Prepared for:

Mekong River Commission

# Flood hazard assessment for Nam Mae Kok

Tributary and combined flood approach

Report

December 2009

Prepared for:

Mekong River Commission

# Appendix 1
# Flood hazard assessment for Nam Mae Kok

Tributary and combined flood approach

H.J.M Ogink; F.L.M. Diermanse

Report

December 2009

# Contents

**1 Introduction ..... 1–1**

**2 Flood hazard assessment procedures ..... 2–1**

2.1 General ..... 2–1

2.2 Outline of procedures ..... 2–1

2.2.1 Tributary floods ..... 2–1

2.2.2 Combined floods ..... 2–1

**3 Basin description ..... 3–1**

3.1 General ..... 3–1

3.2 Basin description ..... 3–1

3.3 Problem description ..... 3–4

3.4 Hydrological data requirement ..... 3–8

3.5 Hydrological network and data availability ..... 3–9

3.6 Hydrological characteristics ..... 3–12

3.6.1 Rainfall ..... 3–12

3.6.2 Evaporation ..... 3–13

3.6.3 Water levels and stage-discharge relations ..... 3–14

3.6.4 Discharges ..... 3–15

**4 Hydrological hazard ..... 4–1**

4.1 General ..... 4–1

4.2 Nam Mae Kok at Ban Pong Na Kham ..... 4–1

4.3 Nam Mae Lao at Ban Pong Pu Fuang ..... 4–7

4.4 Nam Mae Kok d/s Nam Mae Lao confluence ..... 4–12

4.5 Mekong - Nam Mae Kok confluence ..... 4–17

4.5.1 Mekong at Chiang Saen ..... 4–17

4.5.2 Discharge rating Sop Kok ..... 4–21

4.5.3 Nam Mae Kok at mouth ..... 4–22

4.5.4 Correlation between flood peaks and volumes in Nam Mae Kok and Mekong ..... 4–23

**5 Flood hazard ..... 5–1**

5.1 General ..... 5–1

5.2 Hydraulic model ..... 5–1

5.3 Recalibration of the hydraulic model ..... 5–5

**6 Conclusions and recommendations ..... 6–1**

6.1 Conclusions ..... 6–1

6.2 Recommendations ..... 6–2

**7 Literature.....7–1**

# 1 Introduction

This document deals with flood hazard assessment for the Nam Mae Kok. Tributary floods in the Chiang Rai region cause flooding in parts of the city. In the vicinity of the Mekong near the Nam Mae Kok mouth flooding is caused by large discharges from the Nam Mae Kok backed up by high stages in the Mekong. The general procedure used in both cases is presented and its application to the Nam Mae Kok is discussed.

The set up of this report is as follows. The procedure for flood hazard assessment for tributary and combined floods is outlined in Chapter 2. A description of the Nam Mae Kok basin, its hydraulic infrastructure, hydrological monitoring system and data availability is given in Chapter 3. The hydrological hazard is elaborated in Chapter 4. The hydraulic model for the simulation of the floods on the Nam Mae Kok and applied boundary conditions is presented in Chapter 5. Conclusions on the hydrological hazard analyses are drawn in Chapter 6 with recommendations on hazard reduction.

# 2 Flood hazard assessment procedures

## 2.1 General

The procedure for flood hazard assessment in case of tributary and combined floods is discussed in this chapter. It deals with the computation of flood level elevations and flood extent of selected return periods and the depth and duration of flooding. 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 procedures

### 2.2.1 Tributary floods

Tributary floods refer to floods on tributaries of the Mekong but not affected by backwater from the Mekong. These floods are of limited duration caused by extreme discharge in the tributaries. When a homogeneous discharge series of sufficient length (> 15 years) is available for the concerned river reach the hydrological hazard can be derived from statistical analysis of annual flood peaks and flood volumes and their interrelation. A hydraulic model of river and flood plain is subsequently used for the transformation of hydrological hazard into flood hazard. A selection of representative flood hydrographs, covering the full spectre of flood peaks and flood volumes, are transformed into water levels using the hydraulic model. The levels and flood volumes are input to a Monte Carlo procedure to derive the frequency of occurrence of water levels as a function of time and space. Comparing the levels for selected frequencies with a DEM flood hazard maps can be created.

Reference is made to the Flood Hazard Assessment Guidelines for a full description of the procedure.

### 2.2.2 Combined floods

The flood hazard of combined floods uses also 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 Nam Mae Kok:

- The maximum discharge in the Mekong river at Chiang Saen;
- The total volume of the flow in the Mekong river at Chiang Saen;
- The maximum discharge in the Nam Mae Kok near the river mouth.

The first two variables determine the downstream water level in the Mekong and the last one the upstream inflow to the Nam Mae Kok river reach at mouth. 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 is applied to derive the relevant hydraulic features like maximum water level at a number of locations in the Nam Mae Kok. Formally, this means the hydraulic model should be run *N* times, but since *N* is generally quit large, that would require such a long computation time that the procedure would become unpractical. Instead, the model is run for 150 different combinations of the three random variables that basically cover the whole spectre of possible outcomes. The results of the 150 simulations are stored in a database. Results of the *N* Monte Carlo runs are then determined by interpolation of the results of the 150 simulations. Since 3 random variables are involved, the interpolation is 3-dimensional.

Reference is made to the Flood Hazard Assessment Guidelines for a full description of the procedure.

# 3 Basin description

## 3.1 General

The Nam Mae Kok basin has been selected by the TNMC for Integrated Flood Risk Management. The area concerns the Nam Mae Kok river from Chiang Rai to its confluence with the Mekong just downstream of Chiang Saen at rkm 2,359.

## 3.2 Basin description

The Nam Mae Kok basin (see Figure 3.1) covers an area of 10,730 km$^2$. The length of the river from source to mouth is 320 km. The river takes it rise in Myanmar and crosses the Thai border after 170 km near Ban Tha Ton. In Thailand the river is joined by the Nam Mae Fang near to Thai-Myanmar border, at Chaing Rai upstream of the Chiang Rai weir by the small but for flooding important Nam Korn, and just downstream of the weir by the largest tributary the Nam Mae Lao. From Chiang Rai to the river mouth a few smaller tributaries like the Mae Hang and Mae Phue join before the Kok drains into the Mekong at Sop Kok, some 5 km downstream of Chiang Saen gauging station at an elevation of 355 masl. The basin is mountainous on the divides with elevations up to 2,000 m, see Figure 3.2. The valleys of the Fang, the Lao and the Kok rivers from Chiang Rai to the mouth are flat and flood prone, see Figure 3.3. The confluence of the Kok with Mekong is shown in Figure 3.4.

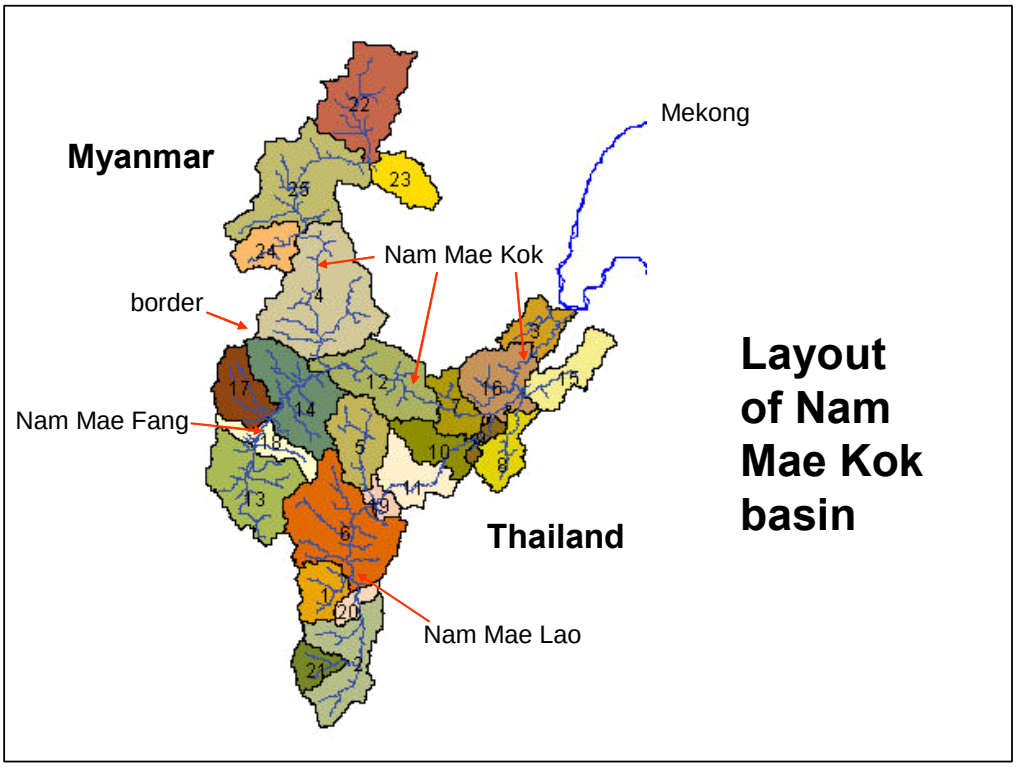


Figure 3.1 Layout of Nam Mae Kok basin

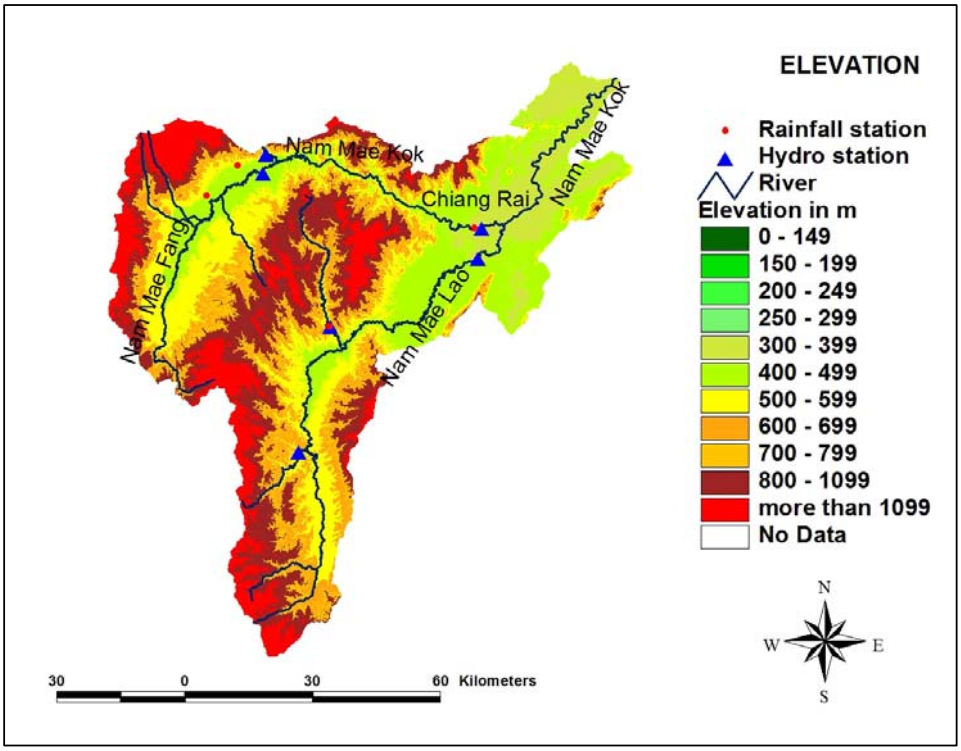


Figure 3.2 Nam Mae Kok elevation map

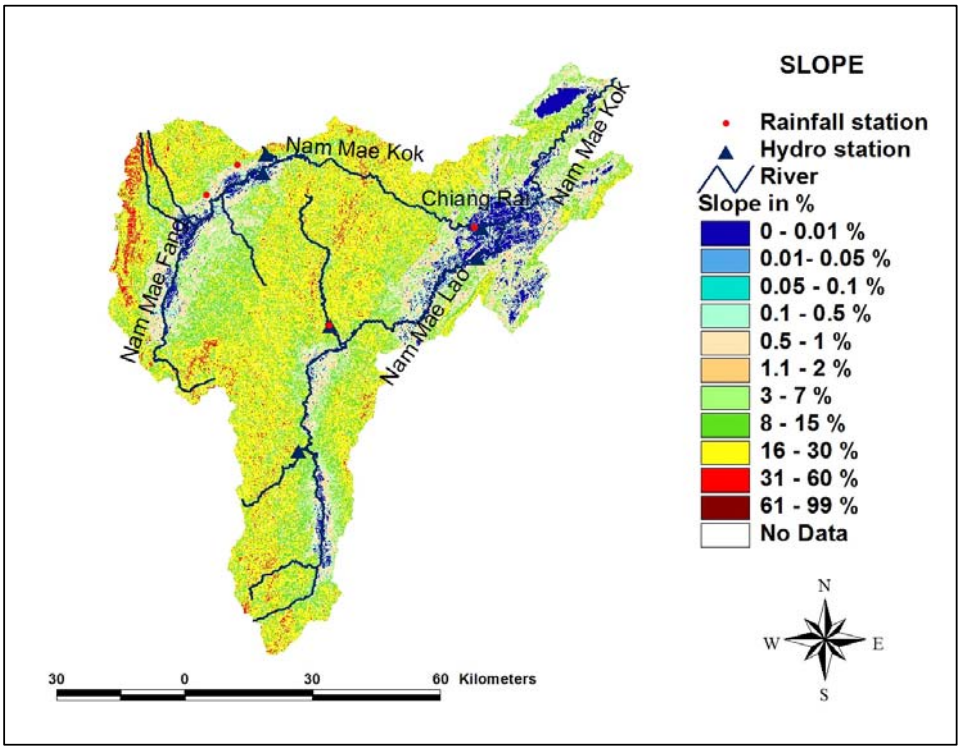


Figure 3.3 Nam Mae Kok slope map

Figure 3.4 Confluence of Nam Mae Kok with Mekong, 7 km d/s of Chiang Saen

Some 31% of the total basin area of the Nam Mae Kok is located in Myanmar. The first mayor tributary in Thailand, the Fang, with a length of 120 km drains 18% of the Kok basin. At Chaing Rai Bridge above the mouth of Korn and Lao rivers the basin area amounts 6,133 $km^2$ (see Table 3.1). The 37 km long Nam Korn drains only 162 $km^2$, whereas the Nam Mae Lao with a length of 190 km discharges the runoff of an area of 3,115 $km^2$, or 29% of the total area. At the confluence of the Nam Mae Lao, just downstream of the Chiang Rai weir, the Kok conveys already the flow of some 88% of the basin.

Table 3.1 Catchment areas in Nam Mae Kok basin according to SWAT (note that the areas differ slightly from those presented in the MRC yearbooks)

| **Location** | **Area ($km^2$)** |
|---|---|
| Kok at Ban Pong Na Kham | 5,890.4 |
| Kok at Chiang Rai | 6,133.4 |
| Nam Korn | 162.0 |
| Lao at Ban Pong Pu Fuang | 2,584.8 |
| Lao at mouth | 3,115.1 |
| Kok d/s Lao confluence | 9,410.5 |
| Kok at Ban Mae Phaeng | 10,475.2 |
| Kok at mouth | 10,730.1 |

The soils in the Nam Mae Kok basin belong mainly (88%) to the Hydrologic Soil Group B with a soil composition of 21% clay, 24% silt and 55% sand (MRC soil codes Ao, Nh and SC). Some 70% of the basin area is covered with forest found in the upper areas. Agriculture has developed in the lower reaches covering some 18% of the basin.

The natural river regime has been modified by irrigation water use and storage for hydropower. According to BDP (2006) in 1998 in the basins of the Kok and adjacent Ing together, about 150,000 ha were irrigated in the wet season and some 15,000 ha in the dry season. Irrigation water requirement for 2000 was estimated at 770 MCM, whereas the needs for domestic and industrial water supply amounted 31 MCM. Some 8 reservoirs are planned, to achieve an expansion of 30% of the irrigated area in the Kok basin. These projects will at least partly be multipurpose, combining irrigation water supply and hydropower production. The present and planned hydropower projects in the Nam Mae Kok

basin affecting the flow regime are presented in Table 3.2. The present storage capacity is seen to be very small compared to the annual Kok flow of about 5.24 BCM. However, with the Nam Kok hydropower dam implemented in Myanmar (at present at pre-feasibility status) some 30% of the flow in the Nam Mae Kok can be fully controlled as the storage capacity will be large (about 60 % of the annual river flow at mouth).

Table 3.2 Existing and planned hydropower projects in Kok basin (source BDP, 2006)

**Existing**

| Project | Capacity (MW) | Storage (MCM) |
|---|---|---|
| Nam Mae Mao | 4.6 | 20 |
| Mae Chai, Mae Kum Luang | 7.2 | 0 |
| Chiang Rai weir on Nam Mae Kok | - | 1.3 |

**Planned**

| Project | Storage (MCM) |
|---|---|
| Nam Kok hydropower dam (Myanmar) | 3,033 |
| Fang sub-basin (3 reservoirs) | 134 |
| Lao sub-basin (4 reservoirs) | 204 |
| **Total** | **3,370** |

## 3.3 Problem description

The major part of the city of Chiang Rai is enclosed by the Kok and Korn rivers. Expansions of the city are taking place north of Kok river and between the Korn and Lao rivers.

Flood prone areas in the Nam Mae Kok basin are following (see also the slope map in Figure 3.3):

- Valley of Nam Mae Fang
- Chiang Rai Province
- Mouth of Nam Mae Kok

The possible flood extent in the lower part of the Kok basin derived from hydraulic model calculations is presented in Figure 3.5 (Kittipong, 2009). It shows flooding near the confluences of the tributaries in Chiang Rai and along the Kok river between Chiang Rai and the river mouth.

Floods around the city are generated either by the Kok, the Korn and/or by the Lao. The city is flood prone when the rivers convey large discharges. In the past, Chiang Rai city was mostly endangered by floods from the Lao and the Korn, Figure 3.6. Water was spilling over from the Lao upstream of Chai Sombat Weir and entered the flood plain of the Korn, aggravating the flooding in Chiang Rai. To reduce the flooding the Chiang Rai Municipality and the Royal Irrigation Department have implemented in 2005 a number of flood protection measures (see Figure 3.7), including:

- The Nam Korn-Nam Kok Diversion Canal including intake and outlet weirs,
- Improvement of additional 4 weirs in the Nam Korn,
- Improvement of Lao embankment upstream of Chai Sombat Weir over a distance of 15 km.

Annual maximum rivers discharges generally occur in the period july-november as can be observed from Table 3.3. In the Period 1971-2007 the largest annual peak in the Kok upstream of Chiang Rai occurred in 1971. The hydrograph is shown in Figure 3.8. It shows a fairly rapidly rising and falling flood, lasting for about 1 week, which is characteristic for

the floods in the Nam Mae Kok at Chaing Rai. The floods in the Nam Mae Lao generally have a shorter duration. Very recently, in 2005 (and also 2006), the Lao received one of its biggest floods, while the Korn was also extreme in that year, see Figure 3.9. The Lao peaked in 2005 two times, with values higher than the annual maximum of the other years.

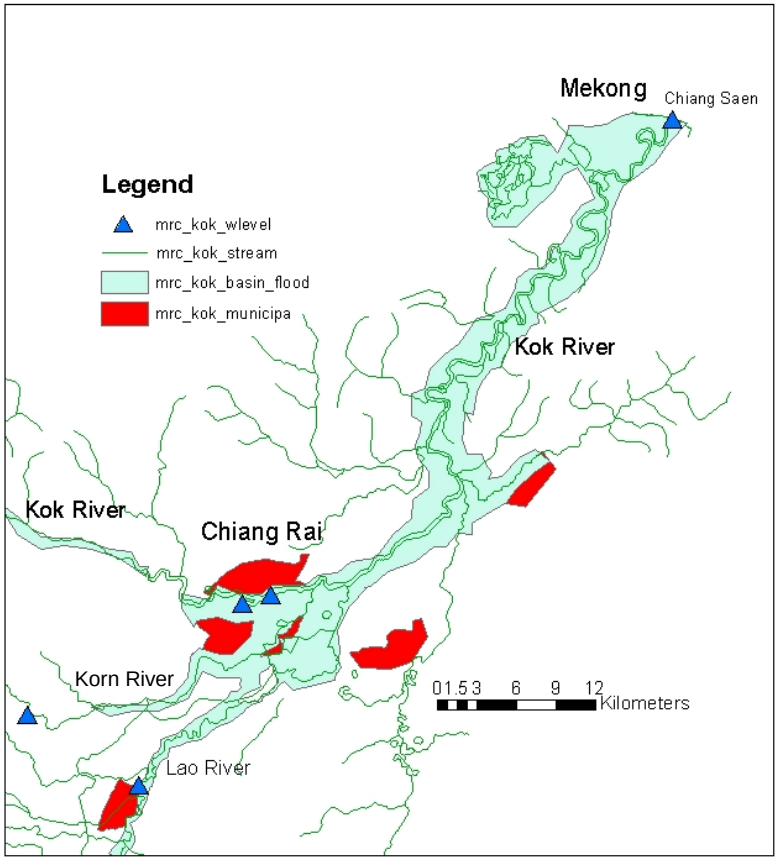


Figure 3.5 Flooding around Chiang Rai and along lower Nam Mae Kok.

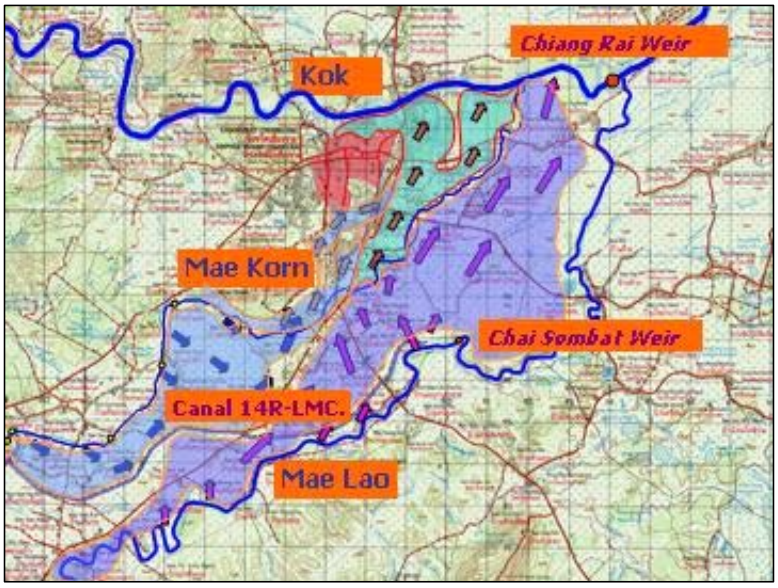

Figure 3.6 Flooding in Chiang Rai Province near the city of Chiang Rai

Figure 3.7 Flood mitigation measures around Chaing Rai, including a diversion canal from Korn to Kok, weirs in the Nam Korn and embankments along the Lao u/s Chai Sombat Weir

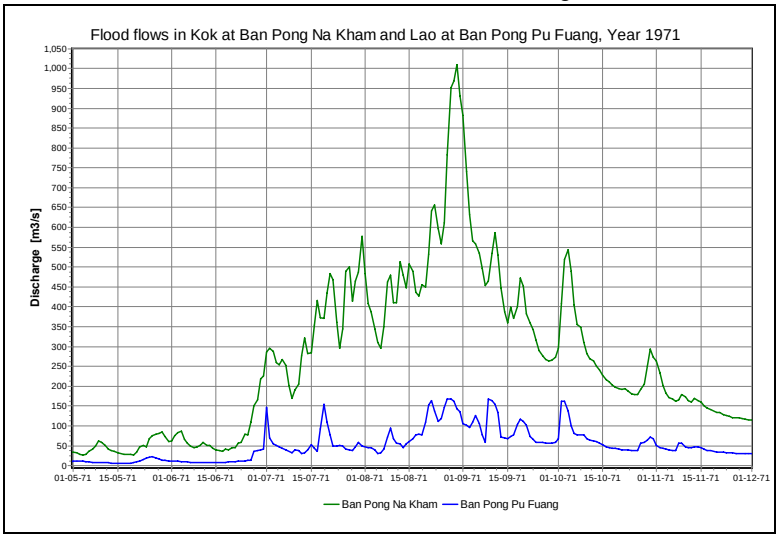


Figure 3.8 Flood of 1991 on Nam Mae Kok at Ban Pong Na Kham u/s of Chiang Rai and Nam Mae Lao at Ban Pong Pu Fuang

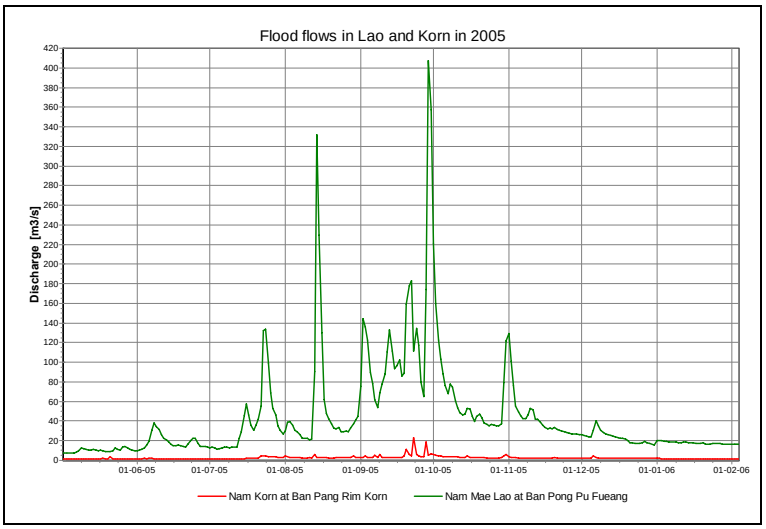


Figure 3.9 Floods of 2005 in Nam Mae Lao at Ban Pong Pu Fuang and Nam Korn at G4

| Nam Mae Kok at Ban Pong Na Kham | | | | Nam Mea Lao at Ban Pong Pu Fuang | | | | Nam Mae Kok d/s Lao confluence | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Mnth | Day | $Q_{max}$ ($m^3/s$) | Year | Mnth | Day | $Q_{max}$(($m^3/s$) | Year | Mnth | Day | $Q_{max}$ ($m^3/s$ |
| 1971 | 8 | 30 | 1010 | 1973 | 9 | 21 | 515 | 1973 | 9 | 21 | 1266 |
| 1973 | 9 | 23 | 846 | 2005 | 9 | 29 | 407 | 1971 | 8 | 30 | 1233 |
| 1987 | 8 | 26 | 781 | 2006 | 9 | 24 | 313 | 1972 | 8 | 26 | 1133 |
| 2004 | 9 | 12 | 781 | 1994 | 9 | 1 | 304 | 1994 | 8 | 31 | 1113 |
| 1995 | 9 | 5 | 774 | 1972 | 8 | 26 | 277 | 1995 | 9 | 5 | 1099 |
| 1972 | 8 | 26 | 751 | 1980 | 9 | 3 | 254 | 2005 | 9 | 30 | 1098 |
| 1994 | 8 | 31 | 721 | 1975 | 9 | 23 | 252 | 1987 | 8 | 25 | 1060 |
| 1988 | 8 | 17 | 697 | 1987 | 8 | 24 | 248 | 2004 | 9 | 12 | 990 |
| 2005 | 10 | 1 | 661 | 2003 | 9 | 13 | 247 | 2003 | 9 | 13 | 949 |
| 1981 | 8 | 6 | 644 | 2002 | 9 | 10 | 234 | 1980 | 9 | 10 | 928 |
| 1980 | 9 | 10 | 614 | 1995 | 9 | 5 | 231 | 2006 | 9 | 23 | 867 |
| 2003 | 9 | 13 | 611 | 1976 | 9 | 27 | 222 | 1976 | 9 | 28 | 862 |
| 1976 | 9 | 28 | 561 | 1999 | 9 | 25 | 198 | 1988 | 8 | 17 | 830 |
| 1996 | 8 | 21 | 555 | 2001 | 8 | 6 | 186 | 1981 | 8 | 6 | 823 |
| 1983 | 9 | 16 | 546 | 2004 | 9 | 22 | 181 | 2001 | 8 | 6 | 796 |
| 2001 | 8 | 6 | 538 | 1988 | 6 | 7 | 180 | 1996 | 9 | 4 | 716 |
| 1982 | 8 | 20 | 531 | 1991 | 9 | 5 | 174 | 1983 | 9 | 16 | 714 |
| 2006 | 9 | 22 | 527 | 1974 | 8 | 19 | 173 | 1991 | 9 | 5 | 708 |
| 1999 | 9 | 1 | 506 | 1971 | 8 | 27 | 168 | 2002 | 9 | 10 | 705 |
| 1978 | 9 | 13 | 488 | 1984 | 9 | 6 | 167 | 1977 | 9 | 23 | 699 |
| 1997 | 9 | 3 | 485 | 1977 | 9 | 23 | 166 | 1975 | 9 | 24 | 687 |
| 1984 | 9 | 8 | 484 | 1978 | 7 | 4 | 164 | 1984 | 9 | 6 | 678 |
| 1977 | 9 | 23 | 469 | 1979 | 8 | 9 | 163 | 1978 | 9 | 13 | 637 |
| 1991 | 9 | 5 | 468 | 1997 | 9 | 29 | 156 | 1982 | 8 | 20 | 604 |
| 1975 | 9 | 15 | 449 | 1985 | 11 | 17 | 155 | 1989 | 9 | 27 | 603 |
| 2007 | 9 | 6 | 448 | 1986 | 9 | 9 | 134 | 1974 | 8 | 19 | 595 |
| 1985 | 9 | 15 | 439 | 1996 | 9 | 4 | 128 | 2000 | 8 | 9 | 590 |
| 2000 | 8 | 10 | 438 | 1983 | 11 | 13 | 127 | 1999 | 9 | 1 | 584 |
| 1989 | 9 | 27 | 431 | 2000 | 8 | 9 | 126 | 1985 | 9 | 15 | 580 |
| 2002 | 8 | 7 | 421 | 2007 | 9 | 29 | 122 | 1997 | 9 | 3 | 567 |
| 1998 | 8 | 26 | 388 | 1989 | 9 | 27 | 122 | 2007 | 9 | 6 | 563 |
| 1974 | 8 | 20 | 371 | 1982 | 9 | 10 | 121 | 1979 | 8 | 9 | 541 |
| 1986 | 7 | 27 | 359 | 1981 | 8 | 6 | 120 | 1998 | 9 | 10 | 522 |
| 1979 | 8 | 7 | 355 | 1998 | 9 | 10 | 118 | 1986 | 7 | 27 | 480 |
| 1990 | 8 | 2 | 306 | 1992 | 9 | 19 | 87 | 1990 | 8 | 1 | 421 |
| 1993 | 9 | 12 | 298 | 1990 | 7 | 31 | 87 | 1993 | 9 | 12 | 360 |
| 1992 | 7 | 27 | 255 | 1993 | 9 | 21 | 75 | 1992 | 9 | 19 | 294 |

Table 3.3 Summary of ranked annual flood peaks of the period 1971-2007 in the Kok at Ban Pong Na Kham and d/s Lao confluence and the Lao at Ban Pong Pu Fuang

## 3.4 Hydrological data requirement

The flood risk is assessed for the Chiang Rai area along the Nam Mae Kok, which requires determination of the flood hazard for the environs of the city. The flood extent, depth and duration are determined for the following return periods: 2, 10, 25 and 100 years. The flood hazard follows from the hydrological hazard using a hydraulic model. The type of approach is dependent on the variables determining the flood levels. In the upper and middle part the river discharge and downstream conveyance capacity are of importance. Near the river mouth an additional variable is involved due to backwater from the Mekong. An estimate of the distance over which the effect of the Mekong river is felt on the flood levels in the Nam Mae Kok can be derived from a first order backwater calculation (see also Figure 3.10 for a definition sketch):

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

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

$$L_{5\%} = \frac{h_e}{S_0} \quad with: \quad h_e = 9\,m\ and\ S_0 = 4.34x10^{-4}, \quad it\ follows: \tag{3.1}$$

$$L_{5\%} = \frac{h_e}{S_0} = \frac{9}{4.34x10^{-4}} = 20,743\ m \approx 21\ km$$

with: $\Delta h_0$ = deviation from equilibrium depth at x=0
$\Delta h_L$ = deviation from equilibrium depth at x = L
$h_e$ = equilibrium depth
$S_0$ = bed slope
Fr = Froude number

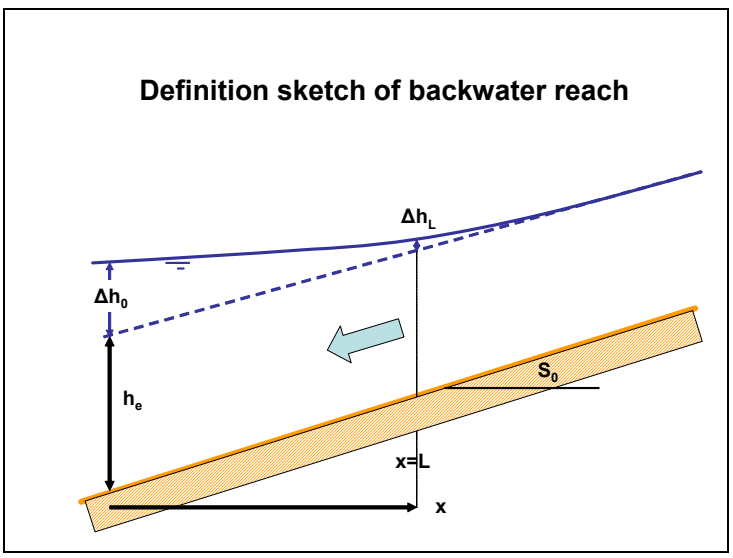


Figure 3.10 Definition sketch of extent of backwater reach

In (3.1) the equilibrium depth $h_e$ is taken as the maximum observed water level reach at station Sop Kok on Mekong River at Nam Mae Kok mouth. The bed slope $S_0$ is derived

from the gauge zero difference between station Chiang Rai (GZ = 387.85 m) distanced some 75 km from the mouth and station Sop Kok (GZ = 355.31 m). It follows that the effect of the Mekong practically vanishes at a distance of 21 km from the mouth. It implies that the flood hazard in the Chiang Rai region is only determined by the river flow, channel capacity and Chiang Rai weir operation but not by the Mekong river. The comment in the Mekong Hydrological Yearbook e.g. of 1997 that the gauge at Chiang Rai is affected by backwater from the Mekong is therefore incorrect; it is affected by the weir, 5 km downstream of the station, near the confluence of the Nam Mae Lao, but not by the Mekong.

The hydraulic model of the Nam Mae Kok extends from Ban Pong Na Kham on Kok, to Sop Kok at the mouth, including the Lao from Ban Pong Pu Fuang and the Korn from 14 km d/s of Ban Pang Rim Korn Hydrological Station (G4). The Mekong is included from Chiang Saen to Sop Kok.

For assessing the hydrological hazard and running the hydraulic model for flood risk assessment around Chiang Rai the following data is required:

- Discharge record for the Nam Mae Kok at Ban Pong Na Kham
- Discharge record for the Nam Mae Lao at Ban Pong Pu Fuang
- Discharge record for the Nam Korn at 14 km d/s G4
- Lateral inflow d/s of the upper model boundaries

For risk assessment near the Nam Mae Kok mouth over its last 20-25 km the Mekong river stages and Kok river capacity in combination with the river flow determines the hydrological and flood hazard. This requires:

- Peak flows and flood volumes of the Mekong at Chiang Saen,
- A stage-discharge relation for the Mekong d/s Sop Kok
- Peak flows and flood volumes in the Nam Mae Kok at the upper end of the backwater affected reach of the Kok.
- Lateral inflow d/s of the Kok boundary.

## 3.5 Hydrological network and data availability

Organizations that collect and use hydrological data of the Mekong Basin in Thailand are:

1. Department of Water Resources, Ministry of Natural Resources and Environment; responsible for hydrological and meteorological (mostly basic synoptic) stations; (variables are observed 5 times a day from 0600 a.m. until 1900 p.m.)
2. Royal Irrigation Department, Ministry of Agriculture and Cooperatives; responsible for hydrological stations.
3. Electricity Generating Authority of Thailand (EGAT); responsible for hydrological stations from hydro-power dams.
4. Thai Meteorological Department, Ministry of Information, Communication and Technology; responsible for meteorological (full synoptic and climate) data and hydro-meteorological data, as national representative of World Meteorological Organization (WMO).

The hydrological network in the Nam Mae Kok basin as available in the MRC HYMOS database is presented in Table 3.4. The gauges zeros of the water level gauging stations are given in Table 3.5. The locations of the discharge stations are shown in Figure 3.11.

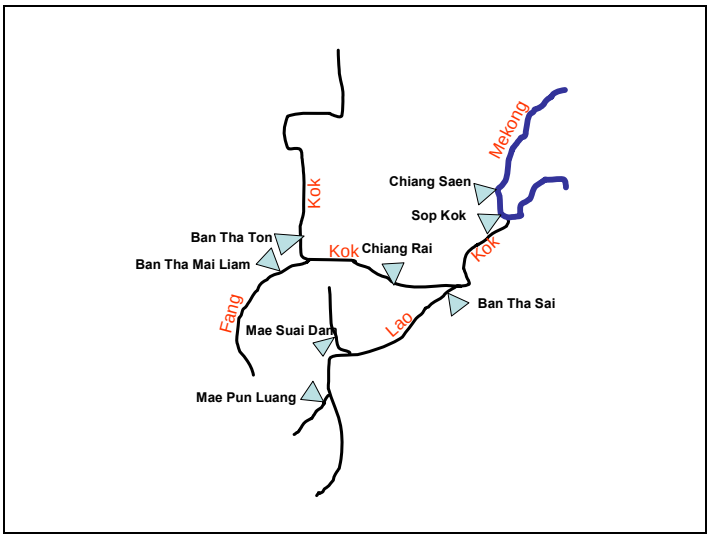


Figure 3.11 Location of discharge gauging stations in Nam Mae Kok basin and on Mekong

Table 3.4 Overview of rainfall, climatic and hydrometric stations in Nam Mae Kok with data availability

| Variable | Stations | ID | Long | Lat | Availability |
|---|---|---|---|---|---|
| Rainfall | Fang | 199901 | 99.2334 | 19.9667 | 1953-72, 75-05 |
| | Chiang Rai | 199907 | 99.8334 | 19.9167 | 1963-2005 |
| | Mae Suai Dam Site | 199913 | 99.5167 | 19.7000 | 1980-2001 |
| | Chiang Saen | 200002 | 100.1000 | 20.2667 | 1966-2005-06 |
| | Ban Mae AI | 209902 | 99.3000 | 20.0334 | 1970-2005 |
| Evaporation | Chiang Rai | 199907 | 99.8334 | 19.9667 | 62-67,72-78,80-95,97-05 |
| | Chiang Rai-FAO | -do- | -do- | -do- | from Climwat database |
| | Mae Suai Dam Site | 199913 | 99.5167 | 19.9167 | 1981-2001 |
| | Chiang Saen | 200002 | 100.1000 | 19.7000 | 1976-2005 |
| | Ban Mae AI | 209902 | 99.3000 | 20.2667 | 1971-2005 |
| Water level | Sop Ruak (rkm 2,372.4) | 010401 | 100.0867 | 20.3484 | 1972-2005 |
| | Chiang Saen (rkm 2,364) | 010501 | 100.0834 | 20.2734 | 1960-2005 |
| | Sop Kok (rkm 2,359) | 010601 | 100.1333 | 20.2417 | 1972-1992 |
| | Chiang Khong (rkm 2,313) | 010801 | 100.4100 | 20.2684 | 1972-2005 |
| | Ban Tha Ton on Nam Mae Kok | 050105 | 99.3634 | 20.0600 | 1969-2005 |
| | Ban Tha Mai Liam on Fang | 050201 | 99.3584 | 20.0200 | 1969-2003 |
| | Chiang Rai on Nam Mae Kok | 050104 | 99.8500 | 19.9184 | 1977-2005 |
| | Dam Site on Nam Mae Suai | 051001 | 99.5200 | 19.8534 | 1971-2001 |
| | Dam Site on N. Mae Pun Luang | 051101 | 99.4584 | 19.4334 | 1976-2003 |
| | Ban Tha Sai on Nam Mae Lao | 050301 | 99.8434 | 19.8534 | 1970-2003 |
| Discharge | Chiang Saen (rkm 2,364) | 010501 | 100.0834 | 20.2734 | 1960-2006 |
| | Sop Kok (rkm 2,359) | 010601 | 100.1333 | 20.2417 | 1972-1987 |
| | Ban Tha Ton on Nam Mae Kok | 050105 | 99.3634 | 20.0600 | 1969-2005 |
| | Ban Tha Mai Liam on Fang | 050201 | 99.3584 | 20.0200 | 1969-2003 |
| | Chiang Rai on Nam Mae Kok | 050104 | 99.8500 | 19.9184 | 1977-1993 |
| | Dam Site on Nam Mae Suai | 051001 | 99.5200 | 19.8534 | 1975-94, 96-99, 01 |
| | Dam Site on N. Mae Pun Luang | 051101 | 99.4584 | 19.4334 | 1976-2003 |
| | Ban Tha Sai on Nam Mae Lao | 050301 | 99.8434 | 19.8534 | 1972-2002 |

With respect to the gauge zeros of stations in the Nam Mae Kok, in the Mekong Hydrological Yearbooks (1960-1997) only for station Chiang Rai a change of 1.00 m in 1987 is mentioned.

Table 3.5 Gauge zero levels of water level gauging stations in and around Nam Mae Kok

| Station | ID | GZ (masl) | Area ($km^2$) |
|---|---|---|---|
| Sop Ruak (rkm 2,372.4) | 010401 | 359.19 | 189,000 |
| Chiang Saen (rkm 2,364) | 010501 | 357.11 | 189,000 |
| Sop Kok (rkm 2,359) | 010601 | 355.31 | 203,825 |
| Chiang Khong (rkm 2,313) | 010801 | 341.96 | 211,000 |
| Ban Tha Ton on Nam Mae Kok | 050105 | 445.05 | 2,980 |
| Ban Tha Mai Liam on Fang | 050201 | 445.39 | 1,800 |
| Chiang Rai on Nam Mae Kok | 050104 | 387.85 | 6,060 |
| Dam Site on Nam Mae Suai | 051001 | 475.00 | 426 |
| Dam Site on N. Mae Pun Luang | 051101 | 455.64 | 258 |
| Ban Tha Sai on Nam Mae Lao | 050301 | 394.84 | 3,080*) |

(*)Note that the areas of the locations in the Kok basin are slightly inconsistent with SWAT based areas presented in Table 3.1).

It is observed that the MRC Hydrological database includes only a very limited amount of the data needed for the assessment of the hydrological hazard and to run the hydraulic model. A first improvement on the data availability was obtained from the hydraulic model boundaries used by (Kittipong, 2009), available as from 1985 onward. Additional data requirements were discussed with the TNMC. These data were received in late March 2009 including daily average levels and discharges at the model boundaries and instantaneous peak flow data. The data received via Kittipong and TNMC , not available in the MRC database, is listed in Table 3.6.

Table 3.6 Overview of additional hydrological data of hydrometric stations in the Nam Mae Kok collected in 2009

| **Station ID** | **Station Name** | **River** | **Period of data availability (received)** | | | |
|---|---|---|---|---|---|---|
| **by TNMC** | | | **Q** | **Max-Min Q** | **H** | **Max-Min H** |
| 030101 | Ban Tha Ton | Nam Mae Kok | 2006 | 1970-2005 | 2006-07 | 1970-2006 |
| 030102 | Ban Pong Na Kham | Nam Mae Kok | 1966-2008 | 1967-2005 | 1966-87, 1995-2007 | 1967-2006 |
| 030107 | Ban Mae Phaeng | Nam Mae Kok | 1994-2006 | 1994-2005 | 1994-2007 | 1994-2006 |
| 030201 | Ban Tha Mai Liam | Nam Mae Fang | 2004-06 | 1969-2005 | 2004-07 | 1969-2006 |
| 030301 | Ban Tha Sai | Nam Mae Lao | 2004-06 | 1971-2005 | 2004-07 | 1971-2006 |
| 030302 | Ban Pong Pu Fuang | Nam Mae Lao | 1971-2007 | 1971-2005 | 1970-2007 | 1971-2006 |
| 030401 | Dam site | Nam Mae Suai | - | 1971-2001 | | 1971-2001 |
| 020102 | Chaing Saen | Mekong | - | | 2006-07 | |
| G4 | Ban Pang Rim Korn | Nam Korn | | | | |
| - | 5 Lateral inflows Kok | Nam Mae Kok | 1985-2008 | | | |
| - | 3 Lateral inflow Lao | Nam Mae Lao | 1985-2008 | | | |
| - | 2 Lateral inflow Korn | Nam Korn | 1985-2008 | | | |

Station Ban Pong Na Kham is located between the Kok-Fang confluence and Chiang Rai station. Ban Mae Phaeng was established on the Kok between Chiang Rai weir and Sop Kok. Station Ban Pong Pu Fuang is located upstream of the weirs in the Nam Mae Lao. Reference is made to Table 3.1 for the catchment areas controlled by the stations.

## 3.6 Hydrological characteristics

### 3.6.1 Rainfall

The MRC database contains only rainfall series in the Nam Mae Kok basin and environs series for 5 stations. A denser network is available, but its data is not stored in the database.

Regarding validation, the available series have been subjected to double mass analysis and no anomalies were detected.

The annual and seasonal variations of the rainfall of selected stations in the basin are presented in Figure 3.12 and Figure 3.13. From the annual rainfall series it appears that around Chiang Rai-Chiang Saen the rainfall is largest (1,700 mm per year) and lowest in the upper reaches of the Nam Mae Kok and in the Nam Mae Fang (1,300-1,400 mm per year). August is generally the month with the largest rainfall with on average 380 mm, followed by July and September, with respectively 320 and 280 mm.

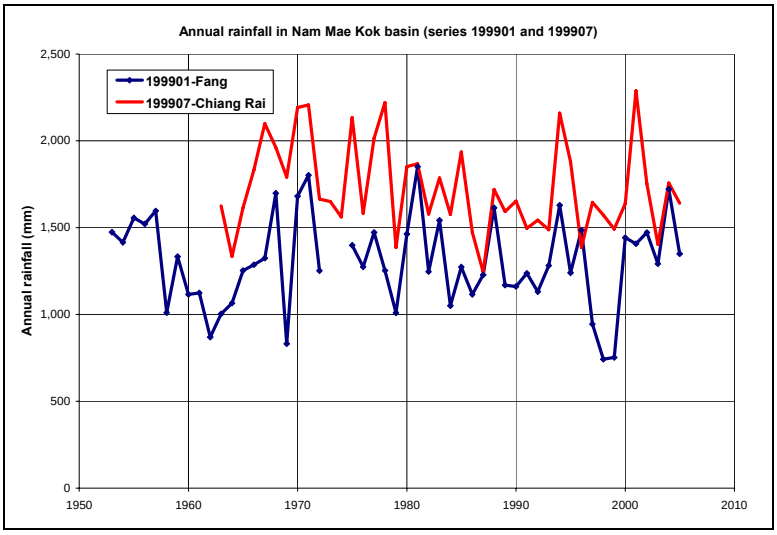


Figure 3.12 Annual rainfall in Nam Mae Kok basin at Fang and Chiang Rai

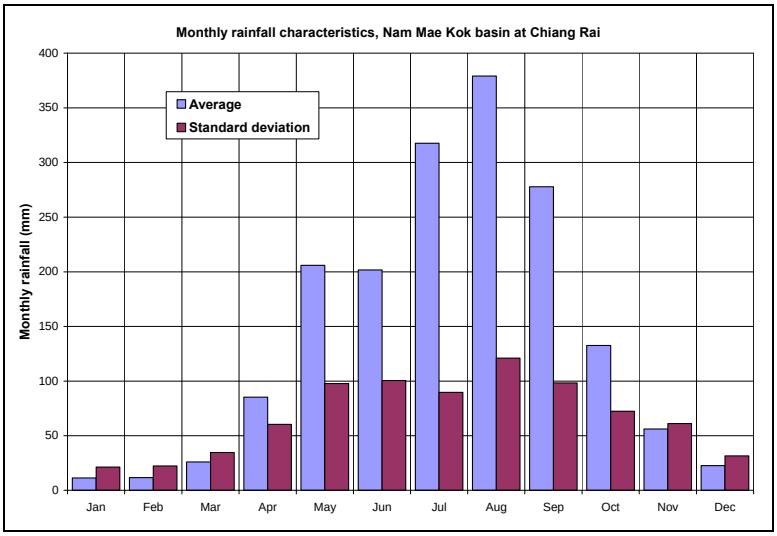


Figure 3.13 Statistics of monthly rainfall at Chiang Rai

Statistics of annual maximum daily rainfall are summarised in Table 3.7 and Figure 3.14. Both EV1 (Gumbel) and GEV–distributions (see Chapter 4 for a description) fit to the annual maxima, with slightly higher values for EV1. According to the distributions the 10-year maximum daily rainfall is about 135 mm, and the 100-year daily rainfall ranges from 170 to 190 mm. Rainfall statistics of shorter duration will be required to evaluate and design the required capacity of the city's sewer system. For analysis of flooding from the river the river discharge and conveyance capacity is of importance.

Table 3.7 Parameters of EV1 and GEV distributions fitted to annual maximum daily rainfall at Chiang Rai and rainfall values for selected return periods

| Parameters | | Return Period | Rainfall (mm) | |
|---|---|---|---|---|
| **Type** | **Value** | **T (years)** | **EV1** | **GEV** |
| EV1 α | 21.4 | 2 | 95 | 97 |
| u | 87.2 | 5 | 119 | 121 |
| GEV k | 0.122 | 10 | 135 | 135 |
| α | 23.7 | 25 | 156 | 151 |
| u | 88.4 | 50 | 171 | 162 |
| | | 100 | 186 | 172 |

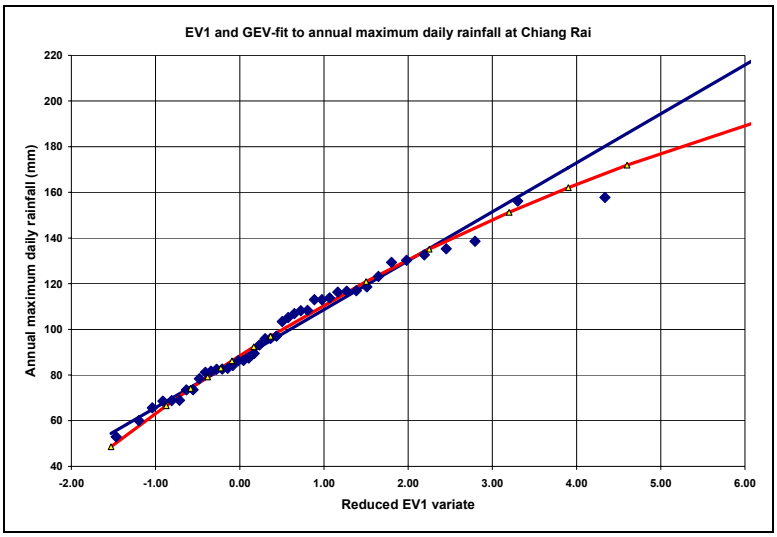


Figure 3.14 EV1 and GEV-fit to annual maximum daily rainfall at Chiang Rai, Period 1963-2005

### 3.6.2 Evaporation

Pan-evaporation data is available in the MRC database for 4 stations in the Nam Mae Kok basin. Average annual totals range from 1330 mm to 1480 mm. FAO-Climwat database indicate annual totals of 1370 mm for reference crop evaporation at Chiang Rai. Highest evaporation occurs in April-May, with about 5 mm/day.

The monthly evaporation data together with the average monthly rainfall for Chiang Rai is presented in Figure 3.15. It is observed that from May to October there is a large water surplus: the average rainfall exceeds the evaporation rate, but in the rest of the year there is a considerable deficit. It is also expected in view of the small storage capacity of the existing reservoirs and the large surplus in the wettest months that the present hydraulic infrastructure will not affect the flood peaks in the rivers.

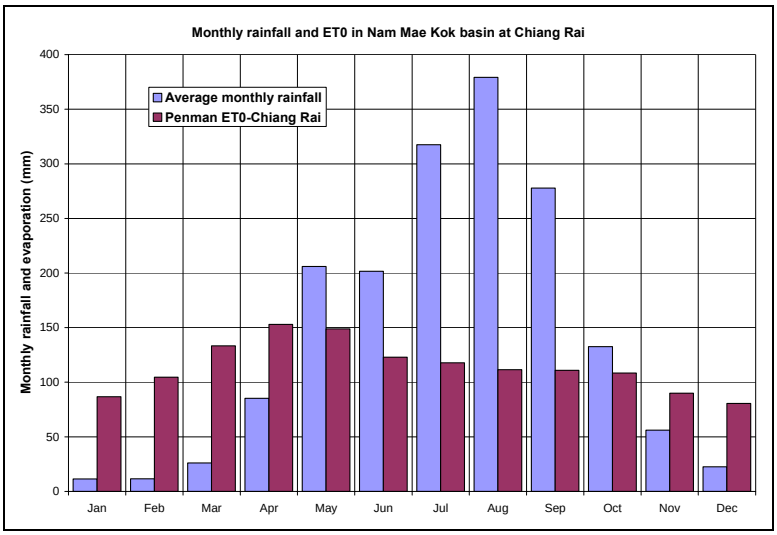


Figure 3.15 Average monthly rainfall and reference evaporation at Chiang Rai

### 3.6.3 Water levels and stage-discharge relations

Water levels are available in the MRC database for 6 gauging stations in the Nam Mae Kok and tributaries, with records from at the earliest 1969 till at the latest 2005. Additional water level data were received to complete the MRC-series up to 2007. The water level series for Ban Pong Na Kham, Ban Mae Phaeng, Ban Pong Pu Fuang were added to the MRC database.

Station Chiang Rai is since the construction of the weir in the early nineties, some 5 km downstream of the measuring location, affected by backwater. Station Ban Tha Sai on Nam Mae Lao is outside the backwater reach of the Nam Mae Kok; the station is at 15.8 km from the mouth and with a river slope of $5.8 \times 10^{-4}$ and an equilibrium depth of 4 m the backwater from the Kok river reaches only to about 7 km from the mouth. However, the Chai Sombat weir on the Nam Mae Lao is located only 3 km downstream of the station, and affects the readings at Ban Tha Sai.

Stages on the Nam Mae Kok and tributaries appear to vary widely for a particular discharge. These variations are found in the stage-discharge relations of basically all stations. A few examples:

- At Chiang Rai the variation in water level for a discharge of 350 $m^3/s$ for the period 1977-1986 is 0.40 m, and for the period 1987-1992 is 0.80 m, whereas for lower discharges the variation is even larger.

- At Ban Tha Ton no gauge change is mentioned in the yearbooks, but the variation in the water level for a discharge of 100 $m^3/s$ is seen to be about 0.75 m, see Figure 3.16. The water level record shows a shift of 1 m on 1/1/2005.

- At Ban Tha Mai Liam, no gauge change is mentioned in the yearbooks, but the variation in the water level for a discharge of 100 $m^3/s$ in the available period amounts 2.20 m.

- At Ban Tha Sai no change is mentioned in the yearbooks, but the variation in the water level for e.g. a discharge of 100 $m^3/s$ is about 0.90 m

Though these variations suggest that not registered changes in the gauge setting may have taken place, from an inspection of the available stage-discharge data it is revealed that sufficient data is available to establish each year a new rating curve. Apparently, the changes can, with a few exceptions only, be attributed to large morphological changes. The large variations from one year to another in the discharge ratings create therefore an additional uncertainty in the computed water levels and should be taken into account as an additional stochastic variable. Its effect can be introduced by adjustment of the hydraulic troughness.

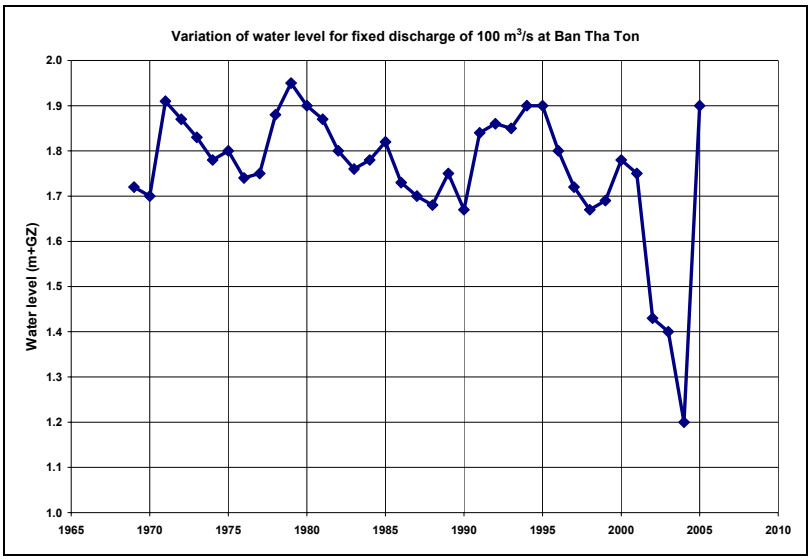


Figure 3.16 Variation in gauge reading for fixed discharge of 100 m3/s in the Nam Mae Kok at Ban Tha Ton

In the frame of the project "Strengthening of Flood Management Capacity for the Kok River in Chiang Rai Province" financed by MRC, which started in 2007, automatic stations at the a number of locations have been implemented. These may provide in future important data for calibration and verification of the hydraulic model. For statistical analysis their series are too short.

### 3.6.4 Discharges

To validate the discharge series double mass analysis has been carried out on the series. Since the rainfall records in the Nam Mae Kok basin showed straight lines on double mass plots, a similar behaviour is expected for the discharge series. In the double mass analysis the series of Ban Tha Ton and Chiang Rai did not show anomalies. However, the series of Ban Tha Mai Liam on Fang compared to Ban Tha Ton shows a break in 1995. Also, the discharge series of Ban Tha Sai on Lao shows a break in 1981 compared to Ban Tha Ton as well as to Ban Tha Mai Liam. One reason may be changing water abstractions as on tributaries of both Fang and Lao rivers reservoirs have been constructed. The series of Ban Pong Pu Fuang can shown to be consistent with the series of Ban Tha Sai. Anomalies were encountered for Ban Pong Na Kham and Ban Mae Phaeng:

- In the series of Ban Pong Na Kham inconsistencies were found for the period 1988-1994, which period coincides with the non-availability of water level data for this site. Apparently, data for this period had been completed by rainfall-runoff modelling.
- The series of Ban Mai Phaeng appears to be entirely inconsistent with the area adjusted sum of the flows at Ban Pong Na Kham and Ban Pong Pu Fuang. Only for a few years a

reasonable match was found. Generally the series is much too high and its peak values are unrealistically large. Since this series was used by Kittipong (2009, page 49)in a water balance analysis to calibrate the lateral inflows from SWAT, it follows that these lateral inflows will be too high as well.

Monthly and annual flow statistics of the Nam Mae Kok at station Chiang Rai (u/s Lao confluence) and Nam Mae Lao at Ban Tha Sai are presented in Table 3.8. Note that the flow series of Chiang Rai has been extended based on records of Ban Tha Ton and Ban Tha Mai Liam, see next chapter. Graphics of the annual flows and of the monthly statistics are shown in Figure 3.17, Figure 3.19 and Figure 3.20. The annual flows show a downward trend in Chiang Rai as well as in Ban Tha Sai. This trend is apparently the result of higher rainfall in the seventies as may be observed from the annual runoff/rainfall ratio which does not show any trend for the same period (see Figure 3.18).

Table 3.8 Monthly and annual flow statistics (in MCM and mm) of the Nam Mae Kok at Chiang Rai and Nam Mae Lao at Ban Tha Sai

| **Chiang Rai** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Year** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean (MCM) | 160.5 | 102.2 | 85.0 | 73.9 | 129.1 | 186.8 | 399.9 | 718.5 | 715.4 | 489.1 | 333.7 | 223.0 | 3617.2 |
| Stdv (MCM) | 32.2 | 20.4 | 18.7 | 18.2 | 60.4 | 58.9 | 151.1 | 249.6 | 182.2 | 118.5 | 93.2 | 58.2 | 725.1 |
| Depth (mm) | 26.5 | 16.9 | 14.0 | 12.2 | 21.3 | 30.8 | 66.0 | 118.6 | 118.1 | 80.7 | 55.1 | 36.8 | 596.9 |
| Stdev (mm) | 5.3 | 3.4 | 3.1 | 3.0 | 10.0 | 9.7 | 24.9 | 41.2 | 30.1 | 19.6 | 15.4 | 9.6 | 119.7 |
| **Ban Tha Sai** | | | | | | | | | | | | | |
| Mean (MCM) | 25.6 | 11.4 | 8.0 | 9.7 | 36.9 | 45.4 | 73.4 | 159.1 | 201.3 | 131.8 | 93.7 | 49.4 | 845.7 |
| Stdv (MCM) | 16.5 | 7.3 | 5.7 | 6.8 | 29.3 | 28.3 | 52.7 | 80.2 | 74.9 | 42.9 | 43.2 | 19.2 | 257.9 |
| Depth (mm) | 8.3 | 3.7 | 2.6 | 3.2 | 12.0 | 14.7 | 23.8 | 51.6 | 65.4 | 42.8 | 30.4 | 16.0 | 274.6 |
| Stdev (mm) | 5.4 | 2.4 | 1.8 | 2.2 | 9.5 | 9.2 | 17.1 | 26.0 | 24.3 | 13.9 | 14.0 | 6.2 | 83.7 |

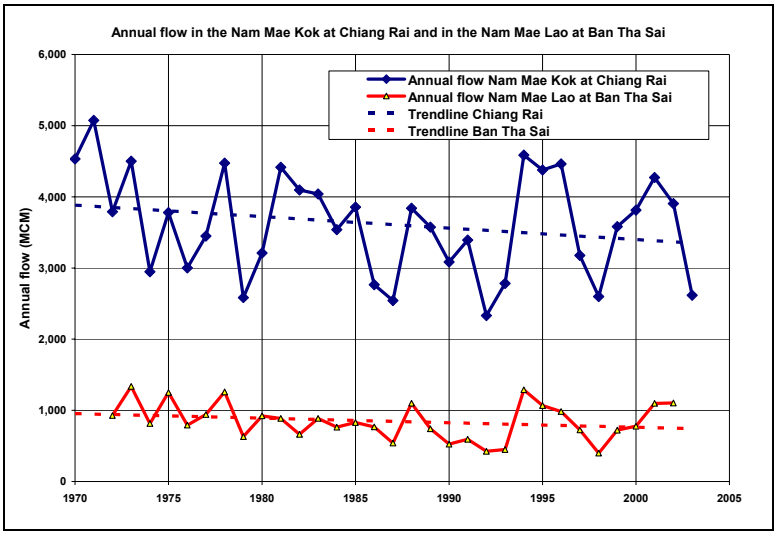


Figure 3.17 Annual runoff in the Nam Mae Kok at Chiang Rai and Nam Mae Lao at Ban Tha Sai

Monthly flows in the Nam Mae Kok at station Chiang Rai are largest in August-September, whereas in the Nam Mae Lao at Ban Tha Sai the maximum flow generally occurs in September. As can be observed from Figure 3.21 the runoff-depth from the Nam Mae Kok at Chaing Rai is larger than of the Nam Mae Lao at Ban Tha Sai. Note that at both locations the flow regime is affected by reservoirs upstream: on Nam Mae Kok at Chiang Rai by reservoirs on tributaries of the Nam Mae Fang and on Nam Mae Lao by tributaries upstream of Ban Tha Sai). Discharge frequency curves of Nam Mae Kok (downstream of Lao

confluence) and Mekong at Chiang Saen are shown in Figure 3.22 and Figure 3.23 with a comparison in Figure 3.24. Special attention is drawn to the latter, which shows that the Mekong peaks slightly ahead of the Nam Mae Kok. This is elaborated further in the next chapter, dealing with the hydrological hazard.

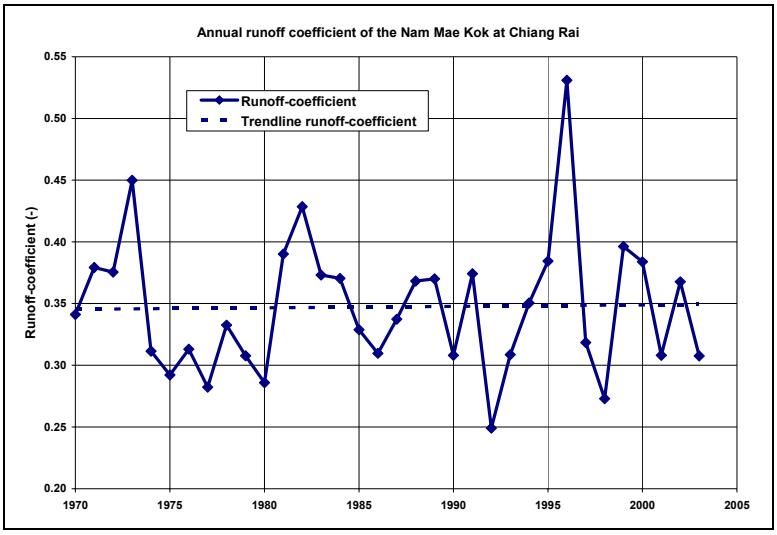


Figure 3.18 Runoff-coefficient of the Nam Mae Kok at Chiang Rai

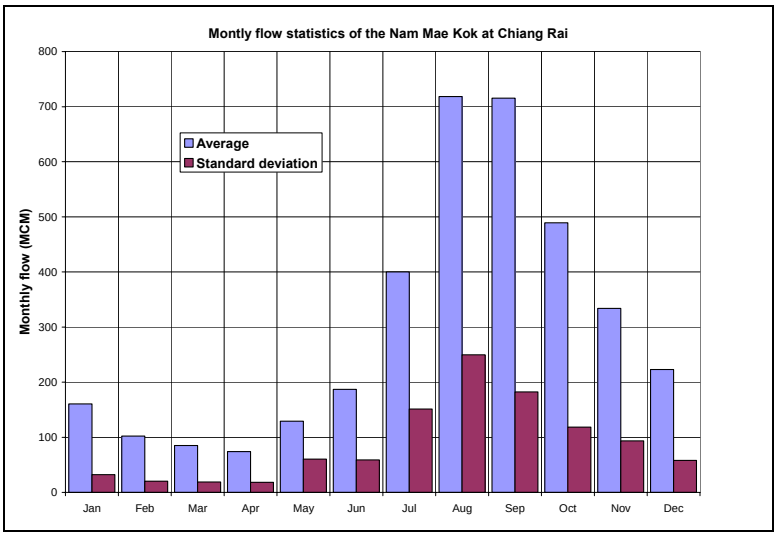


Figure 3.19 Monthly flow statistics of the Nam Mae Kok at Chiang Rai

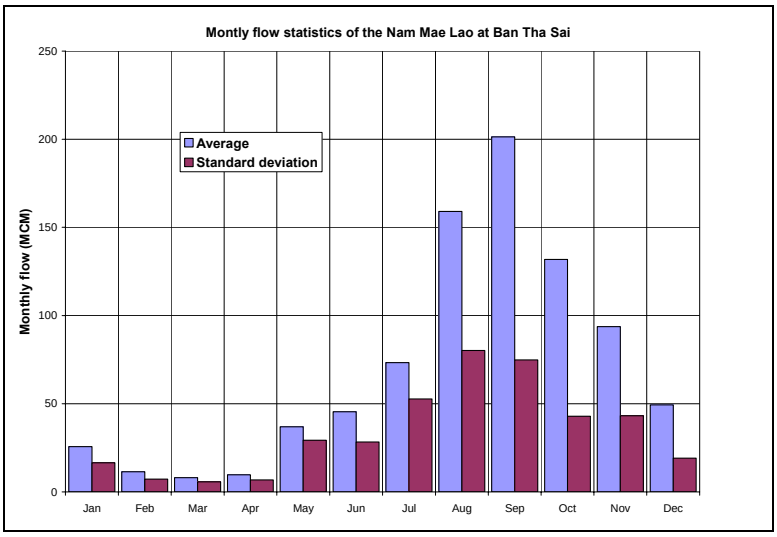


Figure 3.20 Monthly flow statistics of the Nam Mae Lao at Ban Tha Sai

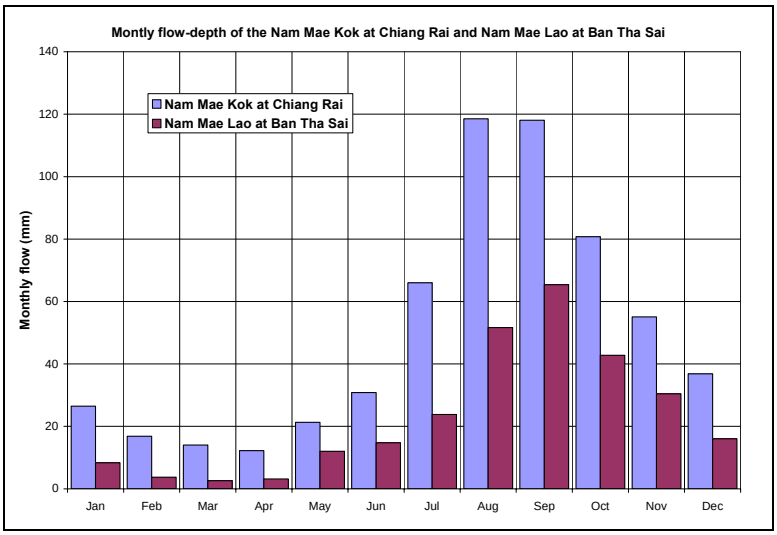


Figure 3.21 Comparison of monthly flow depth in Kok at Chiang Rai and Lao at Ban Tha Sai

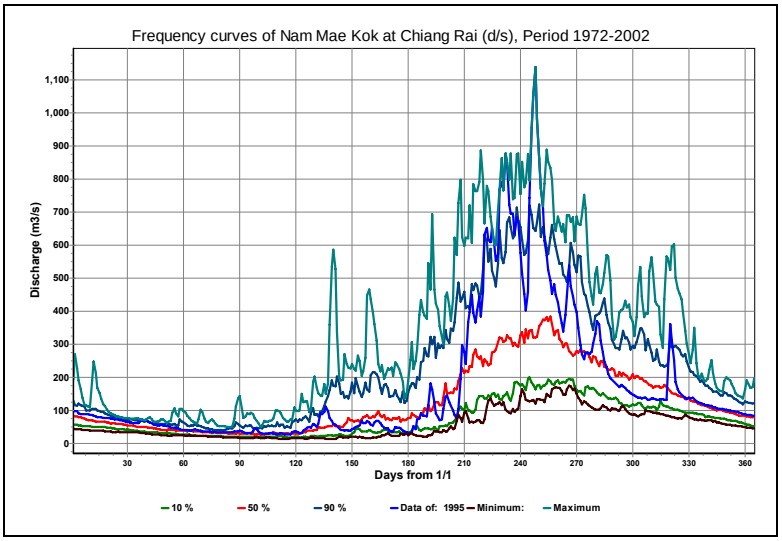


Figure 3.22 Discharge frequency curves Nam Mae Kok d/s Nam Mae Lao, Period 1972-2002

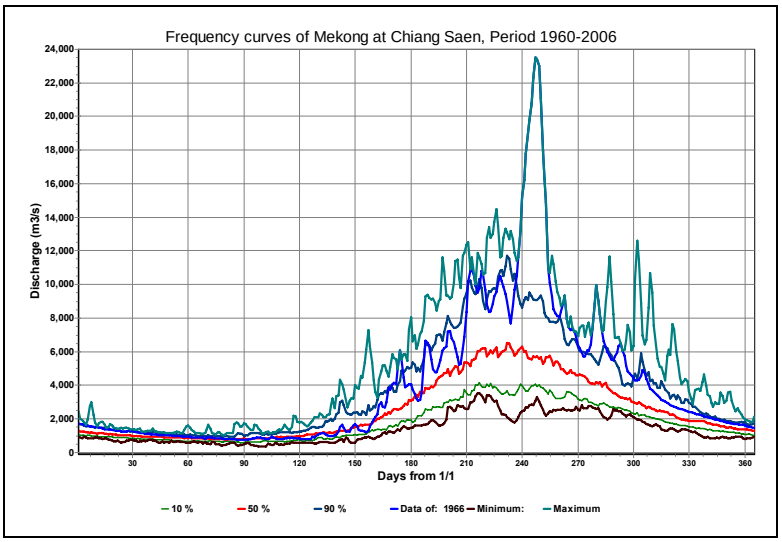


Figure 3.23 Discharge frequency curves Mekong at Chiang Saen, Period 1960-2006

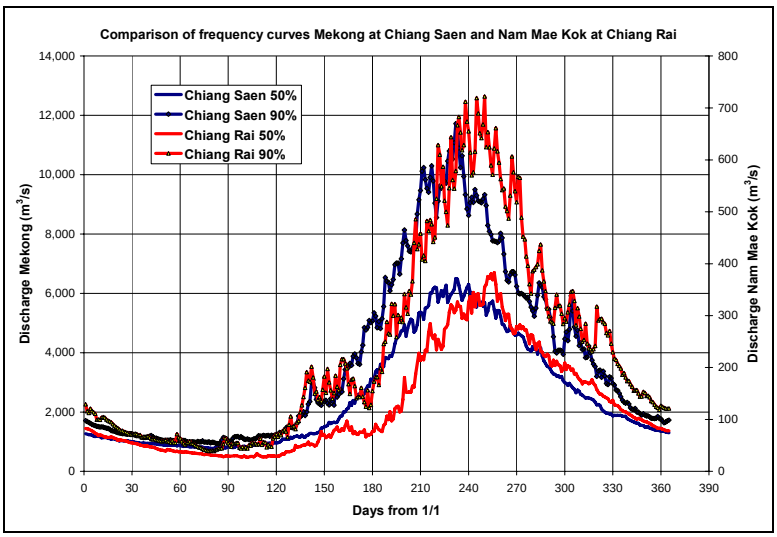


Figure 3.24 Comparison of discharge frequency curves of Mekong at Chiang Saen and Nam Mae Kok d/s of Chiang Rai

# 4 Hydrological hazard

## 4.1 General

The flood hazard in the Nam Mae Kok is derived from the hydrological hazard, i.e. flow probabilities transformed into water levels and flow velocities for selected return periods using a hydraulic model of the river and flood plain. The area of concern is the Chiang Rai region along the Nam Mae Kok and Nam Mae Lao/Nam Mae Korn and the Nam Mae Kok downstream of Chiang Rai up to its confluence with the Mekong. To arrive at the flood hazards the following procedure is advocated:

1. For flood hazard assessment along the Nam Mae Kok in the Chiang Rai region **upstream** of the Lao confluence the analysis can be based on the statistics of the flow in the Nam Mae Kok at station Ban Pong Na Kham. Lateral inflow upstream Chiang Rai weir is from the Nam Korn. The downstream condition is formed by the Chiang Rai Weir formula.
2. For flood hazard assessment along the Nam Mae Kok in the Chiang Rai region **downstream** of the Lao confluence the analysis can be based on the statistics of the total flow in the Nam Mae Kok and Nam Mae Lao at Ban Pong Na Kham and Ban Pong Pu Fuang, corrected for lateral inflow based on drainage areas. For lateral inflow a fraction of the Kok flow at the Lao confluence is taken. The downstream boundary condition is a discharge rating at Sop Kok in the Mekong with an average Mekong hydrograph at Chiang saen
3. For flood hazard assessment along the lower Nam Mae Lao the analysis can be based on the statistics of the flow in the Nam Mae Lao at station Ban Pong Pu Fuang, with for the Nam Mae Kok the flow passing station Chiang Rai at the time of the occurrence of the annual peaks at Ban Pong Pu Fuang, with a similar procedure for the lateral inflow further downstream. The Nam Korn contribution is a derived from Ban Pong Pu Fuang, see under 5.
4. For flood hazard assessment along the lower Nam Mae Kok near to the mouth of the river the combined occurrence of the Nam Mae Kok flow d/s Chiang Rai (Nam Mae Kok + Nam Mae Lao with area correction) and the discharge rating in the Mekong at Sop Kok is considered.
5. The flow in the Nam Korn is proposed to be derived from the flow in the Nam Mae Lao proportional to the areas and corrected for runoff percentages as observed from 2000-2005.

The base of the flood hazard, the hydrological hazard, is elaborated in this chapter.

## 4.2 Nam Mae Kok at Ban Pong Na Kham

### Peak discharge

The flow extremes in the Nam Mae Kok upstream of Chiang Rai at Ban Pong Na Kham have been derived from the annual maximum daily discharge in the period 1967-2007 (see Figure 4.2) as follows:

1. For the periods 1967-1987 and 1995-2007 use has been made of the discharge record of Ban Pong Na Kham.
2. In the original record the data for the period 1988-1994 is missing. The series for this period used by Kittipong (2009) for flood mapping appeared to be inconsistent with the observations at Chiang Rai and the sum of Ban Tha Ton and Ban Tha Mai Liam. Since the series of Chiang Rai and the sum of Ban Tha Ton and Ban Tha Mai Liam are mutually consistent the former has been used to replace Ban Pong Na Kham for the period 1/1/1988-30/11/1993. For the period 1/12/1993-31/12/1994 in view of backwater of the Chiang Rai weir on station Chiang Rai the flow at Ban Pong Na Kham has been estimated from 1.2 x (Ban Tha Ton + Ban Tha Mai Liam). The resulting original and adjusted annual maximum series are shown below.

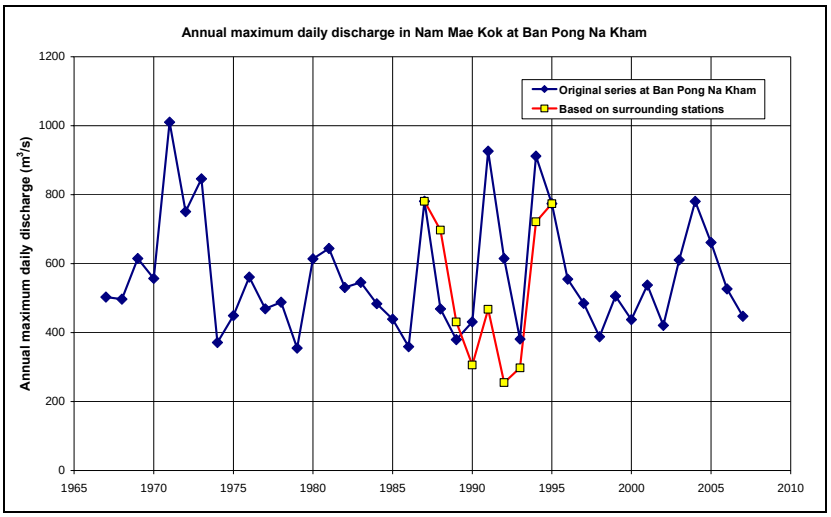


Figure 4.1 Annual maximum daily discharge in Nam Mae Kok at Ban Pong Na Kham, with adjustment based on surrounding stations

Note that the series of annual extreme discharges may not entirely be natural as in the Nam Mae Fang a small part of the discharge is controlled by reservoirs. In-homogeneities in the discharge series caused by reservoir operation are ignored in the following analysis.

EV1 (= Extreme Value Type 1 or Gumbel) and GEV (= General Extreme Value) distributions have been used to fit the observed distribution of annual extreme discharges at Chiang Rai. The distributions have the following form:

$$EV1: \quad F(x) = \exp\left\{-\exp\left[-\left(\frac{x-u}{\alpha}\right)\right]\right\}$$
$$GEV: \quad F(x) = \exp\left\{-\left(1-k\left(\frac{x-u}{\alpha}\right)\right)^{1/k}\right\} \qquad (4.1)$$

where: F(x) = distribution function
k, α, u = shape, scale and location parameters of the distribution

The result, using probability weighted moments (see Cunnane, 1989), is presented in Table 4.1 and Figure 4.2. Tests indicate that the hypothesis of k = 0 (i.e EV1 distribution) is not rejected at a 5% significance level. It may be observed that both distributions give about similar values for the discharges at selected return periods.

It is noted that the tabulated discharges refer to daily average flows. The hazard assessment requires instantaneous maxima. Based on comparison of instantaneous maximum values with daily average values for Ban Pong Na Kham it appears that a correction factor on average of 1.044 is to be applied to the daily average maxima, as shown in Figure 4.3.

Table 4.1 EV1 and GEV-parameters of peak-discharge and values for distinct return periods in the Nam Mae Kok and Nam Mae Lao around Chiang Rai

| Parameter | Nam Mae Kok Ban Pong Na Kham | Nam Mae Lao Ban Pong Pu Faeng | Nam Mae Kok Chiang Rai d/s Lao confluence |
|---|---|---|---|
| years | 1967-2007 | 1971-2007 | 1971-2007 |
| EV1 | | | |
| α | 131.8 | 67.2 | 205.5 |
| u | 464.8 | 153.2 | 635.3 |
| T (years) | | | |
| 2 | 513 | 178 | 711 |
| 5 | 663 | 254 | 944 |
| 10 | 762 | 304 | 1098 |
| 25 | 887 | 368 | 1293 |
| 50 | 979 | 415 | 1437 |
| 100 | 1071 | 462 | 1580 |
| GEV | | | |
| k | 0.034 | -0.160 | 0.065 |
| α | 136.0 | 56.7 | 217.4 |
| u | 466.9 | 149.1 | 641.6 |
| T (years) | | | |
| 2 | 516 | 171 | 720 |
| 5 | 666 | 245 | 952 |
| 10 | 761 | 303 | 1097 |
| 25 | 879 | 386 | 1270 |
| 50 | 963 | 456 | 1391 |
| 100 | 1046 | 534 | 1506 |

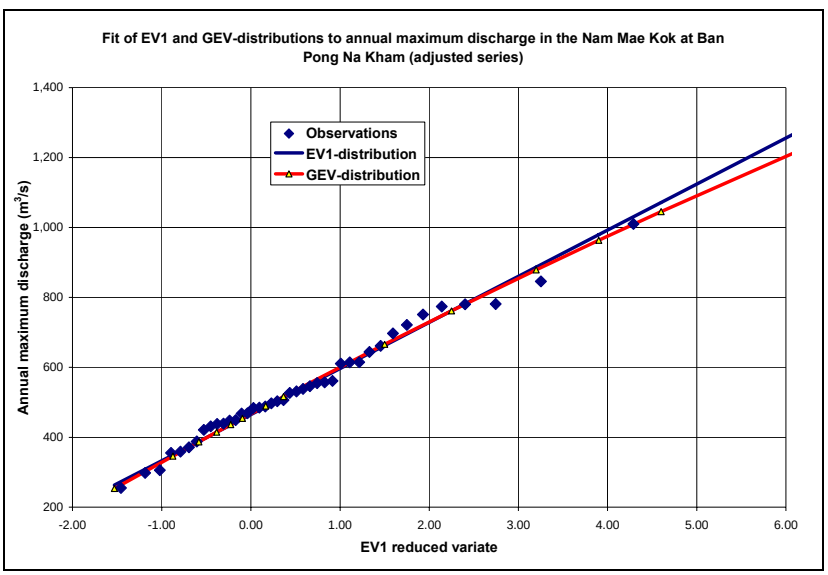


Figure 4.2 Fit of EV1 and GEV-distributions to annual maximum discharge in Nam Mae Kok at Ban Pong Na Kham (adjusted series), Period 1967-2007

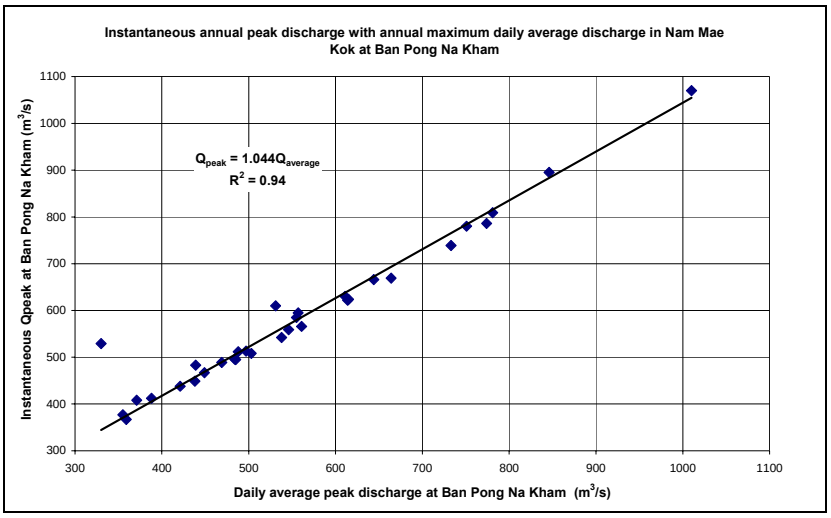


Figure 4.3 Comparison of instantaneous peak discharge and annual maximum daily average discharge in Nam Mae Kok at Ban Pong Na Kham, Periods 1967-1987, 1995-2005

To transform the discharge extremes into water level extremes no use can be made of a discharge rating curve as the water levels in the Nam Mae Kok at Chiang Rai are also controlled by the Chiang Rai weir downstream of the city. Use of a hydraulic model is unavoidable for this location. The annual maximum peaks on the Nam Mae Kok at Ban Pong Na Kham occurred with only a few exceptions in the months August and September, with 1 September as the median occurrence date. There is no relation between peak size and date of occurrence.

## Flood volume and flood shape

Because beside maximum water levels also flood duration is of importance flood volume and flood hydrographs of the Nam Mae Kok at Chiang Rai have been investigated. The relation between flood volume and peak flow has been derived from the annual maximum flow at Ban Pong Na Kham and the flood volume from 15 days before till 15 days after the occurrence of the peak. The relation is shown in Figure 4.4; it has a standard error of 129 MCM.

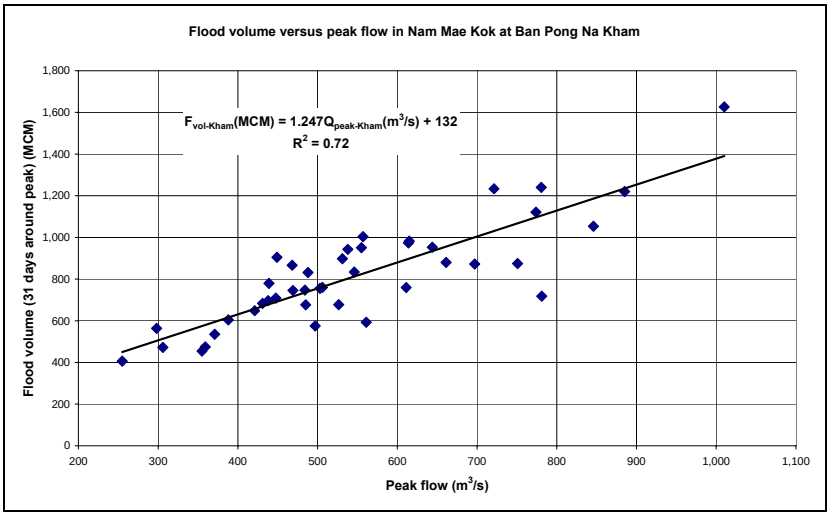


Figure 4.4 Flood volume in Nam Mae Kok at Ban Pong Na Kham as function of daily average peak flow

For defining the hydrograph shape the 20 largest flood peaks since 1966 at Ban Pong Na Kham have been selected, and their shapes from 15 days prior to 15 days after the occurrence of the peak were considered. Each hydrograph has been made dimensionless by dividing the ordinates by their peak value ($Q/Q_{max}(t)$ for t = -15,..,15). Next, for each time t the $Q/Q_{max}(t)$-values were ranked in ascending order and equal ranked values of different times have been combined to arrive at dimensionless hydrographs for 5%, 10%,…,90%, 95% non-exceedance probabilities. Examples of lean, medium and wide hydrographs are shown in Figure 4.5. It is observed that for a median flood wave typically 50% of the peak value is exceeded from 6 days prior to the peak to 6 days after the peak. Hence, the flashiness of tributary floods as observed in the uplands does not exist anymore in the Nam Mae Kok at Chiang Rai.

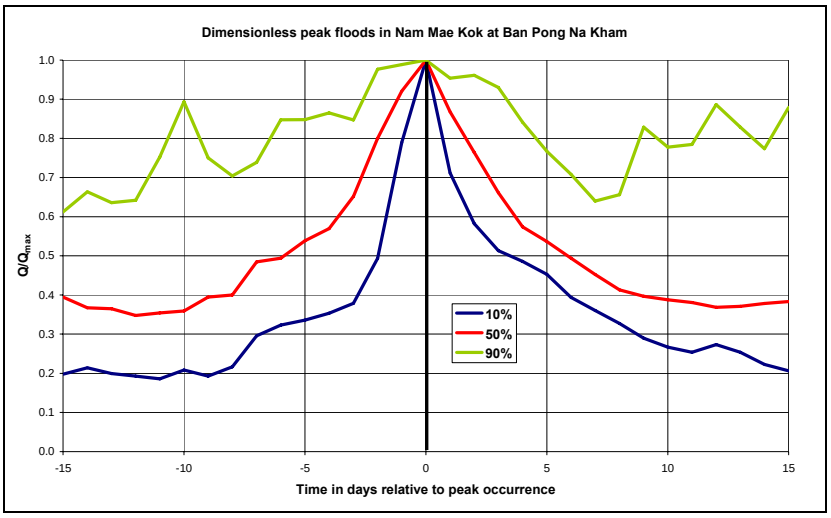


Figure 4.5 Example of dimensionless hydrographs in Nam Mae Kok at Ban Pong Na Kham

## Lateral inflow

Downstream of Ban Pong Na Kham, up to the Chiang Rai weir, the flow in the Nam Mae Kok is augmented with discharge from the Nam Korn. Actual flow records for the Korn are only available for station Ban Pang Rim Korn G4 for the period 4/2000-3/2007. Kittipong (2009) derived lateral inflow to the Korn from rainfall-runoff modelling. The derived inflow appears to be extremely high in comparison to the flow at station G4. At the upstream boundary of the hydraulic model of the Korn the basin area is 114.2 $km^2$. The inflow is taken as 2.3 x G4 and is shown for 2006 in Figure 4.6. The total basin area of the Korn is 162 $km^2$. So the lateral inflow represents the runoff of an urban area of 47.8 $km^2$, i.e less than half of the basin at the model boundary. The lateral inflow for 2006 is also shown in Figure 4.6. The lateral inflow volume from 2000 to 2006 is 2.3 times larger than the upstream inflow (i.e. a 5.5 times higher runoff coefficient), whereas the lateral peak-inflow values are often 4 times larger than the upstream inflow peaks. Also the lateral inflow signal deviates substantially from the recorded upstream inflow. Higher runoff rates per unit area and peak flows are expected in view of the urban terrain but these differences appear to be too large. The lateral inflow as applied by Kittipong (2009) has been based on a water balance between the upstream hydraulic model boundaries and the record of the Nam Mae Kok at Ban Mae Phaeng. But as explained in Section 4.4, the latter series overestimates the actual discharge largely, leading to 2.3 times larger lateral inflow estimates. This scales the

lateral inflow volume down to about the same volume as the upstream inflow volume. The SWAT generated lateral inflow series, however, can shown to be inconsistent with the Lao discharge at Ban Pong Pu Fuang and its peaked ness deviates substantially from the G4-series. In view of this the SWAT-series is completely discarded and the following procedure is proposed for the modelling of the Korn solely:

- The upstream boundary of the Korn is derived from the Ban Pong Pu Fuang series multiplied by a factor 0.16; this series can be shown to provide similar extremes as the original G4 record.
- The lateral inflow to the Korn is taken equal to 0.42 times the upstream inflow accounting for area differences (47.8 versus 114.2 $km^2$); it is assumed that reduced slope further downstream compensates for larger urbanisation (= 0.07 times the flow at Ban Pong Pu Fuang).

So, the total outflow from the Korn into the Kok upstream of Chiang Rai Weir is 0.22 times the flow at Ban Pong Pu Fuang, whereas based on area solely a factor of 0.06 would have been found. Hence, the runoff percentage of the Korn would be almost 4 times larger than of the Lao at Ban Pong Pu Fuang and nearly 2 times larger than of the Kok upstream Chiang Rai. A further investigation into the validity of the G4 record would be required.

For flood hazard assessment along the Kok u/s Chiang Rai weir the model boundary and lateral inflow has to be obtained from Lao hydrographs (see next section) as follows:

- The discharge in Nam Mae Lao during passage of peak in the Nam Mae Kok is on average 185 $m^3/s$ with a standard deviation of 75 $m^3/s$
- The flow volume of the Nam Mae Lao during the passage of the flood in the Nam Mae Kok can be derived from:

$$F_{vol,Fuang} = 0.17\ F_{vol,Kham} + 81 \quad \text{(MCM)} \qquad Se = 70\ \text{MCM} \tag{4.1}$$

where: $F_{vol,\ Fuang}$ = flow volume in Lao at Ban Pong Pu Fuang
$F_{vol,\ Kham}$ = flow volume in Kok at ban Pong Na Kham
Se = standard error about regression

To the above values a multiplier of 0.16 and 0.07 has to be applied for the upstream and lateral inflow respectively.

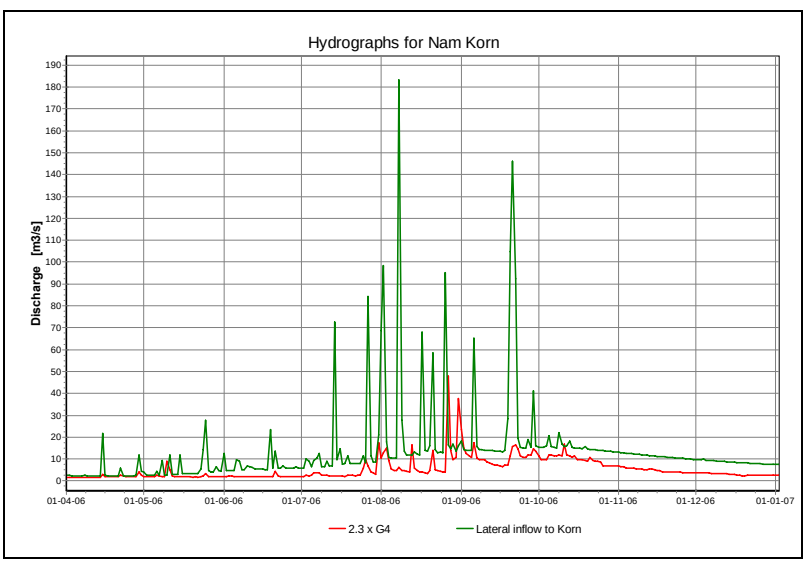


Figure 4.6 Upstream and lateral inflow to hydraulic model of Nam Korn, year 2006

### Downstream boundary

For flood mapping along the Nam Mae Kok in Chiang Rai the hydraulic model results up to Chiang Rai weir are to be used. During extreme floods it is assumed that the gates of the weir will be fully opened. Hence, the weir relation can be applied as a downstream boundary.

### Morphology

The water levels at Ban Pong Na Kham for a discharge of 450 $m^3/s$ have varied historically with about 0.80 m. Relative to the model calibration period the levels for this discharge has been 0.20 m higher to 0.60 m lower. This effect is to be included by adjusting the calibrated Manning n.

## 4.3 Nam Mae Lao at Ban Pong Pu Fuang

### Peak discharge

The annual maximum discharges in the Nam Mae Lao at Ban Pong Pu Fuang have been abstracted from the available discharge series for this station covering the period 1971-2007. The floods peaks are compared with those observed at Ban Tha Sai, further downstream on Nam Mae Lao in Figure 4.7. It is observed that the annual maxima of Ban Pong Pu Fuang are much more pronounced than those at Ban Tha Sai, though the basin area at the latter is about 19% larger (2,585 against 3,080 $km^2$). Inspection of the water level record at the two stations for selected years gives the impression that during peak flows the gauge at Ban Tha Sai has been overtopped a few times, as a constant water level is occasionally observed during the passage of the peaks, see Figure 4.8. However, based on the information gathered during the field visit, overtopping of the embankment between the two sites, limiting the peak flow at Ban Tha Sai in the past (at least prior to 2005), has very likely been the cause of the smooth record. Recent records show more variation at Ban Tha Sai, see Figure 4.9.

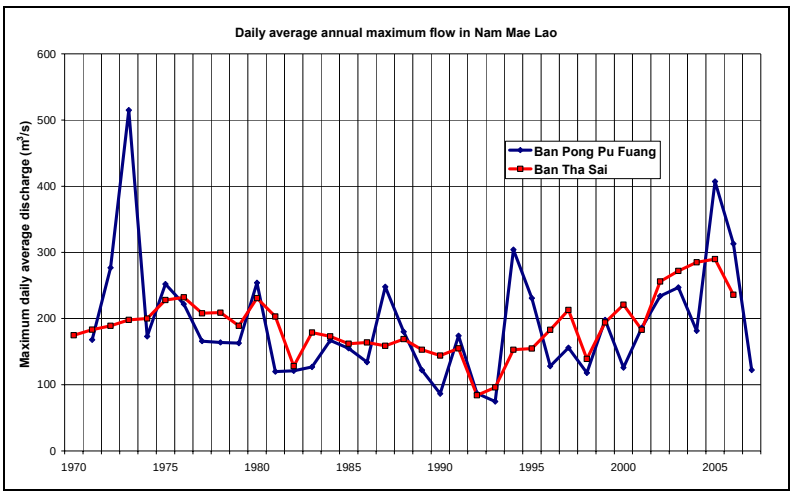


Figure 4.7 Annual maximum discharge in Nam Mae Lao at Ban Pong Pu Fuang and Ban Tha Sai

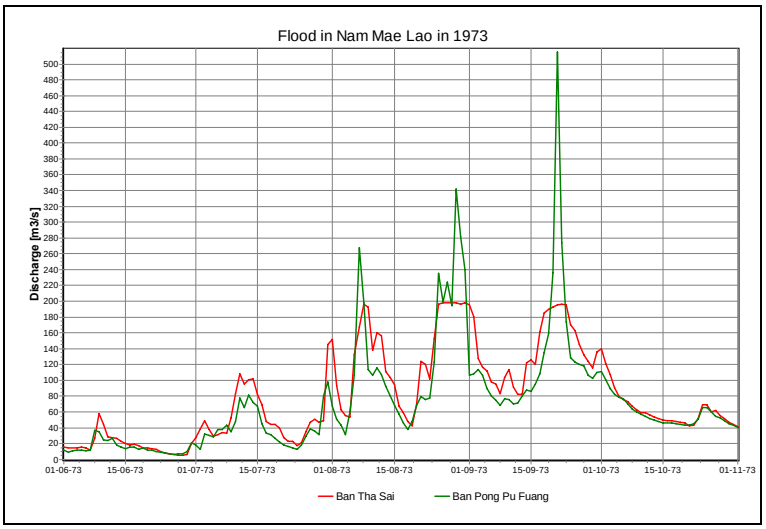


Figure 4.8 Flood hydrographs of Nam Mae Lao at Ban Pong Pu Fuang and Ban Tha Sai, year 1973

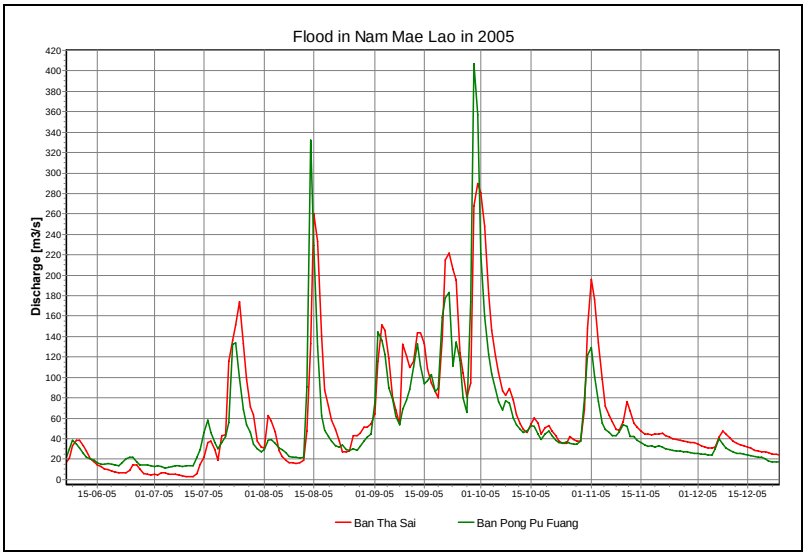


Figure 4.9 Flood hydrographs of Nam Mae Lao at Ban Pong Pu Fuang and Ban Tha Sai, year 2005

It follows that for flood hazard assessment along the Lao the record of Ban Pong Pu Fuang, rather than of Ban Tha Sai has to be used, as Ban Tha Sai has been affected by the flood protection works recently implemented along the lower Nam Mae Lao and its series is therefore inhomogeneous.

Using the existing annual maximum series of Ban Pong Pu Fuang EV1 and GEV distributions have been applied to fit the observed distribution of extremes. The results are presented in Table 4.1 and shown in Figure 4.10. It is observed that the GEV distribution fits better to the data then the EV1 distribution, though the value of the shape parameter of the GEV is still too small to be statistically significant from zero. Nevertheless, preference is given to GEV in this case.

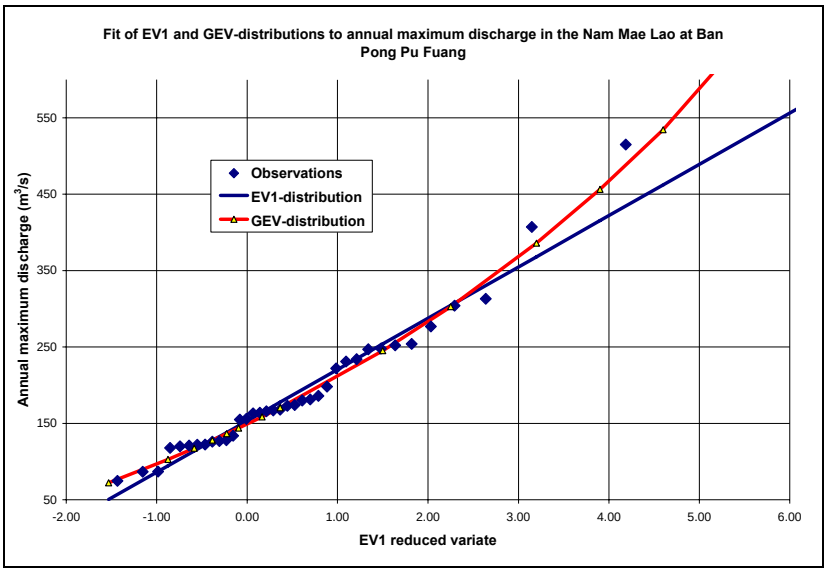


Figure 4.10 Fit of EV1 and GEV-distributions to annual maximum discharge in Nam Mae Lao at Ban Pong Pu Fuang, Period 1971-2007

As for the Nam Mae Kok at Ban Pong Na Kham, a correction has to be applied to account for differences between instantaneous peak discharges and daily averages. From the available instantaneous peak values a correction of 10% to the daily averages is required.

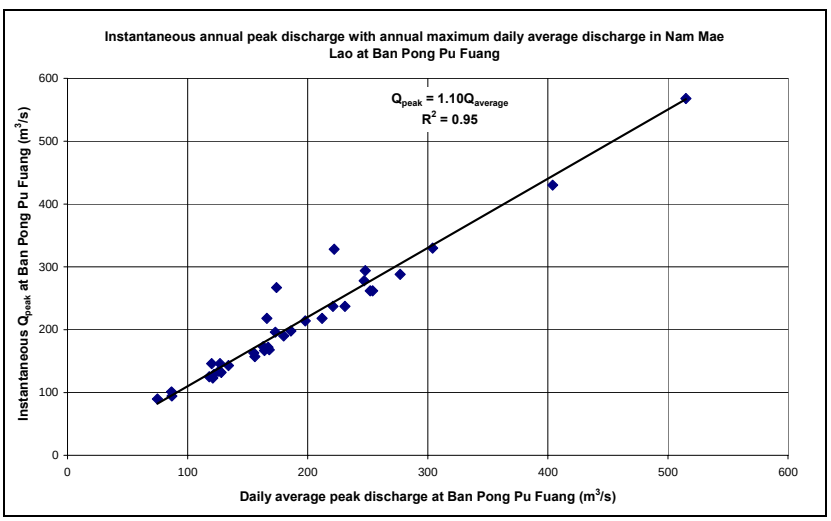


Figure 4.11 Comparison of instantaneous peak discharge and annual maximum daily average discharge in Nam Mae Lao at Ban Pong Pu Fuang, Period 1971-2005

Some 85% of the peaks on the Nam Mae Lao occur in the months August and September, with 7 September as average occurrence date. Occasionally, peaks occur in June/July and in November. There is no relation between the peak size and the day of occurrence of the peak.

## Flood volume and flood shape

For estimation of the flood duration the flood volume and flood hydrographs of the Nam Mae Lao at Ban Pong Pu Fuang have been investigated. The relation between flood volume and peak flow has been derived from the annual maximum flow at Ban Pong Pu Fuang and

the flood volume from 15 days before till 15 days after the occurrence of the peak. The relation is shown in Figure 4.12. The standard error of the presented relation is 55 MCM.

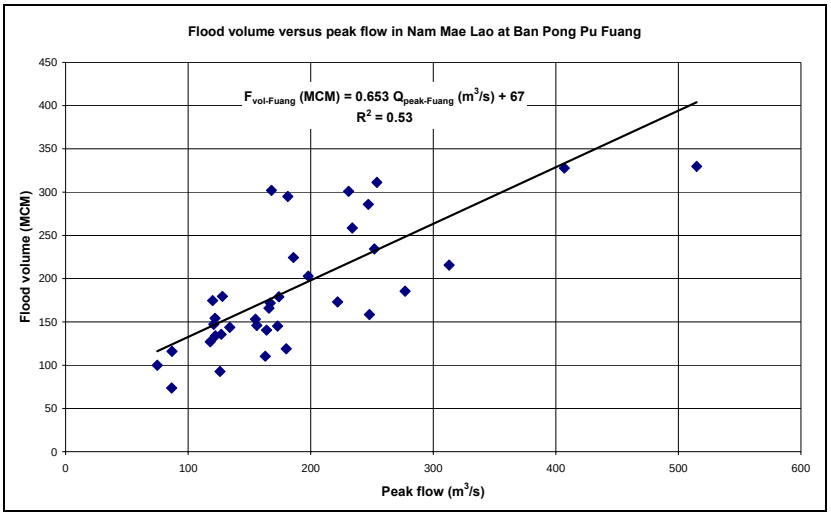


Figure 4.12 Flood volume versus peak flow in Nam Mae Lao at Ban Pong Pu Fuang

The shapes of the flood hydrographs have been derived from the shapes of the 20 largest annual floods in the Nam Mae Lao. The procedure to get the 5%, 10%, etc. hydrograph shapes has been explained in Section 4.2. Examples of lean, medium and wide hydrographs are shown in Figure 4.13. It is observed that for a median flood wave typically 50% of the peak value is exceeded from 2 days prior to the peak to 3 days after the peak, i.e. not very flashy, though it is also seen that the lean floods in Lao have a rather flashy character.

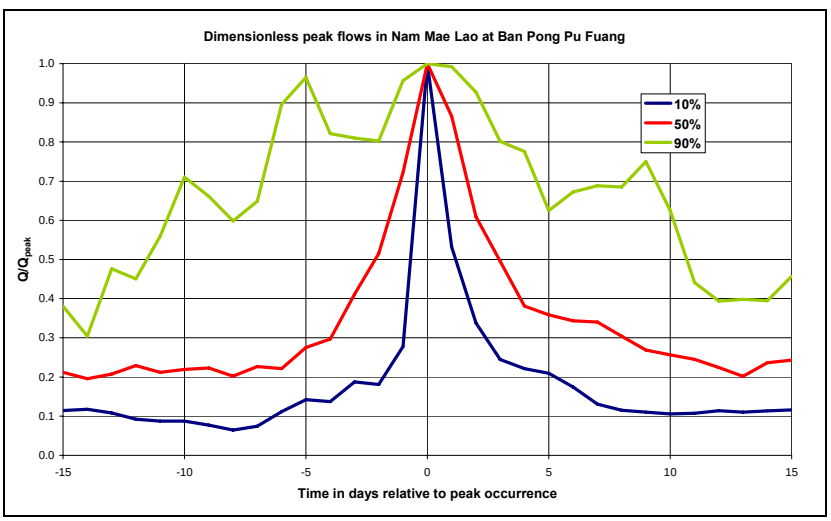


Figure 4.13 Example of dimensionless hydrographs in Nam Mae Lao at Ban Pong Pu Fuang

## Lateral inflow

For calculating the flood levels along the Nam Mae Lao in the Chiang Rai region the conditions in the Nam Korn have to be available as well as the flow over the Chiang Rai weir from the Nam Mae Kok.

The flow of the Nam Korn as used by Kittipong (2009) was discussed in Section 4.2 was found not suitable. The proposed procedure presented in that section is to be applied here as well.

The peak flow in the Nam Mae Lao and the flow in the Nam Mae Kok at the time of the Lao peak hardly correlate. The flow volume in the Nam Mae Kok during the passage of the peak hydrograph in the Nam Mae Lao, however, correlates better as shown in Figure 4.14. Once the volume in the Nam Mae Kok is determined from the flood volume in the Nam Mae Lao a corresponding flow value in the Nam Mae Kok when the peak passes Ban Pong Pu Fuang is obtained from Figure 4.15.

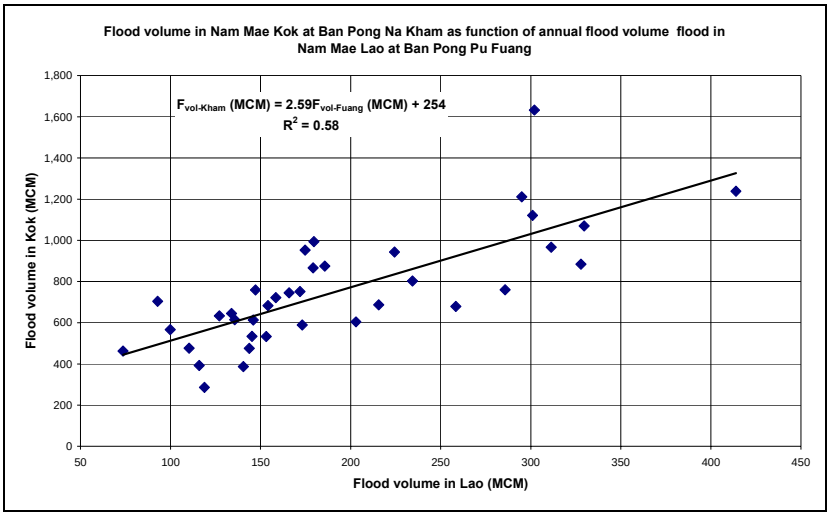


Figure 4.14 Flow volume in Nam Mae Kok at Ban Pong Na Kham during occurrence of peak flow in Nam Mae Lao

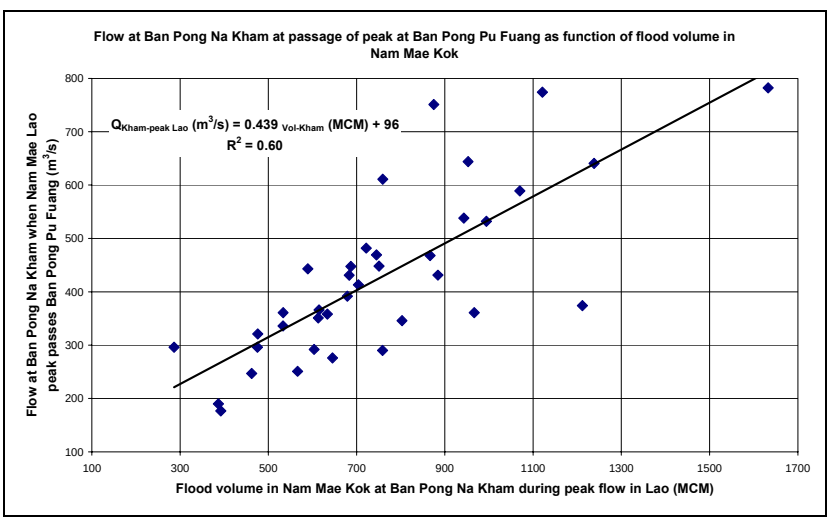


Figure 4.15 Flow in Nam Mae Kok when peak in Lao passes Ban Pong Pu Fuang as function of flow volume in Nam Mae Kok

By using the flood hydrograph shapes for the Nam Mae Kok as derived in Section 4.2 with the above derived "peak"-flow and flow volume in the Kok the boundary at Ban Pong Na Kham is known. From Ban Pong Na Kham till Chiang Rai weir a lateral inflow of 0.029 times the flow at Ban Pong Na Kham is to be applied. Between the Lao-Kok confluence and Ban Mae Phaeng a lateral inflow equal to 0.113 times the sum of the flow from the Kok at

Chiang Rai weir, the Lao at confluence and the flow from the Korn is applied and from Ban Mae Phaeng to the Mekong 0.027 times the said sum.

### Downstream boundary

Since the Mekong does not create backwater on the Kok at the Lao confluence a constant water level may be assumed at the Kok mouth.

### Morphology

The water levels at Ban Pong Pu Fuang for a discharge of 250 $m^3/s$ have varied historically with about 1.90 m. Relative to the model calibration period the levels for this discharge has been 0.70 m higher to 1.20 m lower. This effect is to be included by adjusting the calibrated Manning n.

## 4.4 Nam Mae Kok d/s Nam Mae Lao confluence

### General

The flood levels in the Nam Mae Kok d/s of the Nam Mae Lao confluence but upstream of the backwater reach of the Mekong are determined the discharge and the conveyance capacity of the river. The discharge series of the Nam Mae Kok downstream of the Nam Mae Lao confluence can be derived from the sum of the series of Ban Pong Na Kham (1966-2007) on the Kok and of Ban Pong Pu Fuang (1971-2007) on the Lao, corrected for area, resp. 1.041 and 1.268. By adding the two discharge time series account is given to non-coincidence of peaks on the two rivers. In this way a discharge series covering the years 1971 to 2007 is created. (Note that in view of uncertainties in the Korn record its possible relative larger contribution to the Kok flow has been discarded)

In this section of the river Kok since 1994 also station Ban Mae Phaeng is in operation, which controls a drainage area of 10,474 $km^2$ (for comparison: at the Kok/Lao confluence the drainage area equals 9,410 $km^2$). However, a comparison of the combined Kok and Lao series with the latter reveals that the flow in the Nam Mae Kok as observed at Ban Mae Phaeng with a few exceptions highly overestimates the discharge of the Nam Mae Kok. For 1996 the adjusted sum of the flow at Ban Pong Na Kham and Ban Pong Pu Fuang is in close agreement with the series of Ban Mae Phaeng. But for most other years there is a grave inconsistency, compare e.g. Figure 4.16 with Figure 4.17. In Figure 4.18 the result of a double mass analysis on the daily flow in the Nam Mae Kok at Ban Mae Phaeng and at Lao confluence is presented: a significant deviation from a straight line is observed. As mentioned in Section 4.2 the Ban Mae Phaeng series has been used by Kittipong (2009) to scale the SWAT-runoff for lateral inflow to the hydraulic model. Generally, for the entire period 1994-2007 the flow at Ban Mae Phaeng is 25% too large.

Above observations imply that Kittipong (2009) applied a lateral inflow which is 2.3 times the required inflow. This explains the unrealistic lateral inflow for the Nam Korn as discussed in Section 4.2. Also, by calibration on observed water levels it follows that the

Manning roughness values in this reach of the river have been underestimated by overestimating the discharge.

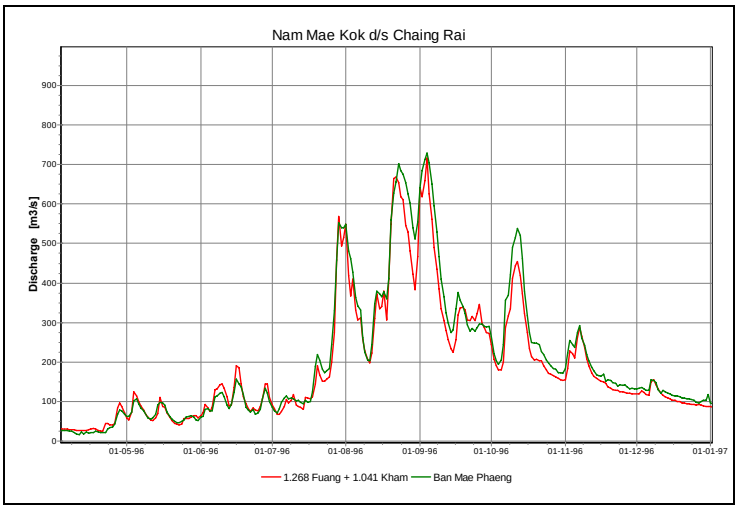


Figure 4.16 Nam Mae Kok at Lao confluence and at Ban Mae Phaeng, Year 1996

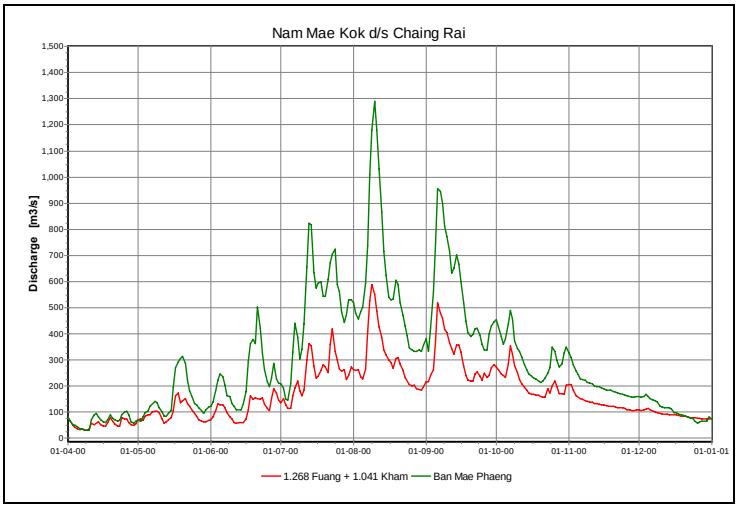


Figure 4.17 Nam Mae Kok at Lao confluence and at Ban Mae Phaeng, Year 2000

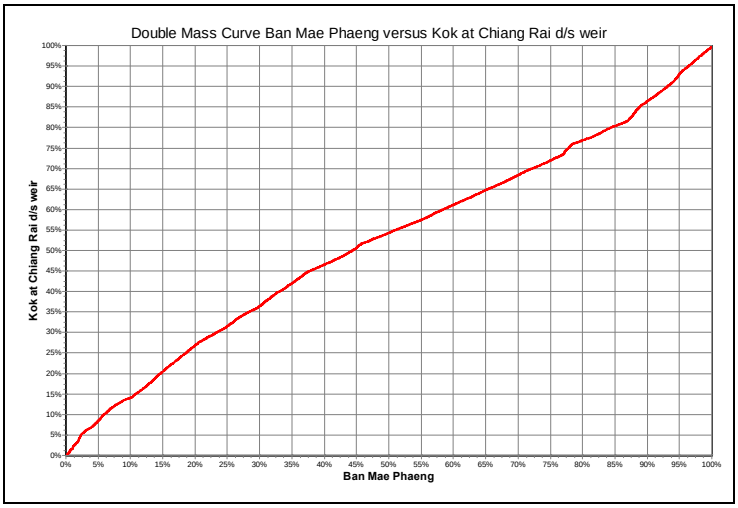

Figure 4.18 Double mass curve of discharge in Nam Mae Kok at Ban Mae Phaeng and at Lao confluence for years 1994-2007

## Peak discharge

In view of above discussed validation, the Ban Mae Phaeng series was discarded and the annual maximum daily discharge for the Nam Mae Kok downstream of Chiang Rai weir has been extracted from the combined Kok and Lao series at Lao confluence. These series are compared with those at Ban Pong Na Kham and Ban Pong Pu Fuang in Figure 4.19. A strong correlation with the peaks at Ban Pong Na Kham is observed from Figure 4.20. The combination leads to 39% higher values downstream of the Lao confluence on average than observed at Ban Pong Na Kham. Estimated based on the increase of area (see Section 4.5.3) a 42% higher value at the confluence than in Ban Pong Na Kham is calculated.

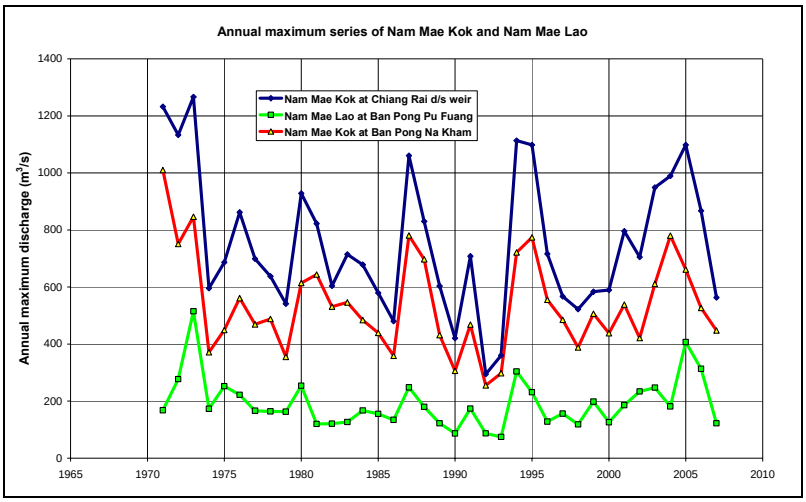


Figure 4.19 Annual maximum series of daily average discharge in Nam Mae Lao at Ban Pong Pu Fuang and Nam Mae Kok at Ban Pong Na Kham and at Lao confluence

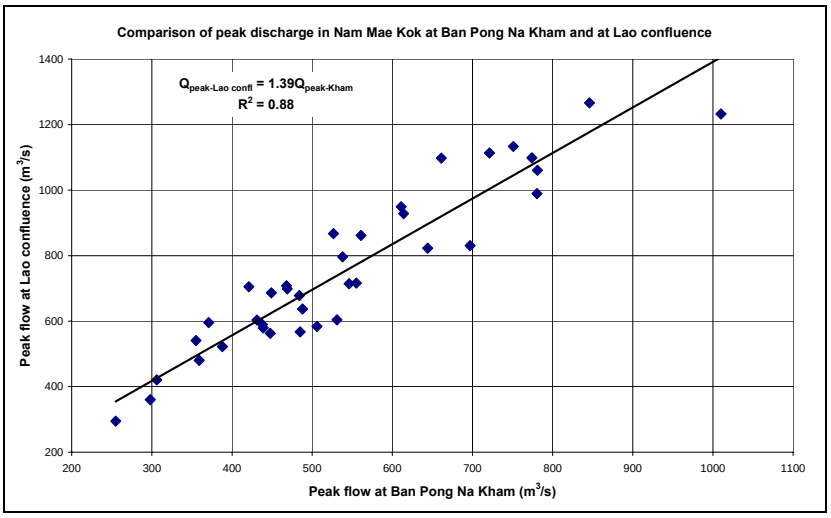


Figure 4.20 Comparison of annual maximum daily average discharges in nam Mae Kok at Ban Pong Na Kham and at Loa confluence

The fit of the EV1 and GEV-distributions to the annual extremes for the Nam Mae Kok at Lao confluence is presented in Figure 4.21. Best fit is obtained with the GEV-distribution, though the k = 0 hypothesis for applicability of EV1 is not rejected at a 5% significance level. The numerical results are presented in Table 4.1.

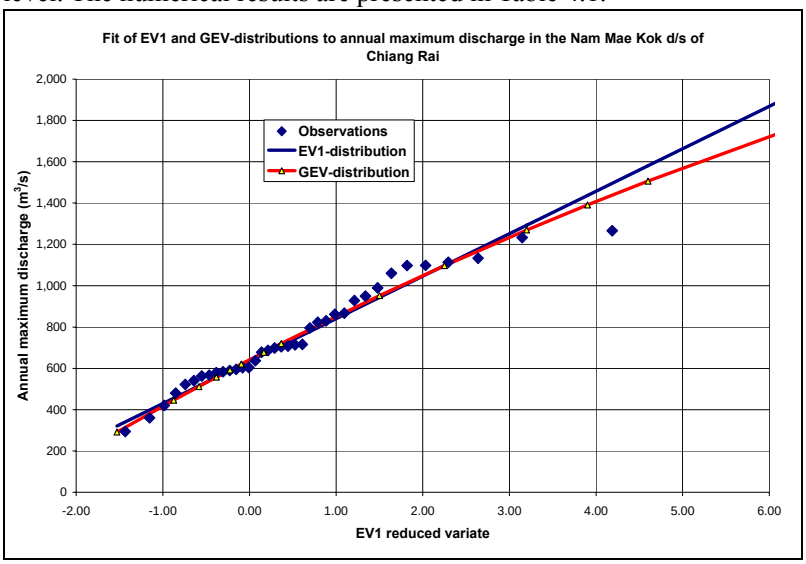


Figure 4.21 Fit of EV1 and GEV-distributions to annual maximum discharge in Nam Mae Kok downstream Chiang Rai weir and Nam Mae Lao confluence, period 1971-2007

It may also be observed from the table that discharge for a distinct return period from this combined series is smaller than the sum of the discharge extremes of the individual contributions, indicating that peak discharges on the two rivers may not occur on the same day. The differences between the sum of the individuals and the combined series according to the GEV-distributions are shown in Figure 4.22 as a function of the return period.

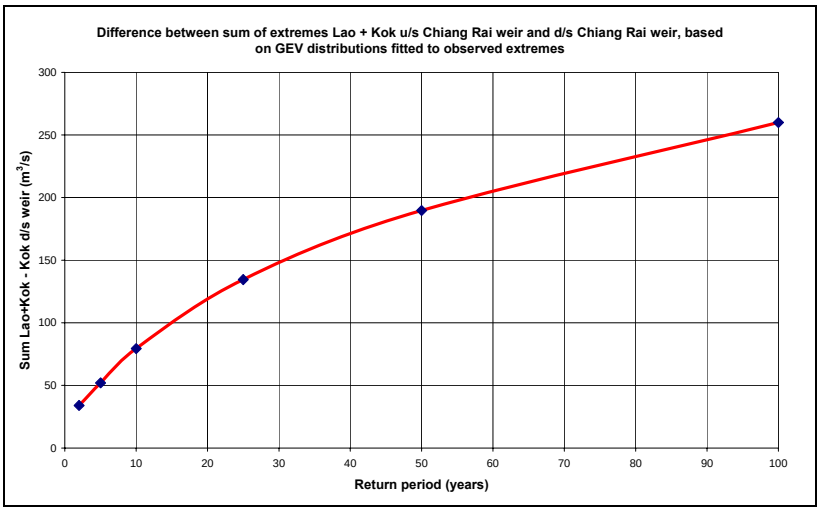


Figure 4.22 Reduction of combined peak discharge d/s Chiang Rai relative to sum of upstream Kok and Lao peaks as a function of return period

## Flood volume and flood shape

Flood volume and hydrographs shape have been analysed similar to the Nam Mae Kok upstream of the Lao confluence and the Nam Mae Lao sec to determine flood duration and related damages. The flood volume refers to the volume from 15 days prior to 15 days after the annual maximum peaks. The flood volume as function of the flood peak is shown in Figure 4.23. The standard error of estimate of te relation is 190 MCM. Characteristic shapes of lean, medium and wide hydrographs are shown in Figure 4.24.

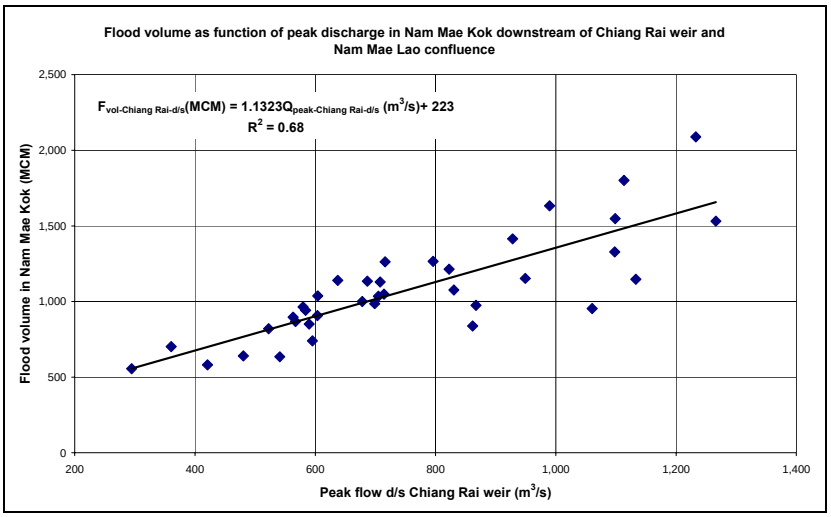


Figure 4.23 Flood volume versus peak flow in Nam Mae Kok at Lao confluence

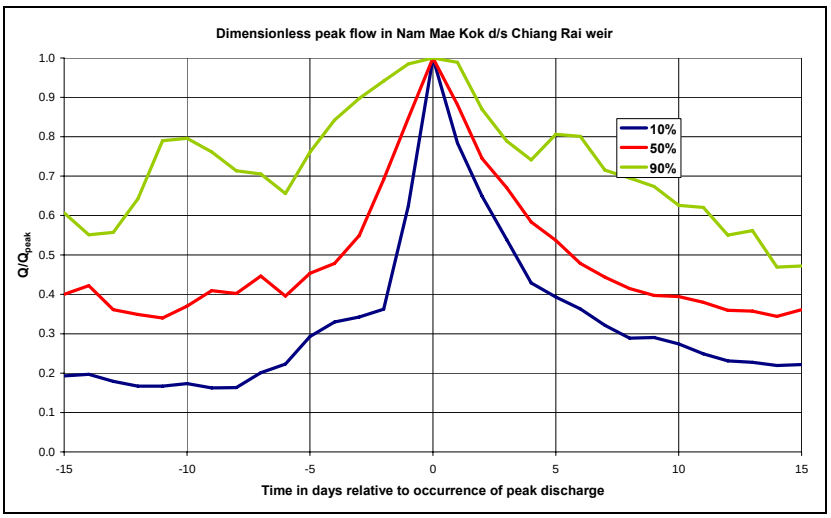


Figure 4.24 Example of dimensionless hydrographs in Nam Mae Kok at Lao confluence

## Lateral inflow

The lateral inflow downstream of the Lao confluence can be taken in proportion to the added area, similar to the procedure proposed in Section 4.3: between the Lao-Kok confluence and Ban Mae Phaeng a lateral inflow equal to 0.113 times the flow at the

confluence and from Ban Mae Phaeng to the Mekong 0.027 times the flow at the confluence is to be applied.

### Downstream boundary

Since the Mekong does not create backwater on the Kok in the concerned reach a representative stage-discharge relation may be assumed in the Mekong at the Kok mouth, see Section 4.5, with an average Mekong regime at Chiang Saen.

## 4.5 Mekong – Nam Mae Kok confluence

At the confluence of the Nam Mae Kok with the Mekong the joint occurrence of water levels in the Mekong and discharge from the Nam Mae Kok at mouth determines the flood hazard. The components of this bi-variate distribution will be elaborated in this section. The water levels in the Mekong at the Nam Mae Kok confluence can be obtained from station Sop Kok. However, this station is not in operation anymore and the length of the series is too short for statistical analysis. But the water levels at Sop Kok correlate well with the nearby station Chiang Saen, which is in operation since 1960. It implies that statistics of peak flows and flood volumes will be elaborated for station Chiang Saen and the results will be translated to Sop Kok using a stage-relation curve.

### 4.5.1 Mekong at Chiang Saen

A flow record for the period 1960-2006 is available for Chiang Saen, the first discharge station in the Lower Mekong basin. Annual maximum discharges and annual flood volume (period June-November) have been extracted from the series. The time-series of peaks and flood volumes is presented in Figure 4.25. The series do not show any trend; peak flow values are generally between 5,000 and 15,000 $m^3/s$, whereas the flood volumes range from 40,000 to 85,000 MCM on average. Only in 1966 and 1971 these ranges were substantially exceeded. From the graph it is observed that the peak flows and flood volumes are correlated. However, Figure 4.26 shows that for a particular peak discharge the flood volume, and consequently the flood duration, may vary considerably. In view of this, the bi-variate distribution of peak flows and flood volume will be considered as well.

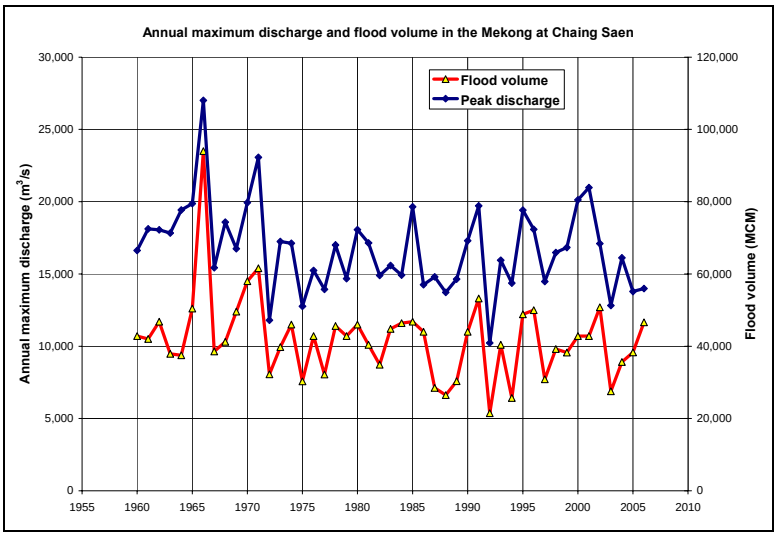


Figure 4.25 Annual maximum discharge and flood volume in the Mekong at Chiang Saen

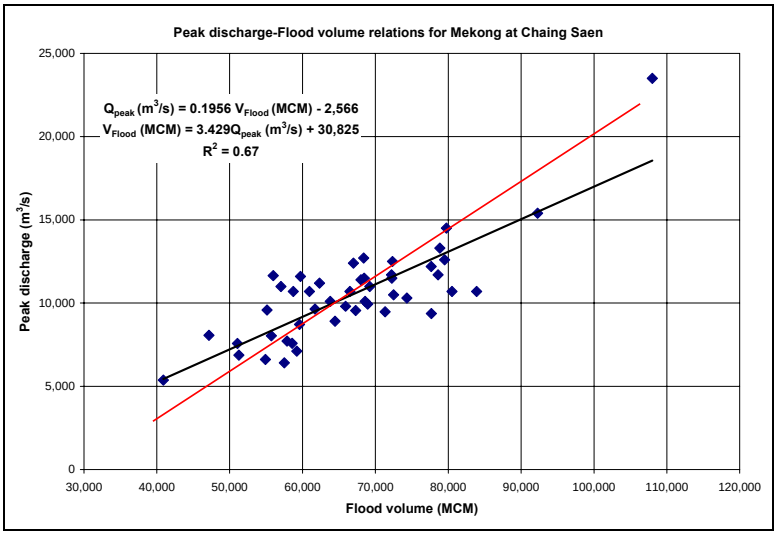


Figure 4.26 Peak discharge – Flood volume relations for the Mekong at Chiang Saen

## Peak discharge

The EV1 and GEV-distributions have been used to fit the observed distribution of annual maximum discharge in the Mekong at Chiang Saen. The computational results have been presented in Table 4.2 and are shown in Figure 4.27.

Table 4.2 EV1 and GEV-parameters of peak-discharge ($m^3/s$) and flood volume (MCM) distributions and values for distinct return periods in the Mekong at Chiang Saen and Nam Mae Kok near the mouth

| Parameter | Peak discharge in Mekong ($m^3/s$) | Flood volume in Mekong (MCM) | Peak discharge Nam Mae Kok ($m^3/s$) | Flood volume Nam Mae Kok (MCM) |
|---|---|---|---|---|
| years | 1960-2006 | 1960-2006 | 1971-2007 | 1971-2007 |
| EV1 | | | | |
| α | 2,126 | 9,895 | | 849.3 |
| u | 9,289 | 61,173 | | 3,685 |
| T (years) | | | | |
| 2 | 10,068 | 64,800 | 784 | 3,997 |

| | | | | |
|---|---|---|---|---|
| 5 | 12,478 | 76,015 | 1,041 | 4,959 |
| 10 | 14,074 | 83,440 | 1,211 | 5,597 |
| 25 | 16,090 | 92,823 | 1,426 | 6,402 |
| 50 | 17,585 | 99,783 | 1,585 | 6,999 |
| 100 | 19,070 | 106,692 | 1,743 | 7,592 |
| | | GEV | | |
| k | 0.096 | 0.1108 | | 0.049 |
| α | 2,307 | 10,854 | | 886.5 |
| u | 9,387 | 61,701 | | 3,705 |
| T (years) | | | | |
| 2 | 10,217 | 65,599 | 795 | 4,027 |
| 5 | 12,608 | 76,701 | 1,050 | 4,987 |
| 10 | 14,054 | 83,320 | 1,210 | 5,595 |
| 25 | 15,737 | 90,933 | 1,400 | 6,331 |
| 50 | 16,890 | 96,087 | 1,534 | 6,856 |
| 100 | 17,960 | 100,820 | 1,661 | 7,360 |

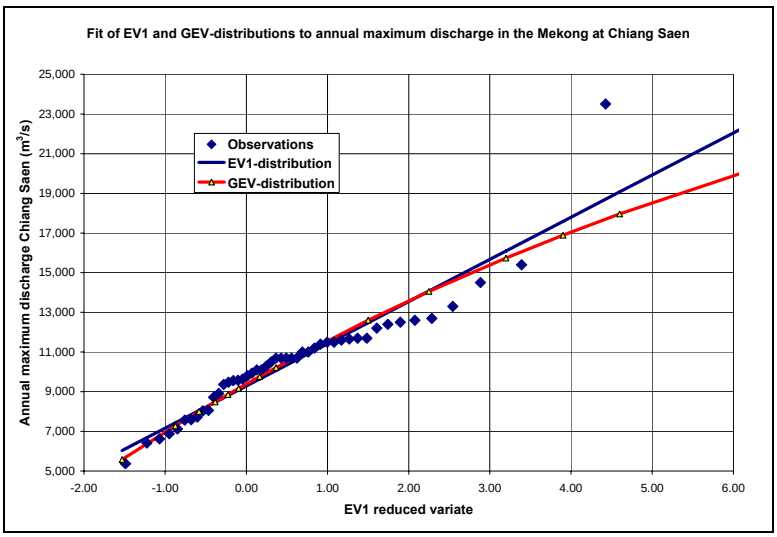


Figure 4.27 Fit of EV1 and GEV-distributions to annual maximum discharge in Mekong at Chiang Saen, period 1960-2006

From the graph it is observed that both distributions fit reasonably, but the value for the year 1966 is an extreme outlier; its return period according to EV1 and GEV amounts respectively 800 and 10,000 years.

## Flood volume

Similar to the procedure for the annual maximum discharge the distribution of the annual flood volume (flow volume in the period 1 June – 30 November) has been fitted to EV1 and GEV-distributions. The parameters and flood values for selected return periods are presented in Table 4.2, and graphically displayed in Figure 4.28. Like for the annual maximum discharge here also the EV1 as well as the GEV functions fit to the observed flood volume distribution. The latter distribution leads to lower values of flood volumes for the selected return periods.

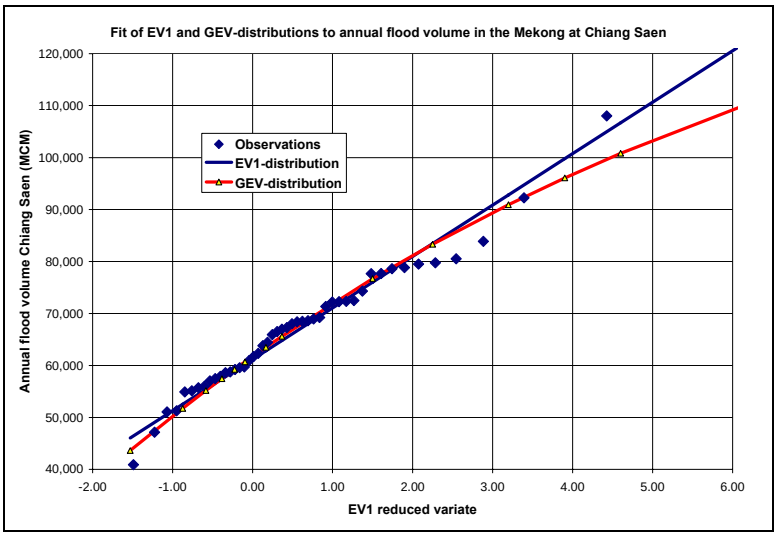


Figure 4.28 Fit of EV1 and GEV-distributions to annual flood volume (June-November) in Mekong at Chiang Saen, period 1960-2006

## 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 (see Figure 4.26):

$$\begin{aligned} X &= a_{x,y} + b_{x,y} Y \\ Y &= a_{y,x} + b_{y,x} X \end{aligned} \qquad (4.2)$$

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

$$\begin{aligned} X_j^{\#} &= a_{x,y} + b_{x,y} Y_j^{\#} + u_x + \frac{\alpha_x}{k_x}\left\{1-(-\ln(R_1))^{k_x}\right\} \\ Y_{j+1}^{\#} &= a_{y,x} + b_{y,x} X_j^{\#} + u_y + \frac{\alpha_y}{k_y}\left\{1-(-\ln(R_2))^{k_y}\right\} \end{aligned} \qquad (4.3)$$

The coefficients of the equations (4.2) and (4.3) and the distribution parameters are presented in Table 4.3. The fits to the residuals are shown in Figure 4.29 and Figure 4.30. It may be observed that in these cases only the GEV-distribution is applicable.

Table 4.3 Regression parameters and parameters of GEV distributions of regression residuals for the peak flows and flood volumes of the Mekong at Chiang Saen

| Regression | Regression parameters | | GEV parameters of regression residuals | | |
|---|---|---|---|---|---|
| Peak on volume | $a_{y,x}$=-2,566 | $b_{y,x}$=0.1956 | $u_y$= -491.3 | $\alpha_y$= 1,660 | $k_y$=0.375 |
| Volume on peak | $a_{x,y}$=30,825 | $b_{x,y}$=3.429 | $u_x$=-2,431 | $\alpha_x$=6,686 | $k_x$=0.266 |

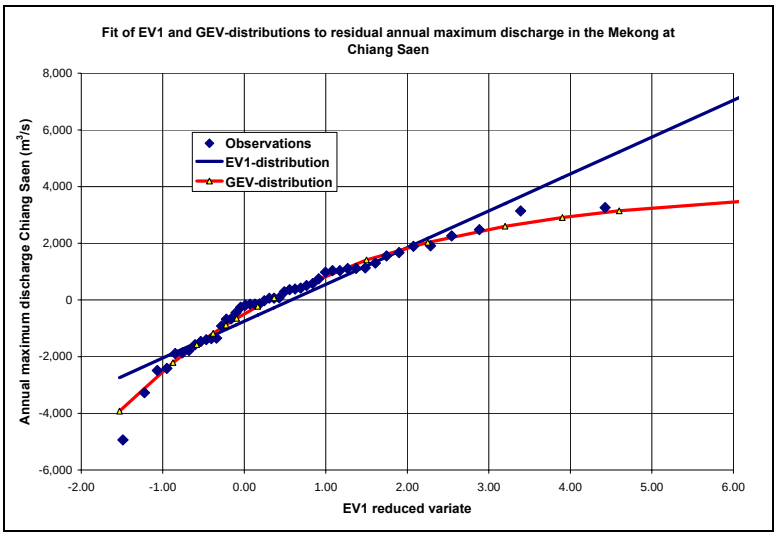


Figure 4.29 EV1 and GEV fit to residual annual maximum discharge in the Mekong at Chiang Saen

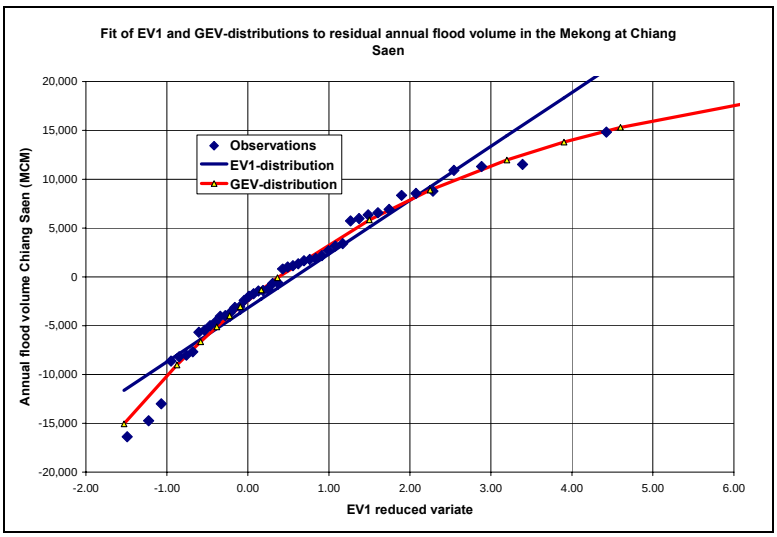


Figure 4.30 EV1 and GEV fit to residual annual flood volume in the Mekong at Chiang Saen

### 4.5.2 Discharge rating Sop Kok

The downstream boundary of the Mekong section of the hydraulic model should be a discharge rating. Since the model only extends up to Sop Kok a discharge rating for Sop Kok is to be included. Based on the available concurrent water level and discharge series for Sop Kok station (010601) the following stage-discharge relation applies:

$$Q_{SopKok}(m^3/s) = 90.1 + 334.8h_{SopKok} + 130.85h^2_{SopKok} - 2.384h^3_{SopKok} \qquad h\ in\ (m+GZ)$$
$$H_{SopKok}(masl) = h_{SopKok}(m+GZ) + 355.31 \qquad (4.4)$$

with: Q= discharge ($m^3$/s)
h = gauge reading relative to gauge zero
H = water level relative to MSL

Note that a stage-discharge boundary at Sop Kok is not ideal as the rating determines due to backwater the levels at the Kok mouth almost entirely for a given combined Mekong and Kok flow.

### 4.5.3 Nam Mae Kok at mouth

Station Sop Kok was located on the Mekong near the mouth of the Nam Mae Kok. The available discharge series for this station includes the flow of the Nam Mae Kok, and could basically be used in combination with Chiang Saen to estimate the flow from the rivers draining between the stations, viz. Nam Mae Kham and Nam Mae Kok. However, the flows of the Kham and the Kok are small compared to the mainstream flows and hence the balance would give an inaccurate estimate of the lateral inflows. Therefore, an alternative procedure described below is advocated.

#### Peak discharge

The distribution of annual maximum discharge of the Nam Mae Kok at mouth is derived from the distribution downstream of Chiang Rai corrected for drainage area (A). Following Adamson (2007), in the Nam Mae Kok environs annual peak values are proportional to $A^{0.75}$. Hence an area factor of $(10{,}730/9{,}410)^{0.75} = 1.103$ has been applied to the annual extremes just downstream of Lao confluence (as presented in Table 4.1). The values (for selected return periods) have been included in Table 4.2.

#### Flood volume

Similarly, EV1 and GEV distributions have been fitted to the annual flood volumes in the Nam Mae Kok at mouth. The flood volumes have been derived from the flow series determined for the Nam Mae Kok at Lao confluence multiplied by the ratio of their respective drainage areas (= 1.14). The results are presented in Table 4.2 and shown in Figure 4.31. From the latter it is clear that both distributions fit to the observations.

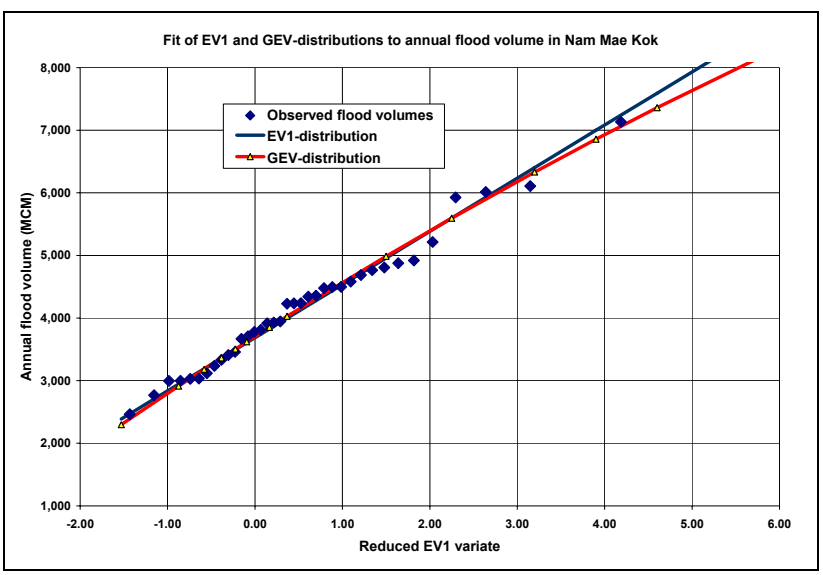


Figure 4.31 Fit of EV1 and GEV-distributions to annual flood volume in Nam Mae Kok at mouth, period 1971-2007

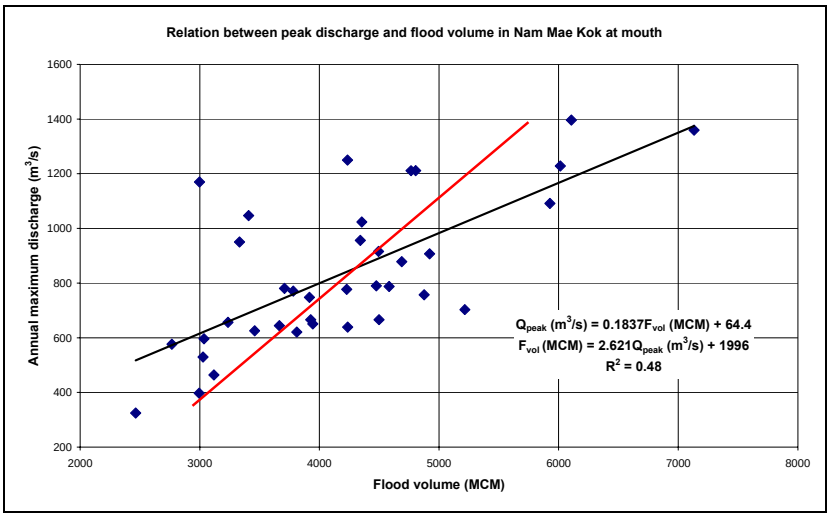


Figure 4.32 Relation between peak discharge and flood volume in Nam Mae Kok at mouth

### 4.5.4 Correlation between flood peaks and volumes in Nam Mae Kok and Mekong

Peak flow and flood volumes of the Nam Mae Kok at mouth have been compared with the same variables on the Mekong to assess possible correlation between the variables for Monte Carlo simulations.

#### Peak flows

Annual peak discharges on Mekong at Chiang Saen and in the Nam Mae Kok downstream of Chiang Rai appear to be uncorrelated, as can be observed from Figure 4.33.

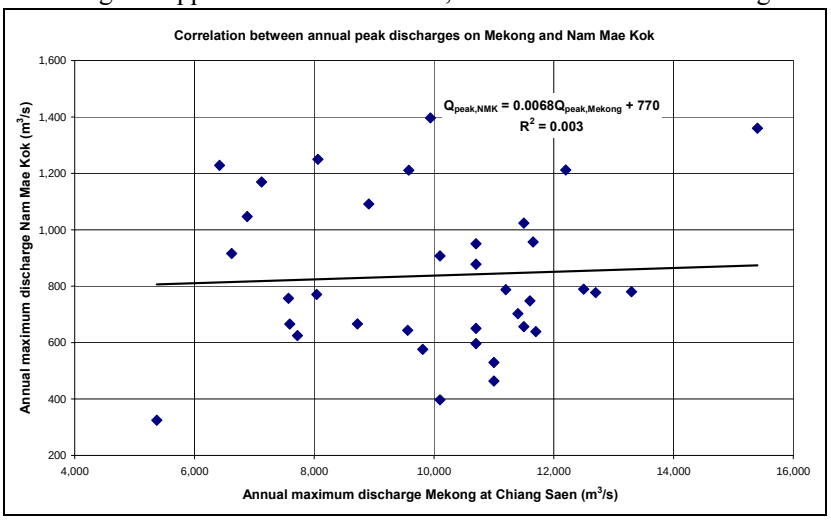


Figure 4.33 Relation between annual peak flows on Mekong and Nam Mae Kok

The distribution of the date of occurrence of the annual peak values in the Mekong at Chiang Saen and the Nam Mae Kok downstream of Chiang Rai is presented in Figure 4.34.

It is seen that on average the Nam Mae Kok peaks about 2 weeks later than the Mekong at the junction of the two rivers, which complies with Figure 3.24.

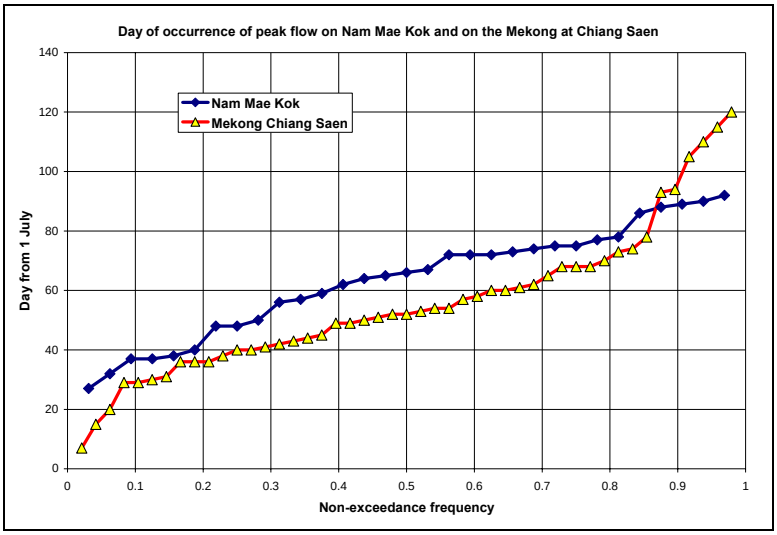


Figure 4.34 Occurrence of annual maximum discharge in Mekong at Chiang Saen and in Nam Mae Kok downstream of Chiang Rai

## Flood volumes

Similar to the flood peaks, also the annual flood volumes in the Mekong and Nam Mae Kok appear not to be correlated, as can be observed from Figure 4.35. This leads to extra combinations of hydrographs on the Mekong with discharge hydrographs in the Nam Mae Kok for Monte Carlo simulations.

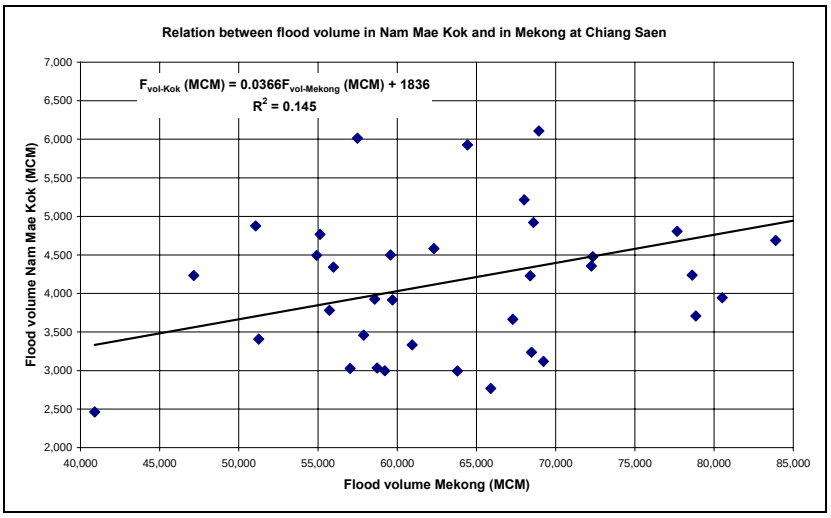


Figure 4.35 Relation between annual flood volumes in Mekong at Chiang Saen and Nam Mae Kok.

# 5 Flood hazard

## 5.1 General

From the previous chapters it can be deduced that for the transformation of the hydrological hazard into flood hazard to identify the flood extent and duration the hydraulic model should include at least the following branches and flood plains of the Nam Mae Kok:

- Nam Mae Kok from Ban Pong Na Kham up to the river mouth at Sop Kok,
- Nam Mae Lao from Ban Pong Pu Fuang to the river mouth at Chiang Rai,
- Nam Mae Korn to its mouth at Chaing Rai, and
- Flood plains inundated by above mentioned rivers.

The boundary conditions of the hydraulic model include (see also Chapter 4):

1. for flood hazard assessment around Chiang Rai:
   1.a Nam Mae Kok **upstream** Loa confluence: discharge hydrographs at Ban Pong Na Kham on Nam Mae Kok (peaks from 2 to 100 year return period and volumes ranging from very low, low, medium, high to very high) with related hydrograph on Nam Mae Korn as input for the Monte Carlo technique;
   1.b Nam Mae Kok **downstream** of Chiang Rai: discharge hydrographs based on an area adjusted sum of Ban Pong Na Kham and Ban Pong Pu Fuang flows (similar to 1.a) as input for the Monte Carlo technique
   1.c Nam Mae Lao/Nam Mae Korn upstream of confluence with Nam Mae Kok: discharge hydrographs on Nam Mae Lao (Korn derived from Lao) at Ban Pong Pu Fuang (similar to 1.a) with related hydrograph on Nam Mae Kok as input for the Monte Carlo technique.
2. for flood hazard assessment near Nam Mae Kok mouth: selection of combination of discharge hydrographs of Mekong at Chaing Saen and a discharge rating at Sop Kok and discharge hydrographs of Nam Mae Kok as input for the Monte Carlo technique.

The hydraulic model and the boundary conditions are elaborated further in this chapter.

## 5.2 Hydraulic model

A 1D mathematical hydraulic model of the Nam Mae Kok and Nam Mae Lao has been developed by DWR/TNMC in 2006 for the Case Study: “Flood/Drought for Kok River Basin”. This model was embedded in a modelling framework with the SWAT rainfall-runoff model and the IQQM water demand model. The quality of the hydraulic model was considered to be insufficient for reliable flood hazard assessment in the Chiang Rai region. Additional bathymetric surveys were required to improve the model simulation results. In the frame of the project ‘Strengthening of Flood Management capacity for the Kok River in Chiang Rai Province” of TNMC/DWR this upgrading has been materialized. The project included establishment of new gauging stations and topographic surveys. The surveys originally comprised 60 cross-sections of river and flood plain and additional 30 cross-sections of the river, all along the main stem from Chiang Rai to the river mouth. Recently, the surveys have been extended to the Nam Mae Lao and the Nam Mae Korn. In January

2009 a report containing the development, calibration, verification and application of the new hydraulic model of the Kok became available (Kittipong, 2009). In addition to the 1D hydraulic model also a 2D model of the region has also been established by the MRCS modelling team, including the flood plain and urban area. Though a 2 D approach for the flood plain is very much welcomed, a 2D approach for the rivers with small cross-sections leads to very high requirements on computational grid size and consequently creates inherent inaccuracies. A 1D/2D approach would have been a far better choice (i.e. 1 D for the rivers and 2 D for the flood plain) and is strongly advocated by Consultants as the flooding in the Chiang Rai region is considered to be very complex.

## Schematisation

The Kok hydraulic model includes the major rivers flood plains and structures of the Nam Mae Kok from upstream Chiang Rai to the Mekong as follows, see also Table 5.1:

1. Nam Mae Kok from Ban Pong Na to Sop Kok with a length of 90.65 km, including the Chiang Rai weir at km 21.70 and outlets of:
   1.a Korn-Kok Diversion Canal (km 10.05)
   1.b Nam Korn (km 19.70)
   1.c Nam Mae Lao (km 22.7)
2. Nam Mae Lao from Ban Pong Pu Fuang to mouth with a length of 69.01 km. It includes 3 weirs
3. Nam Korn from 14 km d/s of station Ban Pang Rim Korn (G4) to mouth with a length of 22.41 km, including the 4 weirs and the Korn-Kok Diversion Canal at km 5.95
4. Korn-Kok Diversion canal with a length of 4.21 km as from 2005 onward.
5. Mekong from Chiang Saen to Sop Kok with a length of 5 km.

Surveyed river cross-sections have been provided from 3 sources:

- DWR,
- RID, and
- CRM (Chiang Rai Municipality)

The cross-sections prior to 2005 conditions included:

- 88 cross-sections for the Kok,
- 145 cross-sections for the Lao,
- 82 cross-sections for the Korn, and
- 19 cross-sections for the Mekong from the MRCS-Digital Atlas DEM.

For the situation from 2005 onward DWR carried out new surveys in 2008 particularly along the Korn and also on the Lao in view of embankment improvements above Chai Sombat weir. The difference in cross-sectional areas along the Lao is depicted in Figure 5.1.

Table 5.1 Extent, stations and structures in the Nam Mae Kok hydraulic model

| River | Location | | Cross-section data (m+MSL) | | | Weir characteristics | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Profile | Distance (m) | Bed level | Left Bank | Right Bank | Height | Width | Crest | Type |
| Kok | Pong Na Kham (Kok01) | 0,000 | 400.01 | 410.85 | 405.65 | | | | |
| | Outlet Korn-Kok Canal (Kok11) | 10,050 | 390.46 | 394.41 | 397.15 | | | | |
| | Mae Fa Luang Bridge (Kok17) | 15,250 | 386.70 | 395.22 | 394.32 | | | | |
| | Chiang Rai Bridge (Kok23) | 17,950 | 385.55 | 391.03 | 389.92 | | | | |
| | Chalerm Prakiat Bridge (Kok26) | 18,700 | 384.40 | 390.11 | 390.17 | | | | |
| | Nam Korn confluence (Kok28) | 19,700 | 382.40 | 390.00 | 389.30 | | | | |
| | Chiang Rai Weir (Kok30) | 21,700 | 380.52 | 388.39 | 389.95 | 4.00 | 11 x 8.00 | 385.75 | 11 radial gates |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Nam Mae Lao confluence (Kok31) | 22,700 | 375.25 | 388.77 | 389.95 | | | | |
| | Ban Mae Phaeng (Kok60) | 54,200 | 368.72 | 375.35 | 374.69 | | | | |
| | Kok mouth at Sop Kok (Kok88) | 90,650 | 354.18 | 364.86 | 360.32 | | | | |
| Lao | Ban Pong Pu Fuang (LAO-145) | 0,000 | 438.74 | 442.44 | 442.83 | | | | |
| | Mae Lao Weir (LAO-120) | 12,450 | 428.24 | 430.96 | 431.18 | 3.50 | 35.50 | 431.00 | Ungated |
| | Tham Wok Weir (LAO-84) | 28,950 | 412.02 | 415.24 | 414.76 | 2.10 | 60.00 | 413.15 | Ungated |
| | G8-Ban Ton Yang (LAO-71-70) | 35,060 | 404.92 | 408.80 | 409.25 | | | | |
| | Ban Rim Lao (LAO-55) | 42,810 | 400.42 | 403.28 | 403.54 | | | | |
| | Ban Tha Sai (LAO-35-34) | 53,060 | 395.15 | 399.72 | 399.67 | | | | |
| | Chai Sombat Weir (LAO-28) | 55,810 | 392.29 | 398.15 | 396.74 | 2.70 | 50.00 | 395.87 | Ungated |
| | Lao mouth d/s CR Weir (LAO-0) | 69,010 | 375.30 | 386.34 | 386.49 | | | | |
| Korn | U/S boundary W4 Weir (Kn 23.0) | 0,000 | 407.85 | 411.85 | 412.35 | 2.10 | 3 x 2.40 | 408.75 | Gated: 3 gates |
| | W3 Weir (Kn21.5) | 1,450 | 405.31 | 408.06 | 408.11 | 2.10 | 3 x 2.40 | 407.41 | Gated: 3 gates |
| | W2 Weir (Kn18.0) | 4,950 | 400.66 | 403.10 | 403.12 | 2.10 | 3 x 2.40 | 402.76 | Gated: 3 gates |
| | W1 Weir Canal Offtake (Kn17.0) | 5,950 | 397.54 | 402.09 | 401.72 | 1.50 | 9 x 1.50 | 397.49 | Gated: 9 gates |
| | C.R.M. Weir (KORN 41-M) | 17,676 | 388.30 | 390.20 | 390.30 | 2.00 | 15.50 | 393.30 | Ungated |
| | Korn mouth (Kn00.0) | 22,410 | 382.42 | 389.53 | 389.18 | | | | |
| Korn-Kok Canal | Canal intake (KK1) | 0,000 | 397.54 | 400.79 | 400.79 | 2.50 | 4 x 2.50 | 397.24 | Gated: 4 gates |
| | Canal outlet (KK25) | 4,210 | 390.46 | 396.14 | 396.14 | 2.50 | 4 x 2.50 | 392.91 | Gated: 4 gates |

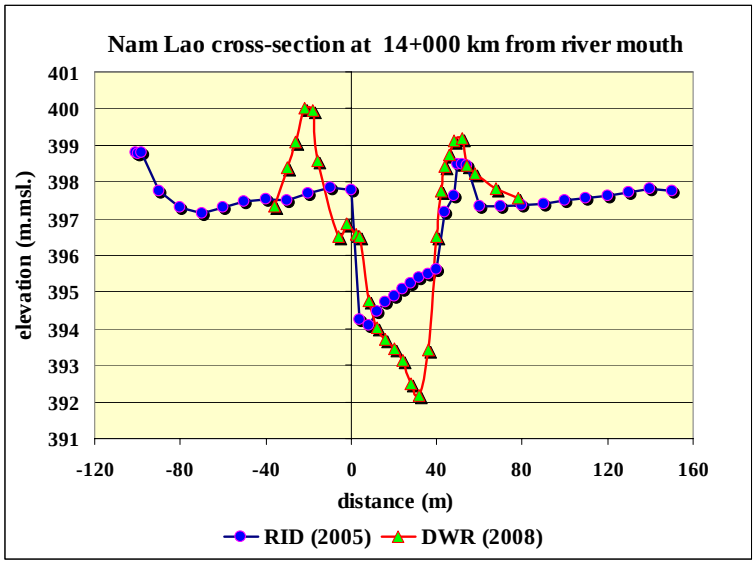


Figure 5.1 Cross-sections of Nam Mae Lao before and after implementation of river embankments

In 2007 DWR made a spot height map of the region including the flood plains comprising 390 elevations, which were transformed into a DEM. The GIS-layers were extended with information on streams, road networks, urban zones, water bodies land use and housing. The DEM has been used for the schematisation of the flood plain into storage cells connected with the river cross-sections via two-way weirs.

## Schematisation

The boundary conditions comprised of discharge time series at the upper boundaries as derived from the observations at the hydrometric stations and lateral inflow from the hydrological model SWAT, calibrated to a water balance between the upper model boundaries and station Ban Mae Phaeng, midway Chiang Rai and Sop Kok. As explained in Section 4.4 the series of Ban Mae Phaeng gives too high flows, hence consequently the lateral inflows are too high. It has been estimated that the lateral inflows are overestimated by a factor 2.3. Figure 5.2 shows all boundary nodes of the model, whereas Table 5.2 present a brief description.

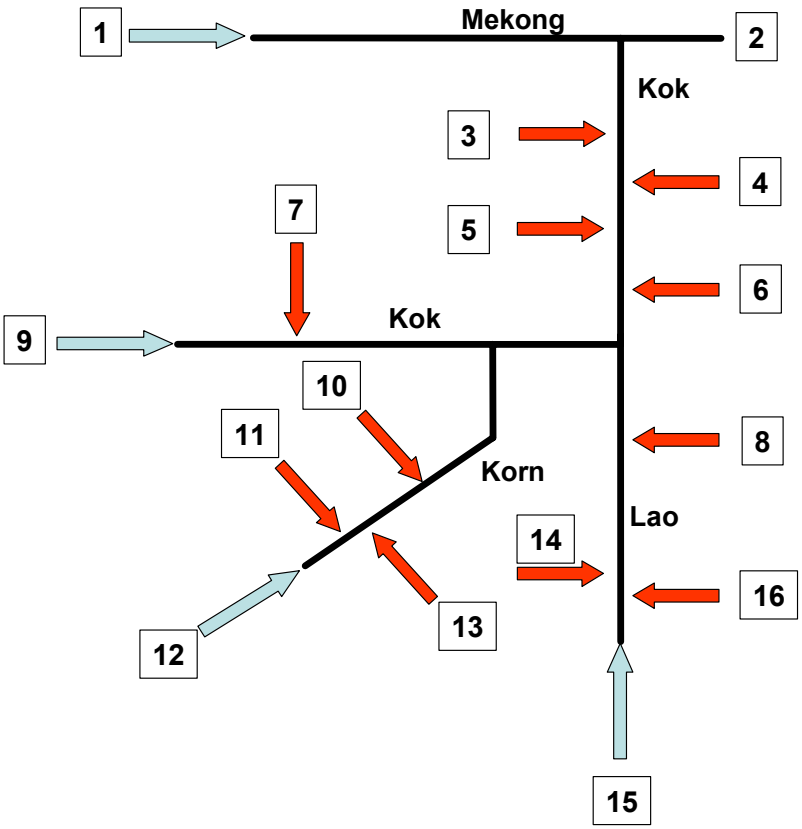


Figure 5.2 Schematic view of the required boundary conditions for running of hydraulic model. The numbers are described in Table 5.2.

Table 5.2 Description of the boundary nodes of the hydraulic model (see Figure 5.2).

| no | description |
|---|---|
| 1 | Inflow from the Mekong river at Chiang Saen Hydro Station. |
| 2 | Water Level of the Mekong at Sop Kok Station. |
| 3 | Lateral flow to the Nam Kok from SWAT sub-basin 3 at cross-section no. 70 to 79. |
| 4 | Lateral flow to the Nam Kok from SWAT subbasin 15 at cross-section no. 45. |
| 5 | Lateral flow to the Nam Kok from SWAT subbasin 16 at cross-section no. 40 to 4. |
| 6 | Lateral flow to the Nam Kok from SWAT subbasin 8 at cross-section no. 44. |
| 7 | Lateral flow from SWAT subbasin 7 to the Nam Kok at cross-sections downstream. |
| 8 | Lateral flow to Nam Lao from SWAT subbasin 9 at the Lower Nam Lao. |
| 9 | Upstream boundary condition for the Nam Kok at Ban Pong Na Kham (030102). |
| 10 | Lateral flow from SWAT subbasin 7 contributing to the Lower Nam Korn. |
| 11 | Runoff from Swat subbasin10 area downstream of cross-section kn23.0. |
| 12 | Upstream boundary condition for the Nam Korn. |
| 13 | Balance node, not relevant here |
| 14 | Lateral flow to the Nam Lao from SWAT subbasin 10 at downstream cross sections. |
| 15 | Upstream boundary condition for the Nam Lao at Ban Pong Pu Fang (030302) |
| 16 | Lateral flow to the Nam Lao from SWAT subbasin 11 at downstream cross sections |

### Calibration and validation

The calibration for the pre-2005 conditions was carried out by Kittipong (2009) for the years 2000-2004, looking particularly at a proper reproduction of the peak values. It appears that the peaks are generally reasonably matched. However, the recession curve is highly overestimated by the model, which is a direct consequence of the overestimation of the lateral inflow. It can be said that due to the overestimated lateral inflow the hydraulic roughness will be underestimated. When the lateral inflows are brought to a realistic level a recalibration of the model will be required.

The model has subsequently been validated implementing the developments in the hydraulic infrastructure since 2005, including the bypass canal from Korn to Kok, rehabilitated weirs in the Korn and raising of the embankments along the Lao from 15 km u/s Chai Sombat weir to the weir. Comparison of the cross-sections in the model prior to and from 2005 onward revealed that the newly surveyed cross-sections were not included in the model as such, but lead only to raised weir sills in the connection between river and flood plain. As can be seen from Figure 5.1, the river cross-section also contains a floodplain. By raising the weir sill, this flood plain is left unchanged and only the floodplain away from the river cross-section is affected. Due to this approach the capacity of the river with its direct flood plain is overestimated (by the measure it is eliminated but by the way of schematisation it is left intact). This erroneous schematisation requires a larger hydraulic roughness to match the observed water levels.

**In summary**: the hydraulic model of the Kok river and flood plain will not be suitable for flood mapping unless a recalibration takes place based on improved lateral inflows and corrected schematisation of the flood mitigation measures since 2005.

## 5.3 Recalibration of the hydraulic model

Still to be described

## 5.4 Selection of model boundary conditions

### 5.4.1 Introduction

Figure 5.2 of section 5.2 showed all boundary nodes of the hydraulic model. In the flood hazard analysis the model is run for various hydraulic scenarios. For each scenario the 16 boundary conditions. Chapter 4 describes the statistics of river discharges on which these scenarios and boundary conditions should be based. Below we describe the step-by-step procedure of how the input series for the scenarios are composed. As explained in section 5.1, the analysis are done executed for different areas in the Kok basin, each area having it's own unique set of representative boundary conditions.

### 5.4.2 Area 1a: Nam Mae Kok upstream of Lao confluence

For this area 90 different scenarios are simulated, which are combinations of

- 6 values of the peak discharge of the Nam Mae Kok at Ban Pong Na Kham
- 5 associated flow volumes of the Nam Mae Kok at Ban Pong Na Kham
- 3 associated flow volumes of the Nam Korn and the Nam Mae Lao

For 90 scenario's synthetic hydrographs are first derived for the Kok and Lao rivers using the following procedure:

1. Select peak discharges of the Nam Mae Kok (at Ban Pong Na Kham) with return periods 2, 5, 10, 25, 50 and 100 years from Table 4.1.
2. Select associated flow volumes of the Nam Mae Kok using [a] the regression equation of Figure 4.3 and [b] deviations of -1.96, -1, 0, 1 and 1.96 times the standard deviation from the regression line (with the standard deviation being equal to 129 MCM)
3. Derive the ratio of volume/peak for all 6×5 combinations of peak discharge and flow volume. Then, for each combination, select a historically observed hydrograph with the same volume/peak ratio. Multiply this observed hydrograph by: (scenario peak/observed peak). The result is a hydrograph with the required peak and volume of the scenario. Note that in stead of using 1 observed hydrograph, generally interpolation between two observed hydrographs is required to obtain the exact volume/peak ratio of the scenario
4. For each of the 30 scenarios of step 1-3 select associated flow volumes of the Nam Mae Lao using [a] regression equation (4.1) and [b] deviations of -1.96, 0, 1.96 times the standard deviation from the regression line (with the standard deviation being equal to 70 MCM).
5. For each of the resulting 90 (6×5×3) flow volumes, construct a synthetic hydrograph for the Nam Mae Lao which has exactly the derived volume of step 4. For this purpose an observed hydrograph is selected with a volume that is relatively close to the desired volume. Subsequently, the hydrograph is rescaled in such a way that it has exactly the desired flow volume.

The resulting hydrographs for the Kok and Lao form the basis of the series of other lateral inflows and upper boundary flows, i.e. the inflow of other nodes are simply determined from these two hydrographs through application of multiplication factors. First, from the analysis of chapter 4, the following 7 series can be determined:

[a] Nam Mae Kok at Ban Pong Na Kham (see above)
[b] Nam Mae Lao at Ban Pong Pu Fuang (see above)
[c] Nam Korn at upstream boundary: 0.16*series [b]
[d] Lateral inflow of the Nam Korn: 0.42*series [c]
[e] Lateral flow for the Nam Mae Lao between Ban Pon Pu Fang and Kok-Lao confluence (Chiang Rai weir): 0.029*series [b]
[f] Lateral inflow between Lao-Korn confluence and Ban Mae Phang: 0.113*(sum of series [1] till [4])
[g] Lateral inflow between Ban Mae Phang and Mekong: 0.027*(sum of series [1] till [4])

From the above series, input for 13 of the 16 boundary nodes of Figure 5.2 are derived (see Table 5.3). The only exceptions are nodes 1, 2 and 13. Node 13 is a dummy node and

therefore not of interest here. Nodes 1 and 2 are the boundary conditions on the Mekong river. For the area under consideration (area 1a, Nam Mae Kok upstream of Lao confluence) the flow in the Mekong river has no influence on the water levels. Therefore, a more or less arbitrary discharge of 10,000 $m^3/s$ is assumed in node 1, resulting in a water level of MSL+363.35 m in node 2 (Chiang Saen). Table 5.3

Table 5.3 Input series for model boundary nodes

| no | Input series |
|---|---|
| 1 | constant discharge of 10,000 $m^3/s$ |
| 2 | constant water level of MSL+363.35 m |
| 3 | series [g] |
| 4 | series [f] / 3 |
| 5 | series [f] / 3 |
| 6 | series [f] / 3 |
| 7 | series [d] / 3 |
| 8 | series [e] / 3 |
| 9 | series [a] |
| 10 | series [d] / 3 |
| 11 | series [d] / 3 |
| 12 | series [c] |
| 14 | series [e] / 3 |
| 15 | series [b] |
| 16 | series [e] / 3 |

### 5.4.3 Area 1b: Nam Mae Lao upstream of Kok confluence

The procedure for area 1b is very similar to the procedure of area 1a in the previous section. Again, 90 different scenarios are simulated, which are combinations of:

- 6 values of the peak discharge of the Nam Mae Lao at Ban Pong Pu Fuang
- 5 associated flow volumes of the Nam Mae Lao at Ban Pong Pu Fuang
- 3 associated flow volumes of the Nam Korn and the Nam Mae Kok

For 90 scenario's synthetic hydrographs are first derived for the Lao and Kok rivers using the following procedure:

1. Select peak discharges of the Nam Mae Lao (at Ban Pong Pu Fuang) with return periods 2, 5, 10, 25, 50 and 100 years from Table 4.1.
2. Select associated flow volumes of the Nam Mae Lao using [a] the regression equation of Figure 4.12 and [b] deviations of -1.96, -1, 0, 1 and 1.96 times the standard deviation from the regression line (with the standard deviation being equal to 54 MCM)

3. Derive the ratio of volume/peak for all 6×5 combinations of peak discharge and flow volume. Then, for each combination, select a historically observed hydrograph with the same volume/peak ratio. Multiply this observed hydrograph by: (scenario peak/observed peak). The result is a hydrograph with the required peak and volume of the scenario. Note that in stead of using 1 observed hydrograph, generally interpolation between two observed hydrographs is required to obtain the exact volume/peak ratio of the scenario
4. For each of the 30 scenarios of step 1-3 select associated flow volumes of the Nam Mae Kok using [a] the regression equation of Figure 4.14) and [b] deviations of -1.96, 0, 1.96 times the standard deviation from the regression line (with the standard deviation being equal to 254 MCM).
5. For each of the resulting 90 (6×5×3) flow volumes, construct a synthetic hydrograph for the Nam Mae Kok which has exactly the derived volume of step 4. For this purpose an observed hydrograph is selected with a volume that is relatively close to the desired volume. Subsequently, the hydrograph is rescaled in such a way that it has exactly the desired flow volume.

The resulting hydrographs for the Kok and Lao form the basis of the series of other lateral inflows and upper boundary flows, i.e. the inflow of other nodes are simply determined from these two hydrographs through application of multiplication factors. First, from the analysis of chapter 4, the following 7 series can be determined:

### 5.4.4 Area 1c: Nam Mae Kok downstream of Lao confluence

# 6 Conclusions and recommendations

## 6.1 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 area in the Nam Mae Kok basin comprise:
   1.a Valley of Nam Mae Fang
   1.b Chiang Rai Province, and
   1.c Mouth of Nam Mae Kok.
2. Floods in the upper reaches of the tributaries are flashy. Flashiness decreases further downstream in the Chiang Rai region. In the lower 20-25 km of the Nam Mae Kok near the mouth the flood levels are affected by backwater from the Mekong.
3. Extreme value distributions of peak flows and the possible range of flood volumes can be used for assessment of the hydrological hazard in the Chiang Rai region regarding peak levels and flood duration. A bivariate distribution for the river mouth.

### Data availability and validation

4. Water level and discharge series of sufficient length are available to asses the hydrological hazard in the Chiang Rai region and near the Nam Mae Kok mouth.
5. Validation of hydrological data does not appear to be common practice according to sources at the data collecting agencies.
6. The applied stage-discharge relations for the stations on Nam Mae Kok and tributaries varied strongly from year to year. The number of discharge measurement taken each year suggest that the changes are due to morphological developments in the station controls. Some re-settings of gauges to different gauge zeros seem to have occurred, but have not been recorded.
7. Whereas the rainfall records are mutually consistent, the discharge series are not. Distinct changes in the records are apparent in the series of Ban Pang Na Kham in the period 1988-1994, whereas the series of Ban Mae Phaeng is inconsistent with the area adjusted sum of the Kok and Lao flows for almost its entire record.
8. As a consequence of the Ban Mae Phaeng inconsistency, the SWAT based lateral inflows are overestimated by a factor 2.3.

### Hydrological characteristics

9. Annual rainfall in the Kok basin is largest towards the river mouth (1,700 mm) with lower values of 1,300 to 1,400 mm in the upper reaches of the Nam Mae Kok and the Nam Mae Fang. Rainfall is highest in the months July-September
10. Evaporation peaks in April-May. Annual totals vary from 1,300 to 1,500 mm. It exceeds rainfall in the period November – April.

11. The annual average flow volume of the Nam Mae Kok at mouth is about 5.24 BCM. Runoff of Nam Mae Kok at Chiang Rai per unit area is twice the runoff of the Nam Mae Lao. At Chiang Rai the runoff is highest in the months August and September, whereas in Nam Mae Lao September is the month with the largest flow volume.
12. The regime of the Nam Mae Kok is a few weeks in spate relative to the Mekong regime.

### Hydrological hazard

13. The hydrological hazard expressed as extreme discharge for selected return periods with a full range of flood volumes have been determined for the Nam Mae Kok at Ban Pong Na Kham, the Nam Mae Lao at Ban Pong Pu Fuang and the Nam Mae Kok downstream of the Loa confluence. Generally, the GEV fits best to the data, but due to the limited data length the EV1 is not rejected as an alternative.
14. The annual discharge peaks on the Nam Mae Kok at Ban Pong Na Kham and the Nam Mae Lao at Ban Pong Pu Fuang do generally not occur at the same time. This should be included in the selected boundary conditions for flood hazard assessment with the hydraulic model.
15. EV1 and GEV distributions fit well to the marginal distributions of observed annual maximum flood peaks and annual flood volumes in the Mekong at Chiang Saen.
16. The bivariate distribution of annual flood peaks and flood volumes in the Mekong at Chiang Saen can be described by regression equations and GEV-distributions for the regression residuals.
17. The observed distribution of annual flood volumes in the Nam Mae Kok is well described by an EV-1-distribution.
18. The bivariate distribution of annual flood peaks and flood volumes in the Nam Mae Kok at mouth can be described by regression equations and GEV-distributions for the regression residuals.
19. Neither the peak discharges nor the annual flood volumes in the Mekong versus the Nam Mae Kok show significant correlation.
20. The annual maximum discharges on the Mekong occur on average about two weeks earlier than the annual peaks on the Nam Mae Kok.

### Flood hazard

21. The flooding around Chiang Rai city is complex and its extent is preferably modelled with a 1D2D hydraulic model.
22. The existing hydraulic model of the Nam Mae Kok needs to be adjusted in the cross-sections particularly for the Lao and recalibrated using appropriate lateral inflows for reliable flood hazard assessment.
23. A full range of hydrographs (flood peaks and related range of flood volumes) have been developed for flood hazard computations around Chiang Rai city.
24. Some 150 combinations of water level hydrographs for the Mekong at Sop Kok and discharge hydrographs of the Nam Mae Kok at mouth will be required for flood simulation near the river mouth as input to the Monte Carlo technique to establish the flood maps of required return periods.

## 6.2 Recommendations

# 7 Literature

Adamson, P.T., A.V. Metcalfe and B. Parmentier (1999)
Bivariate extreme value distributions: An application of the Gibbs sampler to the analysis of floods.
Water Resources Research, Vol 35, No. 9, pages 2825-2832, September, 1999

Adamson P.T. (2007)
Strengthening of the Flood Management Capacity in the Kok River Basin in Chiang Rai Province, Thailand. Hydrological Baseline Study.
Information and Knowledge Management Programme. September 2007

BDP (2006)
Basin Development Planning Atlas: Sub-area 2
Mekong River Commission, June 2006

Cunnane C. (1989)
Statistical distributions for flood frequency analysis.
WMO – No718, Operational Hydrology Report No 33. Geneva, Switzerland

Kittipong Jirayoot (2009)
1D iSIS Model Set-up and Flood Mapping for Kok River Basin.
Report submitted to Mekong River Commission. January, 2009.

Mekong Secretariat (1979),
Inventory of promising tributary projects in the Lower Mekong Basin in Thailand (MKG/80),
Mekong Secretariat , Bangkok, Thailand

Mekong Secretariat (1960-1997)
Mekong Hydrological Yearbooks, 1960, ….-1997
Mekong Secretariat, Bangkok

Salzgitter (1975),
Mae Kok Project Feasibility Report, prepared for the National Energy Administration and the Royal Irrigation Department by Salzgitter Consult GMBH, Salzgitter, Federal Republic of Germany

Seree Supratid (2008)
National Flood Modeter for two-dimensional dynamic flood routing model (FLO-2D model); Case study: Kok river, Chiang Rai Thailand.
National Disaster Research Center, Rangsit University. November, 2008

TNMC (2006)
Case Study 1: Flood/drought Study for Kok River Basin. Implementation and results.
Thai National Mekong Committee, Bangkok, December 2006 (ppt-file)