraulic roughness of lower Se Banfai river (Ban Se Bangfai-That Phanom) as calibrated by LNMC and updated by FMMP-C2

Schematization of Mekong

The Mekong reach between Nakhon Phanom and Mukhdahan has been schematized by 25 cross-sections extracted from the ISIS-model derived from details presented in the Hydrographic Atlas of the Mekong River. A longitudinal profile of the river stretch is presented in Figure 4.7. In the schematization at a number of locations a connection is established between the Mekong river and the flood plain adjacent to the Se Bangfai.

A constant Manning roughness of n = 0.032 is assumed for the Mekong branch of the hydraulic model.

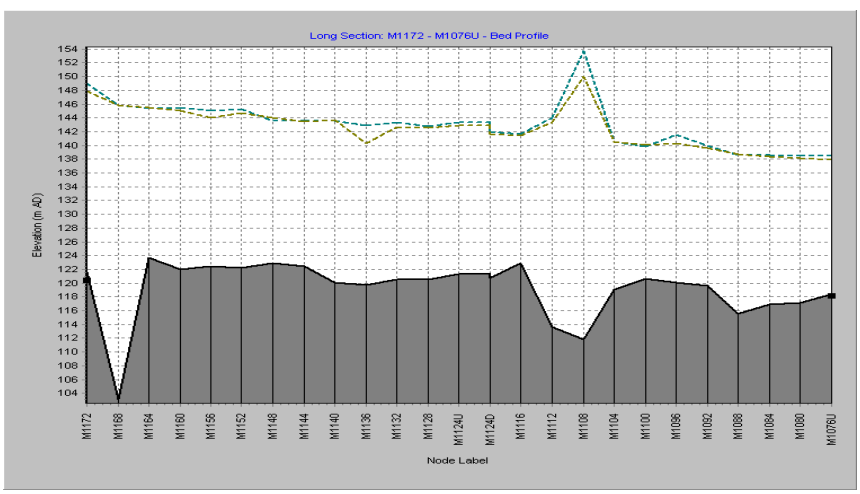

Figure 4.7 Longitudinal profile of Mekong from Nakhon Phanom to Mukhdahan

4.3 Boundary conditions

4.3.1 General

The following boundary conditions are used in the hydraulic model:

- for the Se Bangfai branch:
  - discharge at Mahaxai as upstream inflow;
  - lateral inflow (from Nam Oula, Se Noy, etc) schematized to concentrated inflows at the Se Noy confluence and the locations Q81 and Q38 upstream and location Q35 to flood plain around Ban Se Bangfai;
- for the Mekong branch:
  - discharge at Nakhon Phanom as upstream inflow
  - downstream at Mukhdahan a stage-discharge relation (for model calibration the observed water level at Mukhdahan has been considered, but this is not feasible for flood hazard assessment).

The boundaries are discussed below.

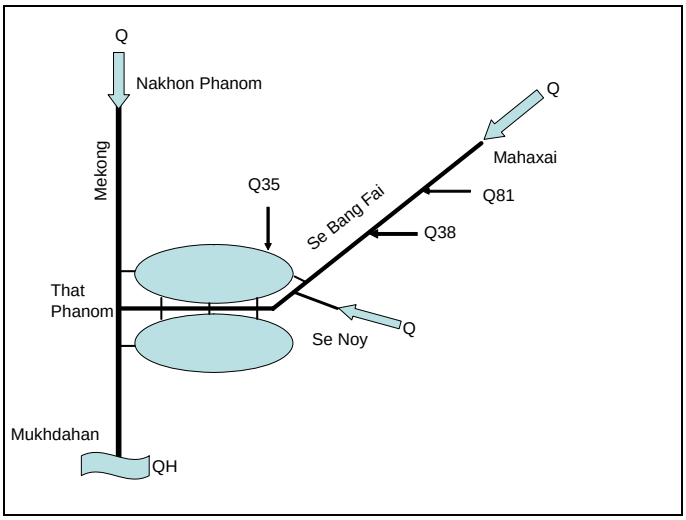

Figure 4.8 Schematic layout of boundary conditions in the hydraulic model of the Lower Se Bangfai

4.3.2 Discharge at Mahaxai

The upstream discharge boundary is derived from the discharge record of the Se Bangfai at Mahaxai, which is available for the period 1988-2006. This series is based on the water level observations at station Mahaxai and regularly updated discharge rating curves. An example of a discharge rating for Mahaxai is shown in Figure 4.9. Though in some years there is substantial difference between the discharge observations and the rating curve used for the creation of discharge series, in general the applied discharge ratings match with the observations. From the applied curves it appears that the river downstream of Mahaxai is not stable. A shift of 1 to 2 m is observed from Figure 4.10 for fixed high discharges. It implies that regular adjustments to the bathymetry of the river in the hydraulic model would be required to match with the observed water levels at the station.

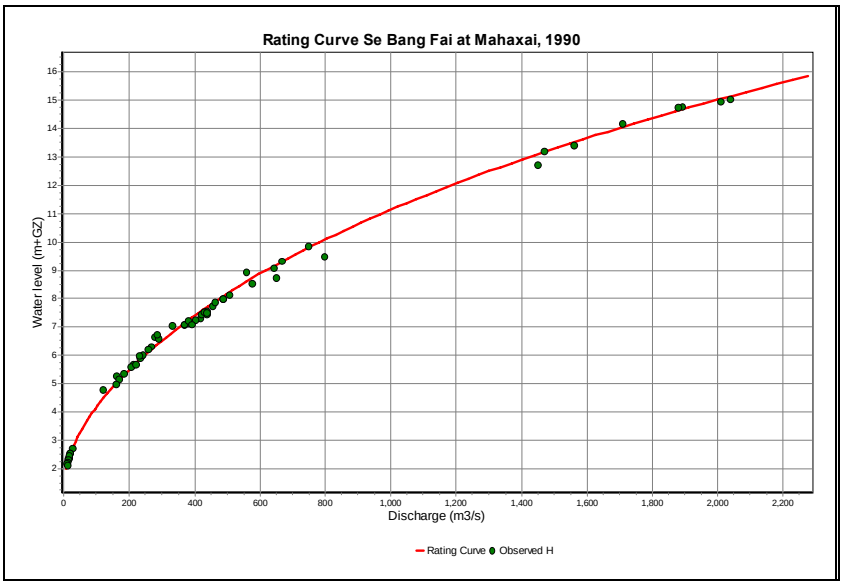

Figure 4.9 Discharge rating of the Se Bangfai at Mahaxai for the year 1990

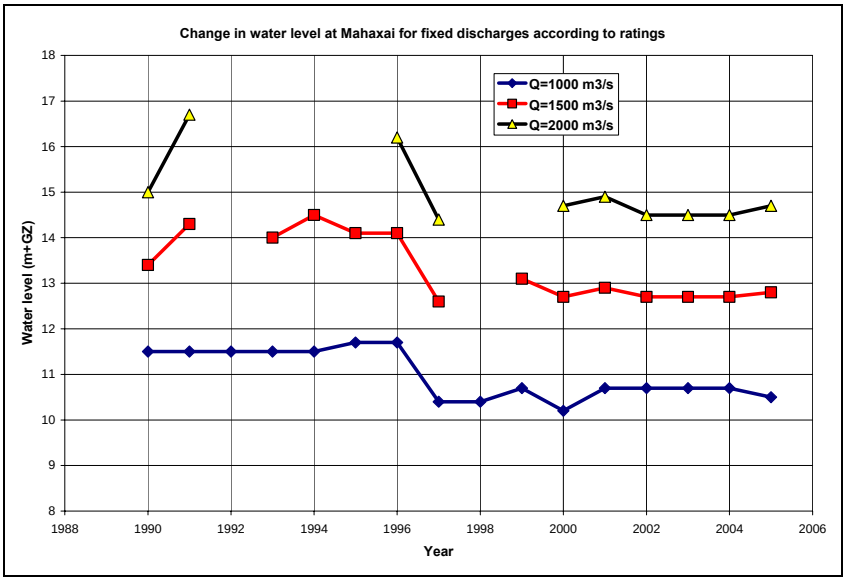

Figure 4.10 Water level at fixed discharge levels in the Se Bangfai at Mahaxai, 1990-2005

Hydrographs show rapid rise and fall, which leads to unsteady flow effects in the stage-discharge relationship. No such corrections seem to have been implemented in the past. Adjustment of the discharge measurements using the Jones correction when establishing the discharge rating curve, and application of this correction in the conversion of stages into discharge would improve the discharge series of the Se Bangfai at Mahaxai.

4.3.3 Lateral inflow

Beside a discharge record for Mahaxai also a long discharge series exists for station Ban Se Bangfai. The difference between the series is the lateral inflow between the two locations. However, the discharge series of Ban Se Bangfai has not correctly been derived. A unique stage-discharge has been applied to the water levels at the station, whereas from a summary of the stage-discharge measurements at Ban Se Bangfai in Figure 4.11 it is immediately

observed that the station is strongly affected by backwater from the Mekong (see also equation (3.2)). In view of the very mild bed slope of the river downstream of Ban Se Bangfai it is estimated that about 40% of the set up at the river mouth is still available at the site. A slope correction is required to adjust the flows, for which a twin gauge approach with the gauge reading at That Phanom as the second series is needed.

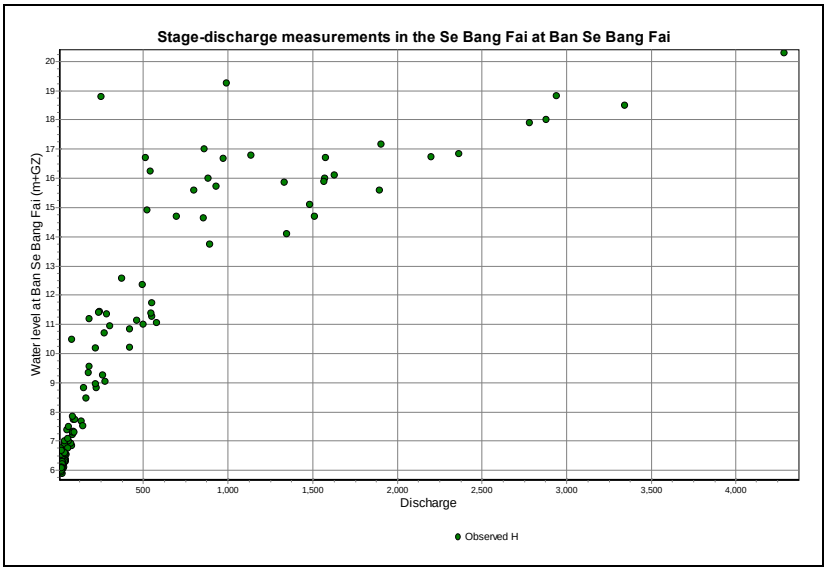

Figure 4.11 Backwater affected and backwater free stage-discharge measurements

However, a simpler procedure has been applied, making use of a relation between the observed discharge at Ban Se Bangfai and the discharge on the same day at Mahaxai. Particularly for the high discharges a fairly unique relationship exists:

$$Q_{BSBF} = 0.838 Q_{Mahaxai}^{1.108} \qquad (4.1)$$

with: Q_{BSBF} = discharge at Ban Se Bangfai
$Q_{Mahaxai}$ = discharge at Mahaxai
Qlat = lateral inflow between Mahaxai and Ban Se Bangfai

This relation is shown in Figure 4.12, and when corrected for the flow at Mahaxai it gives the lateral inflow to the river between Mahaxai and Ban Se Bangfai:

$$Q_{lat} = Q_{BSBF} - Q_{Mahaxai} = Q_{Mahaxai}(0.838 Q_{Mahaxai}^{0.108} - 1) \quad for: \quad Q_{Mahaxai} > 5.2\, m^3/s \quad (4.2)$$

where: Q_{lat} = lateral inflow between Mahaxai and Ban Se Bangfai.
The lateral inflow is seen from Figure 4.13 to increase gradually to about 90% of the discharge at Mahaxai, in case of extreme floods, commensurate with the respective drainage areas (44% of the total basin area lays upstream of Mahaxai and 40% between Mahaxai and Ban Se Bangfai), see Section 3.2. Downstream of Ban Se Bangfai net rainfall also contributes to inundation of the flood plain; it covers an area of some 16% of the total basin area.

The LNMC modelling team followed a different approach and extracted the lateral inflow from the existing SWAT rainfall-runoff model from Vientiane to Mukhdahan. The lateral inflow was taken as the sum of the sub-basins 435, 438 and 439. Though it will be very difficult to get reliable runoff from the SWAT model for these sub-basins as hardly any rainfall station is available, they claim to have obtained an acceptable fit for the SWAT sub-

basins upstream of Mahaxai, calibrated to the flow at Mahaxai, with an efficiency coefficient of 0.6 and a volume ratio of 99.5%. Equation (4.2) shows that the lateral inflow downstream of Mahaxai indeed is strongly correlated with the flow at the station.

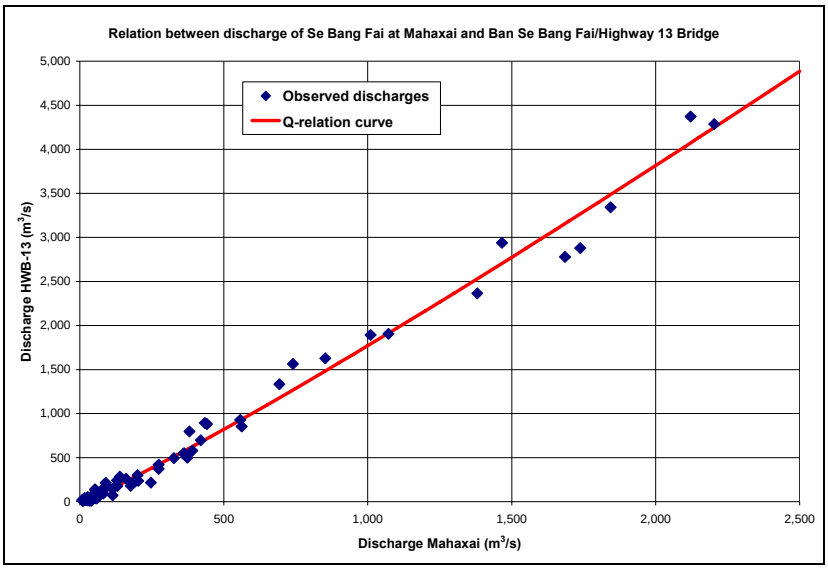

Figure 4.12 Discharge of Se Bangfai at Ban SeBang Fai as function of discharge at Mahaxai

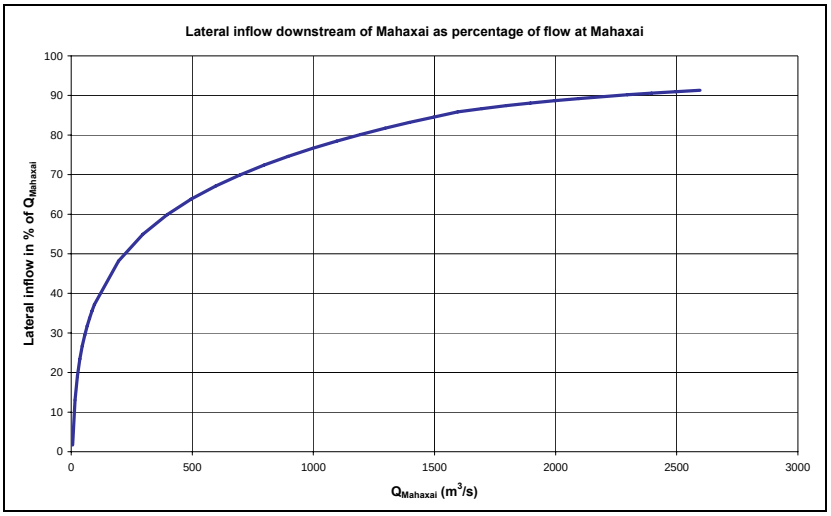

Figure 4.13 Lateral inflow between Mahaxai and Ban Se Bangfai as percentage of the discharge at Mahaxai

4.3.4 Discharge at Nakhon Phanom

The discharge at Nakhon Phanom acts as upstream boundary for the Mekong branch. Discharge series as from 1924 onward are available for this location. A complete review of this series is not possible as water levels are only available for this station since 1972, whereas stage-discharge measurement data are available from 1962 onward. Hence, no information is present as to how the series prior to 1962, resp. 1972 have been created. From Figure 4.14 and Figure 4.15 it is observed that the discharge rating for Nakhon Phanom varies considerably, hinting at large scale morphological development in the control reach downstream of the station. Figure 4.15 shows maximum variations up to about 2.5 m for a fixed high discharge. It also shows that in the years without any stage-discharge

measurement the previous discharge rating is continued to be applied, which may have, in view of the unstable river bed, serious consequences for the quality of the discharge series. To validate the relevant discharge characteristics of Nakhon Phanom (peak flow and flood volume) comparisons have been made with the same quantities at Mukhdahan, downstream. In view of the larger total drainage area at Mukhdahan and limited flood plain storage along the main river it is expected that both annual peak flow and flood volume (1 June- 30 November) will be larger at the downstream site. Figure 4.16 and Figure 4.17 show that generally the peak flows and flood volumes are consistent. Only in a limited number of years consistency is not attained. This is particularly so for the period 1976-1993 when no discharge ratings were available for Nakhon Phanom; at Mukhdahan the availability is slightly better and shows variations where the Nakhon Phanom rating was kept constant. The inconsistencies are, however, not strong. From double mass analysis between the same stations for the same quantities as before also no serious anomalies were found as can be observed from Figure 4.18 and Figure 4.19. Hence, it is concluded that the series of flood peaks and flood volumes that can be obtained from the Nakhon Phanom discharge series are generally reliable, and form a solid basis for flood hazard assessment.

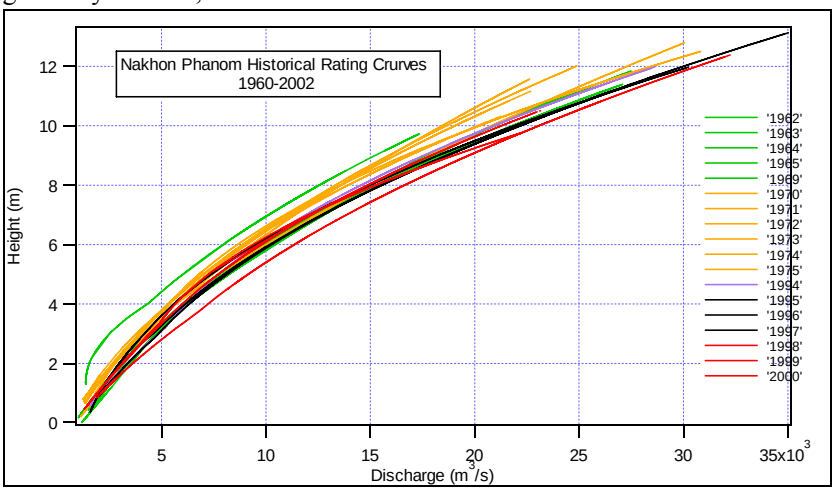

Figure 4.14 Stage-discharge relation of Mekong at Nakhon Phanom (MRC, 2002)

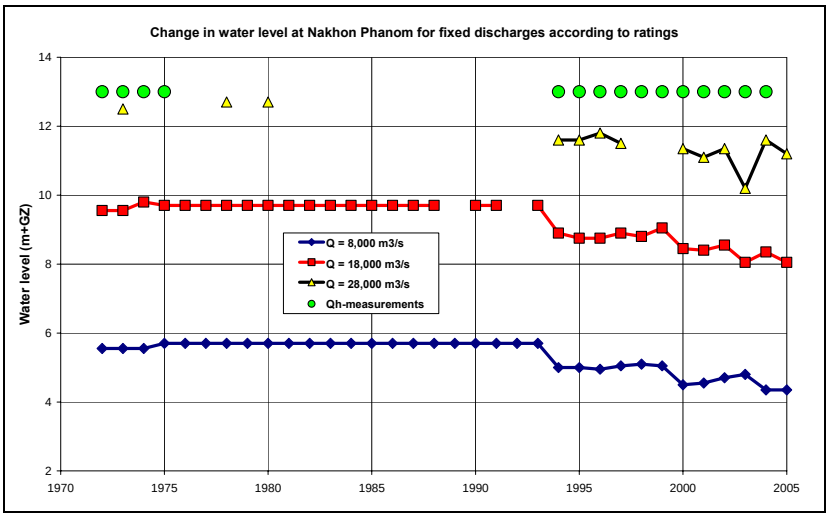

Figure 4.15 Change in water level at Nakhon Phanom for fixed Mekong discharges, Period 1972-2005

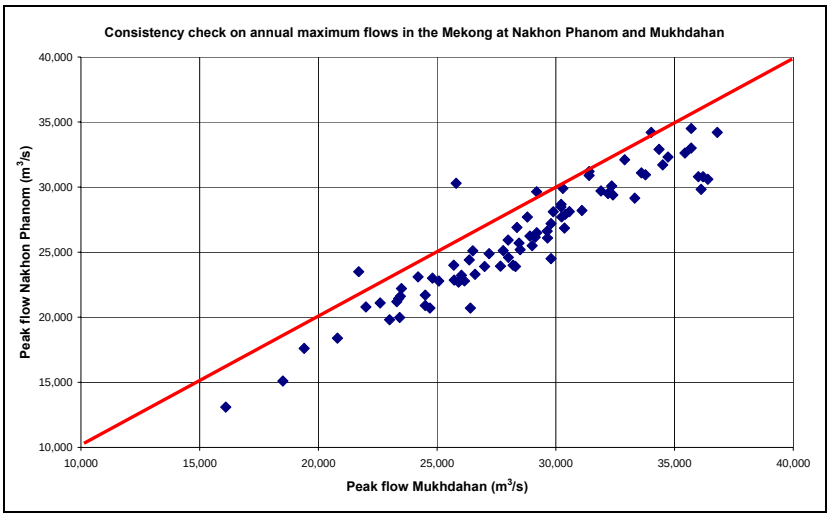

Figure 4.16 Comparison of annual peak flows at Nakhon Phanom with Mukhdahan

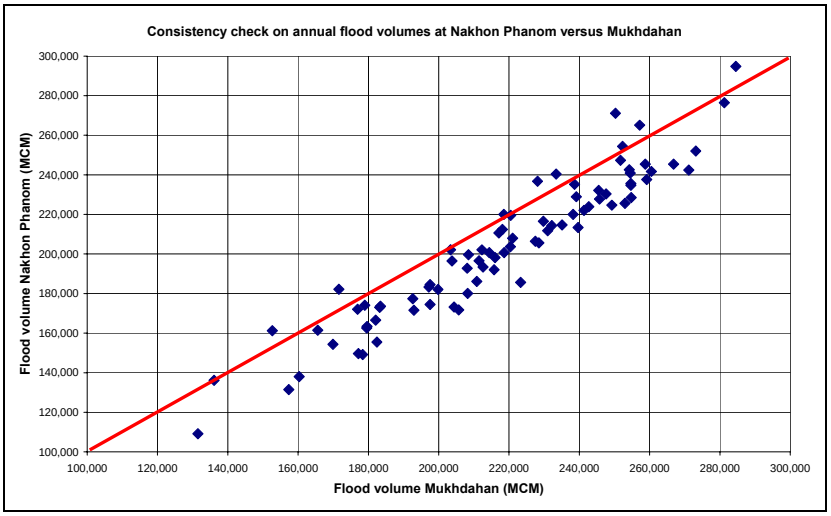

Figure 4.17 Comparison of annual flood volumes at Nakhon Phanom with Mukhdahan

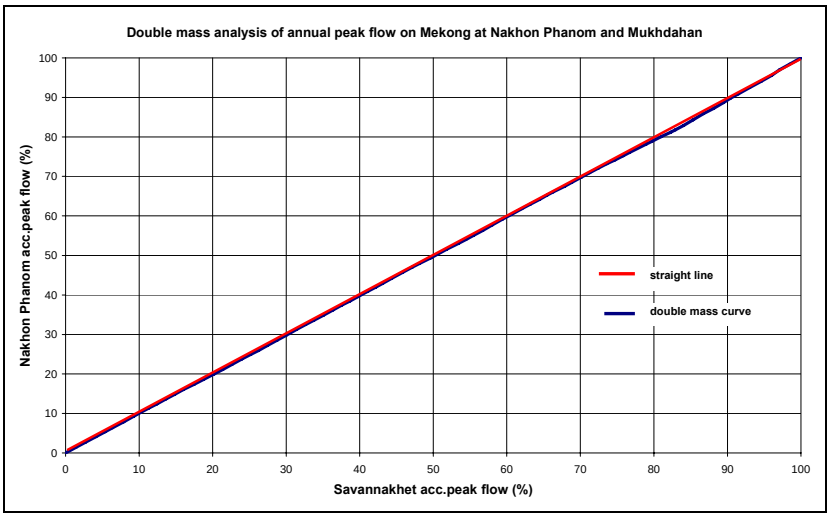

Figure 4.18 Double mass analysis of annual peak flows at Nakhon Phanom and Mukhdahan

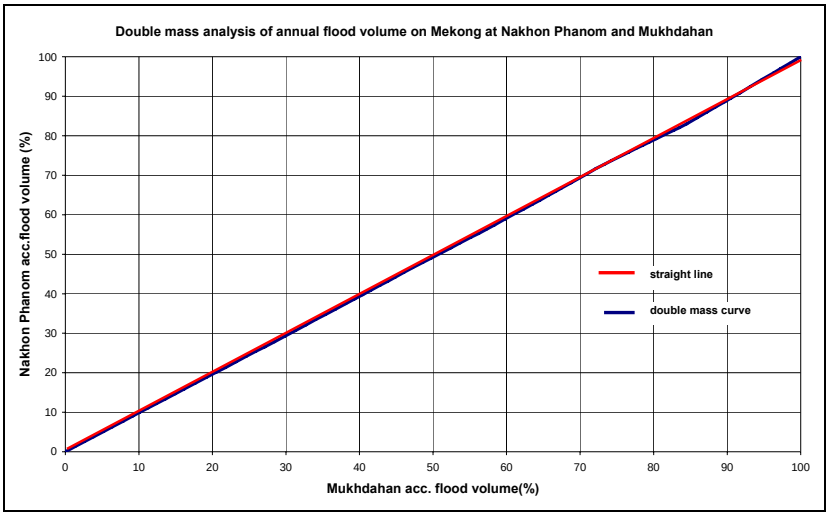

Figure 4.19 Double mass analysis of annual flood volumes at Nakhon Phanom and Mukhdahan

4.3.5 Stage-discharge relation at Mukhdahan

At the downstream end of the model on the Mekong at Mukhdahan a stage-discharge relation has to be imposed rather then a water level. Different from model calibration, applying a water level at that location for analysing development scenarios in the lower Se Bangfai would not be correct as these developments may affect the discharge and hence the levels at Mukhdahan, which in turn gives severe backwater effects on the water level at the Se Bangfai mouth at That Phanom; the characteristic backwater length for the Mekong at high flows for this reach is about 50 km, whereas the distance between Mukhdahan and That Phanom is only 43 km. It follows that of a disturbance in the water level at Mukhdahan still over 40% is left at That Phanom. Therefore a stage-discharge relation is imposed at this site for analysis of developments rather than a water level. Unfortunately, similar to the situation in Nakhon Phanom, the stage-discharge relation at Mukhdahan varies from year to year as can be observed from Figure 4.20 and Figure 4.21. For the highest discharges the levels vary up to 1.5 m.

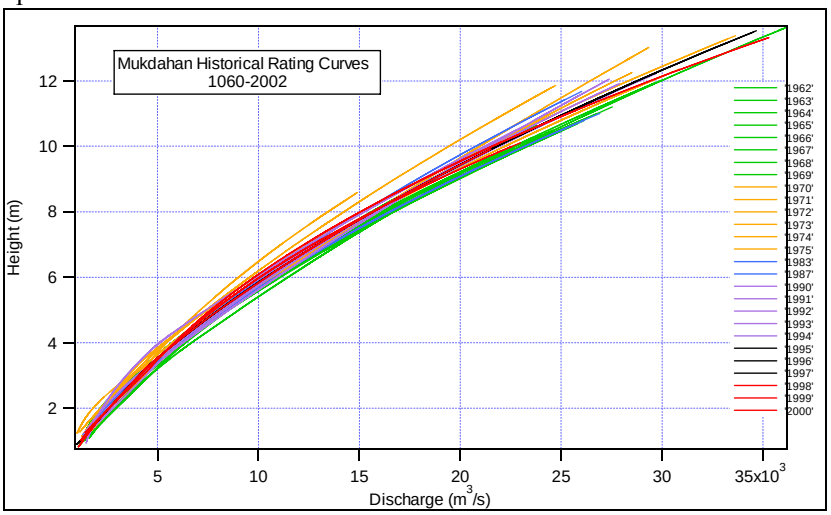

Figure 4.20 Stage-discharge relation of Mekong at Mukhdahan (MRC, 2002)

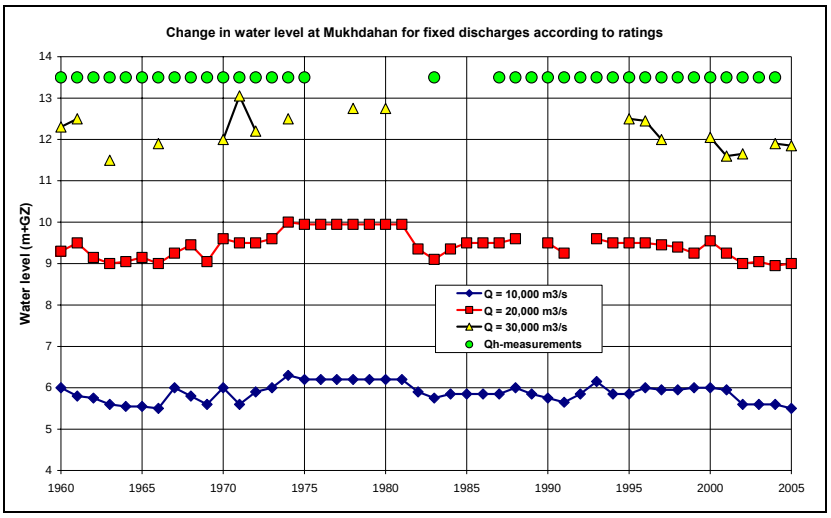

Figure 4.21 Change in water level at Mukhdahan for fixed Mekong discharges, Period 1960-2005

The Mekong branch of the hydraulic model was calibrated for the year 2000 stage-discharge conditions, see Figure 4.22. From Figure 4.21 it is observed that this curve forms a middle position of historical discharge curves observed at Mukhdahan. Hence, levels for high discharges at this location based on the year 2000 curve may be up to 0.75 m off, up and down. At Nakhon Phanom this variation was in the order of +/- 1.25 m, hence at That Phanom in between these locations a variation of about +/- 1.00 m is to be expected, relative to the year 2000 conditions of the river bed. Observed frequency distributions of water level changes relative to year 2000 for fixed high discharges at Nakhon Phanom and Mukhdahan are presented in Figure 4.23. It is observed that these distributions are approximately uniform. This additional uncertainty has to be taken into account in the flood hazard assessment and derived levels. The changes in the ratings observed at Mukhdahan appear to be fully uncorrelated with the peak flows and flood volume at Nakhon Phanom for all years with discharge measurement data. Hence, generated flows at the latter are not indicative for the type of change in the discharge rating at Mukhdahan.

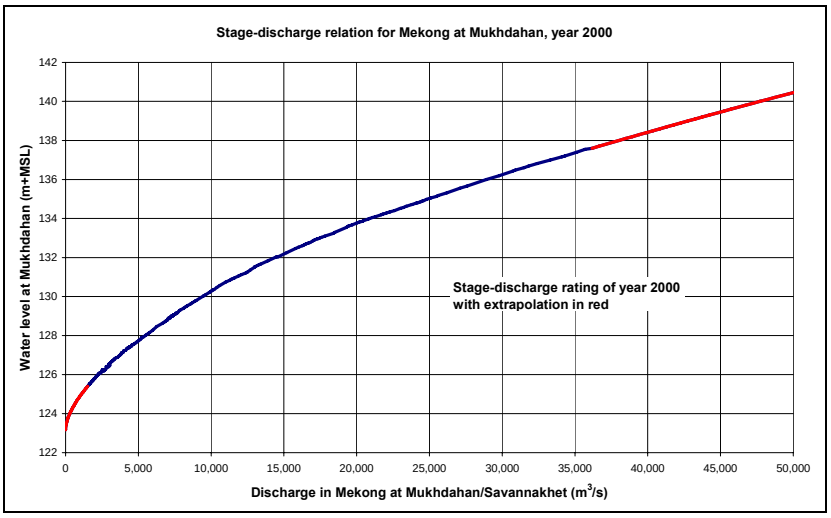

Figure 4.22 Assumed stage-discharge relation for Mukhdahan in hydraulic model, year 2000

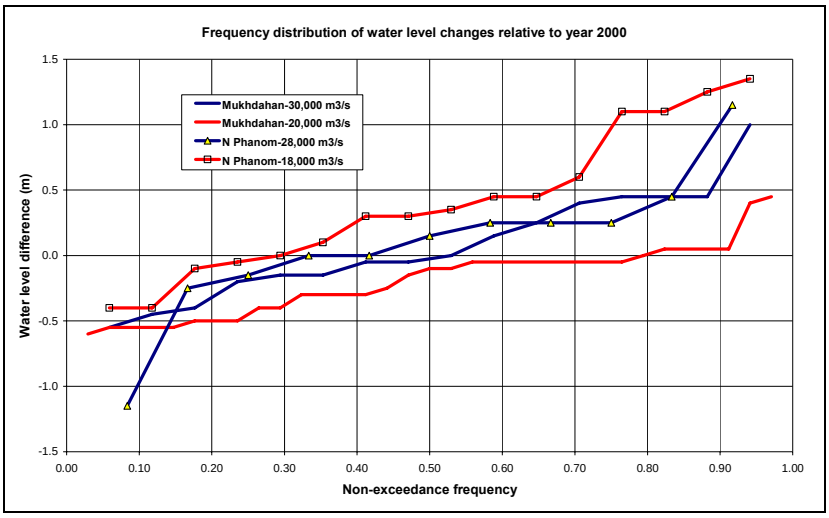

Figure 4.23 Frequency distribution of water level changes relative to year 2000 for fixed high discharges in Mekong at Nakhon Phanom and Mukhdahan

4.4 Model performance test

For the verification of the hydraulic model the gauge readings of Ban Se Bangfai and of That Phanom of the Period 1995-2000 has been used. The model delivered by LNMC with Consultants boundary conditions (lateral inflow derived from the series at Mahaxai according to equation (4.2)) gave a biased result (on average too high values: average difference for h>140 masl = 0.76 m) as is observed from Figure 4.24. To eliminate the bias the hydraulic roughness of the Se Bangfai downstream of Ban Se Bangfai has been changed (reduced) to the values displayed in Figure 4.6. The results are presented below.

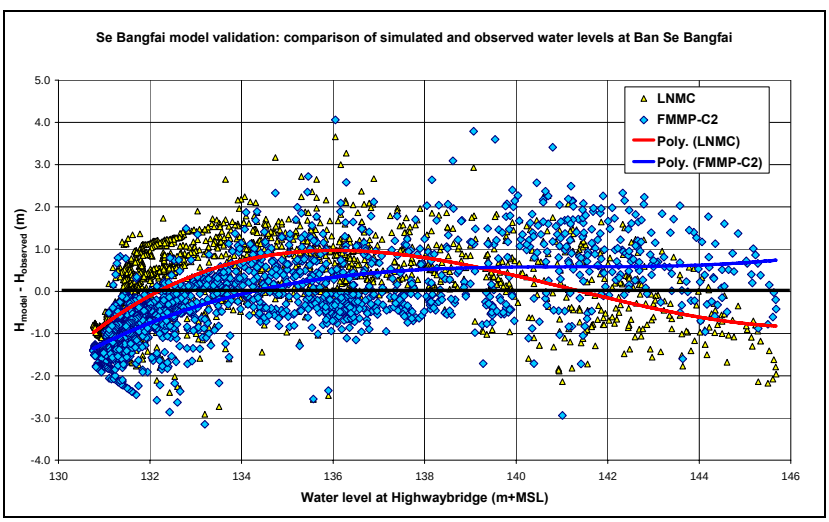

Figure 4.24 Error analysis of Se Bangfai hydraulic model calibration at Ban Se Bangfai, application of LNMC-calibration

Verification on levels at That Phanom

The performance of the model with the adjusted hydraulic roughness has been tested on the computed water levels at Ban Se Bangfai for the period 1995-2000. The results are presented in Figure 4.25 to Figure 4.30, and an error analysis is presented in Figure 4.31.

From Figure 4.25 to Figure 4.30 it is observed that in general the shape of the hydrographs are closely reproduced by the model, indicating that the applied procedure for the lateral inflow is acceptable as far as the water level at Highway Bridge 13S is concerned. The suitability of the model for design can be judged from the differences between the observed and computed water levels at Se Bangfai Bridge. The results for the years 1995-2000 have been summarised in Figure 4.31. From the figure it is observed that the overall model performance is unbiased for water levels > 135 masl values. Individual values, however, may deviate +/- 1.5 m. These differences are partly due to small shifts in the quick rising and falling of the hydrograph and are due to inaccuracies in the supplied tributary discharge. In this respect it is noted that a very high accuracy is not to be expected because about 45% of the discharge at Ban Se Bangfai is estimated via an approximate regression equation from the flow difference between Ban Se Banfai and Mahaxai and not from a discharge rating curve. The quality of the model to determine the inundation depth and extent in the flood is still uncertain as detailed information on the extent of the flooding phenomenon is not available. Hence, there remains doubt on the ability of the model to properly describe the interaction between river and flood plain. It is strongly advocated to use a 1D-2D model for the lower Se Bangfai for appropriate simulation of the river-floodplain inter-action. This also simplifies the model set-up and calibration!

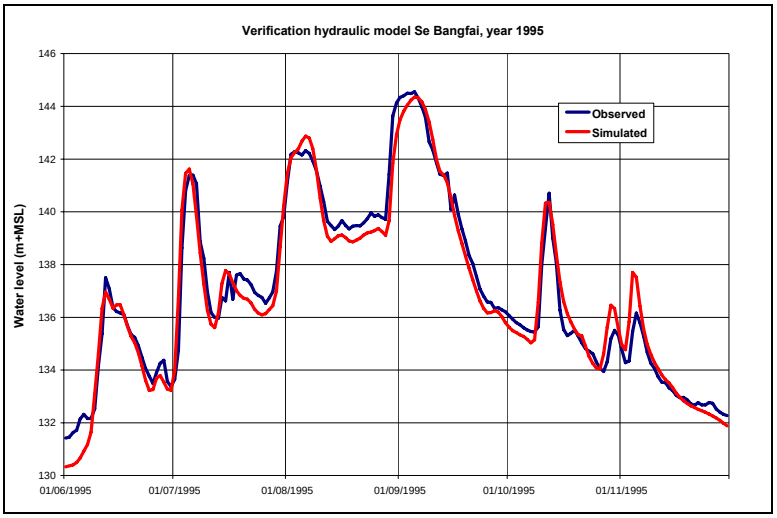

Figure 4.25 Model performance test, observed and simulated water level of 1995 at Ban Se Bangfai

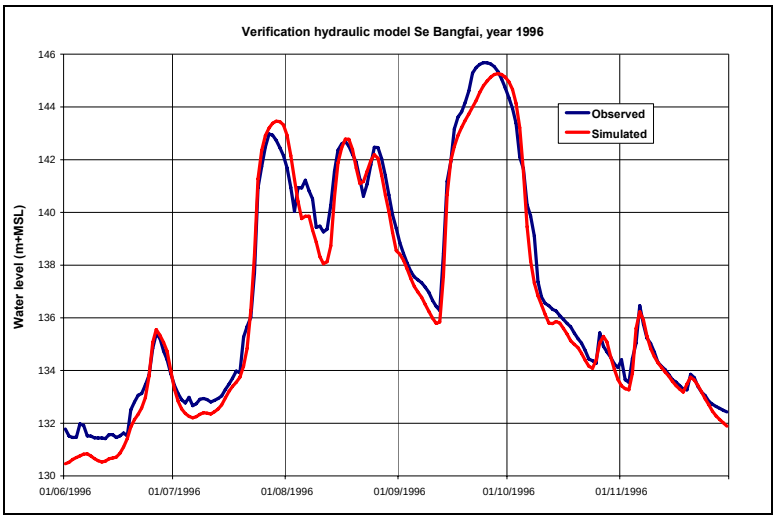

Figure 4.26 Model performance test, observed and simulated water level of 1996 at Ban Se Bangfai

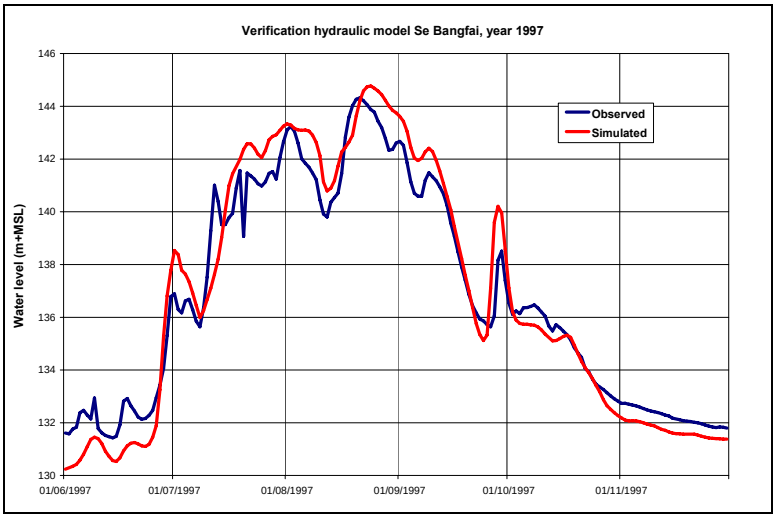

Figure 4.27 Model performance test, observed and simulated water level of 1997 at Ban Se Bangfai

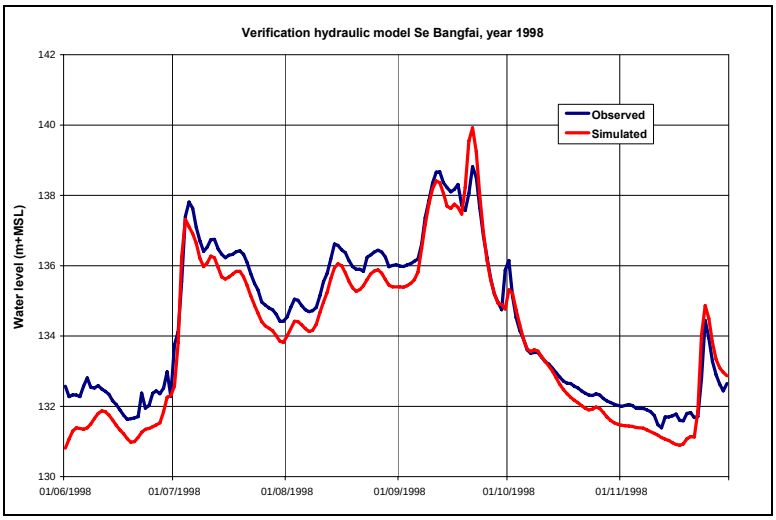

Figure 4.28 Model performance test, observed and simulated water level of 1998 at Ban Se Bangfai

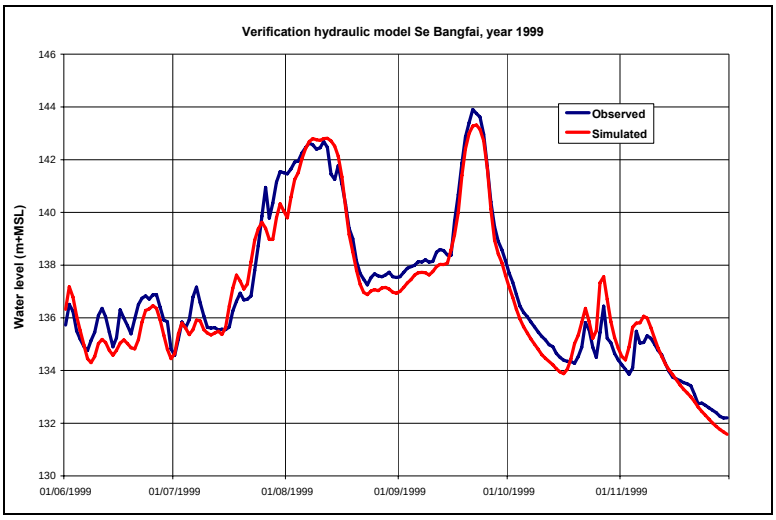

Figure 4.29 Model performance test, observed and simulated water level of 1999 at Ban Se Bangfai

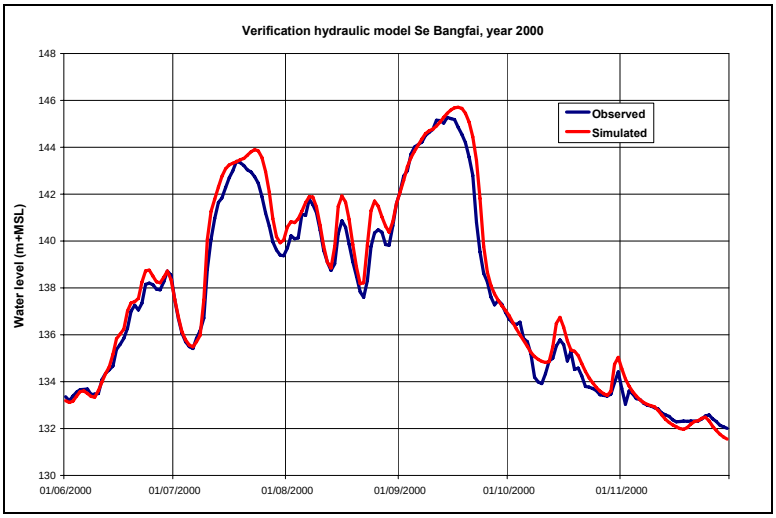

Figure 4.30 Model performance test, observed and simulated water level of 2000 at Ban Se Bangfai

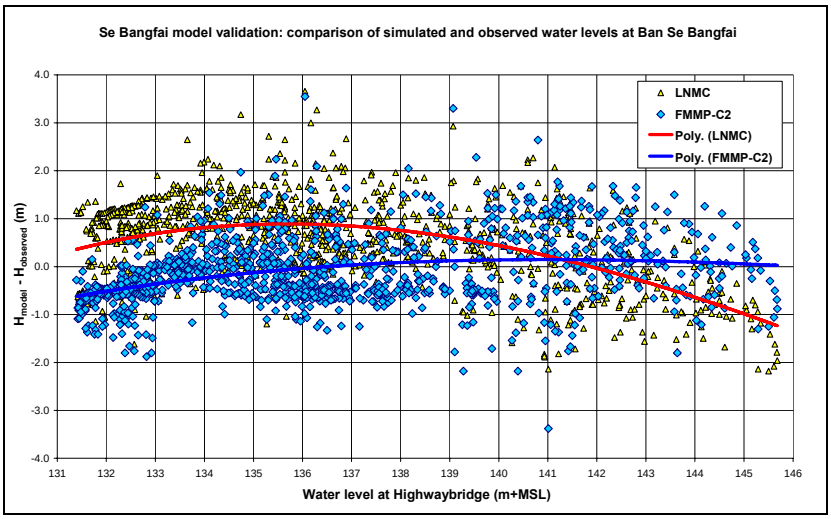

Figure 4.31 Error analysis of Se Bangfai hydraulic model calibration at Ban Se Bangfai

Verification on levels at That Phanom

The computed water levels at That Phanom for the period 1995-2000 have been compared with observed ones as well. Some results are displayed in Figure 4.32 and Figure 4.33, whereas in Figure 4.34 an analysis is given of the model error. From the figures it is observed that a close match is obtained between model result and observations, with deviations generally less than 2 dm. This close match is to a large extent imposed by the water level boundary at Mukhdahan, which gives strong backwater effect on the stage at That Phanom.

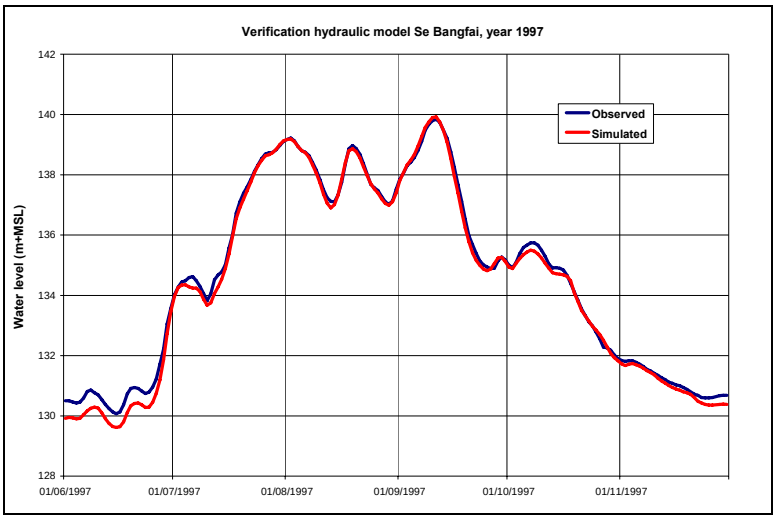

Figure 4.32 Model performance test, observed and simulated water level of 1997 at That Phanom

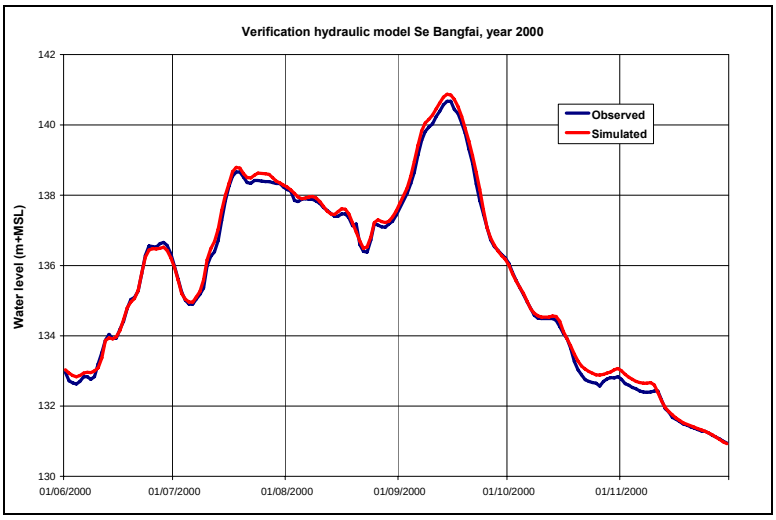

Figure 4.33 Model performance test, observed and simulated water level of 2000 at That Phanom

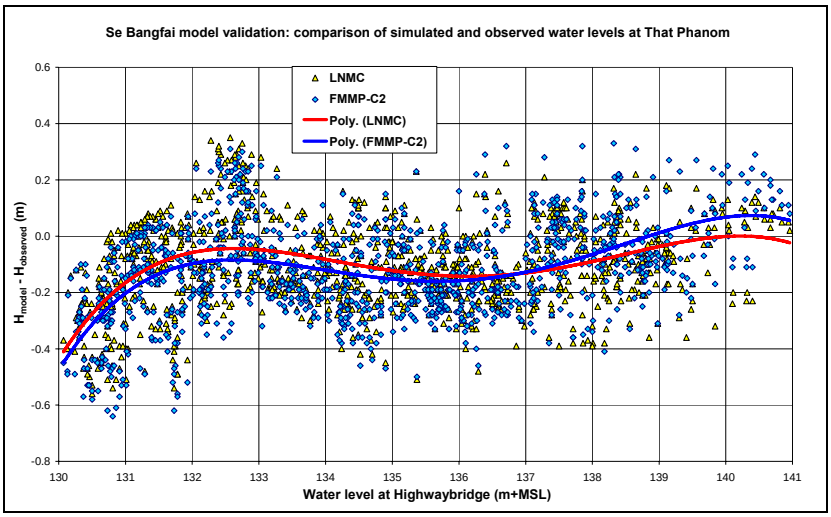

Figure 4.34 Error analysis of Se Bangfai hydraulic model calibration at That Phanom

5 Hydrological hazard assessment

5.1 General

For flood hazard assessment the water levels in the Se Bangfai between Mahaxai and the river mouth opposite That Phanom for distinct return periods (T = 2, 10, 25 and 100 years) will have to be determined for which use will be made of the Monte Carlo procedure discussed in Chapter 2. The hydrological boundary conditions needed for the application of the procedure are presented in this chapter including their interrelation.

5.2 Peak discharge and flood volume Se Bangfai at Mahaxai

Peak discharge

Annual peak discharges in the Se Bangfai at Mahaxai in the period 1988-2006 ranged from 834 m^3/s in 1998 to 2,548 m^3/s in 2005, see Figure 5.1. The peak mainly occurs in the months August and September and occasionally in late June or July, as can be observed from Figure 5.2. The General Extreme Value distribution fits well to the observed annual peak discharges at Mahaxai, as shown in Figure 5.3. This distribution has the form:

$$F(x) = \exp\left\{-\left(1-k\left(\frac{x-u}{\alpha}\right)\right)^{1/k}\right\} \qquad (5.1)$$

where: F(x) = GEV distribution function
k, α, u = parameters of the distribution

The parameters as determined by probability weighted moments and the discharge values for distinct return periods are summarized in Table 5.1.

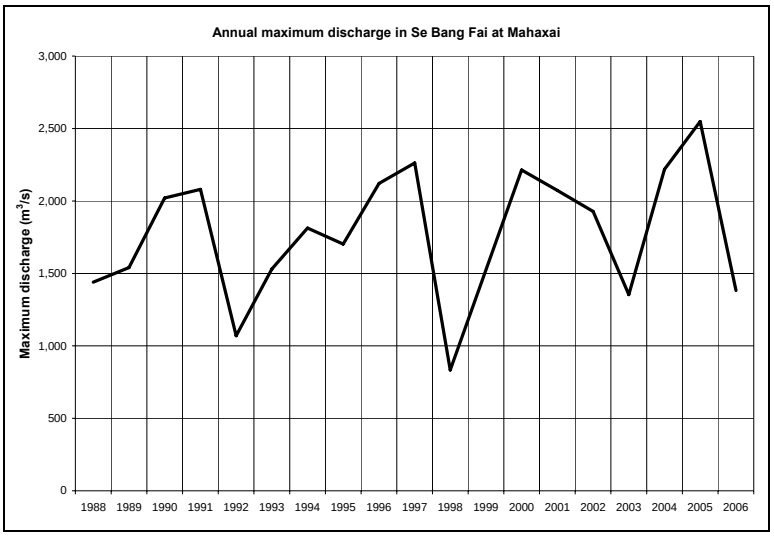

Figure 5.1 Annual maximum discharge in the Se Bangfai at Mahaxai, 1988-2006

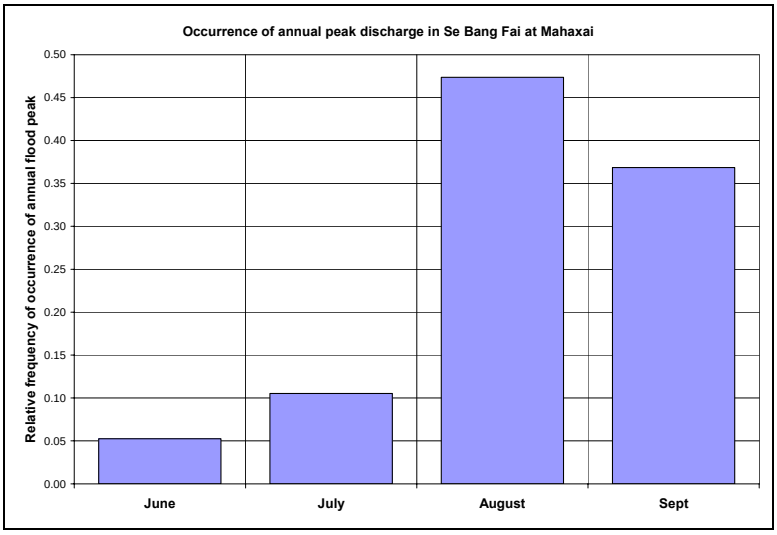

Figure 5.2 Occurrence of annual maximum discharge in the Se Bangfai at Mahaxai

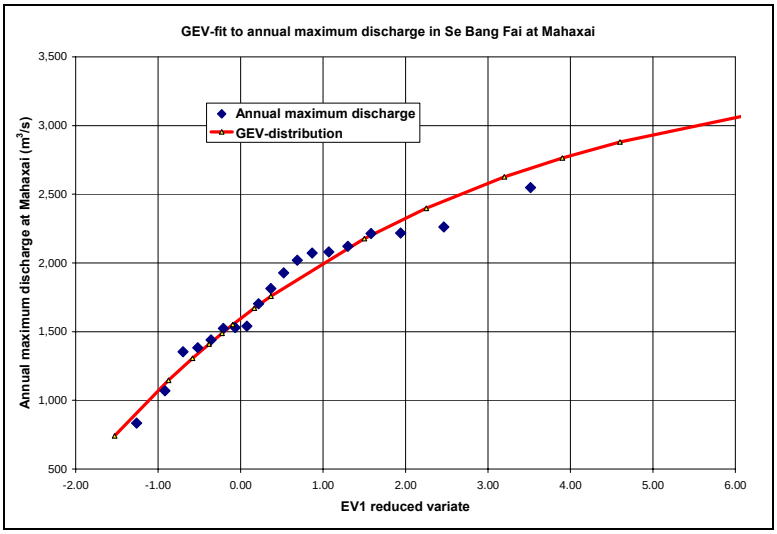

Figure 5.3 GEV-fit to annual maximum discharge in the Se Bangfai at Mahaxai

Table 5.1 GEV-parameters, peak-discharge and flood volumes for distinct return periods in the Se Bangfai at Mahaxai

Parameter	Peak discharge (m^3/s)	Flood Volume (MCM)
k	0.341	0.221
α	498	2,304
u	1,614	6,105
T (years)		
2	1,757	6,916
5	2,177	9,045
10	2,398	10,188
25	2,626	11,386
50	2,765	12,126
100	2,881	12,755

Flood volumes

Similarly, the GEV-distribution fits well to the distribution of annual flood volumes in the Se Bangfai, see Figure 5.4. The annual flood volume is defined here as the volume in MCM occurring in the fixed period from 1 June till 30 November. A fixed time is needed here for proper reproduction of the occurrence of inundations in view of assessment of damage to crops. The parameters of the GEV-distribution and flood volumes for distinct return periods are summarized in Table 5.1.

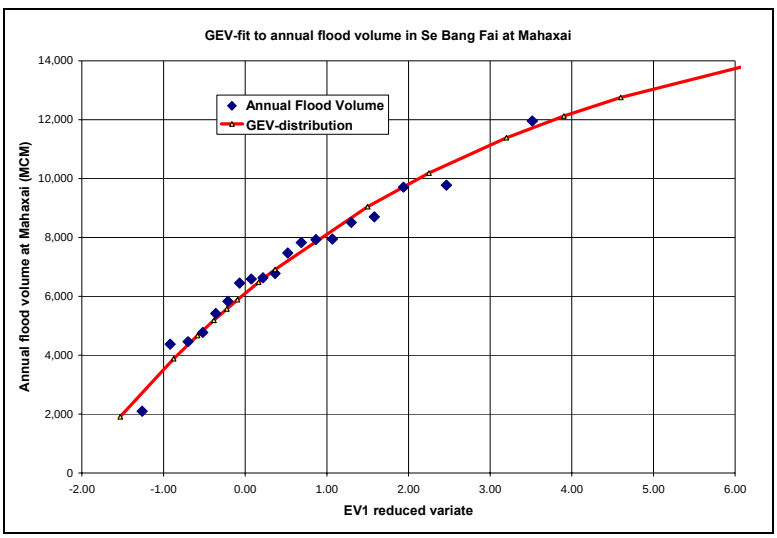

Figure 5.4 GEV-fit to annual flood volume in the Se Bangfai at Mahaxai

Peak discharge – flood volume relation

For the flood hazard assessment with the Monte Carlo procedure for given flood volumes in the Mekong representative flood volumes in the Se Bangfai will be selected. Reference is made to Sub-section 5.4 for the relationship. To improve the selection among historical floods on the Se Bangfai its concurrent realistic peak value has to be known. This can be obtained from the relationship between peak discharges and flood volumes.

The relationship between peak discharge and flood volumes at Mahaxai is presented in Figure 5.5. From this figure it is observed that a fairly close relationship exists between the annual peak-discharge and the flood volume in the Se Bangfai at Mahaxai:

$$Q_{peak,Mahaxai}(m^3/s) = 0.1734\, V_{FV,Mahaxai}(MCM) + 556 \quad (R^2 = 0.78) \qquad (5.2)$$

where: Q = peak discharge in (m^3/s) at Mahaxai
V = flood volume in (MCM) at Mahaxai

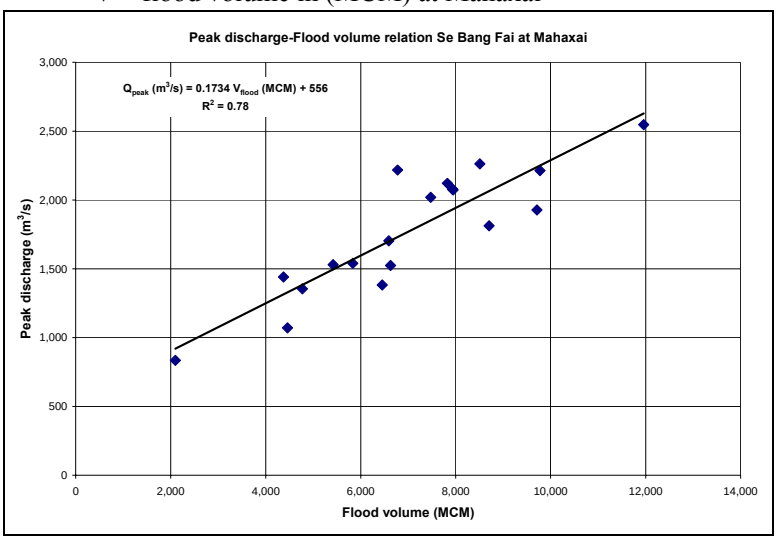

Figure 5.5 Relation between peak discharge and flood volume in the Se Bangfai at Mahaxai

5.3 Peak discharge and flood volume Mekong at Nakhon Phanom

Marginal distributions of peak discharge and flood volume

Statistics of the discharge series of Nakhon Phanom on the Mekong are the key to the formulation of the Mekong boundary in the Monte Carlo procedure as is explained in Chapter 6. The statistics of the peak-flow and annual flood volume (from 1 June to 30 November) at Nakhon Phanom are discussed below. The annual maximum discharge in the Mekong at Nakhon Phanom is presented in Figure 5.6. The long term average annual peak flow amounts 26,049 m^3/s with a standard deviation of 4,486 m^3/s. The observed frequency distribution is well fitted by a GEV-distribution as shown in Figure 5.7. The distribution parameters and the peak flows for distinct return periods are presented in Table 5.2.

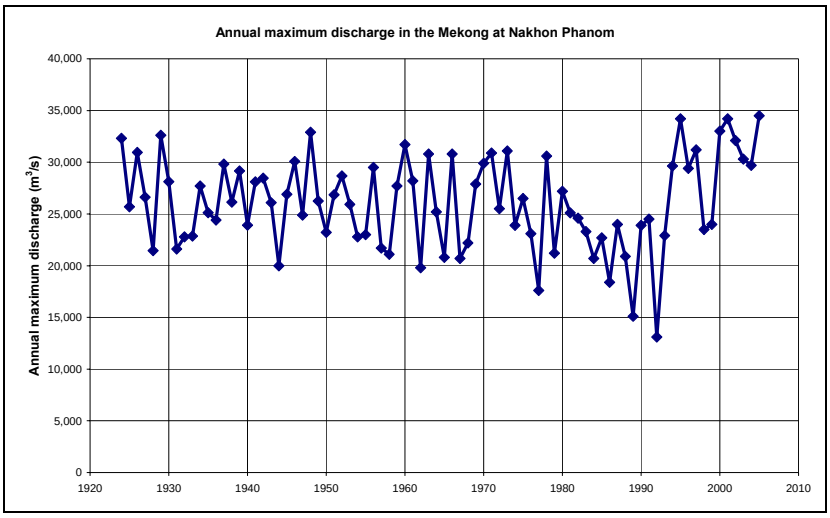

Figure 5.6 Annual maximum discharge in the Mekong at Nakhon Phanom, Period 1924-2005

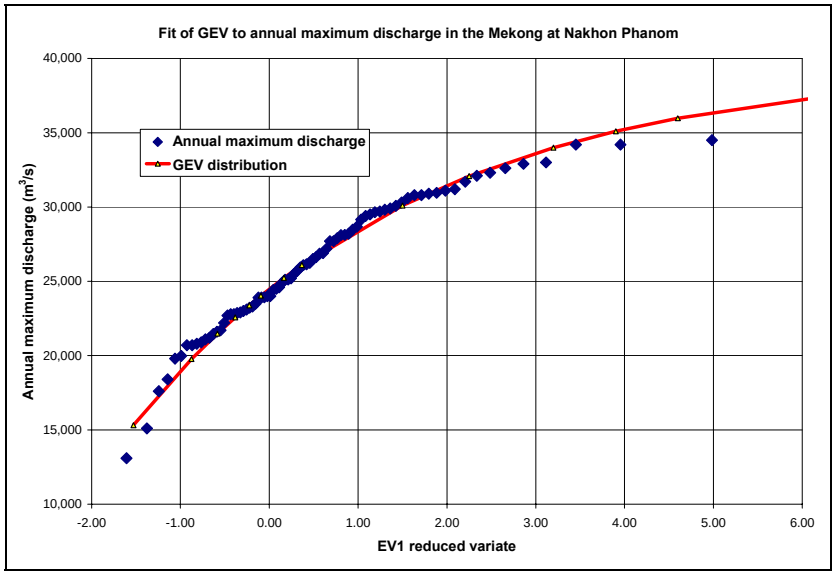

Figure 5.7 GEV-fit to marginal distribution of annual maximum discharge in the Mekong at Nakhon Phanom

The annual flood volumes, defined here as the flow volume between 1 June and 30 November, is displayed in Figure 5.8. Note that the recent years have been extremely voluminous. Like for the annual peak values, the GEV-distribution fits to the annual flood volumes. Distribution parameters and values for selected return periods are shown in Figure 5.9 and Table 5.2. An excellent fit is observed from the graph. The average flood volume amounts 203,895 MCM; the standard deviation is 35,952 MCM.

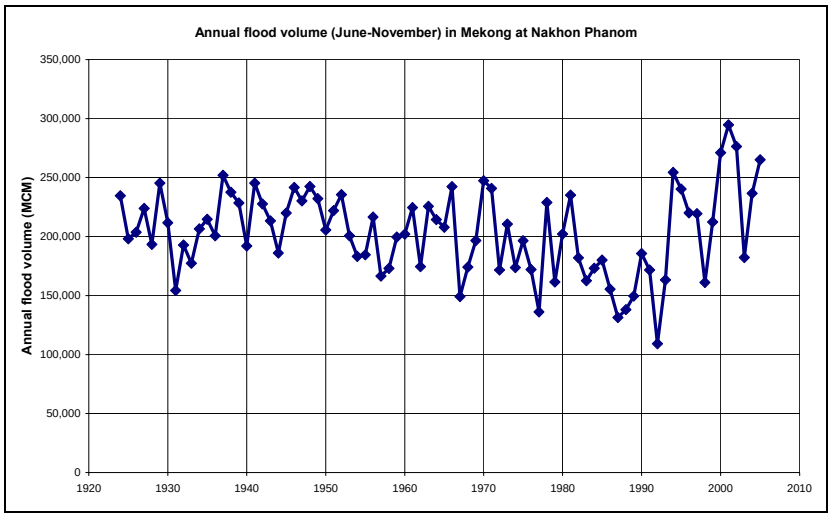

Figure 5.8 Annual flood volume (June-November) in Mekong at Nakhon Phanom, Period 1924-2005

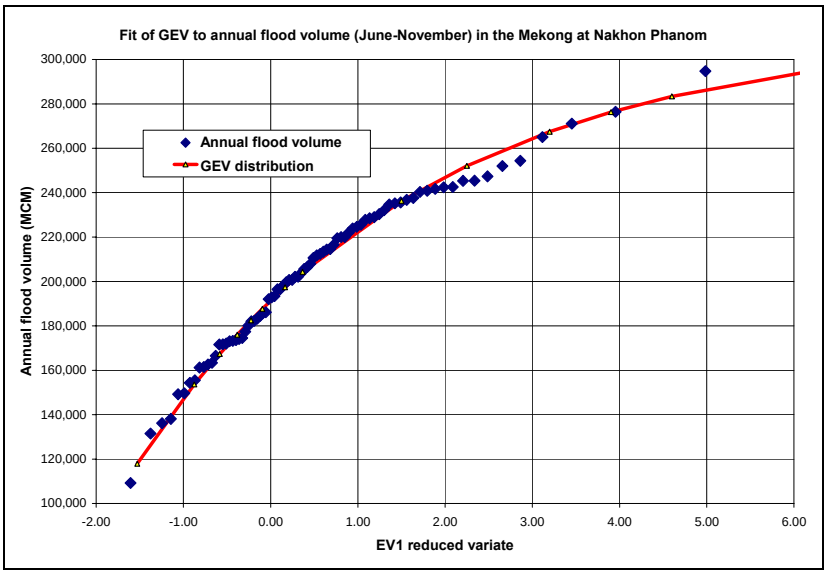

Figure 5.9 GEV-fit to marginal distribution of annual flood volume (June-November) in the Mekong at Nakhon Phanom

Table 5.2 GEV-parameters, peak-discharge and flood volumes (June-November) for distinct return periods in the Mekong at Nakhon Phanom

Parameter	Peak discharge (m^3/s)	Flood Volume (MCM)
k	0.309	0.309
α	4,685	37,515
u	24,475	191,288
T (years)		
2	26,098	204,288
5	30,097	236,318
10	32,070	252,123
25	33,989	267,502
50	35,090	276,328
100	35,970	283,382

Bivariate distribution of peak discharge and flood volume

The bivariate extreme value distribution of flood peaks and flood volumes has been described by Adamson et al. (1999). The joint probability can be generated by the Gibbs sampler Monte Carlo procedure. This technique requires that annual flood peaks (X) and annual flood volumes (Y) are regressed against each other:

$$X = a_{x,y} + b_{x,y} Y$$
$$Y = a_{y,x} + b_{y,x} X \qquad (5.3)$$

and the GEV distributions are used to model the residuals of flood peaks and flood volumes with parameters respectively (u_x, α_x,,k_x) and(u_y, α_y,,k_y). The Gibbs procedure then reads with uniform distributed random numbers R and the generated values marked with #:

$$X_j^{\#} = a_{x,y} + b_{x,y} Y_j^{\#} + u_x + \frac{\alpha_x}{k_x}\left\{1-(-\ln(R_1))^{k_x}\right\}$$
$$Y_{j+1}^{\#} = a_{y,x} + b_{y,x} X_j^{\#} + u_y + \frac{\alpha_y}{k_y}\left\{1-(-\ln(R_2))^{k_y}\right\} \qquad (5.4)$$

The relation between flood volume and peak flow and vice versa is depicted in Figure 5.10, with the coefficients of the equations (5.3) presented in Table 5.3.

Table 5.3 Regression parameters and parameters of GEV distributions of regression residuals for the peak flows and flood volumes of the Mekong at Nakhon Phanom

Regression	Regression parameters		GEV parameters of regression residuals		
Peak on volume	$a_{y,x}$=4,902	$b_{y,x}$=0.1037	u_y= -973.7	α_y= 2,332	k_y=0.1944
Volume on peak	$a_{x,y}$=30,353	$b_{x,y}$=6.6622	u_x=-6,738	α_x=19,951	k_x=0.3063

The GEV-fit to the residual peak discharges and flood volumes is presented in Figure 5.11 and Figure 5.12.The parameters are shown in Table 5.3.

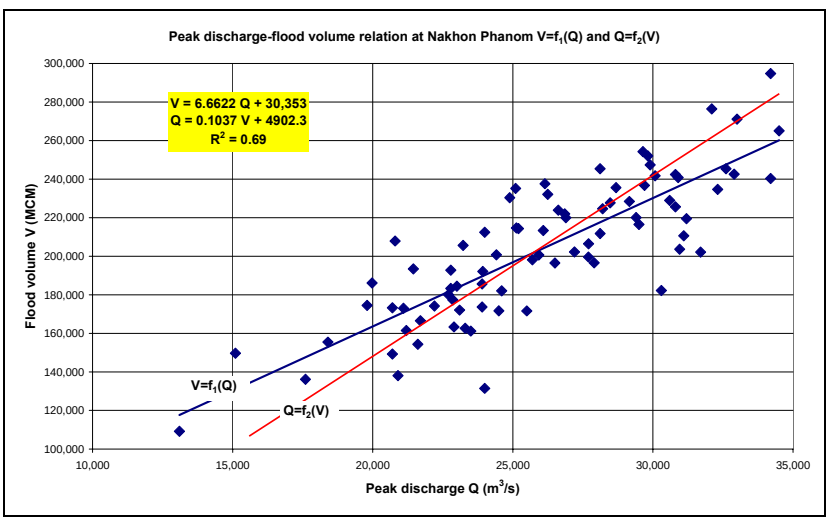

Figure 5.10 Flood volume – peak discharge relations for the Mekong at Nakhon Phanom

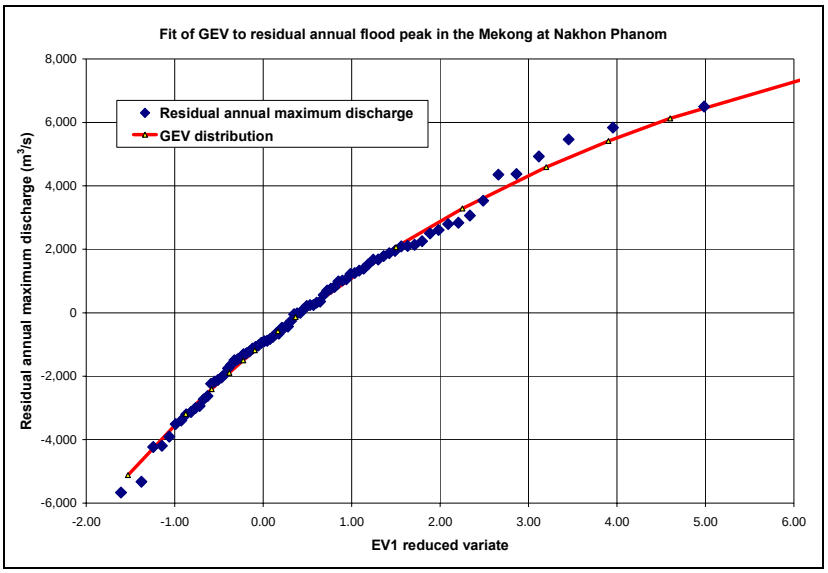

Figure 5.11 GEV-fit to residual annual peak discharge, Mekong at Nakhon Phanom

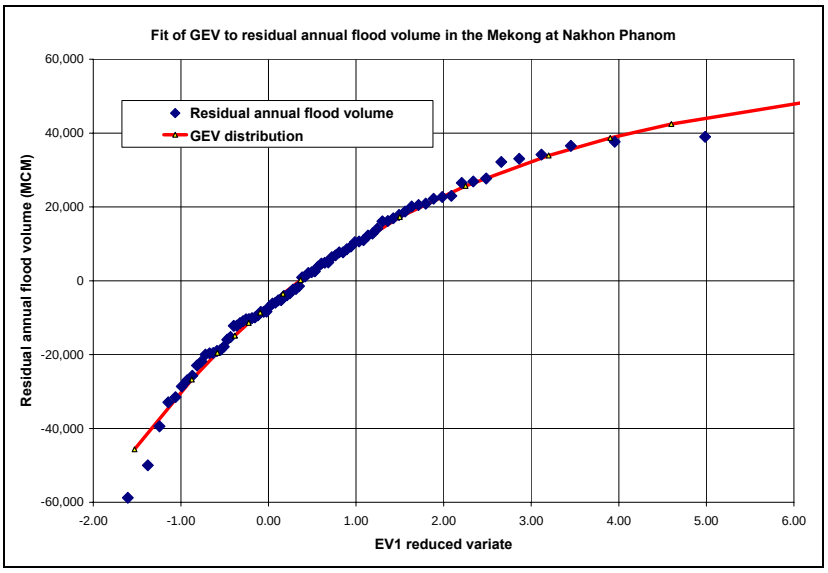

Figure 5.12 GEV-fit to residiual flood volume, Mekong at Nakhon Phanom

5.4 Se Bangfai-Mekong correlation

Another aspect that is of importance in selecting samples for the Monte Carlo procedure is the correlation between flood volumes on the Se Bangfai and on the Mekong and between discharge peaks on both rivers.

The flood volume in the Se Bangfai is correlated with the flood volume in the Mekong, as shown in Figure 5.13. The relation between the flood volumes is given by:

$$V_{Mahaxai}(MCM) = 0.0335\, V_{NakhonPhanom}(MCM) + 52.8 \quad (R^2 = 0.58) \qquad (5.5)$$

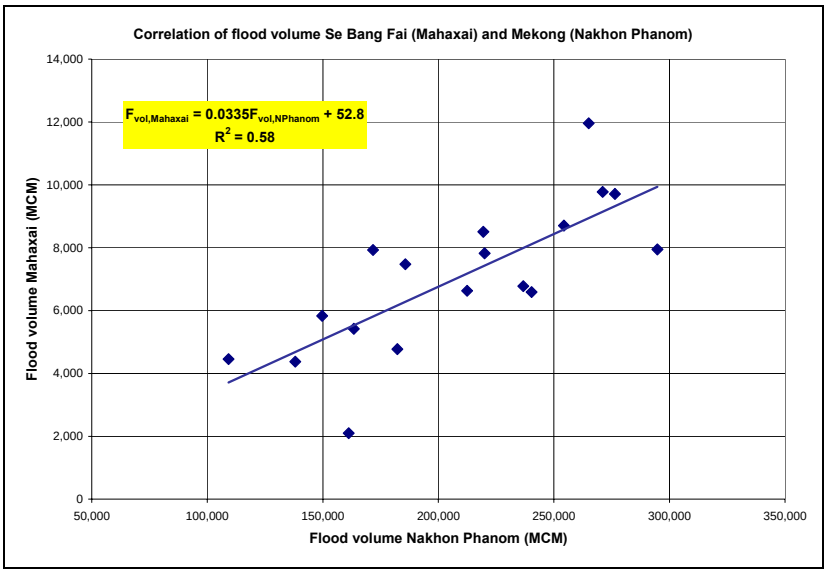

Figure 5.13 Relation between flood volume in the Se Bangfai at Mahaxai and in the Mekong at Nakhon Phanom

The correlation between the peak flows at Mahaxai and at Nakhon Phanom is also significant but less close than between the volumes:

$$Q_{peak,Mahaxai}(m^3/s) = 0.0436\, Q_{peak,NakhonPhanom}(m^3/s) + 561 \quad (R^2 = 0.42) \qquad (5.6)$$

6 Flood hazard assessment

6.1 General

The floods in the lower Se Bangfai are classified as combined floods. The hazard assessment procedure for combined floods was outlined in Chapter 2. The flood hazard is derived from the hydrological hazard, described in Chapter 5.

The steps used to derive the flood hazard from the hydrological hazard using the hydraulic model and subsequently applying the Monte Carlo technique is outlined in Sub-section 6.2. The flood hazard will be determined for:

1. the base case, i.e. without embankments along the lower Se Bangfai
2. the situation with embankments dikes along the left bankof the lower Se Bangfai.
3. the situation with embankment along both banks of the lower Se Bangfai.
4. the situation with a diversion canal from the Se bang fai, dowstream of ban Se Bangfai, to the Mekong river. The results are presented in Sub-section 6.3. The resulting flood maps are presented in Sub-section 6.4. Finally the effect of a bypass canal from the lower Se Bangfai to the Mekong, which as a shortcut for discharge of floodwater., on the flood levels have been investigated in Sub-section 6.5.

6.2 Applied boundary conditions

The procedure used to derive the boundary conditions for the hydraulic model as input to the Monte Carlo method has been:

1. Selection of 5 flood volumes (very low, low, medium, high and very high) at Nakhon Phanom for 6 different peak discharge levels with return periods of T = 2, 5, 10, 25, 50 and 100 years. Use is made of the regression relation between flood volume and peak flow, described Chapter 5, Table 5.3:
   - very low = regression – 1.96 x S_e (S_e = standard error about regression)
   - low = regression -1 x S_e
   - medium = regression
   - high = regression + 1 x S_e
   - very high = regression + 1.96 x S_e.

   The standard error about regression for Nakhon Phanom S_{eNP} = 19,987 MCM
2. Selection of discharge hydrographs of the Mekong at Nakhon Phanom with volumes close to those computed in Step 1.
3. Adjustment of selected historical discharge hydrographs to fit into the scheme of step 1.
4. Using equation (5.5), generation of 3 corresponding flood volumes in the Se Bangfai for each selected flood volume at Nakhon Phanom:
   - low = regression -1.96 x S_e,
   - medium= regression, and
   - high = regression +1.96 x S_e.

   The standard error about regression for Mahaxai S_{eM} = 1,524 MCM

5. Selection of hydrographs in the Se Bangfai series with volumes close to those computed in Step 4.
6. Scaling of Se Bangfai series to match with the required flood volume, and final adjustment based on peak discharges.
7. For the Nam Theun 2 scenario: add 220 m^3/s to the discharge at Mahaxai.
8. Computation of total lateral inflow using equation (4.2), and
9. Partitioning of the lateral inflow between Se Noy (44%), Q81 (29%), Q38 (15%) and Q35 (11%) as proposed by the LNMC & MRC modelling teams.

With this procedure 6 x 5 x 3 = 90 flood seasons have been created to represent the full gamma of physically realistic water level/discharge combinations as input for the Monte Carlo simulation procedure.

Monte Carlo simulations have been executed to derive exceedance frequencies of water levels along the Se Bangfai river at every grid cell. The error introduced by the Monte Carlo techniques decreases with increasing number of samples. Therefore, a relatively large amount of 100,000 samples was taken to make sure errors were small. To test if this is indeed the case, two successive Monte Carlo runs were executed, and results were compared. It turned out that the absolute difference in resulting 100-year water levels between the two runs differed at maximum two centimetres for all locations in the river, which is negligible.

6.3 Simulation results

6.3.1 Cases

Hydraulic model and Monte Carlo simulations were executed for three different schematisations ("cases") of the river system:

Case 1: situation with no embankments, i.e. the river conditions till 2002;
Case 2: situation with embankments along the left bank, which are the present conditions;
Case 3: situation with embankments on both banks, i.e. the planned layout.

In the Cases 2 and 3 the embankments are situated along the stretch from the Se Bangfai Highway Bridge down to the confluence with the Mekong river.

6.3.2 Water levels in the Se Bangfai river

Performance test

For each location along the river and the flood plain exceedance frequency distribution of water levels have been obtained with the Monte Carlo procedure by interpolation between the results obtained with the hydraulic model. Figure 6.1 shows an example of an exceedance frequency distribution for model node XBFi-9822, near Mahaxai station, as derived from the Monte Carlo simulations. These results are for the situation with no embankments along the river. The figure consists of a large number of dots, each representing a threshold value for which the exceedance probability is derived. The

thresholds are all multiples of a centimetre, i.e. the vertical distance between neighbouring dots is exactly one centimetre. For each of these threshold values the exceedance probability is computed in the straightforward crude Monte Carlo manner: the number of exceedances is counted and this number is divided by the total number of simulations (100,000). So for example in case of Figure 6.1 the threshold water level of 154.5 m+MSL is exceeded 1,000 times, which gives a probability of exceedance of 1,000/100,000 = 1/100 per year. In other words: for location XBFi-9822 the 100-year water level is equal to 154.5 m+MSL.

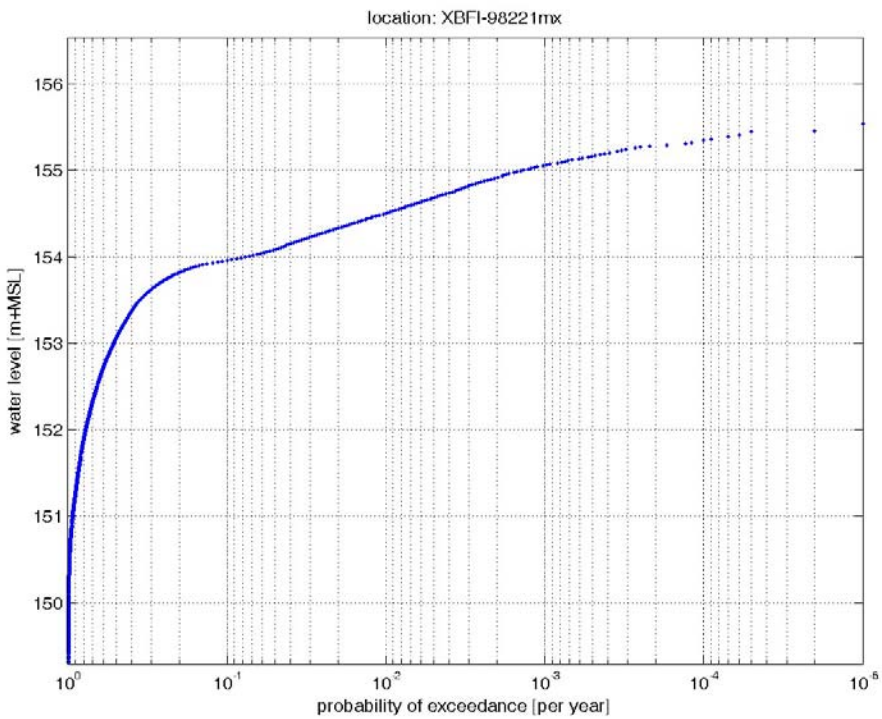

Figure 6.1 Derived flood frequency distribution of water levels at location XBFi-9822, near Mahaxai station; case with no embankments

The performance of the procedure in reproducing the observed water level distribution at Ban Se ban Fai/ Highway bridge mouth is shown in Figure 6.2. For return periods larger than 2 a proper reproduction is observed. Figure 6.3 shows a similar plot for the upstream discharge at Mahaxai. Again, the observed discharges and corresponding return periods are well reproduced by the model. It implies that the boundary conditions as generated by the Monte Carlo procedures are sound.

Comparisons with measurements at the river mouth are a bit more complex, since the Mekong river is morphologically very active. Observed water levels are therefore strongly influenced by the varying bottom level of the Mekong river. To make a fair comparison with between the derived flood hazard statistics and observed water levels, the “observed” water levels at the Se Bangfai river mouth were derived as follows:

- Derive annual maximum discharges at Mukdahan
- Derive annual maximum water levels at Mukdahan by applying the stage discharge relation of Figure 4.20

- Derive annual maximum water levels at That Phanom (Se Bangfai river mouth) by applying an h-h relation that is derived from the hydraulic model.

For the resulting annual maximum water levels at that Phanom, exceedance frequencies are derived and compared with the results of the flood hazard assessment (Figure 6.4). Again results are in accordance.

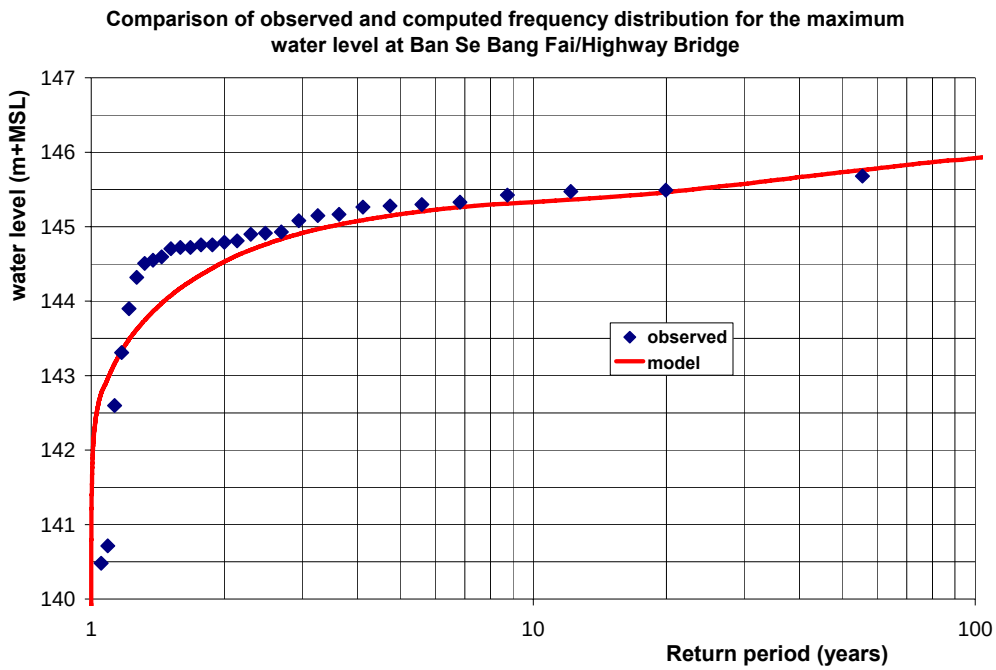

Figure 6.2 Comparison of observed and computed frequency distribution of the annual maximum water level at **Se Bangfai Highway Bridge**

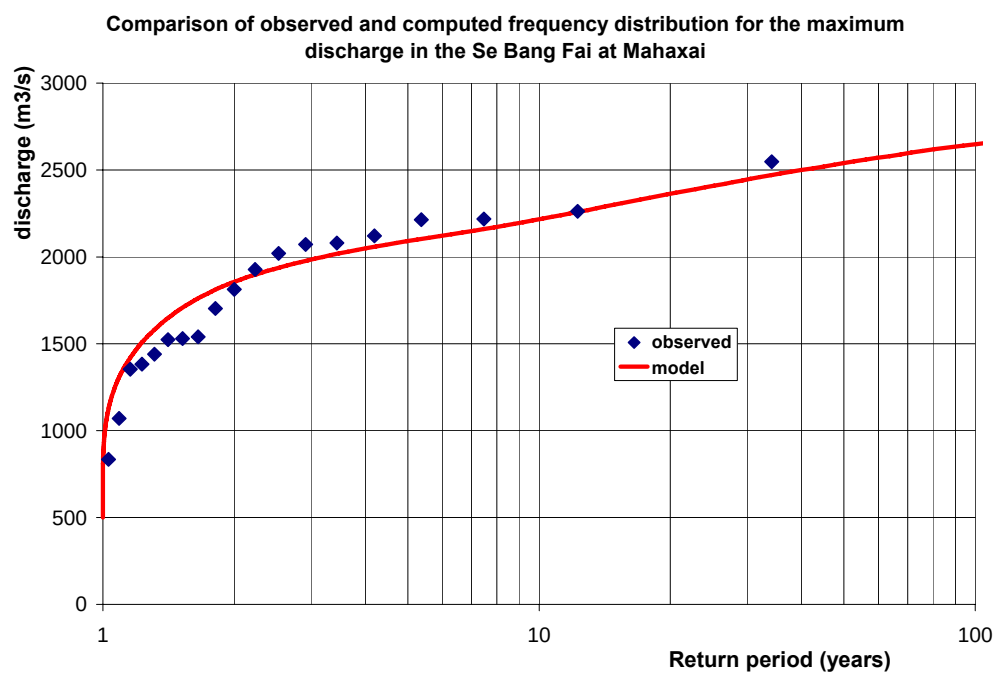

Figure 6.3 Comparison of observed and computed upstream discharge at **Mahaxai**.

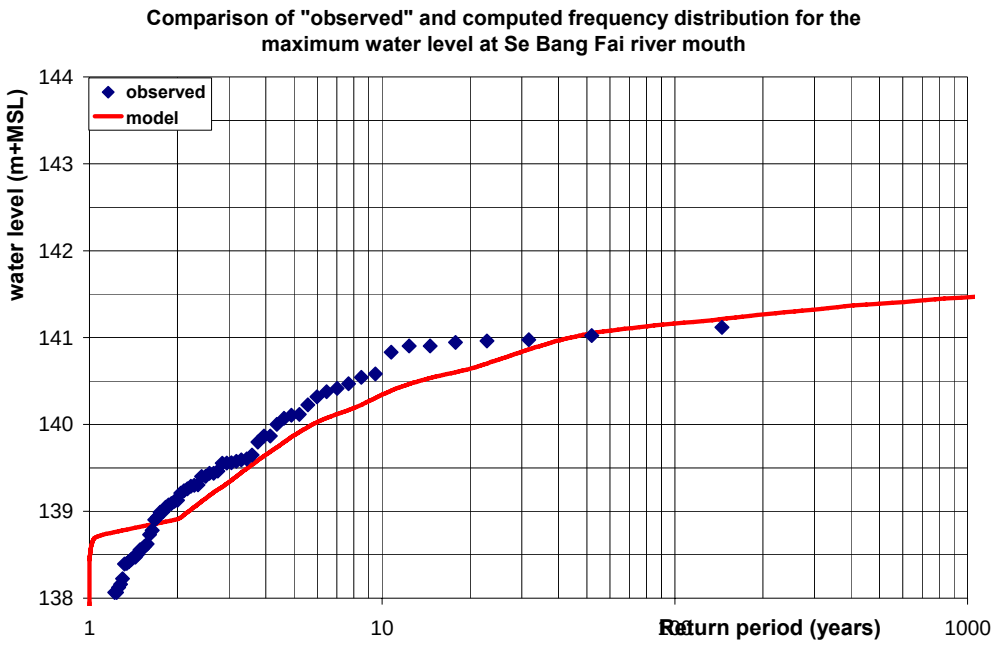

Figure 6.4 Comparison of observed and computed frequency distribution of the water level at the **river mouth**

Comparison of development cases

Based on the method described above, the 2, 10, 25 and 100-year water levels have been derived for all locations along the lower reach of the Se Bangfai River. Figure 6.5 shows the results for Case 1 (no embankments). The horizontal axis shows the distance along the river to the downstream boundary, i.e. the confluence with the Mekong river. The location on the far right is the upstream boundary of the model, and it is located approximately 3 km upstream of the Mahaxai gauge. The location to the far left is the confluence of the Se Bangfai with the Mekong at That Phanom. Figure 6.6 shows a similar figure for Case 3 (embankments on both sides).

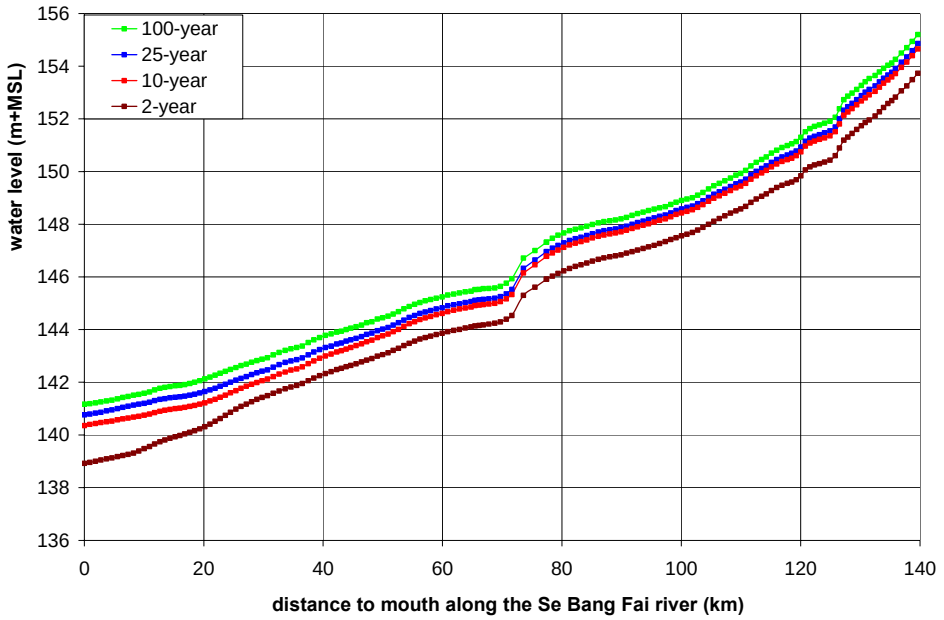

Figure 6.5 Computed 2, 10, 25 and 100-year flood level along the Se Bangfai river for the case with no embankments.

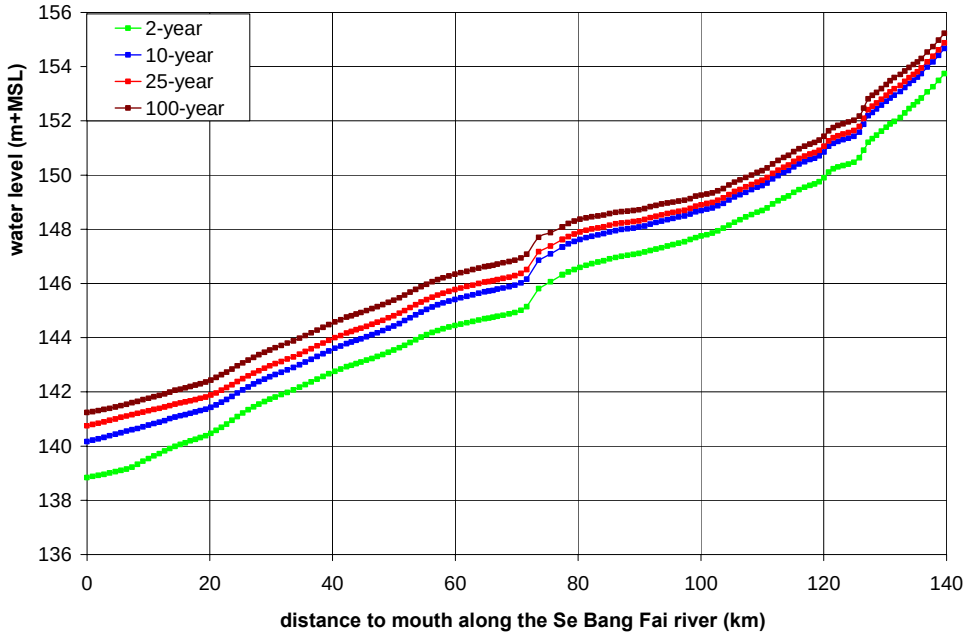

Figure 6.6 Computed 2, 10, 25 and 100-year flood level along the Se Bangfai river for the case with embankments on both sides of the river.

Figure 6.7 shows the results for the three simulated situations of the river. Figure 6.8 shows the mutual differences in 100-year water level between the three cases. From the figures it can be seen that differences are negligible at both the upstream and downstream model boundary. For the upstream boundary this is because it is outside the backwater reach of the location where the embankments begin (at Highway Bridge 13S). At the downstream end differences are small because the flow in the Mekong dominates the water levels and

therefore water levels are not influenced by the embankments along the Se Bangfai. Moving to the middle sections, differences are increasing, being at maximum around 70 kilometres from the river mouth. The embankments cause water to stay in the river and keep the flood plains dry. As a result, water levels in the river rise higher than in case of the situation with no embankments. For the 100-year water level the embankments cause a maximum rise in water level of 1.2 m.

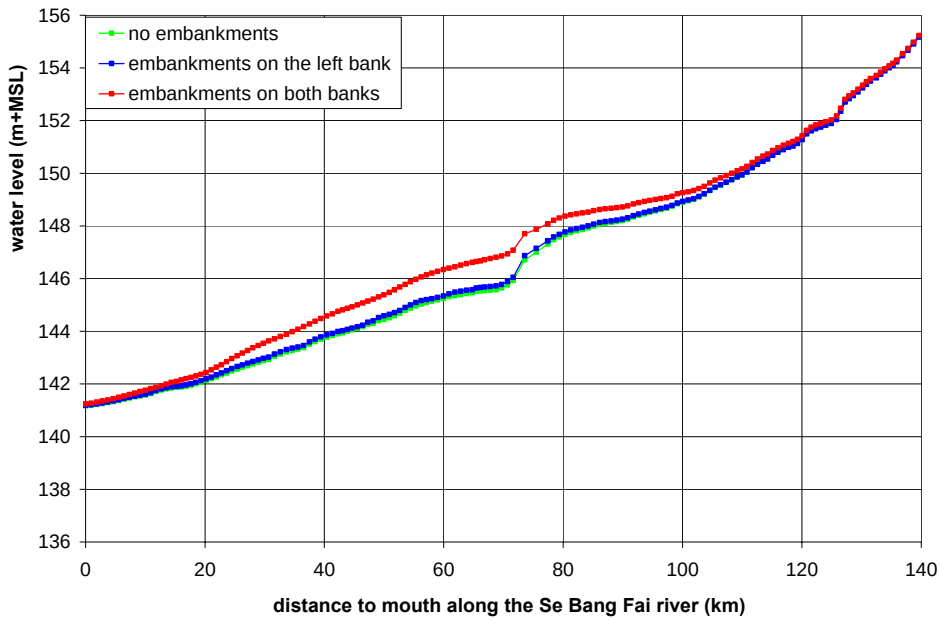

Figure 6.7 Computed **100-year** flood level along the Se Bangfai river for the cases with [a] no embankments [b] embankments along the left bank and [c] embankments along both banks.

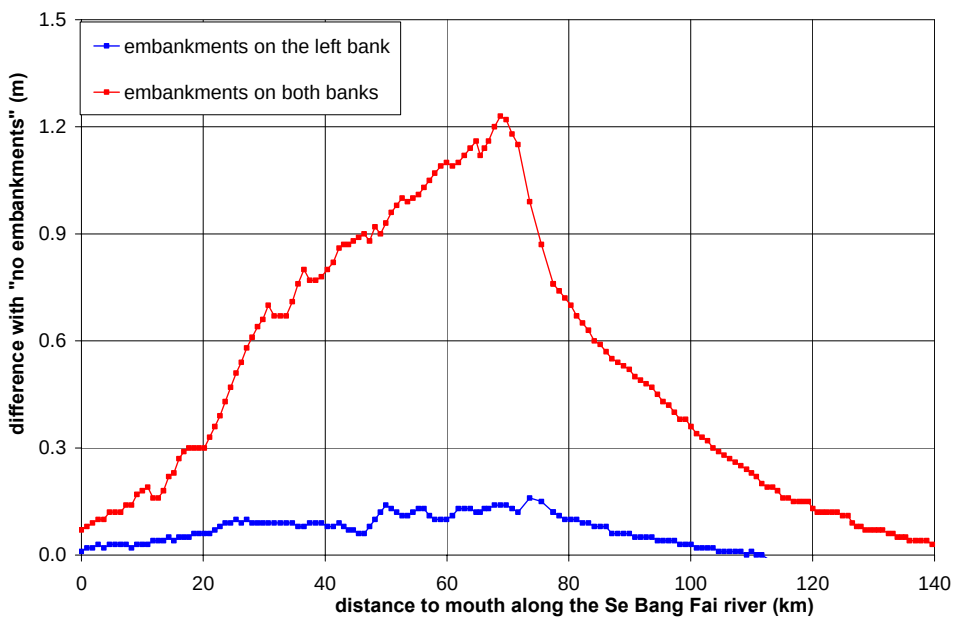

Figure 6.8 Differences in the computed **100-year** flood level along the Se Bangfai river for Cases 2 and 3 relative to case 1, the Base Case.

6.3.3 Water levels in the floodplains

Similar analyses as in the previous section have been executed for the floodplains adjacent to the Se Bangfai river. In the hydraulic model, nodes are defined to represent different floodplain areas. Each node is modelled as a reservoir. For each node the water levels with return periods 2, 10, 25 and 100 years have been derived, and this is repeated for each of the three cases. Figure 6.9 shows the rivers Se BangFai and Mekong in combination with all the floodplain nodes of the Hydraulic model. The nodes have been divided into four different groups:

- Green points: locations in the right floodplain, downstream of the measures
- Light blue points: locations in the left floodplain, downstream of the measures
- Black points: locations in the right floodplain, upstream of the measures
- Red points: locations in the left floodplain, upstream of the measures

The reason for this division is that the protection measures are mainly designed to protect the areas downstream (i.e. the green and blue location). Furthermore, the measure "left bank" is designed to protect the area on the left (blue locations).

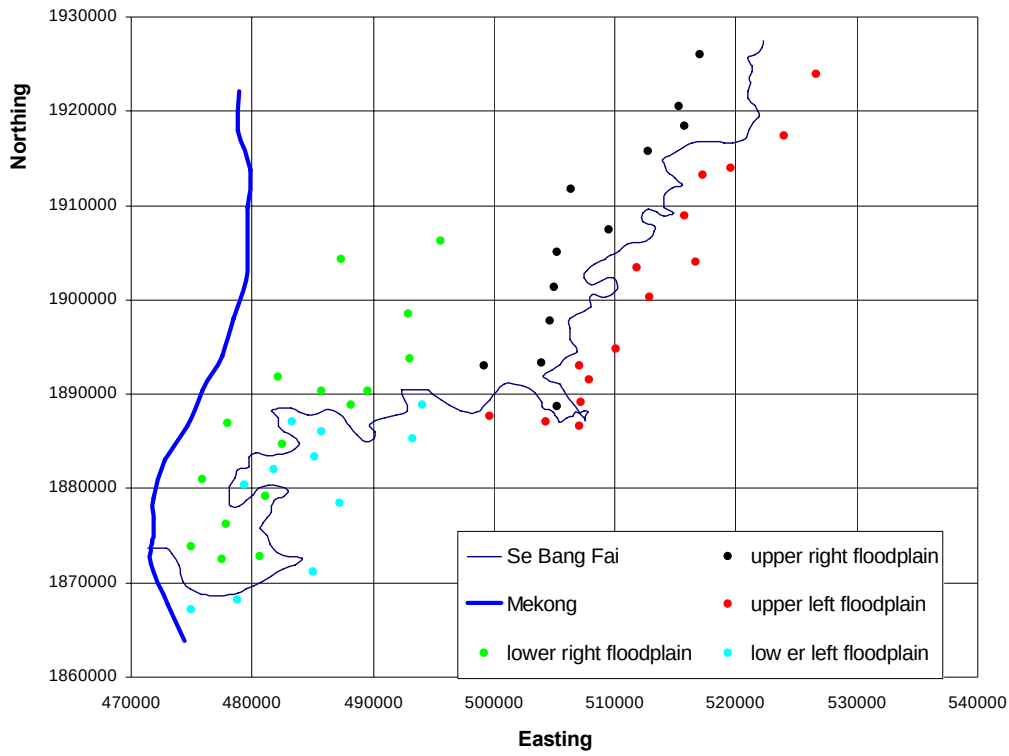

Figure 6.9 Rivers Se BangFai and Mekong and floodplain nodes of the Hydraulic model

Table 6.1 shows [a] the resulting water levels for the situation of no embankments [b] the change in water levels in comparison with situation [a] as result of embankments on the left side and [c] the change in water levels in comparison with situation [a] as result of embankments on both sides. The locations in this table are the ones downstream of the

measures (i.e. green and light blue locations of Figure 6.9). Table 6.2 shows similar numbers for the locations upstream of the measures (i.e. red and black locations of Figure 6.9).

The effects of embankments are clearly visible from the results; the embankment protect the downstream floodplains but back up the water further upstream. The situation with only embankments on the left is profitable for the floodplain locations on the left (light blue points) but disadvantageous for locations on the right (green locations).

It is noted that the values presented in the table have to be used with care in view of the uncertainties in the hydraulic model, particularly with respect to the interaction between river and flood-plain. The results are no more then indicative and should not be used for design.

Table 6.1 Water levels and changes in water levels with return periods of 2, 10, 25 and 100 years in the floodplains of the Se Bangfai river basin; locations **downstream** of embankments.

	no embankments				**change in water level as a result of embankments on the left bank**				**change in water level as a result of embankments on both banks**			
node	**2**	**10**	**25**	**100**	**2**	**10**	**25**	**100**	**2**	**10**	**25**	**100**
	Right bank (green locations of Figure 6.9**)**											
SP246nD	143.99	144.89	145.10	145.51	-0.21	0.03	0.07	0.13	-1.38	-2.28	-2.49	-2.90
SP202D	144.15	144.92	145.12	145.52	-0.05	0.05	0.08	0.13	-2.66	-3.43	-3.63	-4.03
SP226D	144.01	144.76	144.97	145.37	-0.04	0.05	0.07	0.12	-2.60	-3.35	-3.56	-3.96
SP227D	143.49	144.36	144.59	145.01	-0.05	0.05	0.07	0.12	-2.44	-3.31	-3.54	-3.96
SP245D	142.99	143.72	143.99	144.43	-0.06	0.05	0.07	0.13	-5.20	-5.93	-6.20	-6.64
SP245nD	141.34	141.73	142.30	143.32	0.01	0.10	0.19	0.34	-0.08	-0.47	-1.04	-2.06
SP248D	144.10	144.92	145.12	145.52	-0.05	0.05	0.08	0.13	-2.05	-2.87	-3.07	-3.47
SP261D	142.85	143.56	143.83	144.26	-0.07	0.03	0.05	0.09	-1.80	-2.51	-2.78	-3.21
SP266D	142.10	142.76	143.11	143.60	-0.11	0.02	0.04	0.09	-3.06	-3.72	-4.07	-4.56
SP284U	142.28	142.96	143.28	143.75	-0.12	0.01	0.04	0.09	-1.91	-2.59	-2.91	-3.38
SP295D	141.76	142.39	142.74	143.20	-0.11	0.01	0.03	0.09	-3.75	-4.37	-4.72	-5.18
SP307D	141.16	141.61	141.89	142.29	-0.09	0.01	0.02	0.06	-1.17	-1.62	-1.90	-2.30
SP312U	140.98	141.63	142.00	142.48	-0.08	0.00	0.04	0.08	-0.96	-1.61	-1.98	-2.46
SP343D	139.75	140.92	141.37	141.80	-0.11	-0.07	0.00	0.04	-2.76	-3.93	-4.38	-4.81
SP361D	139.35	140.68	141.13	141.50	-0.07	-0.13	-0.03	0.03	-1.34	-2.67	-3.12	-3.49
SP376D	139.17	140.48	140.93	141.30	-0.02	-0.22	-0.05	0.03	-0.11	-1.42	-1.87	-2.24
	Left bank (light blue locations of Figure 6.9**)**											
SP201D	144.15	144.92	145.12	145.52	-4.16	-4.93	-5.13	-5.53	-4.16	-4.93	-5.13	-5.53
SP219D	143.14	144.57	144.83	145.28	-2.50	-3.93	-4.19	-4.64	-2.50	-3.93	-4.19	-4.64
SP238D	141.22	143.58	144.00	144.66	-2.30	-4.66	-5.08	-5.74	-2.30	-4.66	-5.08	-5.74
SP258D	142.75	143.49	143.76	144.20	-2.70	-3.44	-3.71	-4.15	-2.70	-3.44	-3.71	-4.15
SP277D	136.06	137.66	139.27	141.61	-0.65	-2.25	-3.86	-6.20	-0.65	-2.25	-3.86	-6.20
SP285D	135.42	136.45	137.94	140.22	-0.01	-1.04	-2.53	-4.81	-0.01	-1.04	-2.53	-4.81
SP286D	139.87	140.93	141.56	142.14	-0.21	-1.27	-1.90	-2.48	-0.21	-1.27	-1.90	-2.48
SP300D	137.67	138.02	138.84	140.56	0.00	-0.35	-1.17	-2.89	0.00	-0.35	-1.17	-2.89
SP344D	139.56	140.80	141.38	141.84	-0.07	-1.31	-1.89	-2.35	-0.07	-1.31	-1.89	-2.35
SP362D	138.91	140.34	141.07	141.49	-0.03	-1.46	-2.19	-2.61	-0.03	-1.46	-2.19	-2.61
SP375D	133.80	135.50	137.85	139.90	-0.01	-1.71	-4.06	-6.11	-0.01	-1.71	-4.06	-6.11

Table 6.2 Water levels and changes in water levels with return periods of 2, 10, 25 and 100 years in the floodplains of the Se Bangfai river basin; locations **upstream** of embankments.

	no embankments				**change in water level as a result of embankments on the left bank**				**change in water level as a result of embankments on both banks**			
node	**2**	**10**	**25**	**100**	**2**	**10**	**25**	**100**	**2**	**10**	**25**	**100**
	Right bank (black locations of Figure 6.9**)**											
SP109D	147.28	148.15	148.30	148.61	-0.85	-0.03	-0.02	0.05	-0.42	0.29	0.36	0.42
SP131D	146.70	147.59	147.75	148.08	-0.57	-0.02	0.00	0.07	-0.12	0.38	0.47	0.55
SP143D	146.35	147.21	147.39	147.77	-1.07	0.00	0.02	0.10	-0.54	0.49	0.59	0.67
SP188nD	140.01	140.02	140.18	141.25	0.00	0.01	0.25	0.97	0.01	0.95	2.42	4.35
SP41D	141.66	148.67	149.85	151.56	-0.85	-0.91	-0.73	-0.77	0.25	0.28	0.24	0.12
SP434D	143.48	146.09	146.26	146.59	2.35	0.10	0.10	0.16	2.73	0.74	0.86	1.04
SP50D	139.34	145.02	146.51	149.57	-0.81	-1.17	-1.07	-0.59	0.42	0.77	0.82	0.60
SP67D	138.86	143.69	144.82	147.35	-0.94	-0.84	-0.69	-0.32	0.38	0.77	0.93	0.95
SP7D	147.36	151.82	152.57	153.67	-0.37	-0.56	-0.45	-0.46	0.01	0.01	0.03	0.02
SP83D	148.05	149.02	149.17	149.50	-0.81	-0.06	-0.04	0.01	-0.46	0.20	0.25	0.27
SP98D	147.53	148.40	148.55	148.87	-0.14	-0.03	-0.02	0.03	0.17	0.26	0.32	0.36
SP29D	116.20	125.60	128.21	134.56	-1.03	-1.66	-1.52	-0.79	0.24	0.48	0.70	0.85
	Left bank (red locations of Figure 6.9**)**											
SP97D	147.71	148.49	148.64	148.95	-1.20	-0.04	-0.03	0.03	-0.75	0.25	0.30	0.35
SP115D	146.70	148.05	148.20	148.53	-0.93	-0.06	-0.02	0.05	-0.45	0.31	0.38	0.44
SP132D	146.75	147.57	147.72	148.06	-1.16	-0.02	0.01	0.07	-0.70	0.38	0.48	0.56
SP146D	146.45	147.23	147.39	147.76	-1.13	-0.01	0.03	0.10	-0.62	0.46	0.58	0.66
SP162D	138.48	138.49	138.74	139.73	0.00	0.04	0.19	0.44	0.01	0.84	1.68	2.96
SP191D	145.26	145.96	146.13	146.50	-1.38	0.29	0.32	0.38	-0.70	0.89	1.03	1.16
SP30D	151.01	152.26	152.46	152.85	-0.13	-0.10	-0.07	-0.03	0.03	0.05	0.07	0.08
SP40D	143.56	148.96	150.02	151.51	-0.60	-0.79	-0.74	-0.63	0.21	0.27	0.23	0.17
SP416nD	141.65	145.04	145.88	147.13	0.99	0.32	0.17	0.01	2.02	1.75	1.47	0.93
SP424D	139.91	139.92	140.06	140.79	0.00	0.02	0.15	0.50	0.01	0.60	1.55	3.52
SP425D	145.63	146.98	147.23	147.70	-0.29	-0.03	0.00	0.08	0.48	0.64	0.66	0.67
SP51D	145.07	149.70	150.47	151.00	-0.70	-0.27	-0.13	-0.08	0.31	0.24	0.14	0.14
SP68D	143.73	148.56	149.39	150.23	-0.52	-0.30	-0.28	-0.25	0.40	0.35	0.37	0.20
SP84D	148.04	149.01	149.16	149.48	-0.57	-0.06	-0.04	0.01	-0.26	0.19	0.24	0.27
SP8D	147.50	151.95	152.66	153.46	-0.38	-0.29	-0.28	-0.24	0.03	0.04	0.03	0.06

6.4 Flood hazard determination

In order to be able to estimate damages from Table 6.1, water depths have been derived from the water levels. This means ground levels of the floodplains are required. These ground levels need to be very precise, since a few extra decimetres water depth can cause severe damage to the crops. Use is made of the DEM available for the Se Bangfai area.

Flood extend and depth as derived from the difference of the computed water levels and the ground elevation from the DEM are shown in Figure 6.10 to Figure 6.13 for the Base Case for return periods T = 2, 10, 25 and 100 year. Such information is basic input for damage calculations. Further refinements can be made relative to the cropping calendar, as the full

hydrographs for each location for each simulated year is available from the database. Similar pictures can be made for the cases with embankments along one or both sides. The effectiveness of the measures can directly be assessed from maps showing the differences between the maximum levels, water depths etc. or damages between the different cases. Reference is made to Annex 3 for application of the results for flood damage assessment.

Comparison of the flood maps with the observed flooding in the year 2000 (see Figure 6.14) learns that qualitatively the flooding extent in the downstream part is well reproduced by the model.

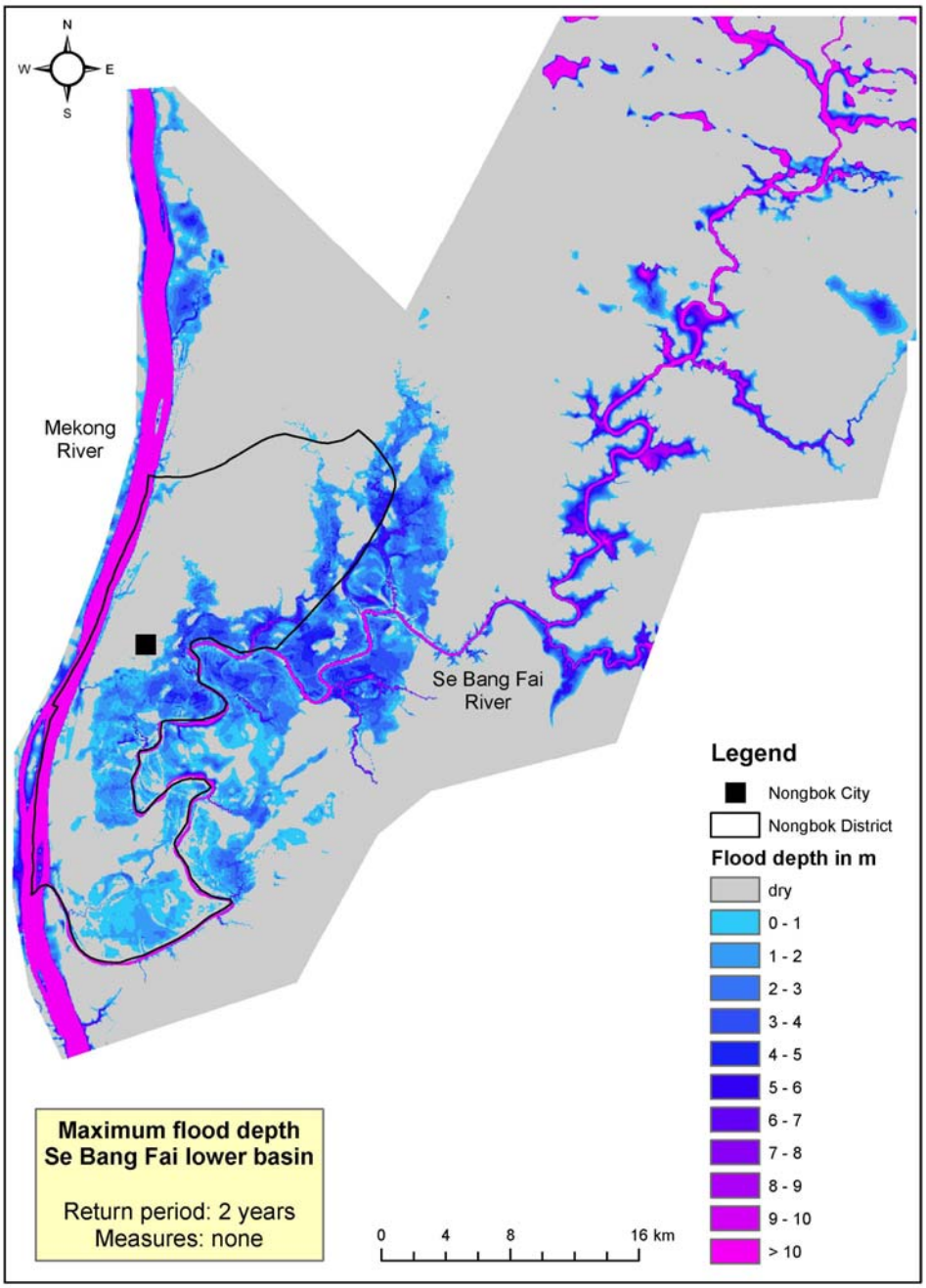

Figure 6.10 Flood depth and extent map Lower Se Bangfai, T= 2 years

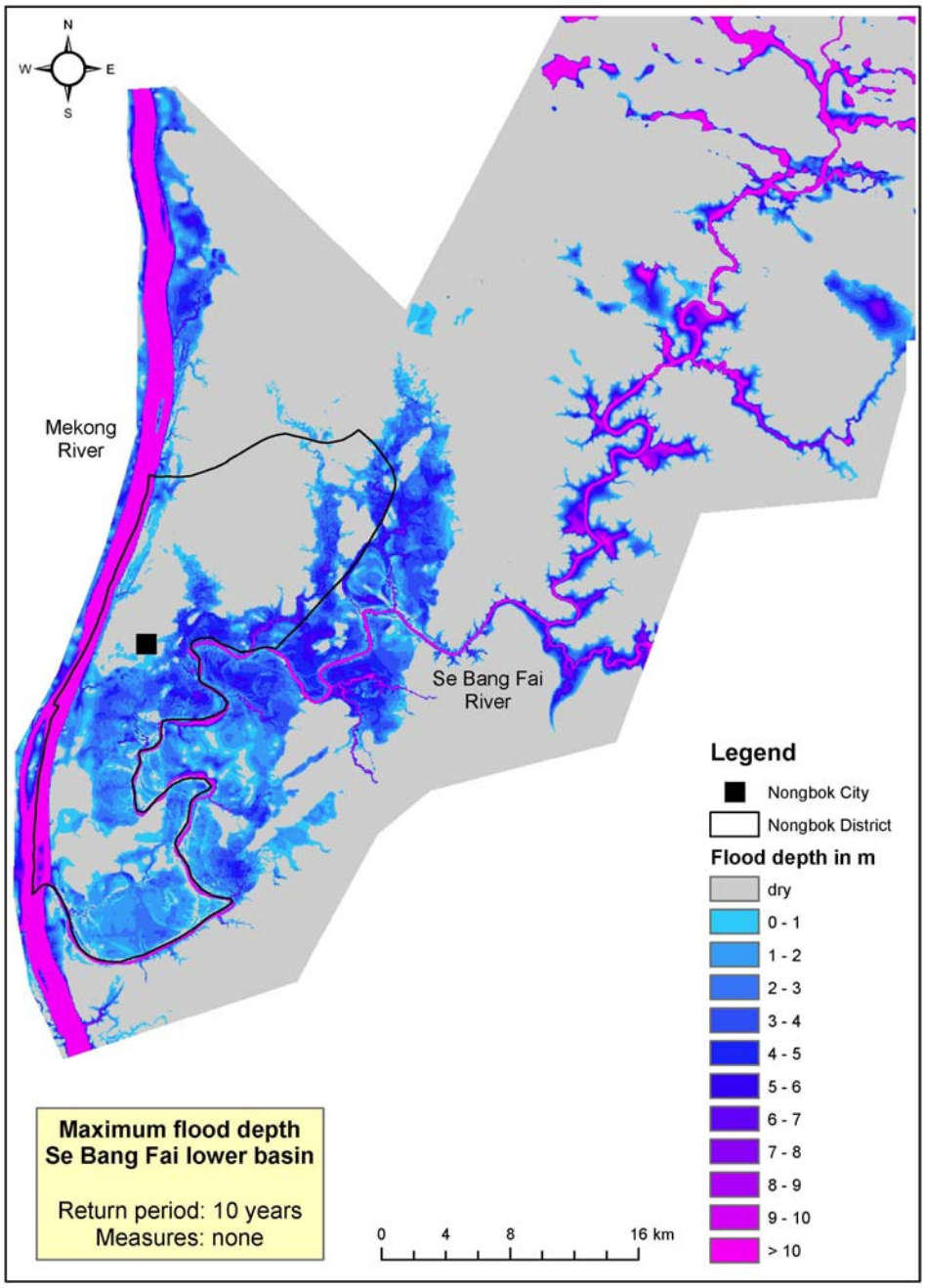

Figure 6.11 Flood depth and extent map Lower Se Bangfai, T= 10 years

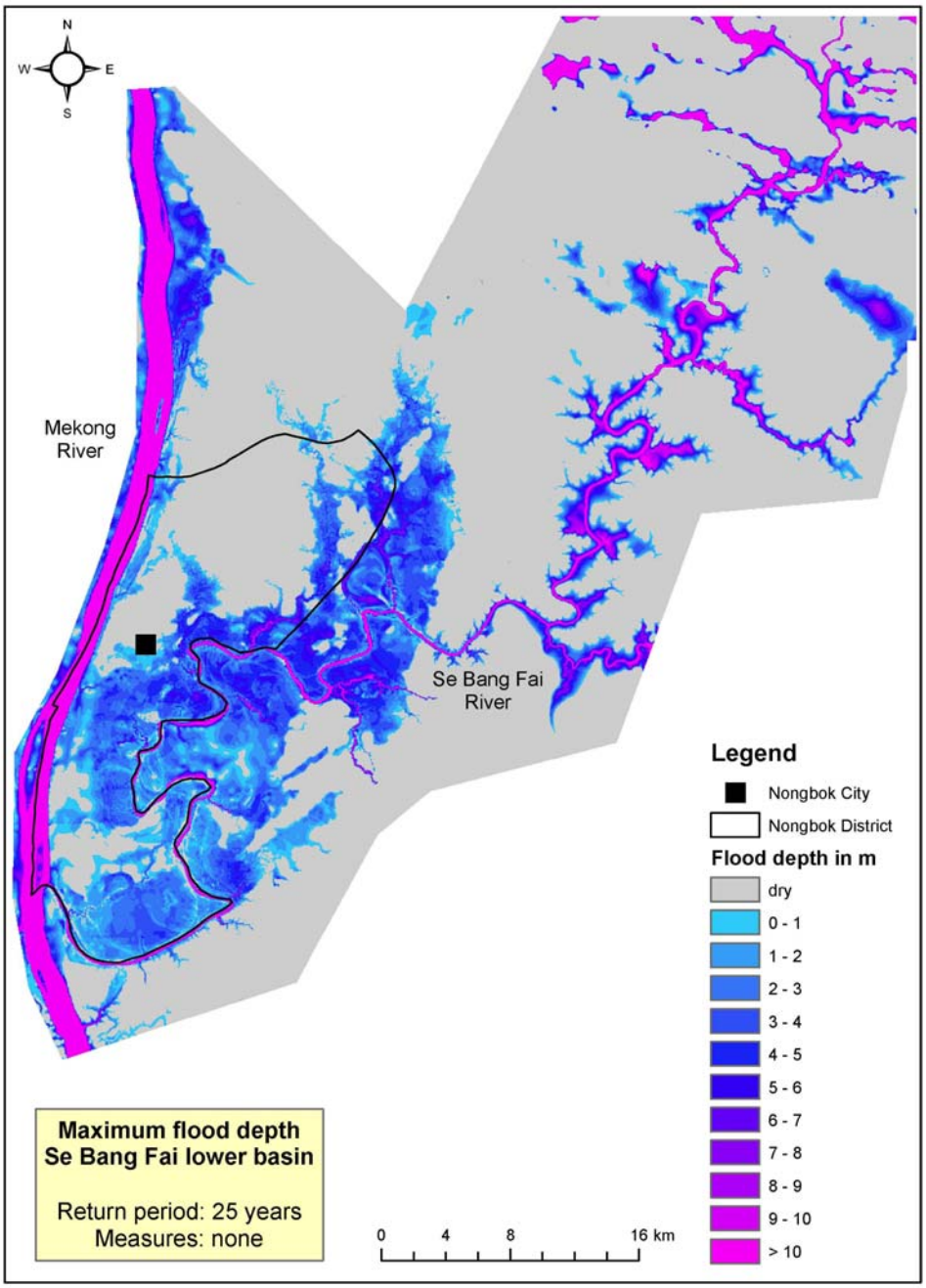

Figure 6.12 Flood depth and extent map Lower Se Bangfai, T= 25 years

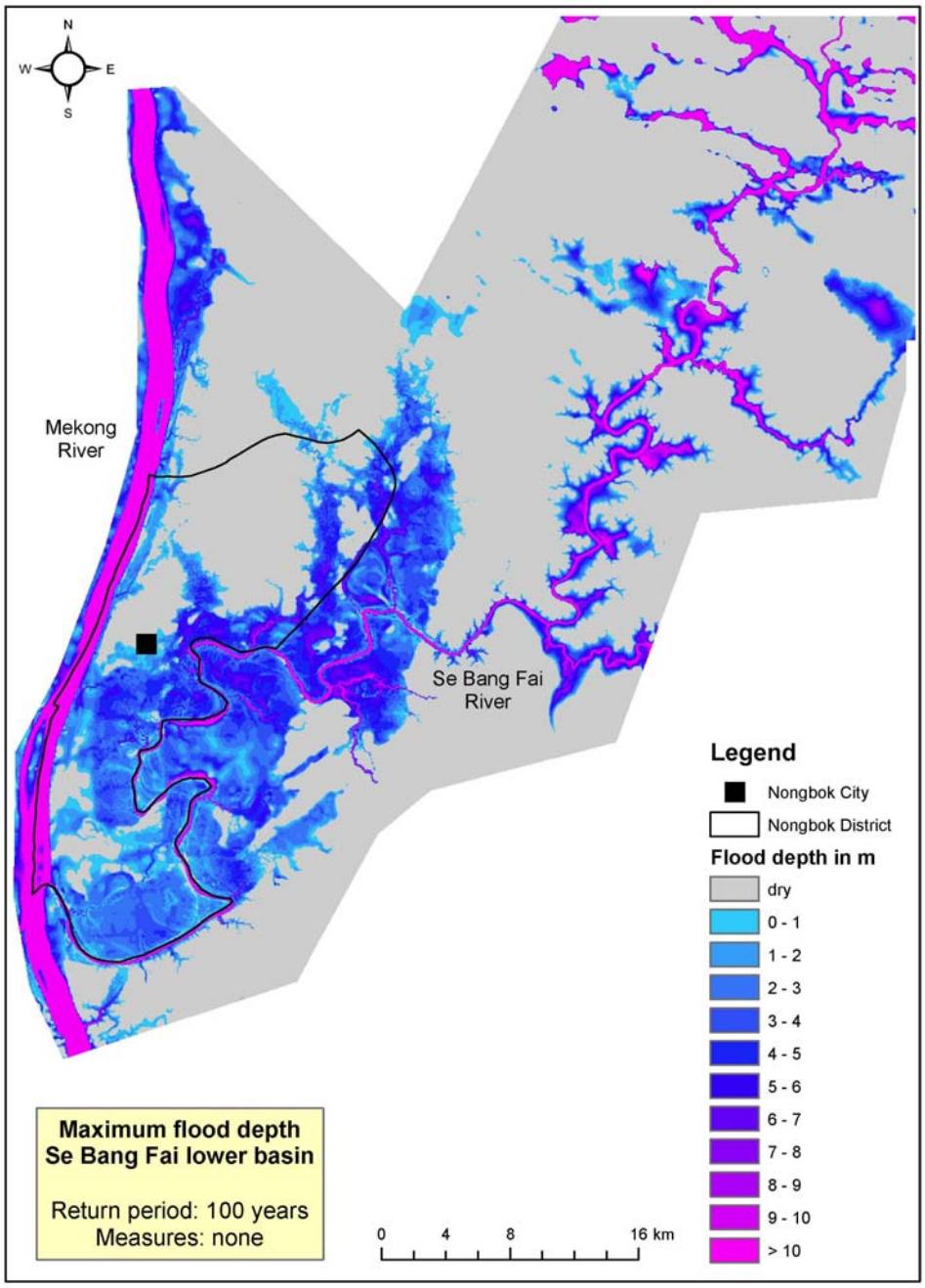

Figure 6.13 Flood depth and extent map Lower Se Bangfai, T= 100 years

Satelite Photo of Flood Extents on Sept 17, 2000 in Xe BangFai

Figure 6.14 Extent of flooding along lower Se Banfai and Mekong in year 2000

6.5 Bypass canal

6.5.1 Introduction

As Option 2 for flood risk reduction a bypass canal from the Se Bangfai (see Figure 3.10) has been presented. First, its effect have been assessed for the flood seasons of the years 1995 to 2000 (section 6.5.2). Subsequently a probabilistic analysis was executed (section 6.5.3) for the diversion canal, similar to the analysis in the previous sections.

A 200 m wide bypass, with bed-elevation at 138 masl and side slopes of 1:2 has been assumed, with a hydraulic roughness of n = 0.025. For this the hydraulic model was extended with the Mekong reach Thakek-That Phanom, see also Chapter 4.

6.5.2 Simulations for the years 1995 until 2000

The results of the simulations are presented in the following Figure 6.15 to Figure 6.27. From these figures it is observed that the canal diverts at maximum discharges up to 500 to 1,000 m^3/s, dependent on the absolute level in the Se Bangfai and the level difference between the level at the off-take and the intake into the Mekong. The effect on the maximum water level in the river at the off-take varies generally from 0.5 to 1.0 m gradually reducing away from the off-take. It implies that a bypass canal will not eliminate the need for improvement of the embankment but rather reduce the required crest level.

The effect of the bypass on the maximum level in the flood plain is of the same order of magnitude as along the river, but as shown in Figure 6.27, its effect on the reduction of the flood duration is also to be taken into account and may be considerable.

For the dry year 1998 the bypass did not function as the level at the off-take hardly exceeded 138 masl.

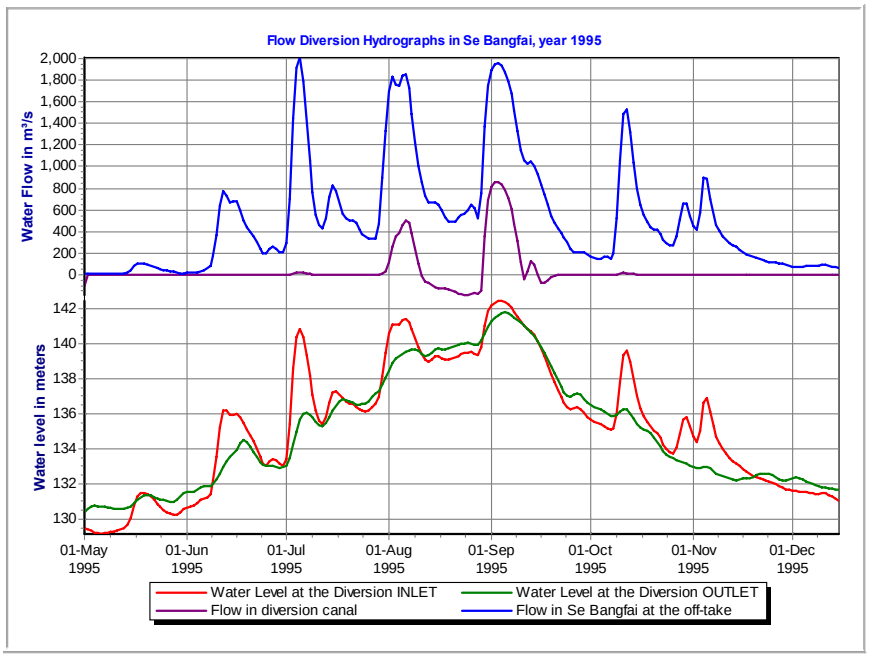

Figure 6.15 Water levels in Se Bangfai and Mekong and discharge in canal and river (20 km d/s offtake) , Year 1995

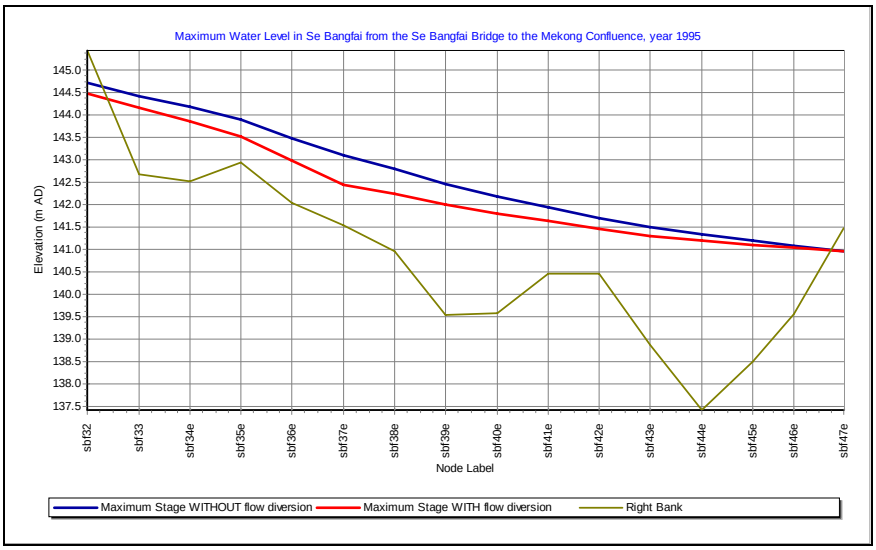

Figure 6.16 Maximum water level along Lower Se Banfai from Highway Bridge to mouth with and without bypass canal, Year 1995

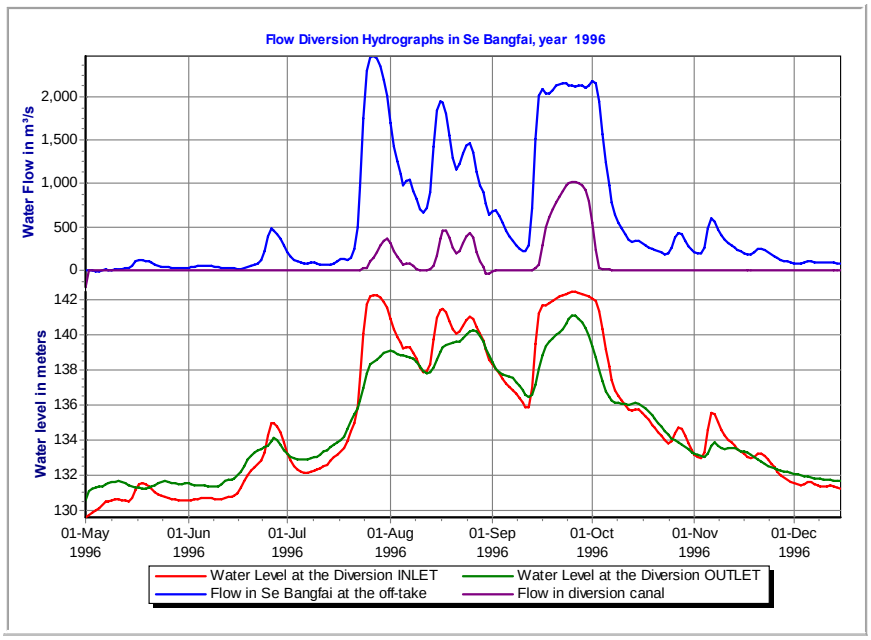

Figure 6.17 Water levels in Se Bangfai and Mekong and discharge in canal and river (20 km d/s offtake) , Year 1996

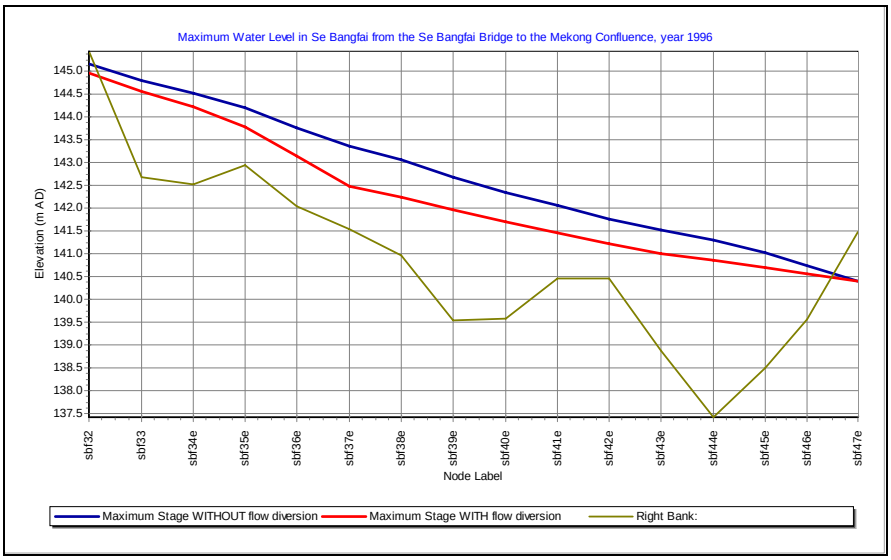

Figure 6.18 Maximum water level along Lower Se Banfai from Highway Bridge to mouth with and without bypass canal, Year 1996

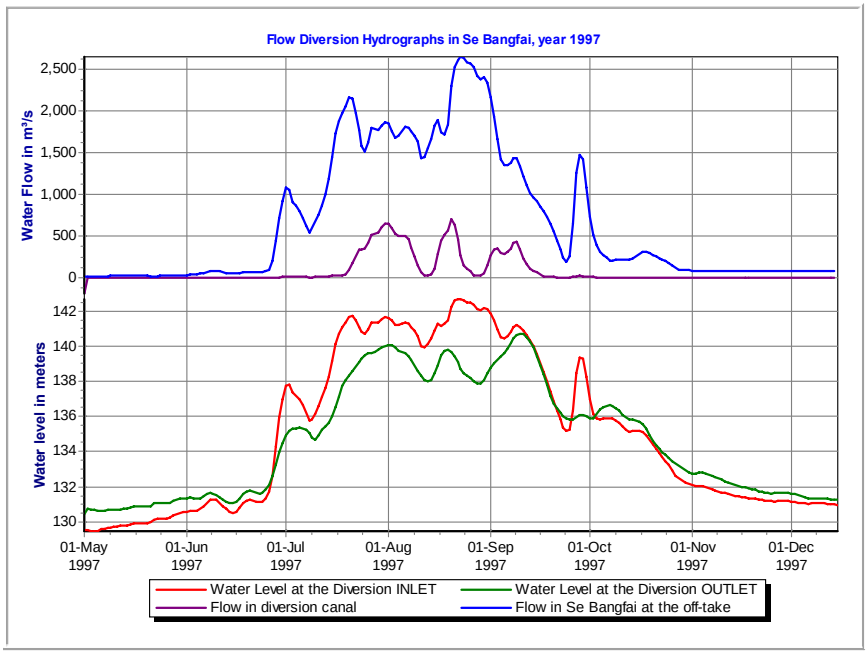

Figure 6.19 Water levels in Se Bangfai and Mekong and discharge in canal and river (20 km d/s offtake) , Year 1997

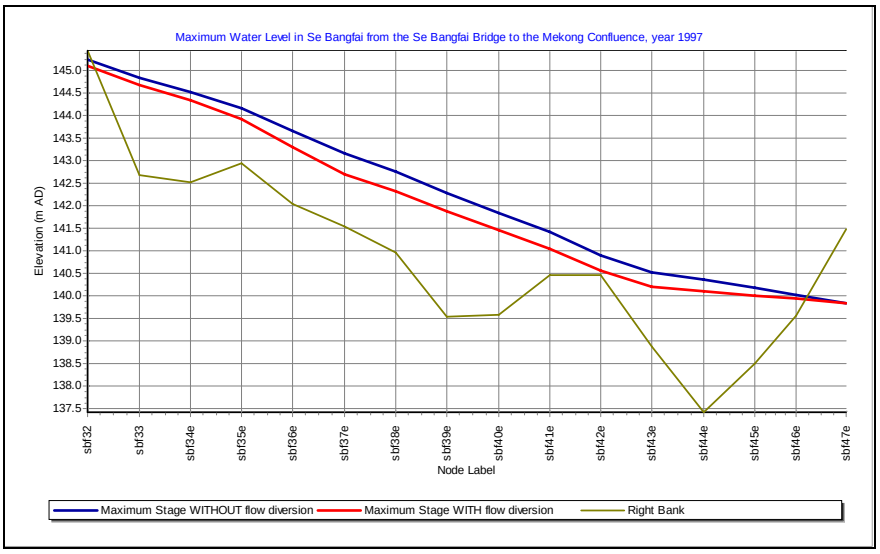

Figure 6.20 Maximum water level along Lower Se Banfai from Highway Bridge to mouth with and without bypass canal, Year 1997

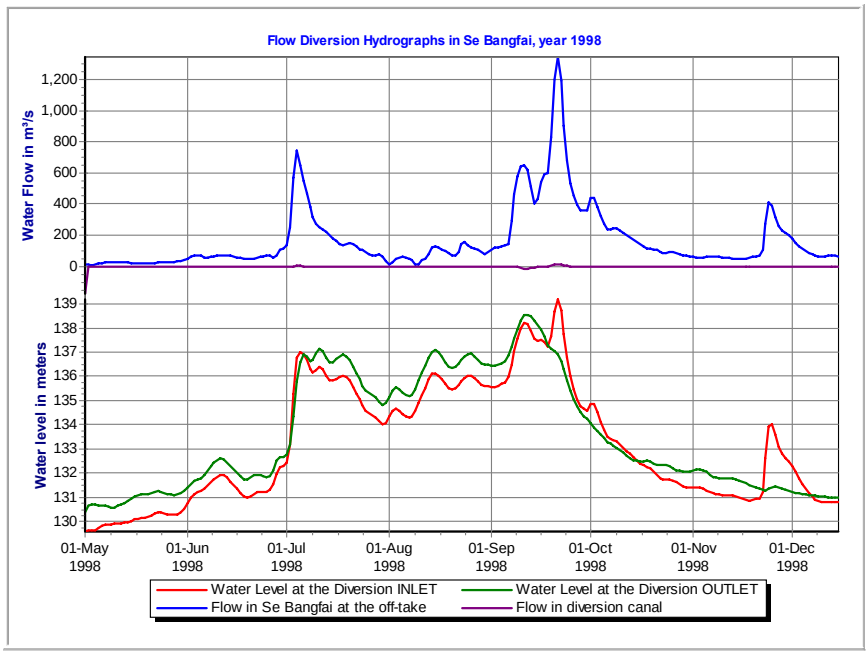

Figure 6.21 Water levels in Se Bangfai and Mekong and discharge in canal and river (20 km d/s offtake) , Year 1998

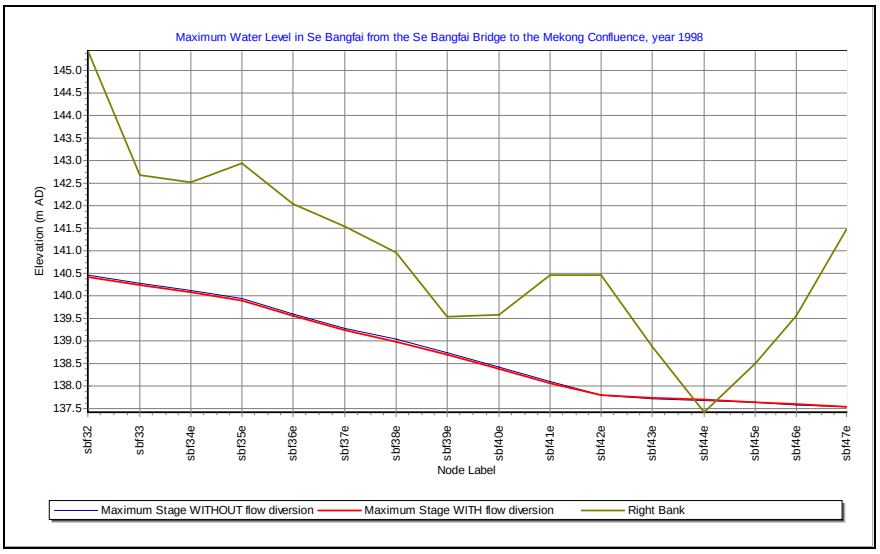

Figure 6.22 Maximum water level along Lower Se Banfai from Highway Bridge to mouth with and without bypass canal, Year 1998

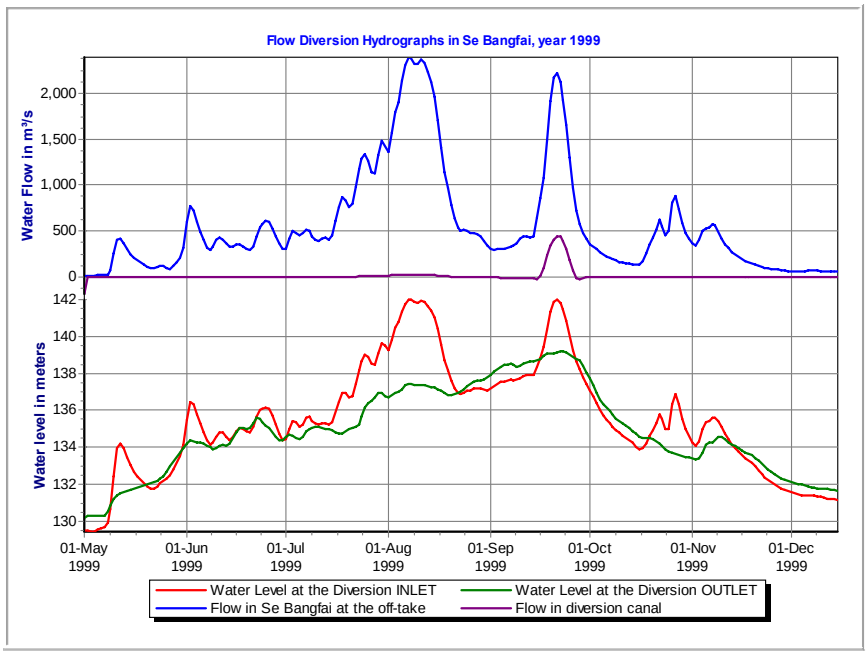

Figure 6.23 Water levels in Se Bangfai and Mekong and discharge in canal and river (20 km d/s offtake) , Year 1999

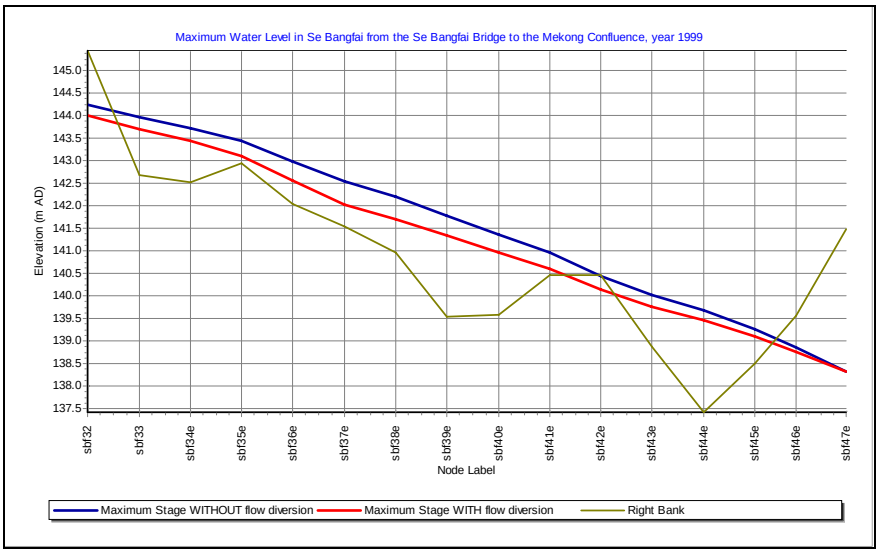

Figure 6.24 Maximum water level along Lower Se Banfai from Highway Bridge to mouth with and without bypass canal, Year 1999

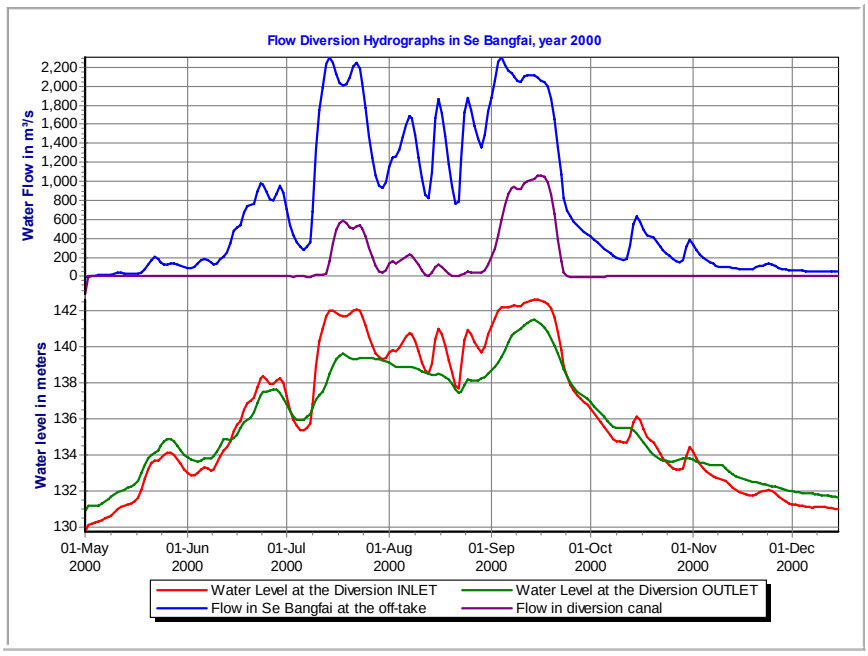

Figure 6.25 Water levels in Se Bangfai and Mekong and discharge in canal and river (20 km d/s offtake) , Year 2000

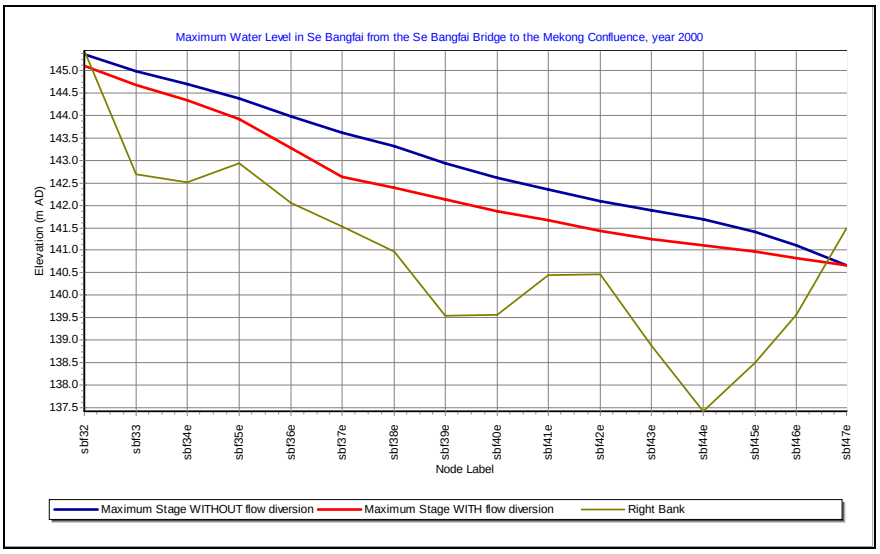

Figure 6.26 Maximum water level along Lower Se Banfai from Highway Bridge to mouth with and without bypass canal, Year 2000

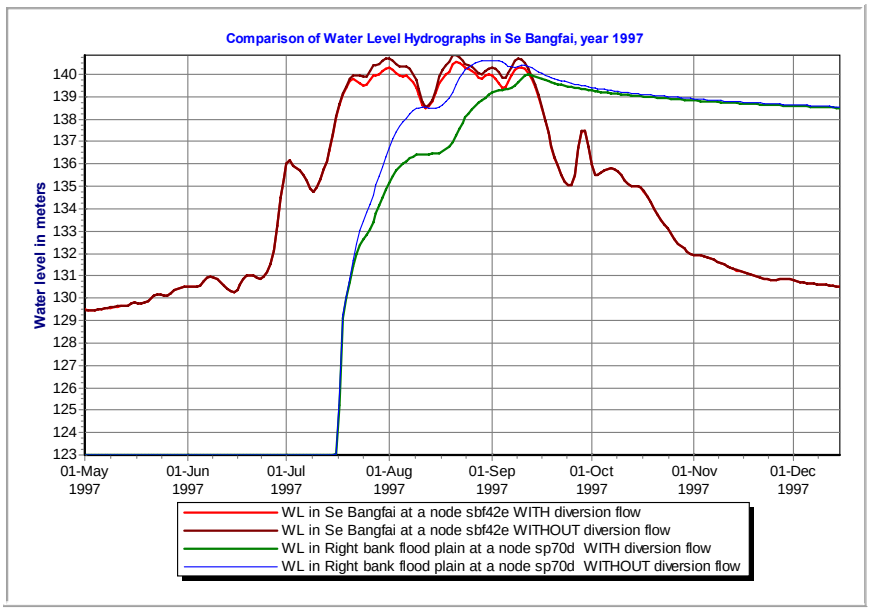

Figure 6.27 Water level in right bank flood plain of Se Bangfai with and without bypass canal, Year 1996

6.5.3 Probabilistic analysis for the diversion channel

Based on the method described in section 6.3.2, the 2, 10, 25 and 100-year water levels have been derived for all locations along the lower reach of the Se Bangfai River, assuming the existence of the diversion canal. shows the results for Case 1 (no embankments). Figure 6.28 compares the resulting 100-year water level with the reference situation in which no diversion canal is present (N.B. this is the same reference situation as before, i.e. the case previously described as “no embankments”). Figure 6.29 shows the difference between the two cases. The diversion canal has a maximum reducing effect of almost 2 m on the 100-year water level in the river, approximately 50 km from the river mouth. Similar to section

6.3.2 the reducing reduces to approximately 0 at the upstream and downstream boundaries. For the 100-year water level a maximum reduction (near the off-take) of 1.83 m is observed

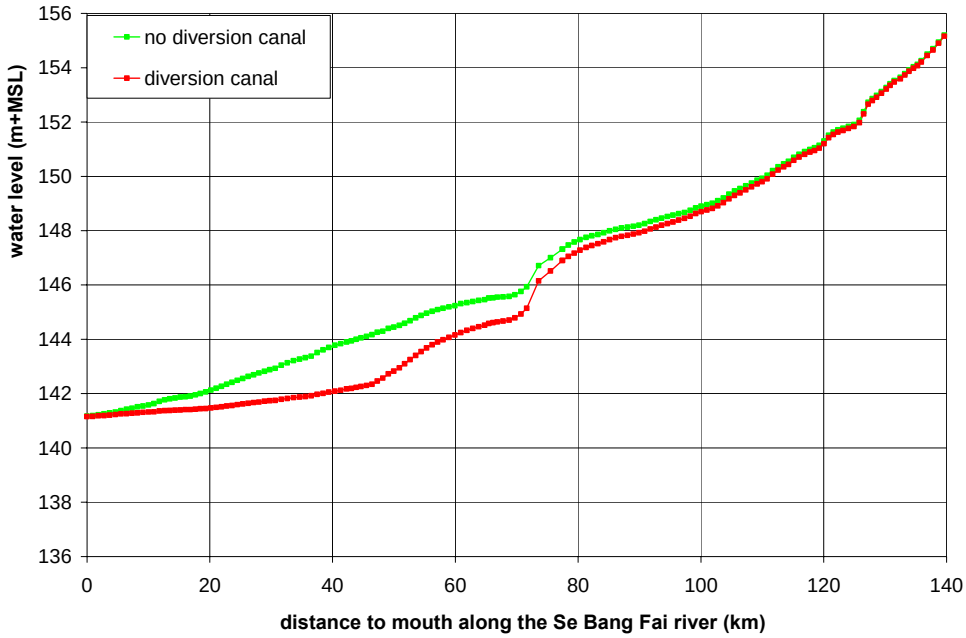

Figure 6.28 Computed **100-year** flood level along the Se Bangfai river for the cases with [a] no diversion canal and [b] diversion canal.

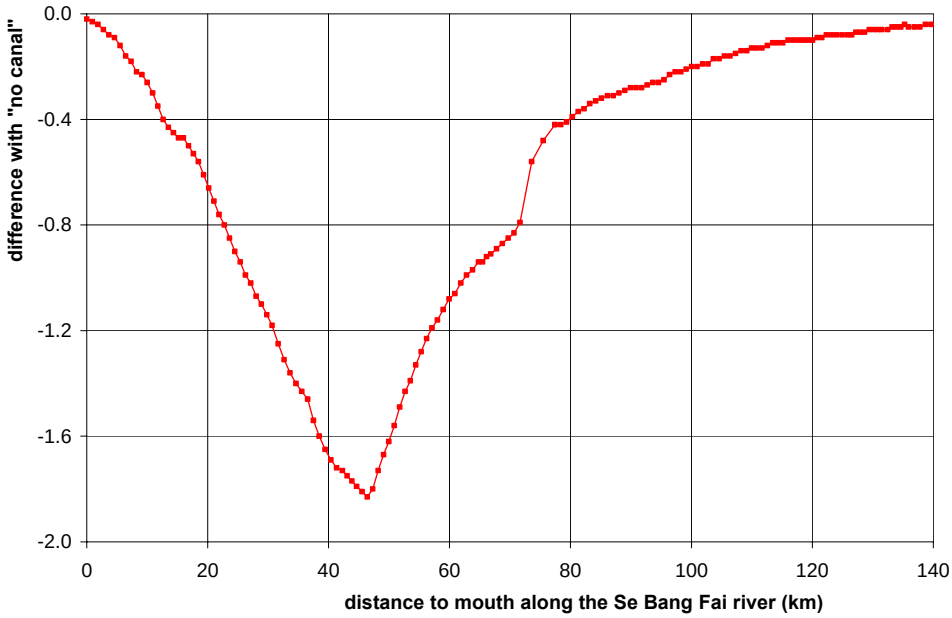

Figure 6.29 Differences in the computed **100-year** flood level along the Se Bangfai river for the case of "diversion canal" relative to the Base Case in which no diversion canal is present.

Table 6.3 and Table 6.4 show the effect of the diversion canals on water levels in the floodplain areas. It can be seen that, in contrast with the embankments, the bypass canal has a reducing effect on water levels for all floodplain locations.

Table 6.3 Water levels and changes in water levels with return periods of 2, 10, 25 and 100 years in the floodplains of the Se Bangfai river basin; locations **downstream** of diversion canal.

	water levels with no diversion canal				**change in water level as a result of the bypass canal**			
node	**2**	**10**	**25**	**100**	**2**	**10**	**25**	**100**
	right Bank (green locations of Figure 6.9**)**							
SP246nD	143.99	144.89	145.10	145.51	-1.14	-1.41	-1.15	-1.01
SP202D	144.15	144.92	145.12	145.52	-0.75	-0.84	-0.85	-0.92
SP226D	144.01	144.76	144.97	145.37	-0.79	-0.88	-0.90	-0.98
SP227D	143.49	144.36	144.59	145.01	-0.97	-1.14	-1.14	-1.23
SP245D	142.99	143.72	143.99	144.43	-1.48	-1.62	-1.61	-1.70
SP245nD	141.34	141.73	142.30	143.32	-0.08	-0.46	-1.03	-1.82
SP248D	144.10	144.92	145.12	145.52	-0.69	-0.84	-0.85	-0.92
SP261D	142.85	143.56	143.83	144.26	-1.36	-1.55	-1.56	-1.67
SP266D	142.10	142.76	143.11	143.60	-1.44	-1.47	-1.47	-1.62
SP284U	142.28	142.96	143.28	143.75	-1.51	-1.58	-1.55	-1.69
SP295D	141.76	142.39	142.74	143.20	-1.31	-1.30	-1.25	-1.36
SP307D	141.16	141.61	141.89	142.29	-0.92	-0.81	-0.73	-0.78
SP312U	140.98	141.63	142.00	142.48	-0.87	-0.88	-0.78	-0.90
SP343D	139.75	140.92	141.37	141.80	-0.58	-0.54	-0.40	-0.42
SP361D	139.35	140.68	141.13	141.50	-0.24	-0.39	-0.25	-0.21
SP376D	139.17	140.48	140.93	141.30	-0.04	-0.31	-0.13	-0.08
	left Bank (light blue locations of Figure 6.9**)**							
SP201D	144.15	144.92	145.12	145.52	-0.75	-0.85	-0.86	-0.93
SP219D	143.14	144.57	144.83	145.28	-1.82	-2.10	-1.65	-1.20
SP238D	141.22	143.58	144.00	144.66	-2.26	-4.09	-3.97	-3.44
SP258D	142.75	143.49	143.76	144.20	-1.80	-1.82	-1.75	-1.83
SP277D	136.06	137.66	139.27	141.61	-0.65	-2.25	-3.85	-6.19
SP285D	135.42	136.45	137.94	140.22	-0.01	-1.04	-2.53	-4.81
SP286D	139.87	140.93	141.56	142.14	-0.20	-0.93	-0.94	-0.86
SP300D	137.67	138.02	138.84	140.56	0.00	-0.35	-1.17	-2.89
SP344D	139.56	140.80	141.38	141.84	-0.06	-0.66	-0.49	-0.46
SP362D	138.91	140.34	141.07	141.49	-0.02	-0.44	-0.21	-0.20
SP375D	133.80	135.50	137.85	139.90	0.00	-0.43	-0.58	-0.15

Table 6.4 Water levels and changes in water levels with return periods of 2, 10, 25 and 100 years in the floodplains of the Se Bangfai river basin; locations **upstream** of diversion canal.

	water levels with no diversion canal				**change in water level as a result of the bypass canal**			
node	**2**	**10**	**25**	**100**	**2**	**10**	**25**	**100**
	Right bank (black locations of Figure 6.9**)**							
SP109D	147.28	148.15	148.30	148.61	-0.18	-0.19	-0.20	-0.22
SP131D	146.70	147.59	147.75	148.08	-0.27	-0.26	-0.27	-0.30
SP143D	146.35	147.21	147.39	147.77	-0.27	-0.34	-0.35	-0.38
SP188nD	140.01	140.02	140.18	141.25	0.00	0.00	-0.16	-1.04
SP41D	141.66	148.67	149.85	151.56	-0.51	-0.55	-0.40	-0.33
SP434D	143.48	146.09	146.26	146.59	-1.50	-0.77	-0.54	-0.52
SP50D	139.34	145.02	146.51	149.57	-0.58	-0.97	-0.92	-0.68
SP67D	138.86	143.69	144.82	147.35	-0.67	-0.86	-0.88	-0.88
SP7D	147.36	151.82	152.57	153.67	-0.14	-0.22	-0.17	-0.13
SP83D	148.05	149.02	149.17	149.50	-0.17	-0.14	-0.14	-0.16
SP98D	147.53	148.40	148.55	148.87	-0.21	-0.18	-0.18	-0.21
SP29D	116.20	125.60	128.21	134.56	-0.58	-0.90	-0.91	-0.95
	Left bank (red locations of Figure 6.9**)**							
SP97D	147.71	148.49	148.64	148.95	-0.15	-0.17	-0.17	-0.19
SP115D	146.70	148.05	148.20	148.53	-0.17	-0.22	-0.21	-0.24
SP132D	146.75	147.57	147.72	148.06	-0.22	-0.27	-0.27	-0.31
SP146D	146.45	147.23	147.39	147.76	-0.25	-0.32	-0.32	-0.36
SP162D	138.48	138.49	138.74	139.73	0.00	0.00	-0.24	-0.87
SP191D	145.26	145.96	146.13	146.50	-0.32	-0.48	-0.49	-0.55
SP30D	151.01	152.26	152.46	152.85	-0.06	-0.06	-0.06	-0.07
SP40D	143.56	148.96	150.02	151.51	-0.38	-0.48	-0.40	-0.28
SP416nD	141.65	145.04	145.88	147.13	-1.07	-2.39	-2.06	-1.40
SP424D	139.91	139.92	140.06	140.79	0.00	0.00	-0.14	-0.67
SP425D	145.63	146.98	147.23	147.70	-0.62	-0.57	-0.56	-0.52
SP51D	145.07	149.70	150.47	151.00	-0.52	-0.30	-0.18	-0.10
SP68D	143.73	148.56	149.39	150.23	-0.49	-0.60	-0.57	-0.20
SP84D	148.04	149.01	149.16	149.48	-0.18	-0.15	-0.14	-0.16
SP8D	147.50	151.95	152.66	153.46	-0.17	-0.18	-0.17	-0.10

6.6 Effects of varying bottom levels in the Mekong river

In section 4.3.5 it was noted that the Mekong river in this area is morphologically very active with varying bottom levels as a consequence. At location Mukhdahan the levels for high discharges, based on the year 2000 curve, may be up to 0.75 m off, up and down. A quickscan was executed to assess the effect varying bottom levels (and, consequently, water levels) in the Mekong on water levels in the Se Bangfai. For this purpose, the 90 model were redone twice for the following adapted conditions:

- Situation of lower bottom level: -0.75 m
  - stage discharge relation at Mukhdahan such that it leads to water levels -0.75 m in comparison with the base case of the previous sections
  - Maning coefficient of 0.028 m. (instead of 0.032 in the base case)

- Situation of higher bottom level: +0.75 m
  - stage discharge relation at Mukhdahan such that it leads to water levels +0.75 m in comparison with the base case of the previous sections
  - Maning coefficient of 0.036 m. (instead of 0.032 in the base case)

In the probabilistic analysis, the bottom level is now introduced as an additional random variable. The above two situations (plus and minus 0.75 m) are considered to be the extremes of a uniform distribution function. In other words, if h* is the water level at Mukhdahan that follows from discharge Q*, using the stage discharge relation based on the year 2000 curve, then the "real" water level at Mukhdahan is uniformly distributed between h*-0.75 and h*+0.75 m. This means on average the water level is still h*. Nevertheless, applying this distribution increases the probabilities of extreme water levels as a result of the contribution of increased bottom levels.

For instance, with the introduction of the new random variable "bottom level", the 100-year water level at Mukhdahan increases from 137.81 to 138.07, an increase of 0.26 m. Figure 6.30 shows the effect on 100-year water levels along the lower Se Bangfai. At the river mouth the effect is about 10 cm, and it diminishes 30 km upstream.

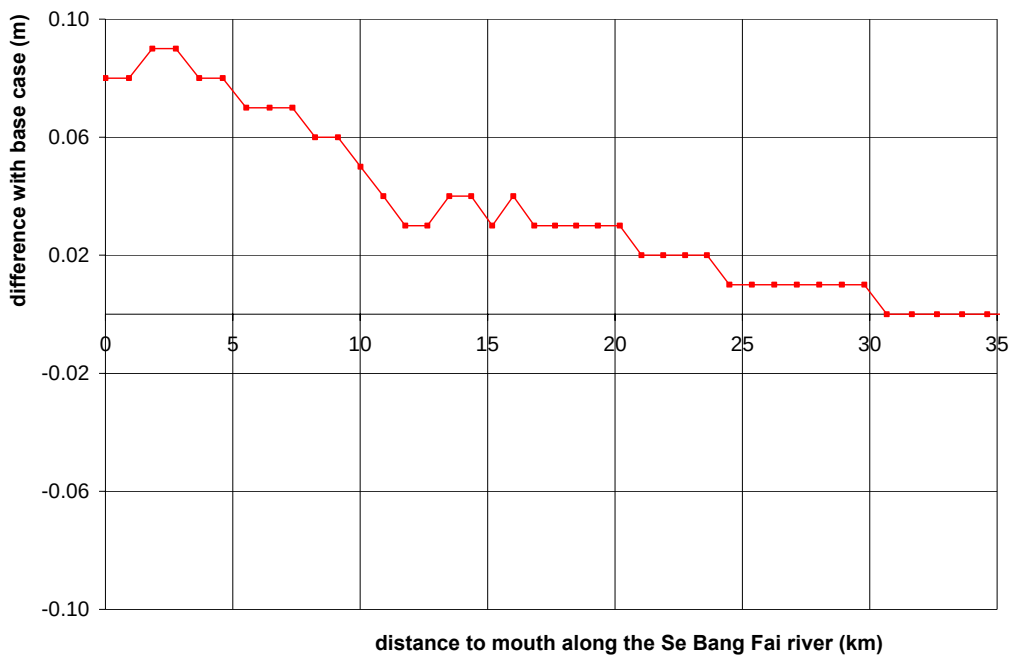

Figure 6.30 Increase of water levels along the Se Bangfai river as a result of the introduction of the varying bottom level as a new random variable.

The reason why the effect at Se Bangfai river mouth is far less than at Mukhdahan is due to the fact that for high discharges the effect of increased (or decreased) water levels at Mukhdahan are almost halved at That Phanom. This is shown in Figure 6.31 and Figure 6.32: for low water levels the differences with the bases case at That Phanom are 0.75 m (similar to Mukhdahan) whereas for high water levels these differences decrease to about 0.40 m. The analysis above provide a good insight in effects of varying bottom depth on the 100-year water level. However, with the assessment of effects of measures like embankments or diversion canals we are mainly interested in relative differences. Therefore,

the analyses of the previous sections (without the varying bottom levels as random variable) are sufficient.

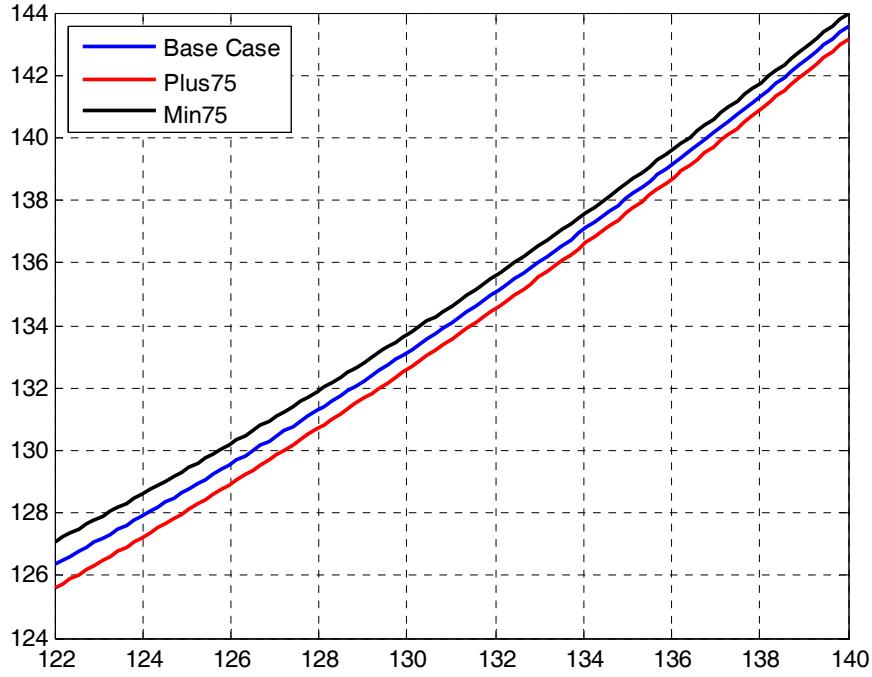

Figure 6.31 Relation between water levels at Mukhdahan and That Phanom for the base case and two additional cases (water level +/- 0.75 m).

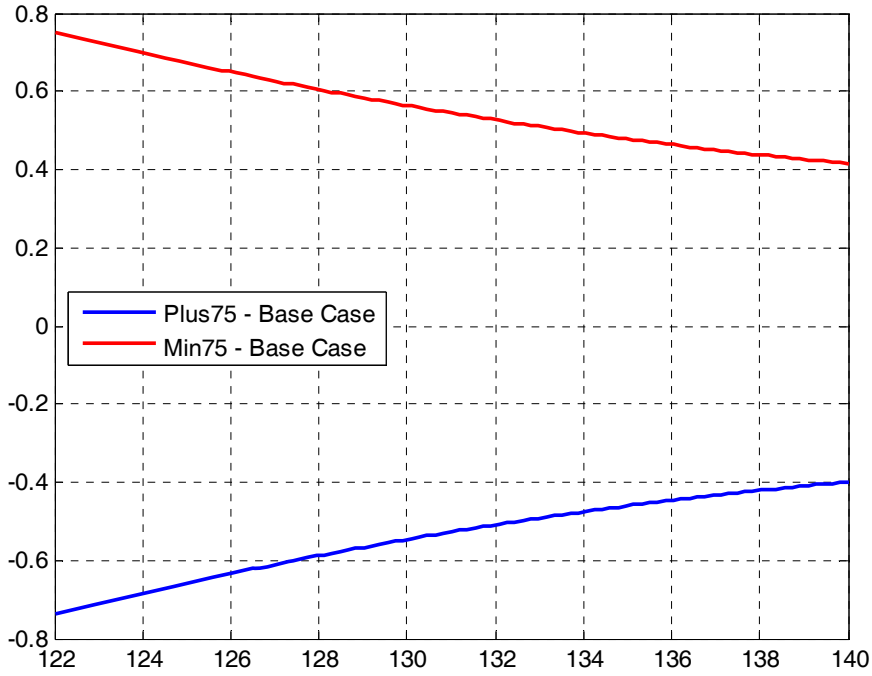

Figure 6.32 Differences in water level at That Phanom between the cases of Figure 6.31.

7 Conclusions and recommendations

7.1 Conclusions

Based on the analyses presented in the previous chapters the following conclusions can be drawn.

Type of floods and flooded area

1. Flood prone areas in the Se Bangfai basin are:
   - between the Mekong and Highway 13S, north of Se Bangfai river, creating extensive and of long lasting flooding, and
   - near Road 1F between Mahaxai and Nam Oula with flooding of one week duration per year on average.
2. The flood levels in the lower Se Bangfai are not only due to high river discharges but are also affected by high water levels in the Mekong at the river mouth at That Phanom. The floods in this region are therefore classified as combined floods. Bivariate distributions of Se Bangfai river flows and Mekong water levels are required to describe the phenomenon in statistical terms.

Data availability and validation

3. Water level series, discharge measurements and discharge series are available for Mahaxai as from 1988 onward. The rating curve is regularly updated. The discharge series are suitable for extreme value analysis
4. Water level series, discharge measurements and discharge series are also available for Se Bangfai Highway Bridge, with a discharge record even from 1960 onward with some gaps. The latter record is not corrected for backwater and therefore not suitable.
5. Discharge measurements at Highway Bridge and flows at Mahaxai do correlate well. A consistent discharge series has been established for Highway Bridge based on regression with Mahaxai. The difference between these series provides an estimate of the lateral inflow between Mahaxai and the flood prone area downstream of Highway Bridge.
6. The water levels at the Se Bangfai river mouth are determined by the combined Mekong discharge recorded at Nakhon Phanom and the Se Bangfai discharge and the conveyance capacity of the Mekong and imposed level conditions in the reach That Phanom – Mukhdahan and beyond, downstream of the confluence.
7. Discharge records for Nakhon Phanom are available since 1924. The series is generally consistent with the flow at Mukhdahan.

Hydrological characteristics

8. Average annual rainfall in Se Bangfai ranges from about 2,500 mm in the upper reaches to less than 1,600 mm near the mouth. Rainfall occurs mainly from May to September with August as the wettest month on average.

9. Annual potential evapo-transpiration in the lower Se Bangfai amounts some 1,550 to 1,600 mm. The values are highest in the period March-May. Evaporation exceeds rainfall from October till April.
10. Annual average flow at Mahaxai amounts 7,000 MCM. The runoff depth is about 1,650 mm, i.e. higher than the average annual rainfall at mouth. The monthly flow is highest in August followed by September and July.
11. The average annual flow at Highway Bridge is estimated at 12,700 MCM or 1,480 mm.
12. The regime of the Se Bangfai coincides with that of the Mekong, hence floods on both rivers may occur at the same time which will aggravate the flooding.
13. From December 2009 onward the discharge of the Se Bangfai will be augmented with the flow of Nam Theun via the Regulating dam and Downstream Channel of the hydro-power plant. On average the discharge of the Se Bangfai will increase with 220 m^3/s.

Hydrological hazard

14. The hydrological hazard expressed as extreme discharge and flood volume for selected return periods have been determined for Mahaxai on Se Bangfai and Nakhon Phanom on Mekong. The GEV-distributions fit well to the distributions of both annual maximum discharge and annual flood volume.
15. Flood volumes and to al lesser extent flood peaks on Mekong and Se Bangfai do correlate.
16. The bivariate distribution of annual flood peaks and flood volumes in the Mekong at Nakhon Phanom can be described by regression equations and GEV-distributions for the regression residuals.
17. The discharge rating of the Mekong at Mukhdahan, which acts as downstream boundary in the hydraulic model, varies from year to year. For a fixed high discharge the water level varies +/- 0.75 m about the assumed rating in the hydraulic model. This affects the water level at That Phanom with +/- 4 dm.

Flood hazard

18. The flooding in the lower Se Bangfai is complex and its extent is preferably modelled with a 1D-2D hydraulic model. Such model eliminates subjectivities in the schematization of the interaction between river and flood plain.
19. The 1D hydraulic model of the Se Bangfai as developed and calibrated by LNMC in 2009 leads on average to 7 to 8 dm higher water levels than observed water levels at Highway Bridge. The roughness of the model has subsequently been adjusted to arrive at an on average unbiased result at the Highway Bridge.
20. The quality of the model to correctly simulate floodplain flooding is uncertain, in absence of detailed data on flooding extent.
21. For flood hazard assessment in regions of combined floods use is made of the Monte Carlo procedure, taking into account the joint occurrence of peak flows and flood volumes in Mekong and Se Bangfai.
22. The water levels in Se Bangfai river and floodplains for some 90 combinations of Mekong and Se Bangfai peak flows and flood volumes have been determined with the hydraulic model to create a database the Monte Carlo procedure is drawing from to determine the flood hazard.

23. The flood hazard for the following cases have been determined including preparation of flood depth and flood extent maps:
    - Case 1: situation with no embankments, i.e. the river conditions till 2002;
    - Case 2: situation with embankments along the left bank since 2002;
    - Case 3: situation with embankments on both banks, i.e. the planned layout.
24. The embankment protect the downstream floodplains but back up the water further upstream. The situation with only embankments on the left is profitable for the downstream floodplain locations on the left but disadvantageous for locations on the right.
25. The flood extent derived by the model for the lower reach of the Se Bangfai is qualitatively in line with flood maps of the year 2000.
26. Effects of a bypass channel from Se Bangfai to Mekong to improve the drainage conditions have been investigated. A 200 m wide bypass with bed level at 138 masl conveyed for selected years up to 500 to 1000 m^3/s, lowering the maximum water levels along the rivers near the off-take with about 0.5 to 1.0 m. Similar values are found for the flood plains with substantially reduced flood duration. For the 100-year water level a maximum reduction (near the off-take) of 1.83 m is observed.

7.2 Recommendations

To improve the flood hazard assessment for the lower Se Bangfai the following recommendations are made:

1. Establish a discharge measuring station on the Se Noy and (temporary) water level stations in the river (one additional) and flood plains downstream of Highway Bridge.
2. Carry out a detailed topographic survey of river, floodplain and embankment levels from Mahaxai to river mouth and develop an accurate DEM.
3. Update the land use maps valid for flood and dry seasons.
4. Develop a new 1D/2 D hydraulic model of the lower Se Bangfai including the Mekong from Nakhon Phanom to Mukhdahan. With the availability of the DEM and land use data the development of such a model is much easier than of a 1D-model as the river-floodplain interaction is objectively derived from the DEM.
5. Simulate the water level and flow conditions in the Se Bangfai river and flood plain downstream of Mahaxai for the selected 90 combinations of water levels at That Phanom and discharge hydrographs at Mahaxai under different river and flood plain settings (Cases 1 to 3 and bypass channel).
6. Apply the Monte Carlo procedure to arrive at the water levels for selected return periods.
7. For design purposes always verify your calculations on flood levels with the larger values of two cases:
   - 7.a Case 1: 100 year peak flow at Mahaxai with annual peak level at mouth (derived from annual peak flow at Nakhon Phanom),
   - 7.b Case 2: annual peak flow at Mahaxai and 100 year peak level at mouth (derived from annual peak flow at Nakhon Phanom).

   In both cases the maximum effect of bed level changes on the discharge rating at Mukhdahan should be taken into consideration, as well as effects of extreme winds (speed and direction) during typhoons.

8 Literature

ADB (2004)
Summary Environmental and Social Impact Assessment Nam Theun 2 Hydroelectric Project in Lao People's Democratic Republic.
Asian Development Bank, November, 2004.

Malone, Terry (2007)
URBS Calibration Report – Basin 32. Se Bangfai.
MRC, May, 2007

MRC (2007)
Review of the hydraulic Study for Discharges from the NT2 Regulating Pond and Impacts on the Xe Bang Fai.
Mekong River Commission Secretariat, November, 2007.

Mekong Secretariat (1981)
The Se Ban Fai Plain, Lao PDR. Feasibility study of floodway and small structures.
Interim Progress Report. MKG/R314, May 1981

Verger, Robert (2006)
"Surplus or no surplus" of water in the Se Bangfai river?
MSc thesis University of Twente, Department of Civil Engineering, Enschede, The Netherlands, March-June 2006