THE MEKONG RIVER COMMISSION SECRETARIAT

Hydrological and Flood Hazards in the Focal Areas

The Flood Management and Mitigation Programme, Component 2: Structural Measures & Flood Proofing in the Lower Mekong Basin

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UNESCO IHE

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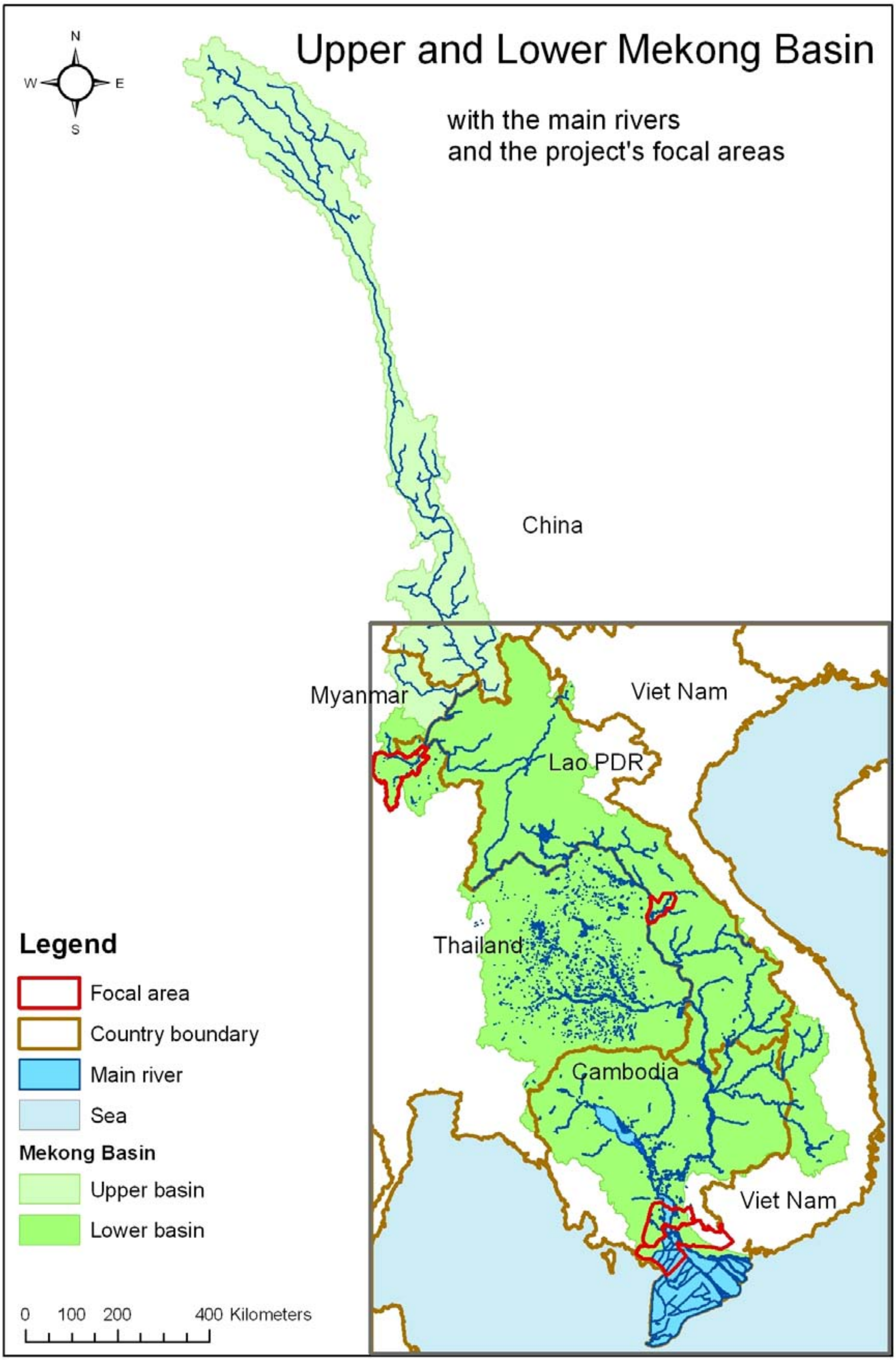
Upper and Lower Mekong Basin
with the main rivers
and the project's focal areas
N
W
E
S
China
Myanmar
Viet Nam
Lao PDR
Thailand
Cambodia
Viet Nam
Legend
Focal area
Country boundary
Main river
Sea
Mekong Basin
Upper basin
Lower basin
0 100 200 400 Kilometers

GLOSSARY

Direct damage	All harm which relates to the immediate physical contact of flood water to people, property and the environment. This includes, for example, damage to buildings, economic assets, loss of standing crops and livestock, loss of human life, immediate health impacts and loss of ecological goods.
Exposure	The people, assets and activities that are threatened by a flood hazard.
Flood control	A structural intervention to reduce the flood hazard.
Flood damage	Damage to people, property and the environment caused by a flood. This damage refers to direct as well as indirect damage.
Flood damage curve	The functional relation between inundation characteristics (depth, duration, flow velocity) and damage for a certain category of elements at risk.
Flood damage risk (= Flood risk)	The combination or product of the probability of the flood hazard and the possible damage that it may cause. This risk can also be expressed as the *average annual possible damage* or *expected damage*.
Flood hazard	A flood that *potentially may* result in damage. A hazard does not necessarily lead to damage.
Flood hazard map	Map with the predicted or documented extent/ depth/ velocity of flooding with an indication of the flood probability.
Flood proofing	A process for preventing or reducing flood damages to infrastructural works, buildings and/or the contents of buildings located in flood hazard areas.
Flood risk management	Comprehensive activity involving risk analysis, and identification and implementation of risk mitigation measures.
Flood risk management measures	Actions that are taken to reduce the probability of flooding or the possible damages due to flooding or both.
Flood risk map	Map with the predicted extent of different levels/ classes of *average annual possible damage.*
Hydrological hazard	A hydrological event (discharge) that may result in flooding.
Indirect damage	All damage which relate to the disruption of economic activity and services due to flooding.
Integrated flood risk management	The approach to Flood Risk Management that embraces the full chain of a meteorological hazard leading to flood damages and considers combinations of structural and non structural solutions to reduce that damage.

Meteorological hazard	A meteorological event (storm) that may result in a hydrological hazard and, eventually, in flooding
Resilience	The ability of a system/ community/ society to cope with the damaging effect of floods
Susceptibility	The opposite of resilience, that is to say the inability of a system/ community/ society to cope with the damaging effect of floods
Vulnerability	The potential damage that flooding may cause to people, property and the environment

ABBREVIATIONS

N.B.Abbreviations that occur only once and that are explained in the text are not included in the table below.

ADB	Asian Development Bank
ADPC	Asian Disaster Preparedness Center
BCM	Billion Cubic Meters
BDP	Basin Development Planning
BPG	Best Practise Guidelines
CBA	Cost Benefit Analysis
CBDRM	Community Based Disaster Risk Management
CNMC	Cambodian National Mekong Committee
d/s	downstream
DARD	Department of Agriculture and Rural Development
DSF	Decision Support Framework
EC	European Commission
EU	European Union
FHA	Flood Hazard Assessment
FMM	Flood Management and Mitigation
FMMP-C2	Flood Management and Mitigation Programme, Component 2
FPS	Flood Proofing System
FRA	Flood Risk Assessment
FV	Future Value (economic analysis)
GIS	Geographic Information System
HEC	Hydrologic Engineering Center
HH	Household(s)
IFRM	Integrated Flood Risk Management
IKMP	Information and Knowledge Management Programme
ISIS	Hydrodynamic simulator for modelling flows and levels in open channels and estuaries
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
KOICA	Korean International Cooperation Agency
LMB	Lower Mekong Basin
LMD	Lower Mekong Delta
LXQ	Long Xuyen Quadrangle (Vietnam)
MAFF	Ministry of Agriculture, Fisheries and Forestry
MARD	Ministry of Agriculture and Rural Development
MCM	Million Cubic Meters
MLUPC	Ministry of Land Management, Urban Planning and Construction
MONRE	Ministry of Natural Resources and Environment

MOWRAM	Ministry of Water Resources and Meteorology
MRC(S)	Mekong River Commission (Secretariat)
MSL	Mean sea level, the average (mean) height of the sea, with reference to a suitable reference surface
NAP	Navigation Programme (MRC)
NCDM	National Committee on Disaster Management
NEDECO	Netherlands Engineering Consultants
NMC	National Mekong Committee (NMCs are not part of the MRC 1995 Agreement, are structured differently in each country and are funded by their respective countries)
NPV	Net Present Value (economic analysis)
PDR (Lao)	(Lao) People's Democratic Republic
PDS	Project Description Sheet (ProDIP)
PDWRAM	Provincial Department of Water Resources and Meteorology
PoR	Plain of Reeds (Vietnam)
ProDIP	Project Development Implementation Plan
PV	Present Value (economic analysis)
RFMMP	Regional Flood Management and Mitigation Programme
RN	Route Nationale (National Road)
XBF	Xe Bangfai (Lao PDR)
SIWRP	Southern Institute of Water Resources Planning
SWAT	River basin scale model quantifying the impact of land management practices in large, complex watersheds
TA	Technical Advisor
u/s	upstream
UNDP	United Nations Development Program
USD	US$
VND	Vietnamese Dong
VRSAP	Vietnam River Systems and Plains (hydrological/ landuse model)
WUP	Water Utilisation Programme

CHAPTER 1

INTRODUCTION

1 INTRODUCTION

1.1 Guide to the reporting structure of the Flood Management and Mitigation Programme - Component 2, Structural Measures and Flood Proofing

Component 2 on Structural Measures and Flood Proofing of the Mekong River Commission's Flood Management and Mitigation Programme was implemented from September 2007 till January 2010 under a consultancy services contract between MRCS and Royal Haskoning in association with Deltares and Unesco-IHE. The Implementation was in three stages, an Inception Phase, and two Implementation Stages. During each stage a series of outputs was delivered and discussed with the MRC, the National Mekong Committees and line agencies of the four MRC member countries. A part of Component 2 - on 'Roads and Floods' - was implemented by the Delft Cluster under a separate contract with MRC. Component 2 prepared five Demonstration Projects which have been reported separate from the main products.

The consultancy services contract for Component 2 specifies in general terms that, in addition to a Final Report, four main products are to be delivered. Hence, the reports produced at the end of Component 2 are structured as follows:

Volume 1	**Final Report**
Volume 2	**Characteristics of Flooding in the Lower Mekong Basin**
Volume 2A	*Hydrological and Flood Hazards in the Lower Mekong Basin;*
Volume 2B	*Hydrological and Flood Hazards in Focal Areas;*
Volume 2C	*Flood Damages, Benefits and Flood Risk in Focal Areas;*
Volume 2D	*Strategic Directions for Integrated Flood Risk Management in Focal Areas.*
Volume 3	**Best Practice Guidelines for Integrated Flood Risk Management**
Volume 3A	*Best Practice Guidelines for Flood Risk Assessment;*
Volume 3B	*Best Practice Guidelines for Integrated Flood Risk Management Planning and Impact Evaluation;*
Volume 3C	*Best Practice Guidelines for Structural Measures and Flood Proofing;*
Volume 3D	*Best Practice Guidelines for Integrated Flood Risk Management in Basin Development Planning;*
Volume 3E	*Best Practice Guidelines for the Integrated Planning and Design of Economically Sound and Environmentally Friendly Roads in the Mekong Floodplains of Cambodia and Vietnam*[1]*.*
Volume 4	**Project development and Implementation Plan**
Volume 5	**Capacity Building and Training Plan**
Demonstration Projects	
Volume 6A	*Flood Risk Assessment in the Nam Mae Kok Basin, Thailand;*
Volume 6B	*Integrated Flood Risk Management Plan for the Lower Xe Bangfai Basin, Lao PDR;*
Volume 6C	*Integrated Flood Risk Management Plan for the West Bassac Area, Cambodia;*
Volume 6D	*Flood Protection Criteria for the Mekong Delta, Vietnam;*
Volume 6E	*Flood Risk Management in the Border Zone between Cambodia and Vietnam.*

The underlying report is **Volume 2B** of the above series

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[1] Developed by the Delft Cluster

1.2 General

Assessment of flood damage risks involves the estimation and linkage of flood hazards (probability of flooding) and flood vulnerability (extent of damage that can result from flooding). Flood hazard assessment involves analysis of the type of flooding, flood frequencies, duration, extent, inundation depths and flow velocities. The flood hazard (probability of high water levels) results from hydrological hazard (probability of high discharges/flood volumes), which is determined by the meteorological boundary conditions and the drainage characteristics of the watershed. Representative areas, called Focal Areas, have been selected by the National Mekong Committees for demonstration of integrated flood risk management in the Lower Mekong Basin (LMB), covering various types of floods. This report comprises the assessment of the flood hazard and boundary conditions for river bank protections in the selected Focal Areas, which include:

1. Nam Mae Kok, flood hazard from tributary and combined floods
2. Bokeo, boundary conditions for river bank protections
3. Xe Bangfai, flood hazard from combined floods
4. Upper Se San, flood hazard from flash floods
5. Kratie, boundary conditions for river bank protections, and
6. Mekong Delta, i.e. flood hazard from delta flooding in:
   1.a West of Bassac: Takeo and Long Xuyen Quadrangle
   1.b East of Mekong: Prey Veng and Plain of Reeds.

The hydrological characteristics of the Mekong Basin are summarised in Sub-section 1.2. In Sub-section 1.3 of this Volume, the classification of floods in the Lower Mekong Basin is presented, followed by an overview of the character and nature of flooding in the LMB per sub-area. For background to this overview reference is made to Volume 2A. Chapters 2 to 7 of this Volume summarizes the results of the analyses on flood hazards and boundary conditions in the focal areas. The details of the analyses are presented in the following appendices to this Volume:

- Appendix 1: Flood hazard assessment for Nam Mae Kok
- Appendix 2: Hydraulic design conditions for Bokeo river bank protection
- Appendix 3: Flood hazard assessment for Xe Bangfai
- Appendix 4: Flood hazard assessment for Upper Se San
- Appendix 5: Hydraulic design conditions for Kratie river bank protection
- Appendix 6: Flood hazard assessment for Mekong delta
- Appendix 7: Modelling support FMMP-2
- Appendix 8: Inflow to the Mekong delta
- Appendix 9: Boundary conditions for Mekong Delta Model
- Appendix 10: Probabilistic computation techniques
- Appendix 11: Flow diversion to Tonle Sa

1.3 Hydrological characteristics of the Mekong Basin

In this sub-section, the hydrological characteristics of the Mekong Basin are presented as far as relevant for background information for flood hazard assessment and determination of the hydraulic boundary conditions for the river bank protections in the Focal Areas.

1.3.1 Basin geography

The Mekong River Basin measures 795,000 km^2. The river takes its rise in Tibet, at an elevation of about 4,800 m, some 4,500 km away from its mouth in Southern Vietnam. The major landforms in the basin comprise (MRC, 2006):

- Lancang Basin in China forming the upper basin, which is steep and narrow;
- The Northern Highlands, which is a series of highly folded, steep sided mountain ranges that cover southern Yunnan, Myanmar, northeast Thailand around Chiang Rai and northern Laos upstream of Luang Prabang;
- The Khorat Plateau, an extensive saucer-shaped tableland covering eastern Thailand;
- The Eastern Highlands, running parallel to the Vietnamese coast, which are part of the Annam chain of mountains. They form the eastern boundary of central and southern Laos and eastern Cambodia;
- The Southern Uplands comprising the Elephant and Cardamon Mountains in southwest Cambodia;
- The Southern Lowlands, a vast flat saucer-shaped area around Tonle Sap, which covers most of Cambodia, and
- The Lower Basin flood plains of Cambodia and the Cuu Long Delta in Vietnam, which covers the Mekong, the Bassac and their flood plains.

1.3.2 Hydro-meteorological monitoring network

The hydro-meteorological monitoring network in the Lower Mekong basin is dealt with in the appendices 1 to 11 for each of the sub-areas separately. As reference, an overview of the main stations and their location along the Mekong and the outflow of the major tributaries are presented in Table 1.1

1.3.3 Climatic conditions

The climate in the Mekong basin is described in the ‘Overview of the Hydrology of the Mekong Basin’ (MRC, 2005) to which reference is made. In short, the climate of the Mekong basin is governed by the Southwest and Northeast monsoons, separated by a transition period. The Southwest Monsoon brings rains in the period from May until September-October. During the Northeast Monsoon from November until March, when the winds blow from China mainland, temperatures drop and rainfall becomes low. For the floods the Southwest Monsoon is of importance as well as the occurrence of tropical cyclones, which landfall in the period from June to December, where the occurrence in the upper LMB is predominantly in the beginning of the cyclone season, whereas further downstream, the latter part of the season is of importance. The cyclone rains create extreme high rainfall and runoff and create events of different magnitude compared to the monsoon-generated extremes.

Table 1.1 Overview of key hydrological stations along the Lower Mekong up to Phnom Penh and the location of the junction of the tributaries with the Mekong.

Station		**kilometer**	**area**	**level**	**variables**	**Tributary**	**Country**	**location**
				m+MSL		Upper Mekong	China	
Chiang Saen (T)	K	2363	189,000	357.11	G,Q,S,W			
						Nam Mae Kham	Thailand	2360
						Nam Mea Kok	Myanmar/Thailan	2356
						Nam Ngaou	Lao	
						Nam Mea Ing	Thailand	2297
						Nam Ngeo	Thailand	
Chian Kong (T)	B	2305	204,000	341.963	G,Q			
						Nam Ngeun	Lao	
						Nam Tha	Lao	2271
PakBeng (L)	B	2170			G			
						Nam Beng	Lao	2169
						Nam Ou	Lao	2035
						Nam Suang	Lao	2025
						Nam Khan	Lao	2011
Luang Prabang(L)	K	2010	268,000	267.195	G,Q,S,W			
Ban Pakkhone (L)	B	1930		241.069	G			
						Nam Huong	Lao	1923
Muan Paklay (L)	P	1800		210.088	G			
						Nam Heung	Thailand	1736
						Nam Loei	Thailand	1725
Chiang Khan (T)	K	1717	292,000	194.118	G,Q,S,W???			
Ban Sangkhom (T)	P	1618		162.644	G			
Pa Mong Damsite (T)	B	1601	299,000	160.46	G,Q			
Vientiane (L)	P	1580	299,000	158.04	G ???			
						Huai Mong	Thailand	1571
Nong Khai (T)	K	1551	302,000	153.648				
						Huai Suai	Thailand	
						Nam Huai Luang	Thailand	1503
Ban Phon Phisai (T)	P	1503		149.69	G			
Pak Kagnung (L) Nam Ngum	K			159.02	G,Q,S	Nam Ngum	Lao	1486
						Nam Mang	Lao	
						Nam Nhiep	Lao	1401
Ban Nong Bua (T)	B	1436	???	144.577	G			
						Nam Sane	Lao	1395
Paksane (L)	P	1394		142.125				
Ban Phonesy (L) Nam Ca Ding	K			13.75 +TBM	G,Q	Nam Theun/Nam Ca Ding	Lao	1352
Pak Huai Lang Ka (T)	B	1300		136.079	G			
						Nam Songkhram	Thailand	1263
						Nam Hinchoune	Lao	1247
Nakhon Phanom (T)	K	1217	373,000	130.961	G,Q,S,W			
Tha Khek (L)	B	1216	373,000	129.629	G,Q,S,W			
						Se Bang Fai	Lao	1166
That Phanom (T)	P	1166		127.94	G			
						Nam Kam	Thailand	1165
						Huai Bang Sai	Thailand	
Savannakhet (L)	B	1126	391,000	125.41	G,Q,S,W			
Mukhdahan (T)	K	1123	391,000	124.219	G,Q,S,W			
Khemarat (T)	P	1040		108.225	G			
						Huai Sang	Thailand	
Ban Keng Done (L) Se Bang Hiang	K			121.29	G,Q	Se Bang Hiang	Lao	1037
						SE Bang Nouane	Lao	1012
Ban Kum (T)	B	916		89.244	G,Q			
Khong Chiam (T)	K	910	419,000	89.03	G,Q,S,W			
Ubon (T) Nam Mun	K			105.074	G,Q,S,W	Nam Mun/Nam Chi	Thailand	909
Ban Dan Mai (T)	B				G,Q			
						Se Done	Lao	869
Pakse (L)	K	869	545,000	86.49	G,Q,S,W			
Ban Chan Noi (L)	P	767	549,000	80.224	G			
Hatien datum								
Cham Tangoy				11.077+BM1		Se Kong	Cambodia/Lao	
Ban Komboun (C) Se San	K			40.11	G,Q	Se San	Cambodia/Vietna	668
						Sre Pok	Cambodia	
Stung Treng (C)	K	668	635,000	36.79				
						Prek Preah	Cambodia	
						Prek Krieng	Cambodia	
						Prek Kampi	Cambodia	
Kratie (C)	K	545	646,000	-1.08	G,Q	Mekong	Cambodia	
						Prek Te	Cambodia	530
						Prek Chhlong	Cambodia	500
Kompong Cham (C)	K	410	660,000	-0.93	G,Q,S			
Chrui Changvar (C)	P	332	663,000	-1.08	G,Q,S			

The mean annual rainfall in the LMB is presented in Figure 1.1. It is observed that from west to east the rainfall increases from about 1,100 mm to some 2,500 mm due to orographical effects as the Laotian mountains lift the moist air masses entering from the southwest. The monthly distribution of the rainfall closely follows the monsoons, with rainfall mainly from May to September in the North, and May to October in the South, see Figure 1.2

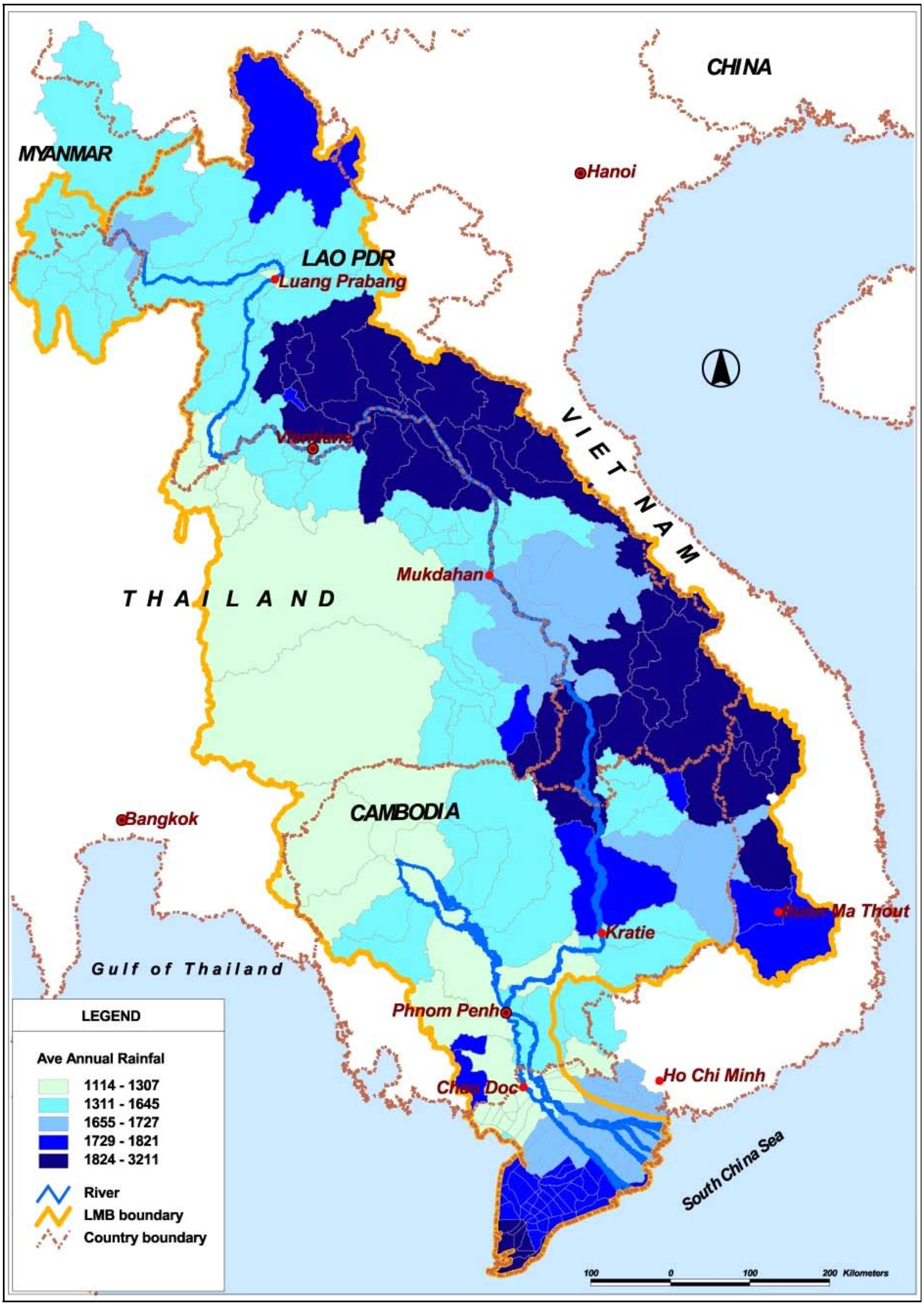


Figure 1.1 Mean annual rainfall in LMB (BDP, 2006)

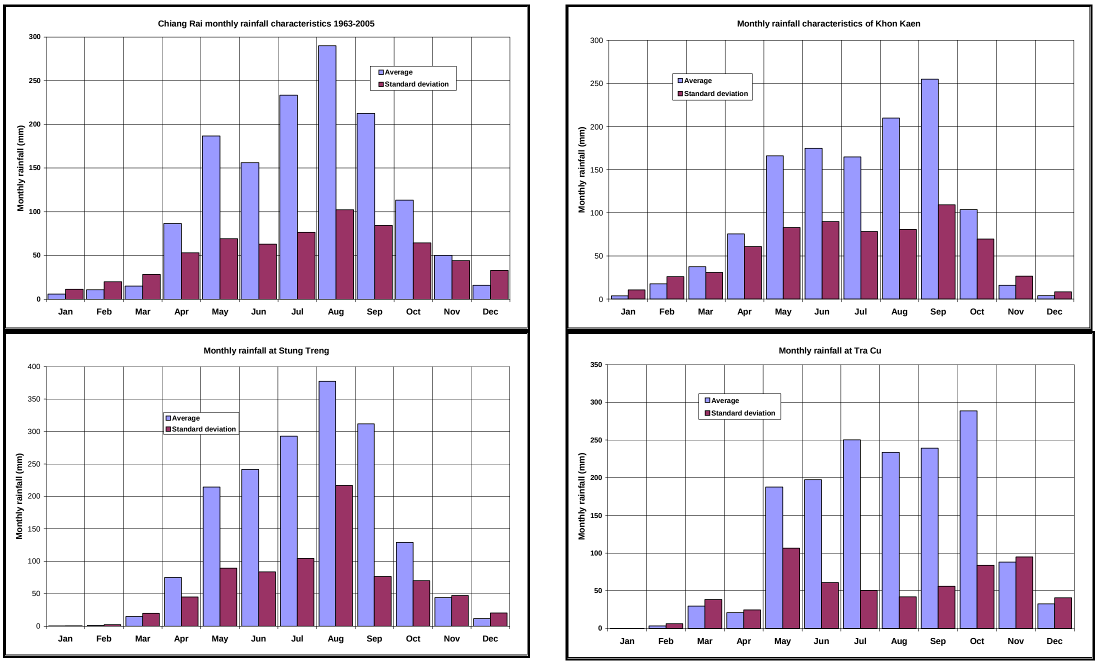


Figure 1.2 Monthly rainfall characteristics of Chiang Rai (SA2), Khon Kaen (SA5), Stung Treng (SA8) and Tra Cu (SA10).

1.3.4 River flows

The annual river flows at key locations along the Mekong River are presented in Figure 1.3. It is observed that the flows increase from less than 100 BCM at Chiang Saen to over 400 BCM at Stung Treng, just downstream of the mouth of the Se San, Sre Pok and Se Kong.

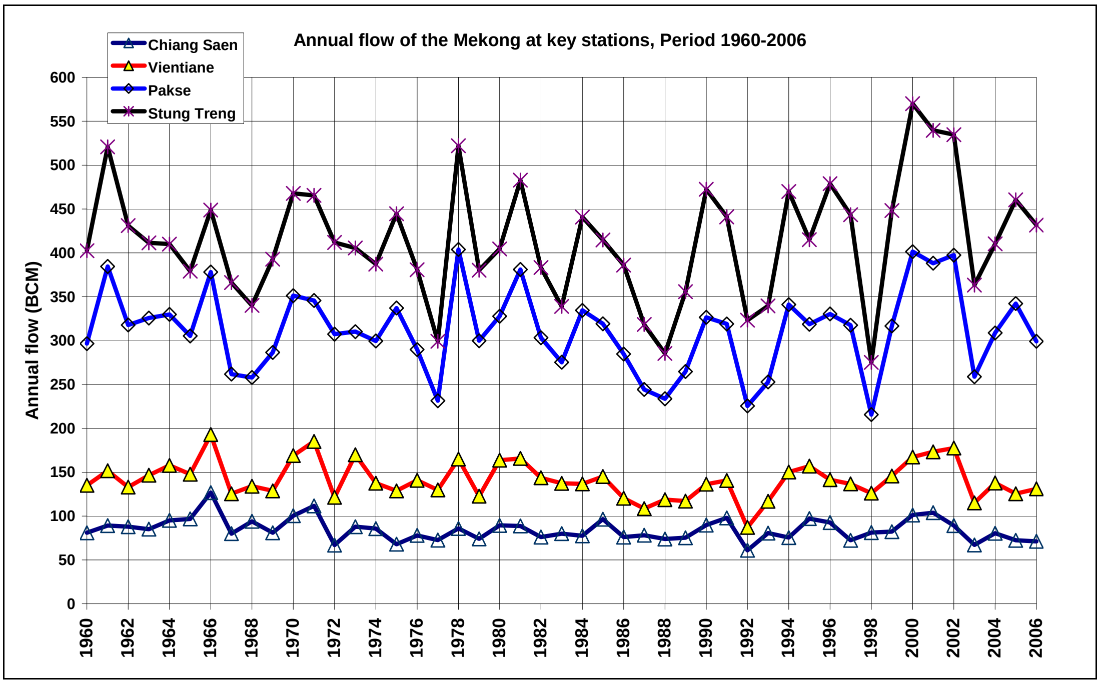


Figure 1.3 Annual flow of the Mekong at key stations, Period 1960-2006

The seasonal variation of the flow is presented in Figure 1.4. The figure shows that the peak runoff in the upper reaches of LMB occurs in August, whereas in the downstream reaches the peak shifts to September. Note also that the runoff at Chiang Saen in the dry season is relatively much larger than at Stung Treng. This is due to contributions of snowmelt in Chinese Yunnan, and is indicated as the Yunnan component. It is important in the upper reaches of the LMB, but its importance gradually diminishes further downstream. This may be observed from the contributions of the various Mekong reaches to the flow at Stung Treng, which is depicted in relative and absolute sense in Figure 1.5 and Figure 1.6.

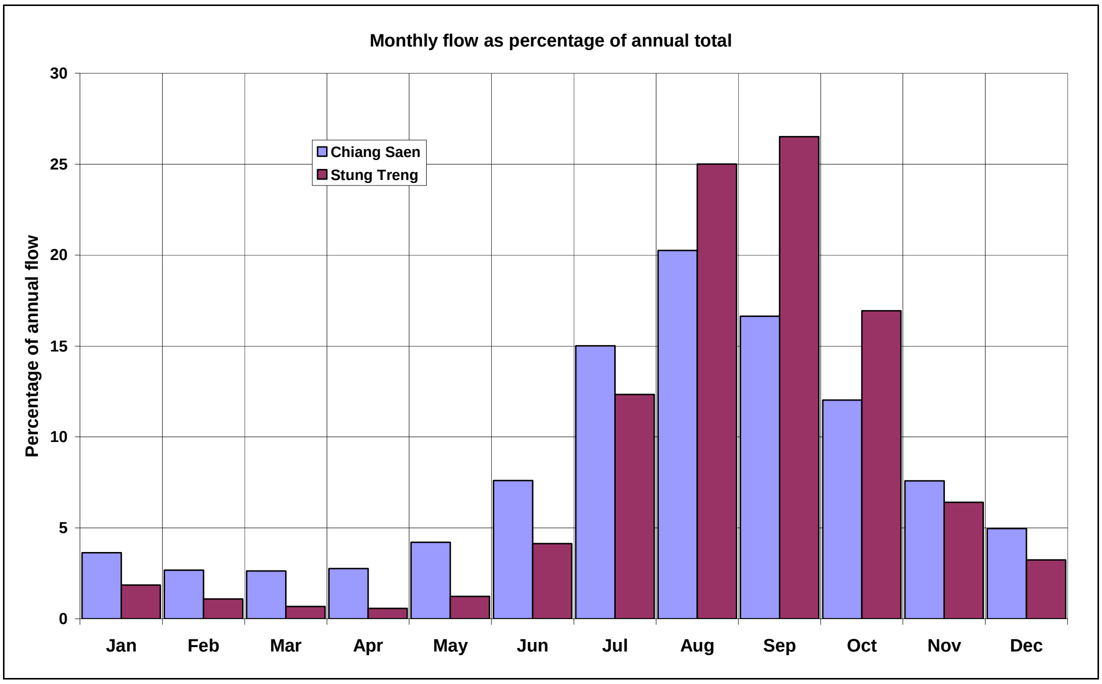


Figure 1.4 Monthly flows at Chiang Saen and at Stung Treng as percentage of annual total

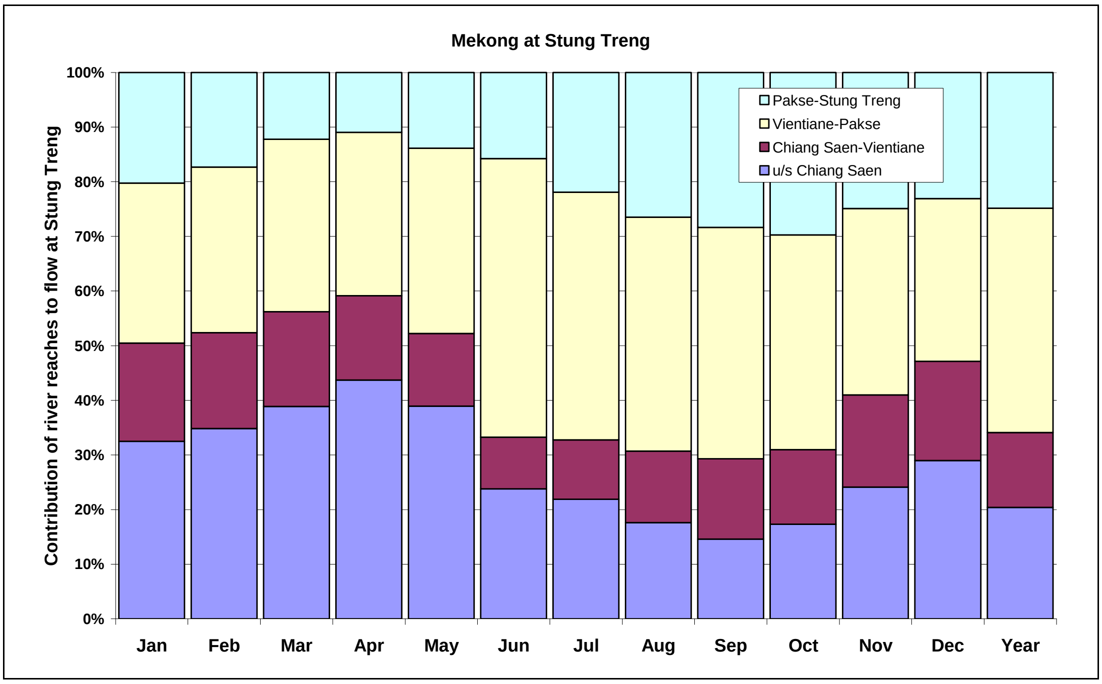


Figure 1.5 Relative weight of contributions of river reaches to the flow at Stung Treng

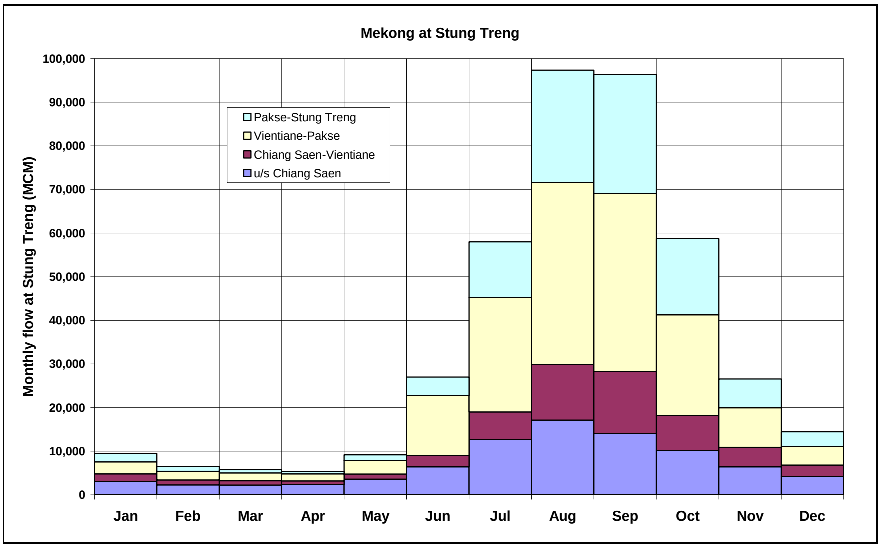


Figure 1.6 Contribution of river reaches to the flow at Stung Treng

From the above figures it is observed that during the dry season the flows are low in absolute sense but the contribution from the UMB (the Yunnan component) is still very large (almost 40%). In the period June to October the Mekong reach from Vientiane to the mouth of the Se San is by far the most important contributor to the flow at Stung Treng and Kratie, just upstream of the Delta.

The development of the flow along the river, the variation through the year and the occurrence of floods can be read from Figure 1.7. It is observed that the period in which extreme flows may occur gradually increases, also because peak rainfall shifts from July-August in the north to September-October in the south.

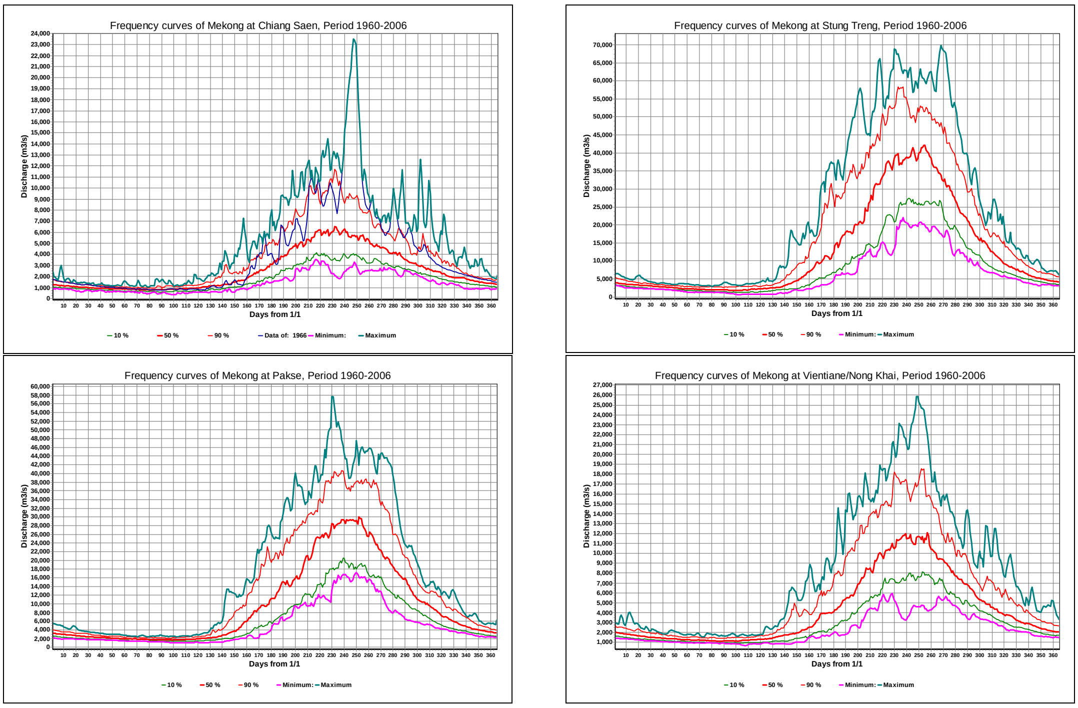


Figure 1.7 Frequency curves of daily flows for the Mekong at Chiang Saen, Vientiane, Pakse and Stung Treng

The distributions of annual maximum discharges of key stations on the Mekong are presented in Figure 1.8. The 100-year flood is seen to increase from 20,000 m^3/s at Chiang Saen to almost 80,000 m^3/s in Kratie, just before the Mekong enters the Cambodian flood plain. For flood mapping the peak water level is of importance, which can be derived from the peak flow level.

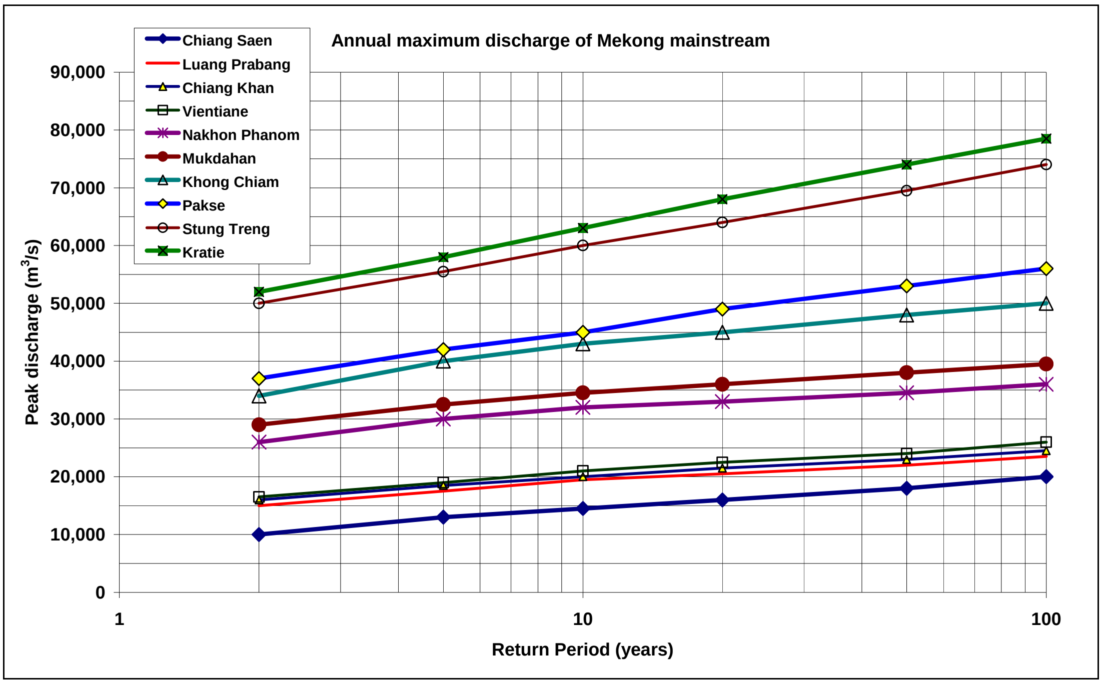


Figure 1.8 Distribution of annual maximum discharge of Mekong at key stations

Besides level and extent, also the duration of the flood is of importance for damage estimation. The exceedance duration is beside the flood discharge also a function of the flood volume, which is defined as the flow volume derived from the discharge hydrograph between its upcrossing and the downcrossing with the long term average flow each year, roughly corresponding with the period from 1 June to 30 November. The flood, as characterised by peak discharge and volume, has been modelled by Adamson (see MRC, 2005) by a joint distribution. An example is given in Figure 1.9 for Vientiane. It is observed that for the same peak discharge the flood volume can vary considerably. Nevertheless, there clearly is a correlation between flow volume and peak discharge.

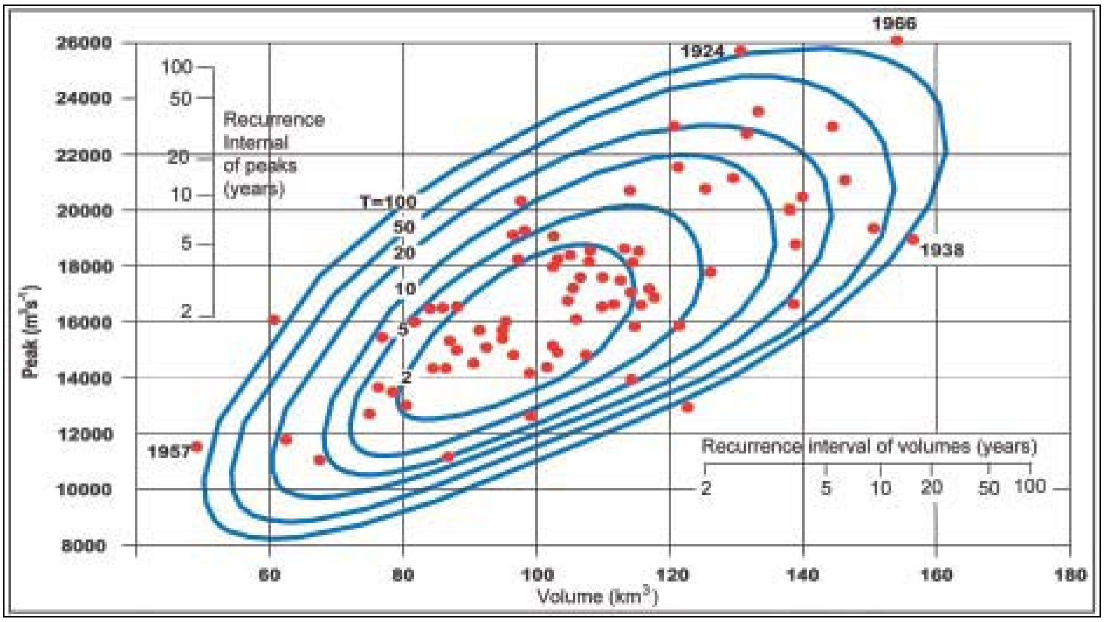


Figure 1.9 Joint statistical distribution of the peak and volume of the annual flood hydrograph on the Mekong at Vientiane (MRC, 2005)

1.3.5 Basin developments

Various developments may affect the river floods, including:

- Hydropower development in China and Laos,
- Land use changes, including deforestation, and
- Climate change and sea level rise.

Regarding hydropower large scale developments are planned on the Mekong mainstream in China. Furthermore, significant developments are taking place and are being planned on the Mekong tributaries in Laos, the upper Se San and Sre Pok in Vietnam and on the Se San in Cambodia and Mekong mainstream at Stung Treng and Kratie, see also Table 1.2. The existing effective storage capacity of

Table 1.2 Existing and planned reservoir capacity in Mekong basin (various sources)

Section	Mean annual flow (BCM)	Total (BCM)	Existing and planned reservoir capacity (BCM)
u/s Chiang Saen	84.5	84.5	32.2 (active)
Chiang Saen-Luang Prabang	38.5	123.0	22.5
Luang Prabang-Vientiane	17.6	140.6	0
Vientiane-Mukdahan	104.8	245.4	32.8
Mukdahan-Pakse	65.9	311.3	11.0
Pakse-Kratie	106.2	417.5	29.7 + 3.35 (active)
Kratie-Delta	39.8	457.3	>2.0
Total	457.3	457.3	98.0 + 35.55 (active)

The size of the developments varies from one publication to another. Assuming that 50% of the gross storage is effective, the active storage could grow to about 85 BCM in 2025, which is almost 20% of the average annual flow in the Mekong at mouth. It implies that the potential to reduce the hydrological hazard at locations is substantial. Effects on floods of the Chinese dams and of various development scenarios further downstream have been investigated a.o. by Beecham and Cross (2005). The results show (see Figure 1.10) that the Chinese dams with an assumed active storage of 28.5 BCM have a high potential to reduce flood peaks in the upper part of the LMB (about 1.8 m at Luang Prabang), which, however, rapidly reduces further downstream. Together with a high development of hydropower in the LMB (total active storage 47.6 BCM) reductions of the annual flood peak of 4 to 5 dm can be achieved. In the delta the effect is limited; on average the reduction is 1 to 2 dm, but for the extreme flood of the year 2000 the effect is only 5 cm. Though the effect is small on the flood levels and inundated area, a significant effect was found on the duration of flooding, which reduced substantially for some 40% of the flooded area.

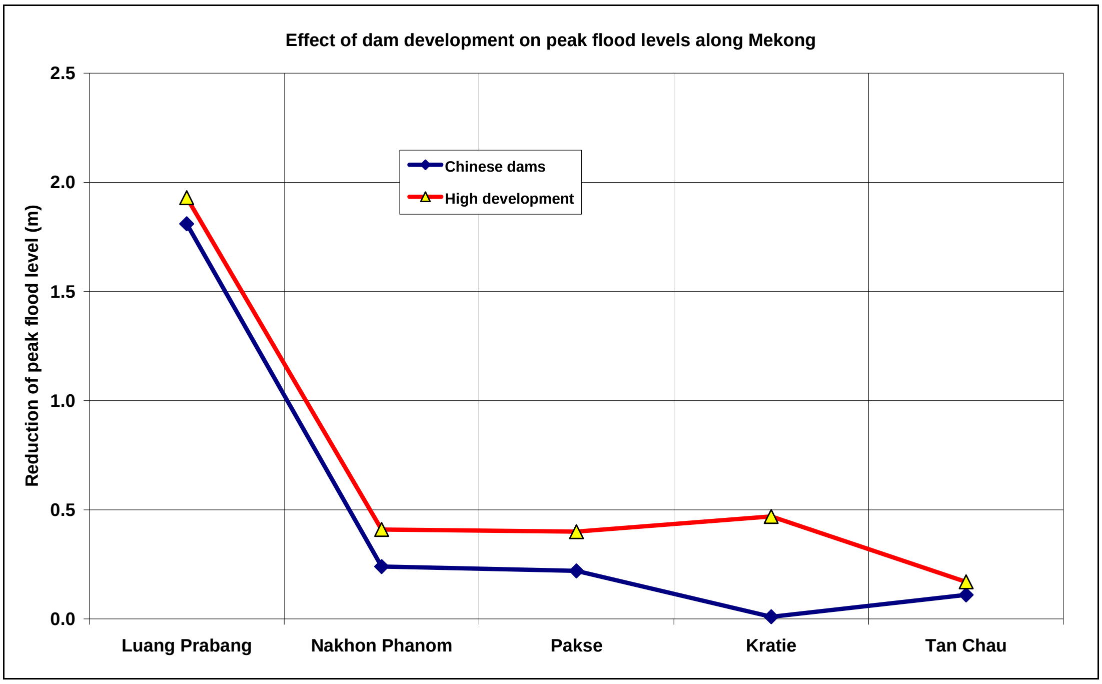


Figure 1.10 Effect of development scenarios on peak flood levels at selected locations along the Mekong River

It is noted that the results are indicative, as neither reservoir operation rules for the planned dams nor the actual implementations are known. Nevertheless, studies indicate that the hydropower development has at locations significant impact on the flood conditions and should be taken into consideration, particularly, when projects are developed in the upper reaches of the LMB.

The effects of land use changes in the Mekong basin on the flow parameters of Vientiane has been carried out by Adamson (2007). The parameters included annual maximum flood, annual discharge exceeded 25% of the time, annual median and annual minimum flow and were analysed for the period 1913-2006. No evidence was found on any systematic change in frequency and magnitude of the annual flood or hydrological conditions in general.

Regarding climate change Adamson (2007) investigated possible changes in the rainfall climate from the fifties until present. Based on an analysis of the annual maximum 1-day and 10-day storm rainfall for five locations in the upper reach of the LMB it was concluded that there was no evidence that the incidence of extreme storms had changed over the last 50 years or so. It is noted, however, that the analysis has been carried out on single maximum values per year and the conclusion of no change may not be valid for peaks over threshold. In the same study regional floods were analysed. Here the conclusion was made that sufficient evidence existed that the extreme floods have become more frequent over the last 15 years, but whether this is due to climate change is not clear.

Relations of peak discharges with El Nino/La Nina have also been reported. Kiem et al (see MRC, 2006) found that during El Nino years floods at Pakse tend to rise faster, but to a lower peak discharge than during non-El Nino years.

GCM models predictions for the type of change in the climate in the Mekong basin (MRC, 2006) vary, and appear to be often contradictive. From the review, it is learned that the influence of climate change on the flooding regimes of the Mekong is very uncertain. Regarding sea level rise there is consensus: the level will rise with some 2 to 5 dm in the next century (IPCC, 2007).

1.4 Classification of floods in the LMB

The Annual Flood Report 2005 (MRC, 2006) distinguishes the following types of floods:

1. Flash floods or tributary floods,
2. Mainstream floods,
3. Combined floods affected by backwater from the mainstream,
4. Floods in the Cambodian Flood Plain, and
5. Flood in the Mekong Delta.

1.4.1 Tributary floods

Tributary floods are generally flash floods, which occur in the steep sloped upper reaches of the basins due to intense rainfall after a long rainy period forcing the catchment to respond quickly to the rainfall. Flash floods are short lived, rise and fall rapidly and the flow velocities are very high. Effects of flash floods, when accompanied with landslides, are equivalent to dam break waves. To avoid the latter, conservation of forest is an important measure. The hydrological hazard can be reduced by reservoirs upstream, increase of infiltration capacity and flow diversion. The flood hazard can be mitigated by improvement of the discharge capacity of the river and by diking.

Design hydrographs will be required to design the measures for which due attention is to be given to its volume (for reservoirs), its shape (rate of rise and fall, velocities, duration) for design of revetments/embankments. For transformation of discharges into levels, inundated area and flow velocities, a hydraulic model is required.

1.4.2 Mainstream floods

Mainstream floods are caused by high water levels on the Mekong. The hydrological hazards for the mainstream stations along the Mekong have been presented in Annual Flood Report 2006 (MRC, 2007). To reduce the hydrological hazard large storages are required to create some effect, like the implementation of hydropower dams in China and in Laos. The flood hazard can be reduced by construction of dikes along vulnerable areas. Transformation of hydrological hazard into flood hazard requires a discharge-stage relation and a digital elevation model to convert level into flood extent. Discharge-stage relations are only available for the gauging locations. Hence a hydraulic model will be required to determine the discharge–stage relation for any location along the river, whereas for the extent of the flooding an appropriate DEM of the flood plain is needed. Exceedance durations have to be assessed for the various flood hazard levels, which can easily be derived from the available hydrological data of the mainstream stations.

1.4.3 Combined floods

Combined floods are floods that occur in the downstream sections of the tributaries, where the flood level is determined by the combination of tributary flow and the water levels in the Mekong, backing up the tributary levels and impeding the drainage. Also, when the levels in the Mekong are high, backwater flowing into the tributaries may occur. The character of these floods is not flashy; they may stay for weeks. In view of the shallow areas along the Mekong downstream of Vientiane a large number of tributaries in their lower reaches face this type of flooding. Measures may attack the upstream inflow (retention) or protect against the high levels (diking).

1.4.4 Flood in the Cambodian floodplain

The flood in the Cambodian flood plain describes the conveyance and storage of the flood in the Mekong and its flood plain downstream of Kratie to Phnom Penh, inclusive of the flooding around Tonle Sap Lake and the inflow to and outflow from the lake via the Tonle Sap River. Important aspects here are the spill levels of the rivers, the flood plain conveyance in relation with the road infrastructure and existence and dimensions of embankments. Flow diversion and diking are options to reduce the hydrological and flood hazard.

1.4.5 Flood in the Mekong delta

The flood in the Mekong delta deals with the conveyance of floodwater via the Mekong and Bassac Rivers and via their flood plains, including the use of colmatage canals to divert and control the flow from and to the River. In the delta the levels rise slowly due to the storage in Tonle Sap Lake and in the Mekong flood plains. Flooding here is recognized as essential for soil fertility, biodiversity and aquaculture. At the same time, it hampers use of agricultural land. The flood levels in the Mekong Delta in its downstream part are essentially the result of upstream inflow and downstream water levels at sea.

1.5 Summary of floods in the LMB sub-areas

The character and nature of flooding in the LMB is presented in Appendix 1 of Volume 2 of the Inception Report. In that document the characteristics are described for each of the 10 sub-areas in which the LMB has been divided in the frame of the Basin Development Plan of MRC (BDP, 2006) of which a summary is presented below. The sub-areas comprise (see also Figure 1.11):

1. Sub-area 1: Northern Laos
2. Sub-area 2: Northern Thailand (Kok and Ing basins)
3. Sub-area 3: Nong Khai/Songkhram
4. Sub-area 4: Central Laos
5. Sub-area 5: Lower Esaan (Mun/Chi)

6. Sub-area 6: Southern Laos (Khone Falls)
7. Sub-area 7: Se San/Sre Pok/Se Kong
8. Sub-area 8: Kratie
9. Sub-area 9: Tonle Sap
10. Sub-area 10: Mekong Delta

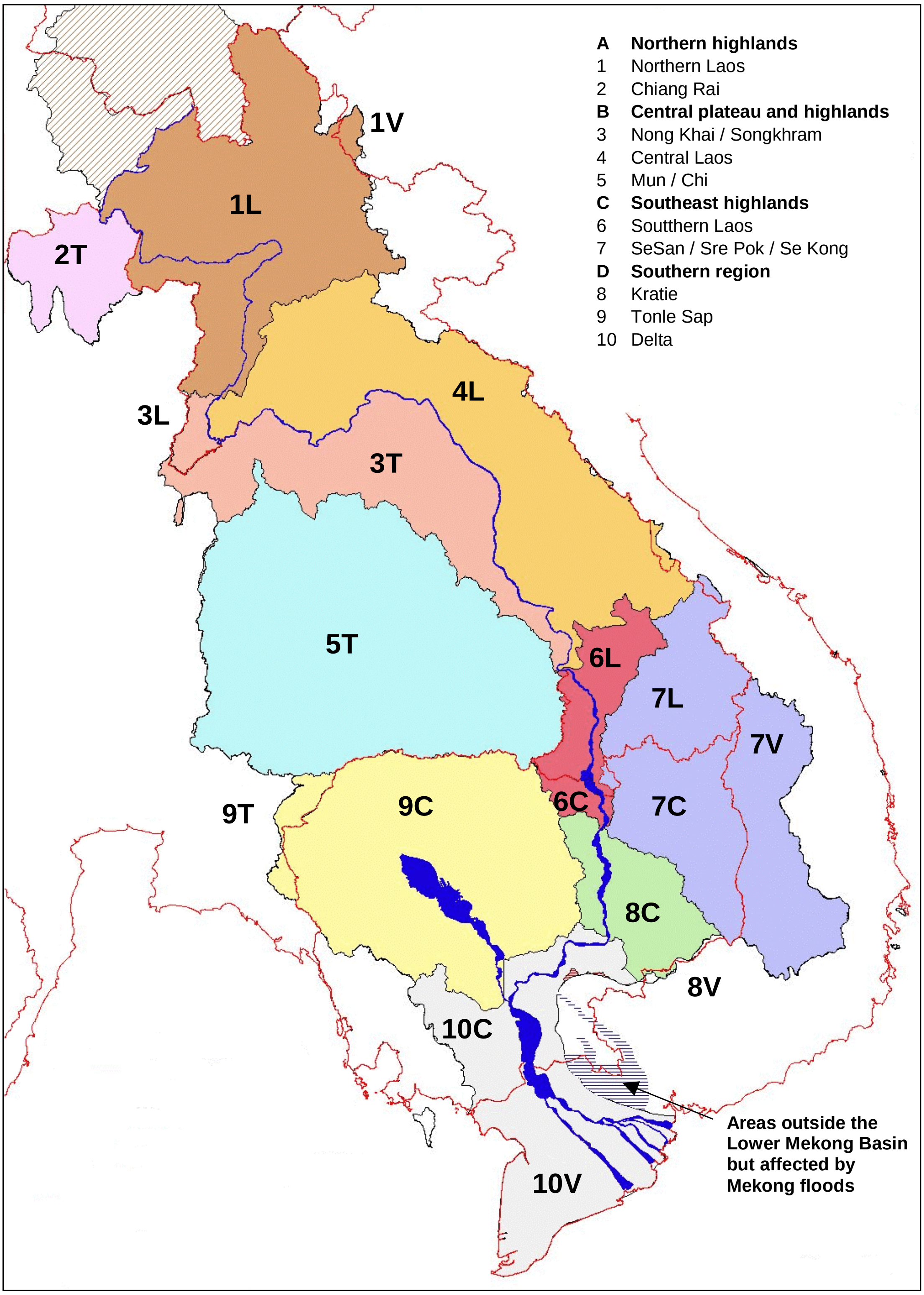


Figure 1.11 Overview of sub-areas in the Lower Mekong Basin

1.5.1 Sub-area 1: Northern Laos

- The type of floods that occur in SA1 are:
  - flash floods on the tributaries, and
  - mainstream floods along the Mekong.
  - combined floods are not an issue in SA1
- Regarding tributary floods:
  - the hydrological hazard for a limited number of gauged streams can be obtained from available discharge records, after a thorough screening of the available data. For the remaining area two procedures may be followed:
    - for small upland basins design hydrographs are derived by rainfall-runoff modelling using scaled rainfall statistics,
    - for larger areas the procedure proposed by Adamson (2007) by scaling of extremes based on the mean annual flood could be applied, provided that a suitable relationship can be developed between the mean annual flood, the rainfall and basin characteristics.
  - the flood hazard can only be determined when the bathymetry of the tributaries is known. No such information is available. Hence, only when such measurements are being made, flood hazard can be mapped.
- Regarding Mekong floods:
  - the hydrological hazard for stations in SA1 has been presented in the Annual Mekong Flood Report 2006.
  - Mapping of the flood hazard will require an extension of the ISIS-model for the reach Chiang Saen – Pakse with proper cross-sections of the floodplain. The current model is not suitable for such activity. However, if sufficient satellite based flood maps would be available for different times during the passage of the flood, inundation maps for different hazard levels could be made.

1.5.2 Sub-area 2: Northern Thailand (Kok & Ing basins)

- The type of floods that occur in SA2 are:
  - flash floods on the tributaries,
  - mainstream floods along the Mekong, and
  - combined floods at the junctions of the main tributaries with the Mekong.
- Regarding tributary floods:
  - the hydrological hazard for the gauged streams can be obtained from available discharge records, whereas for the remaining area the procedures as proposed for SA1 are advocated.
  - the flood hazard can only be determined when the bathymetry of the tributaries is known. Such information is at present not available. Hence, only when such measurements are being made, flood hazard can be mapped.
- Regarding mainstream floods:
  - the hydrological hazard for stations along the Mekong in SA2 has been presented in the Annual Mekong Flood Report 2006.
  - mapping of the flood hazard will require an extension of the ISIS-model with proper cross-sections of the floodplain. The current model is not suitable for such activity. However, if sufficient satellite based flood maps would be available for different times during the passage of the flood, inundation maps for different hazard levels could be made.

- Regarding combined floods:
  - in the lower reaches of the Nam Mae Kok and the Nam Mae Ing rivers combined floods do occur.
  - hydrological boundary conditions are available. Transformation into flood levels require hydraulic modelling. Development of a suitable hydraulic model for the Nam Mae Kok is planned but not yet available.

1.5.3 Sub-area 3: Nong Khai/Songkhram

- The type of floods that occur in SA3 are:
  - flash floods on the tributaries,
  - mainstream floods along the Mekong, and
  - combined floods at the junctions of the main tributaries with the Mekong.
- Regarding tributary floods:
  - flash floods do occasionally occur in the upper reaches of the westernmost tributaries of SA3.
  - the hydrological hazard can be determined using the procedures proposed for SA1 and SA2.
  - the flood hazard can be determined for a number of tributaries including Nam Loei, Huai Mong and Nam Songkhram for which basic bathymetric data is available and hydraulic models have been developed.
- Regarding mainstream flooding:
  - urban areas along the Mekong have been protected from mainstream flooding by dikes.
  - the hydrological hazard for stations in SA3 along the Mekong has been presented in the Annual Mekong Flood Report 2006.
  - if sufficient satellite based flood maps is available for different times during the passage of the flood inundation maps for different hazard levels can be made.
- Regarding combined floods:
  - combined flooding in SA3 is a major problem in view of its low laying areas adjacent to the Mekong and occurs frequently in the provinces of Nong Khai, Mukdahan and Nakhon Phanom. Floods are due to impeded drainage by backwater from the Mekong, last long and occur annually.
  - for a number of tributaries including Nam Loei, Huai Mong and Nam Songkhram basic bathymetric data is available for flood hazard mapping and investigation of flood mitigation measures.

1.5.4 Sub-area 4: Central Laos

- The type of floods that occur in SA4 are:
  - flash floods in the upper and middle reaches of the tributaries,
  - mainstream floods along the Mekong, and
  - combined floods at the junctions of the main tributaries with the Mekong.
- Regarding tributary and combined floods:
  - floods on the tributaries vary from flash floods in the steeper upper reaches to less flashy but of longer duration in the shallower middle and lower reaches, where backwater from the Mekong also extends the duration of flooding since the occurrence of mainstream and tributary floods are likely to coincide.
  - the hydrological hazard for the locations with records larger then say 15 years can be derived from the available data. Extension with rainfall-runoff modeling is not an option in view of the limited available and partly unreliable rainfall data. A regional analysis,

  like the one proposed by Anderson (2007) but extended with local rainfall and physical basin information as discussed in the previous sections, is an option.
  - For the Nam Ngum, Xe Bangfai and Se Bang Hieng models are available to translate the hydrological hazard into flood hazard.

- Regarding mainstream floods:
  - the hydrological hazard for stations in SA4 along the Mekong has been presented in the Annual Mekong Flood Report 2006.
  - the presently available hydraulic models are not capable of transforming hydrological hazard into flood hazard; however, if sufficient satellite based flood maps are available for different times during the passage of the flood, inundation maps for different hazard levels can be made.

1.5.5 Sub-area 5: Mun Chi

- Floods in the Mun-Chi system are flashy in the upper reaches and less rapid, but much longer lasting in the middle and lower parts of the Nam Mun and Nam Chi mainstream, where they cause annual flooding. Extra backup due to high stages in the Mekong is unlikely as the floods on Nam Mun and Mekong are shifted by about 1 month.
- The hydrological hazard can be determined for 12 locations, whereas for the remaining tributaries first the database of RID may be consulted or a regional approach is being embarked on.
- For the mainstream, satellite imagery combined with hydraulic modelling (Mike-11) is an option, provided the model is properly calibrated.

1.5.6 Sub-area 6: Southern Laos (Khone Falls)

- Major flood prone areas are centred near Pakse just downstream of the confluence of the Se Done with the Mekong and along the lower reach of the Se Done due to backwater from the Mekong.
- Hydrological hazards for mainstream and tributaries can be determined based on the available data from annual flood reports and the hydrological database.
- Flood hazard analysis will require a major effort on bathymetric surveys unless flood maps from satellite imagery can be made available.

1.5.7 Sub-area 7: Se San/Sre Pok/ Se Kong

- For the middle reaches of the Se Kong near Attapeu, and the upper reaches of the Se San and Sre Pok sufficient data is available for estimating the hydrological hazard and design hydrographs.
- Hydraulic models for transformation of hydrological hazard into flood hazard are only available for the Se San (downstream of Kontum), but not for the Se Kong and Sre Pok.
- For the upper reaches of the Se Kong no data is available for assessment of the hydrological hazard. A regional approach will be required for developing design conditions.
- For the analysis of combined floods in the Lower Se San, Se Kong and Sre Pok a complete review of the data for Ban Kamphun will be required.

1.5.8 Sub-area 8: Kratie

- Mainstream flooding and combined flooding occurs.
- Frequent flooding occurs particularly at Kratie, which has a much lower flood protection level than Stung Treng.
- Hydrological hazards can be determined from the available discharge records for Stung Treng and Kratie. A thorough review is required of the discharge ratings of Stung Treng and of Kratie. Reference is made to Appendix 8 of this report.
- Upstream of Kratie no hydraulic model is available to translate the hydrological hazard into a flood hazard, but with the help of satellite photos such translation can be made.
- Downstream of Kratie satellite imagery as well as hydraulic models are available for the translation of hydrological hazard into flood hazard.

1.5.9 Sub-area 9: Tonle Sap

- Tributary, mainstream and combined floods are an annual phenomenon in SA9.
- Regarding the flooding of Tonle Sap Lake and River calibrated models are available for flood hazard determination.
- Regarding tributary and combined floods:
  - the hydrological hazards can be determined making use of additional databases available with MRC from WUP-FIN, WUP-JICA and TSLV Projects
  - translation into flood hazards with hydrodynamic models of the tributaries can only be done for Stung Pursat and Stung Battambang. However, it is expected that sufficient flood maps will be available covering the surrounding of Tonle Sap to make use of in the translation of hydrological hazard into flood hazard.

1.5.10 Sub-area 10: Mekong Delta

- The hydro-meteorological database needs to be updated/extended to derive the hydrological hazards, see also Chapter 7. Additional data has been collected from project databases and from the Southern Regional Hydro-Meteorological Centre in Ho Chi Minh City.
- For the translation of hydrological hazard into flood hazard sufficient tools (hydraulic models and flood maps) are available for SA10 to describe the flooding in the area for various boundary conditions (hydrological hazards). The accuracy of the models for present conditions has been checked.

CHAPTER 2

NAM MAE KOK

2 NAM MAE KOK

2.1 General

The Nam Mae Kok basin has been selected by the TNMC as Focal Area 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.

Floods on the Nam Mae Kok are classified as tributary floods around the city of Chiang Rai and combined floods near the river mouth. In this chapter the hydrological hazard (probabilities of discharges and flood volumes) in the Nam Mae Kok is presented. The required procedures and boundary conditions for flood hazard assessment in the basin are given. Execution of the flood hazard assessment awaits the availability of a reliable hydraulic model.

This chapter provides a summary of the activities on flood hazard assessment for the Nam Mae Kok. For details of the analyses reference is made to Appendix 1 to This report: “Flood hazard assessment for Nam Mae Kok”.

2.2 Basin description and hydrological characteristics

2.2.1 Basin layout

The Nam Mae Kok basin covers an area of 10,730 km^2 of which 31% is located in Myanmar. It joins the Mekong at Sop Kok, some 5 km downstream of Chiang Saen gauging station on the Mekong, at an elevation of 355 masl. Major tributaries are the Nam Mae Fang and the Nam Mae Lao. The basin is mountainous on the divides with elevations up to 2,000 m, see Figure 2.1.

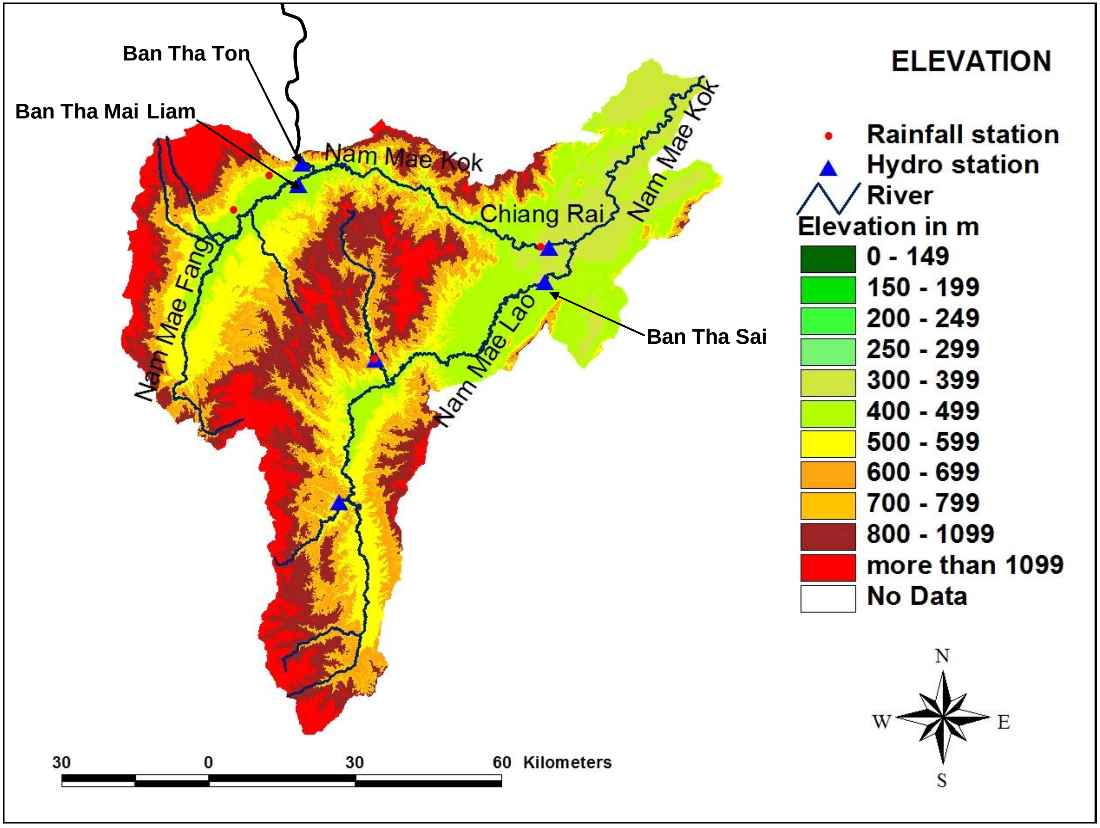


Figure 2.1 Nam Mae Kok elevation map with location of major discharge measuring stations

The valleys of the Fang, the Lao and the Kok rivers from Chiang Rai to the mouth are seen to be flat and flood prone. The basin is densely forested in the upper areas with agricultural development in the lower reaches.

2.2.2 Rainfall and evaporation

Average annual rainfall in the Kok basin varies from 1,300 to 1,400 mm in the upper reaches to 1,700 mm towards the river mouth, whereas totals for individual years range from 750 to 2,250 mm. Rainfall is highest in the months July to September. Little rainfall is experienced from December to March. The average monthly rainfall distribution for Chiang Rai is shown in Figure 2.2.

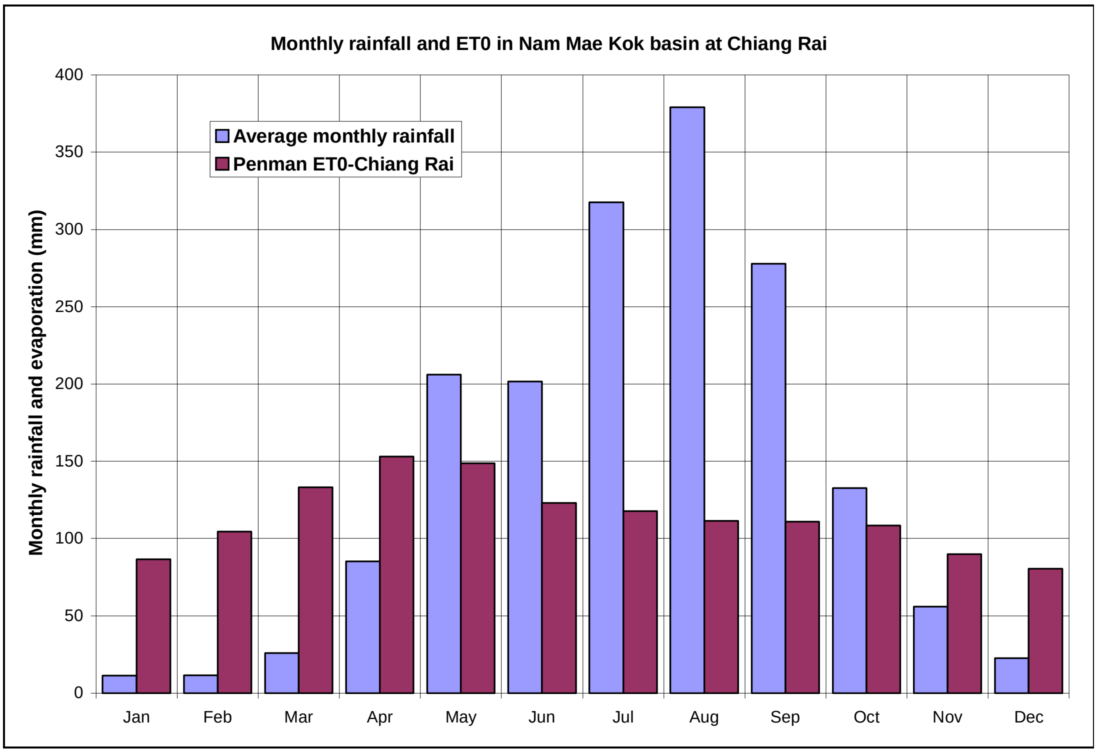


Figure 2.2 Average monthly rainfall and reference evaporation at Chiang Rai

In the same figure also the variation of the reference evaporation (potential evapo-transpiration of short grass) through the year is presented. Evaporation is seen to peak in April-May. Annual totals vary from 1,300 to 1,500 mm. The reference evaporation exceeds the average rainfall in the months November to April.

2.2.3 Runoff

The main discharge-measuring stations on the Nam Mae Kok and tributaries are:

- Ban Tha Ton on upper Nam Mae Kok
- Ban Tha Mai Liam on Nam Mae Fang
- Chiang Rai on Nam Mae Kok, upstream of confluence with Lao, and
- Ban Tha Sai on Nam Mae Lao.

The water levels at Chiang Rai are since 1994 affected by backwater from Chiang Rai weir and it is therefore not a suitable discharge station anymore. Downstream of the Lao-Kok confluence no station exists on the Nam Mae Kok with a long historical flow record to derive the flow statistics of the total basin. Assessing the total flow from the difference between the Mekong stations Sop Kok (inclusive Nam Mae Kok and Nam Mae Kham) and Chiang Saen (exclusive Nam Mae Kok and Nam Mae Kham) is not an option as the contribution of the two tributaries to the flow in the Mekong is relatively small, which would result in a large uncertainty in the tributary flow. The total Nam Mae Kok flow is therefore estimated as the sum of the flow at Chiang Rai and Ban Tha Sai, adjusted for additional drainage area (1.174 = 10,730 km^2/9,140 km^2).

The annual flows of the Nam Mae Kok at Chiang Rai and the Nam Mae Lao at Ban Tha Sai are shown in Figure 2.3. Their annual averages are respectively 3.62 BCM and 0.85 BCM, leading to a flow volume of the Nam Mae Kok at mouth of 5.24 BCM. The annual totals both show a downward trend, which can be attributed to higher rainfall in the seventies and increased abstractions in recent years.

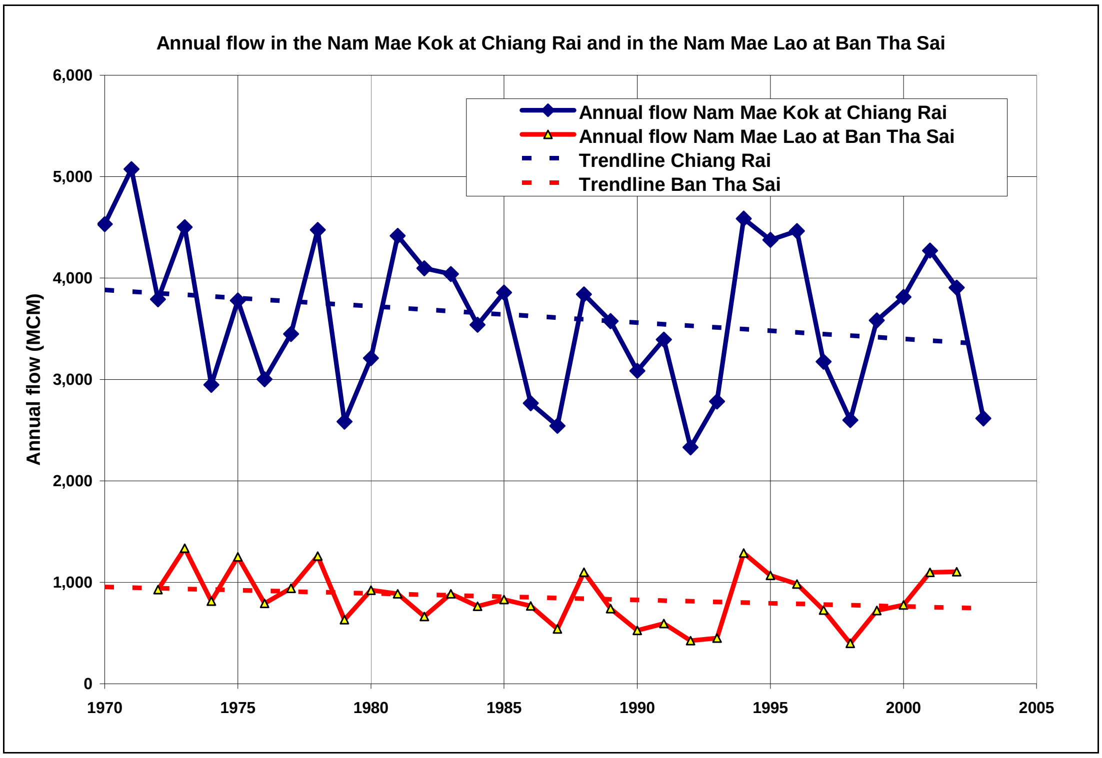


Figure 2.3 Annual flow in the Nam Mae Kok at Chiang Rai and Nam Mae Lao at Ban Tha Sai

The monthly flow statistics of Chiang Rai and Ban Tha Sai are presented in Figure 2.4 and Figure 2.5. Monthly averages are summarised in

Table 2.1. 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. The runoff per unit area differs considerably: in the latter is less than half of the runoff depth of the Nam Mae Kok at Chiang Rai. Compared with the Mekong it appears that the Nam Mae Kok is a few weeks in spate relative to the Mekong regime as can be observed from the 50 and 90% frequency curves of the Mekong at Chiang Saen and the Nam Mae Kok downstream of Chiang Rai (Figure 2.7).

Table 2.1 Average monthly and annual flows (in MCM) of the Nam Mae Kok at Chiang Rai, the Nam Mae Lao at Ban Tha Sai and the Nam Mae Kok at mouth

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Chiang Rai	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
Ban Tha Sai	25.6	11.4	8.0	9.7	36.9	45.4	73.4	159.1	201.3	131.8	93.7	49.4	846
at mouth	218.5	133.4	109.2	98.1	194.9	272.6	555.7	1030.3	1076.2	728.9	501.8	319.8	5240

The data show that the natural river regime has only marginally been modified by irrigation water use and storage for hydropower; the present storage capacity is less than 0.5% of the average annual flow of 5.24 BCM of the Nam Mae Kok. However, with the Nam Kok hydropower dam implemented in Myanmar (at present studied at pre-feasibility level), which has a planned storage capacity of 3.033 BCM, some 30% of the total flow in the Nam Mae Kok at mouth can be fully controlled.

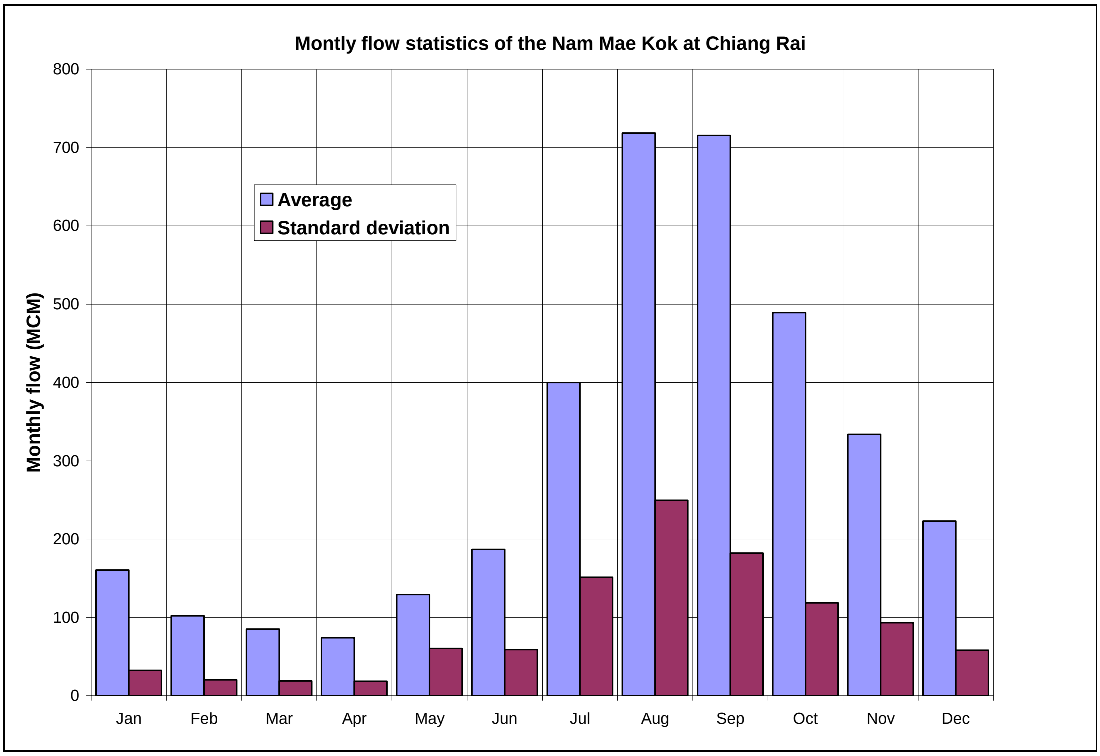


Figure 2.4 Monthly flow statistics of the Nam Mae Kok at Chiang Rai

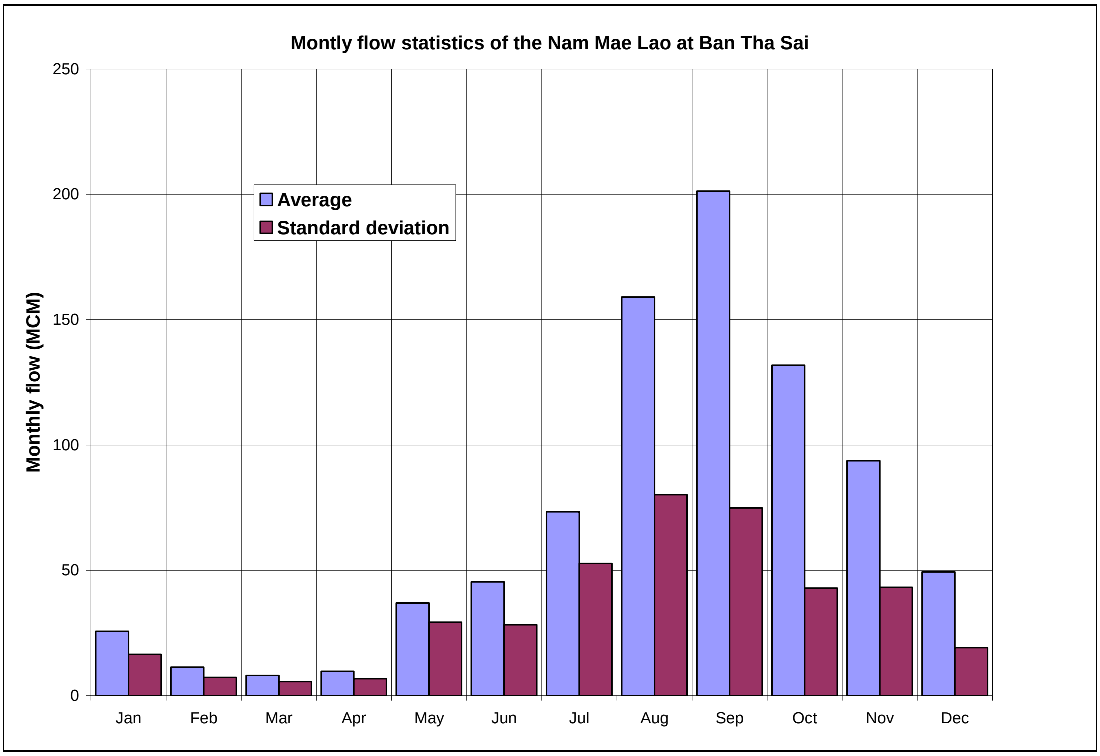


Figure 2.5 Monthly flow statistics of the Nam Mae Lao at Ban Tha Sai

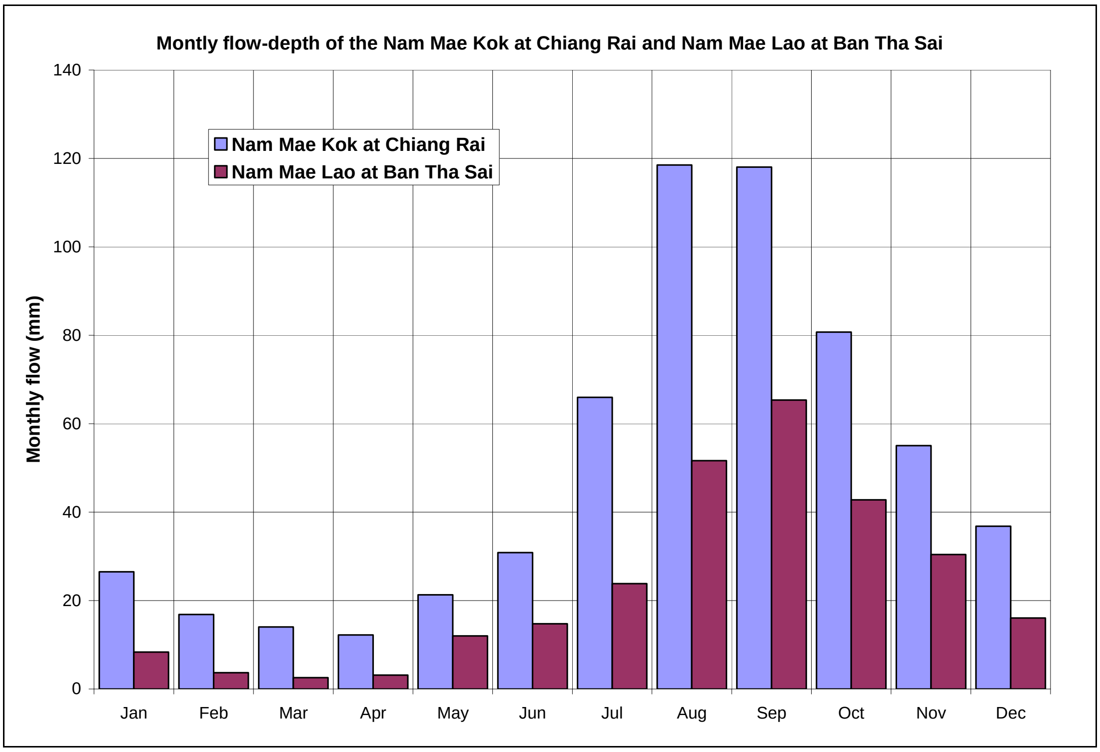


Figure 2.6 Comparison of monthly flow depth in Kok at Chiang Rai and Lao at Ban Tha Sai

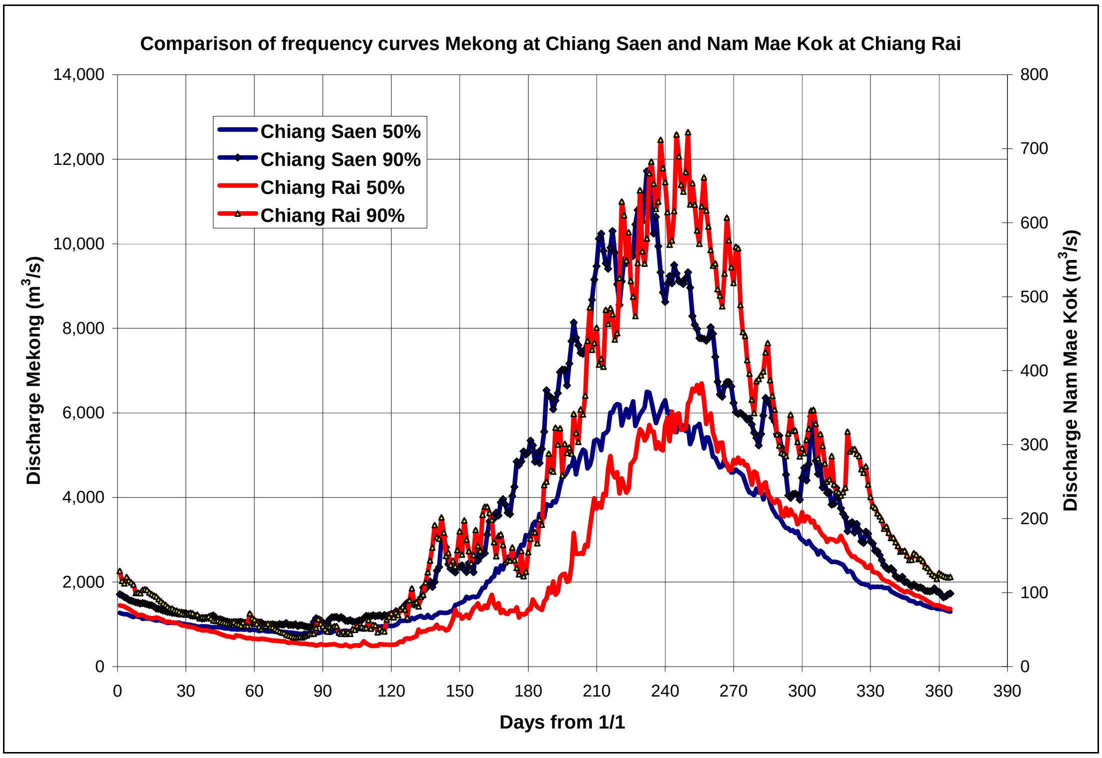


Figure 2.7 Comparison of discharge frequency curves of Mekong at Chiang Saen and Nam Mae Kok d/s of Chiang Rai

2.3 Type of floods and flooded area

Flood prone areas in the Nam Mae Kok basin comprise the valley of Nam Mae Fang, Chiang Rai Province and the mouth of the Nam Mae Kok.

Floods along the Nam Mae Fang and in Chiang Rai province are classified as tributary floods. In the upper reaches of the tributaries these floods are flashy. The flashiness of the floods decreases further downstream in Chiang Rai Province. Here flooding takes place near the city of Chiang Rai, located at the confluence of the Nam Mae Kok and Nam Mae Lao. The city is flood prone when the rivers convey large discharges. The last major flood (2006) originated from the Nam Mae Lao and a small creek named Nam Mae Korn, see Figure 2.8. The flooded area comprised the flood plain of the Korn up to the left bank of the Nam Mae Lao.

One of the solutions studied by the TNMC for Chiang Rai is the construction of a bypass canal from the Korn to the Kok west of Chiang Rai, d/s of the Korn-Lao connection. This bypass increases the discharge of the Nam Mae Kok in the city.
In the lower 20-25 km of the Nam Mae Kok near the mouth floods are of the combined type: flood levels are not only determined by high discharges in the Nam Mae Kok but are affected by backwater from the Mekong as well.

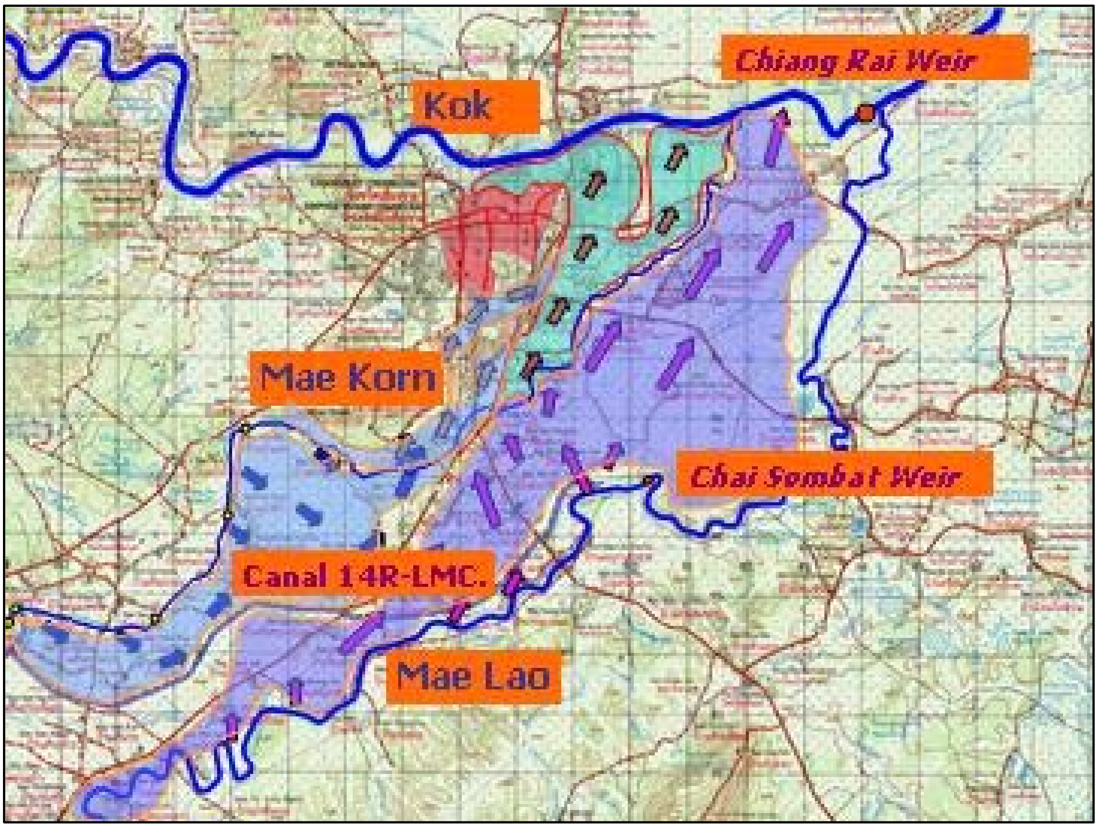


Figure 2.8 Flooding in Chiang Rai Province near the city of Chiang Rai

2.4 Flood hazard assessment procedures

Floods on the Nam Mae Kok as described in Sub-section 2.3 can be classified as tributary floods around the city of Chiang Rai and combined floods near the river mouth. The procedures required for assessment of the flood hazard for these types of floods are outlined below.

2.4.1 Hazard assessment for tributary floods around Chiang Rai city

Tributary floods here refer to floods on the Nam Mae Kok and Nam Mae Lao not affected by backwater from the Mekong. These floods are of limited duration caused by extreme discharge in the rivers. Discharge series of sufficient length are available for statistical analysis. Univariate extreme value distributions are applied to fit the observed distributions of annual maximum discharges for assessment of the hydrological hazard. Flood levels are derived from a transformation of the hydrological hazard (i.e. peak discharges of selected return periods) using a hydraulic model of river and flood plain. Design hydrographs are attached to the design discharge for damage assessment related to flood depth and duration. When damage of agricultural land is at stake special attention is to be given to the timing of the flood in relation to the crop calendar.

2.4.2 Hazard assessment for combined floods near Nam Mae Kok mouth

The procedure applied to derive the flood hazard of combined floods uses the Monte Carlo sampling technique to derive exceedance probabilities of water levels and damages. The procedure uses three random variables, representing the main causes for high water levels in the downstream part of the Nam Mae Kok:

1. The maximum discharge in the Mekong river at Chiang Saen;
2. The total volume of the flow in the Mekong river at Chiang Saen;
3. 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 quite large (10,000 in this case) 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. The procedure needs to be applied separately for each location in the area in which one is interested. This is because the relation between the three random variables on one hand and the resulting maximum water level on the other hand may vary significantly from one location to the other.

This procedure has not been implemented in the study because [a] the main interest is in flood hazards for the city of Chiang Rai and its environs and [b] the hydraulic model of the Kok basin does not contain flood plain location in the downstream part of the basin, which makes it hard to execute proper flood hazard analysis in that area.

2.5 Flood hazard assessment for Chiang Rai city

The flood hazard assessment for Chiang Rai city involves the following steps:

1. assessment of the hydrological hazard with the aid of univariate extreme value distributions of annual maximum discharges;
2. development of a hydraulic model of river and flood plain to translate discharges into water levels;
3. development of design hydrographs with peak values of desired return periods derived in step 1 as boundary conditions for the hydraulic model;
4. determination of water level hydrographs and flow velocities for selected return periods with the hydraulic model using the boundary conditions defined in step 3, and
5. determination of flooding extent, depth and duration and flow velocities at required locations as input for flood hazard mapping and damage assessment.

These steps are shortly discussed below. For a detailed analysis reference is made to Appendix 1 of this report.

2.5.1 Step 1: Hydrological hazard assessment

Discharge series of the Nam Mae Kok and tributaries are only available from 1969 onward at the most. Hence, annual maximum discharges abstracted from these series are too short to obtain peak flows of up to 100 year return period from the observed distributions. Therefore, theoretical extreme value distributions are fitted to the observations. Extreme Value Type 1 or

Gumbel (EV1) and General Extreme Value (GEV) distributions have been used to fit the observed distribution of annual extreme discharges in the Nam Mae Kok and Nam Mae Lao. The distributions have the following form:

$$EV1: \quad F(x) = \exp\left\{-\exp\left[-\left(\frac{x-u}{\alpha}\right)\right]\right\}$$

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

where: F(x) = distribution function of annual maximum discharge

k, α, u = shape, scale a

Note that for k = 0 the GEV distribution reduces to EV1. The method of probability weighted moments (see Cunnane, 1989) has been applied to estimate the distribution parameters. Tests are applied on the validity of the hypothesis of k = 0, i.e whether the application of an EV1 distribution is justified.

Extreme value analysis of annual maximum discharge has been executed for the following river sections around Chiang Rai:

1. Nam Mae Kok upstream of the confluence with Nam Mae Lao, based on the series of station Chiang Rai and extended with discharge series available at Ban Tha Ton (upper Nam Mae Kok) and Ban Tha Mai Liam (Nam Mae Fang)
2. Nam Mae Lao at Ban Tha Sai, and
3. Nam Mae Kok downstream of the confluence with Nam Mae Lao, based on the (extended) series of Chiang Rai and Ban Tha Sai.

The results are summarised in Table 2.2 and Figure 2.9. The EV1-distribution fits only well to the discharge extremes in the Nam Mae Kok at Chiang Rai u/s of the Lao confluence. Downstream of the confluence and for the Nam Mae Lao the GEV-distribution is applicable. Some 5% is advised to be added these data to arrive at the instantaneous peak values of given return period as the base data refer the daily average flows. For details of the fit reference is made to Appendix 1.

Table 2.2 EV1 and GEV-parameters of annual maximum discharge distributions and values for distinct return periods in the Nam Mae Kok and Nam Mae Lao around Chiang Rai

Parameter/Return period	Nam Mae Kok Chiang Rai u/s Lao confluence (m^3/s)	Nam Mae Lao Ban Tha Sai (m^3/s)	Nam Mae Kok Chiang Rai d/s Lao confluence (m^3/s)
Period	1969-2005	1972-2002	1969-2005
Distribution	EV1	GEV	GEV
k	-	0.339	0.260
α	137.0	41.8	196.0
u	482.3	165.7	654.8
T (years)			
2	532	180	723
5	688	215	898
10	790	232	989
25	920	247	1080
50	1017	256	1135
100	1112	263	1181

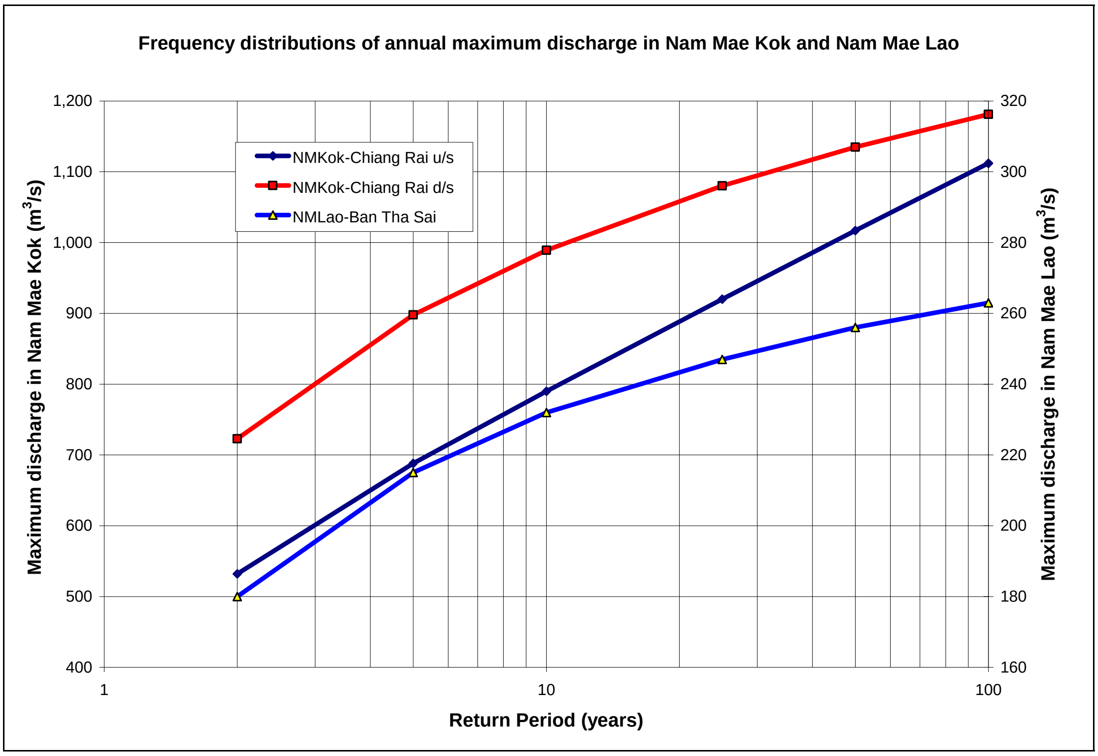


Figure 2.9 Frequency distributions of annual maximum discharge in the Nam Mae Kok at Chiang Rai and d/s confluence with Nam Mae Lao and in the Nam Mae Lao at Ban Tha Sai.

Note that the discharge extremes in the Nam Mae Kok d/s of the Lao are less than the sum of the extremes at Chiang Rai and Ban Tha Sai, which indicates that the peaks on the Kok and the Lao generally do not coincide.

2.5.2 Step 2: Development of a hydraulic model of Nam Mae Kok

To translate the discharges for selected return periods established in step 1 to water levels along the river and in the flood plains a hydraulic model is required. A 1D mathematical hydraulic model of the Nam Mae Kok and Nam Mae Lao was developed by DWR/TNMC in 2006 for the Case Study: “Flood/Drought for Kok River Basin”. However, the quality of this hydraulic model was considered to be insufficient for reliable flood hazard assessment in the Chiang Rai region. Improvements and extensions based on new bathymetric surveys are under way but have not yet been completed (scheduled for late 2008). So, no hydraulic model was available for translation of the hydrological hazard into flood hazard.

It is noted that the flooding around Chiang Rai city is complex and its extent is preferably modelled with a 2D hydraulic model.

2.5.3 Step 3: Development of design hydrographs

To determine beside flood peaks also flood durations representative hydrographs are attached to the peak discharges as boundary conditions to the hydraulic model. Synthetic hydrographs have been developed based on the shape of the 20 largest independent flood peaks observed in the Nam Mae Kok and Nam Mae Lao. Each of the selected hydrographs have been scaled to the maximum and the ordinates prior to and after the peak have been sorted to arrive at the required 10, 50 and 90% dimensionless hydrographs, representative for lean, median and wide flood waves. These hydrographs are made dimensional by substituting for Q_{max} the Q_T-value for the required return period T = 2, 10, 25 and 100 years.

An example of a series of synthetic hydrographs is given in Figure 2.10.

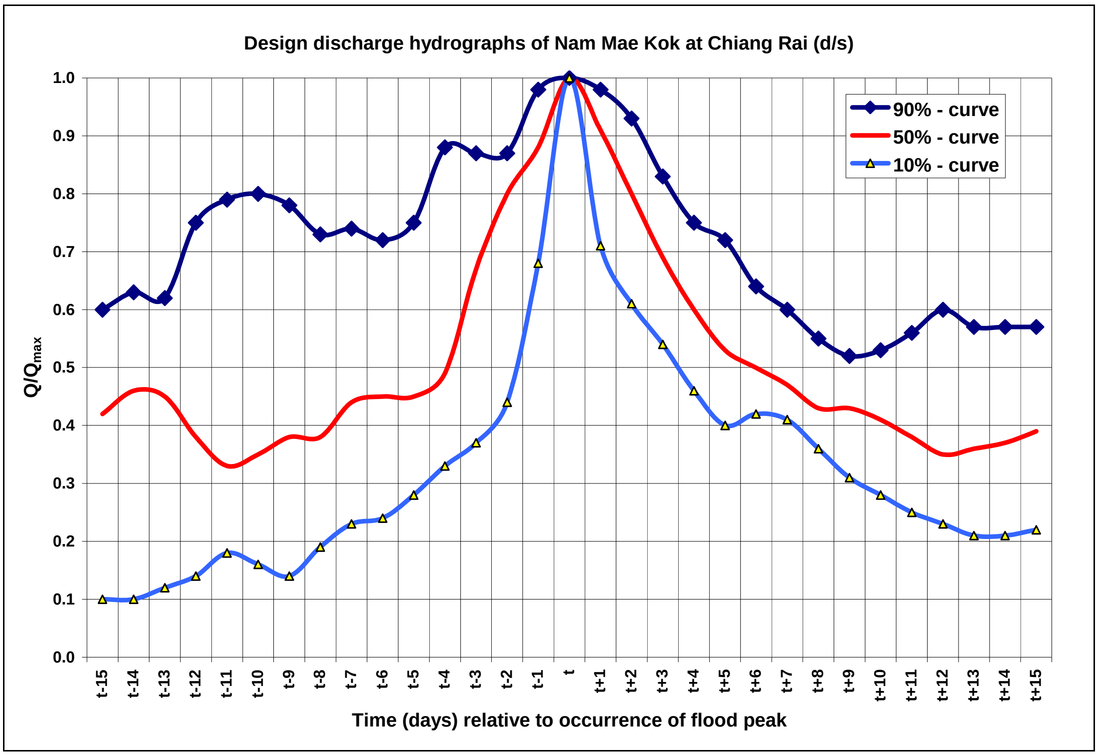


Figure 2.10 10%, 50% and 90% design hydrographs of Nam Mae Kok at Chiang Rai downstream Lao junction

When in the application of the hydraulic model a hydrograph at a secondary site is required (like the Nam Mae Lao in case of extremes in the Nam Mae Kok upstream of the Lao confluence and of the Nam Mae Kok in case of extremes in the Nam Mae Lao), the flow volume flow for the synthetic flood at the secondary site is determined from a regression analysis on the flow volume at the primary site:

$$\begin{aligned} V_{Lao} &= 0.17\ V_{Kok} + 81 \quad (\mathrm{MCM}) \qquad \mathrm{Se} = 70\ \mathrm{MCM} \\ V_{Kok} &= 2.59\ V_{Lao} + 254 \quad (\mathrm{MCM}) \qquad \mathrm{Se} = 176\ \mathrm{MCM} \end{aligned} \qquad (2.2)$$

2.5.4 Step 4: Determination of water level hydrographs and flow velocities

By running the hydraulic model established in Step 2, with the boundary conditions determined in Step 3 water level hydrographs and flow velocities for selected return periods are obtained. This awaits the availability of a recalibrated hydraulic model of the Nam Mae Kok.

2.5.5 Step 5: Determination of flooding extent, depth and duration

By comparing the water level hydrographs, derived in Step 4 for selected return periods, with the topography in the DEM of the flood prone areas the flooding extent, depth and duration can be established. This information, together with the flow velocities are input to the flood damage assessment.

2.6 Flood hazard assessment for Nam Mae Kok mouth

The lowest 20-25 km of the Nam Mae Kok is subject to combined flooding as the water levels are affected by the river stage in the Mekong. Flood hazard assessment for this area involves the following steps:

1. assessment of the hydrological hazard at the Nam Mae Kok mouth;
2. development of a hydraulic model of river and flood plain to translate water levels and discharges into flood levels;
3. selection of 150 combinations of Mekong and Nam Mae Kok floods;
4. running of the hydraulic model for 150 combinations of inflows and downstream water levels as input to Monte Carlo analysis;
5. application of Monte Carlo technique to the simulations, and
6. determination of flooding extent, depth and duration.

These steps are shortly discussed below. For a detailed analysis reference is made to Appendix 1.

2.6.1 Step 1: Hydrological hazard assessment

The flood hazard near the mouth of the Nam Mae Kok is determined by the water levels in the Mekong at Sop Kok, i.e. at the mouth of the Nam Mae Kok, and the peak discharges and flood volumes in the Nam Mae Kok. Sop Kok used to be a hydrometric station on the Mekong but has been abandoned since 1993. The water levels at Sop Kok can be derived from the discharge series at Chiang Saen, a key hydrological station some 5 km upstream of Sop Kok. Water levels at both sites relate well. Hence, the hydrological hazard at the Nam Mae Kok mouth can be expressed in terms of peak flows and flood volumes at Chiang Saen. Flood volumes are important here as they are an important indicator for flood duration. The hydrological hazard in the Nam Mae Kok upstream of the backwater reach of the Mekong is derived from the sum of the discharge series at Chiang Rai and Ban Tha Sai, with corrections for additional drainage area.

As before, EV1 and GEV distributions were fitted to annual maximum discharges and flood volumes, where the latter is defined here as the flow volume between 1 June – 30 November. The EV1 distribution fits well to the annual maximum discharge and flood volume in the Mekong at Chiang Saen, whereas the GEV distribution applies to the lower Nam Mae Kok discharge and flood volumes. The results are presented in Table 2.3 and Figure 2.11and Figure 2.12. Neither the peak discharges nor the annual flood volumes in the Mekong versus the Nam Mae Kok show any significant correlation. Furthermore, it appears that the annual maximum discharges on the Mekong occur on average about two weeks earlier than the annual peaks on the Nam Mae Kok.

Table 2.3 EV1 and GEV-parameters of annual maximum discharge and flood volume distributions and values for distinct return periods in the Mekong at Chiang Saen and Nam Mae Kok near the mouth

Parameter/Return period	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)
Period	1960-2006	1960-2006	1969-2005	1972-2002
Distribution	EV1	EV1	GEV	GEV
k	-	-	0.260	0.231
α	2,126	9,895	190.6	954.0
u	9,289	61,173	738.5	3,749
T (years)				
2	10,068	64,800	815	4,084
5	12,478	76,015	1,013	4,959
10	14,074	83,440	1,115	5,424
25	16,090	92,823	1,218	5,907
50	17,585	99,783	1,280	6,203
100	19,070	106,692	1,332	6,453

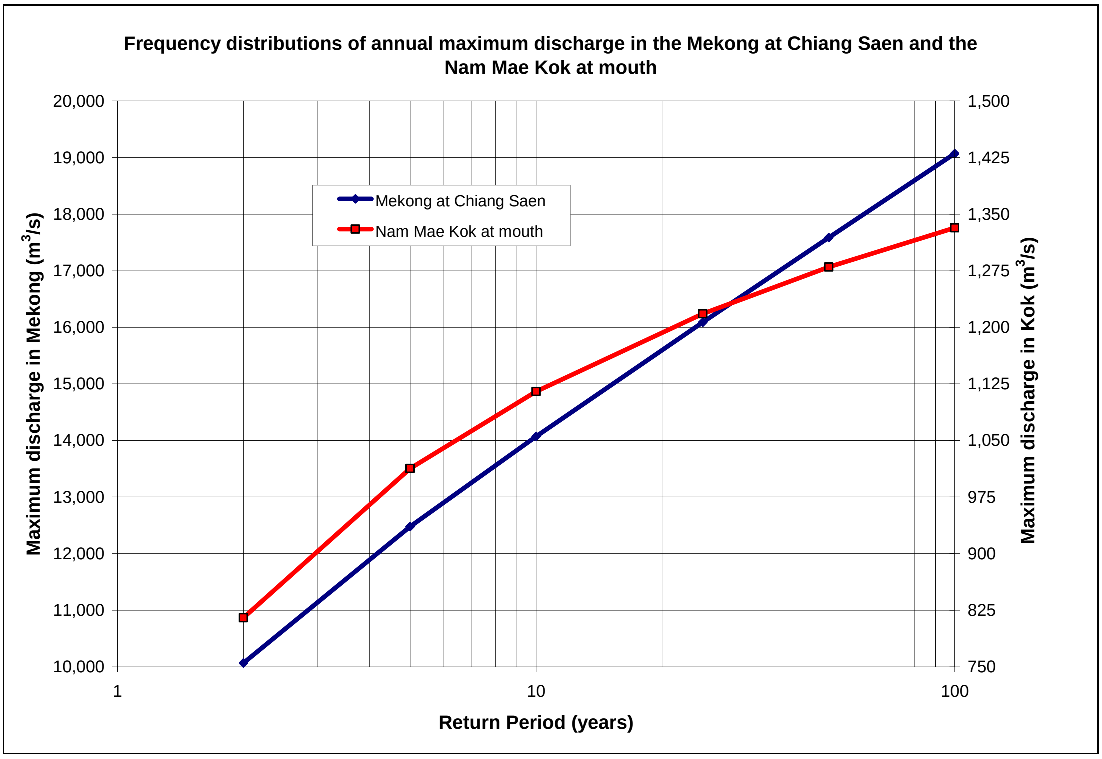


Figure 2.11 Frequency distributions of annual maximum discharge in the Mekong at Chiang Saen and in Nam Mae Kok at mouth

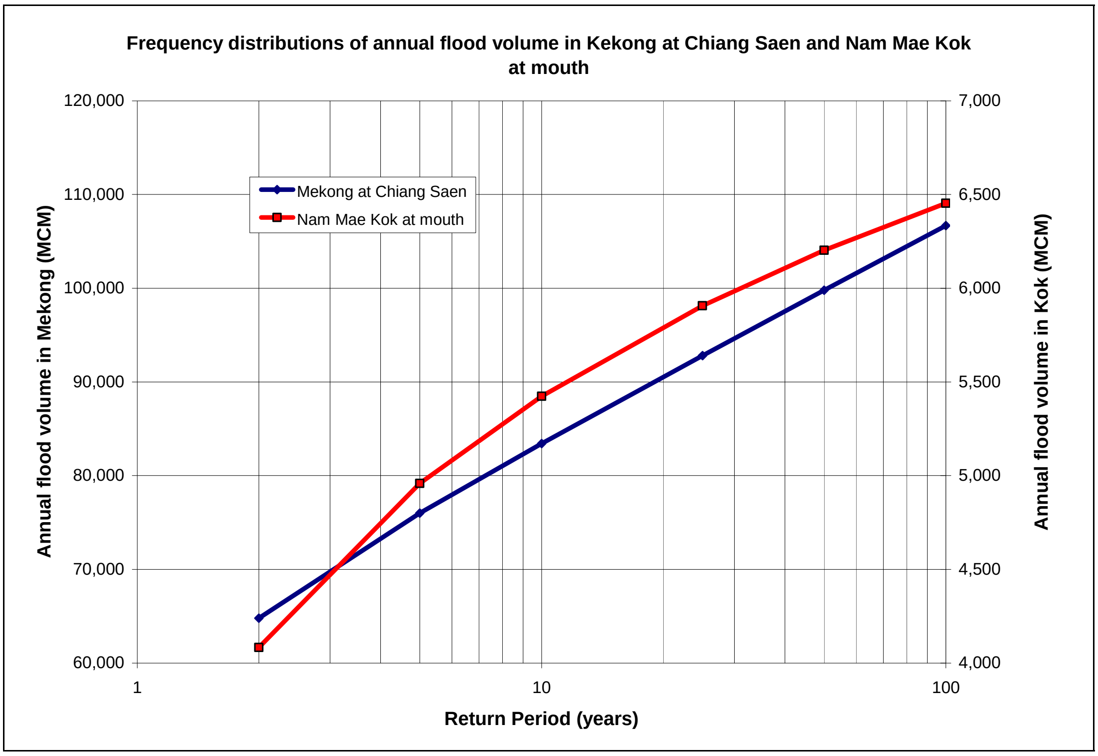


Figure 2.12 Frequency distributions of annual flood volume (1 June-30 November) in the Mekong at Chiang Saen and in Nam Mae Kok at mouth

Above distributions refer to the marginal distributions of annual maximum discharge and flood volume. The peak discharges and flood volumes for Chiang Saen as well as those for Lower Nam Mae Kok are strongly correlated. These correlations are used in Step 3 to select combinations of floods. The regression relations of flood volumes on peak discharge read:

$$V_{ChiangSaen}(MCM) = 3.429\,Q_{peak,ChiangSaen}(m^3/s) + 30{,}825 \quad R^2 = 0.67$$
$$V_{NMKok}(MCM) = 3.208\,Q_{peak,NMKok}(m^3/s) + 1{,}606 \quad R^2 = 0.52 \qquad (2.3)$$

where:

V_x = flood v
$Q_{peak,x}$ = pea
R = c

Instead of using these regressions for selection of combinations of peak flows and flood volumes use can also be made of the bivariate distributions of peak discharge and flood volume. These have also been developed for Chiang Saen and the Lower Nam Mae Kok , see Appendix 1.

2.6.2 Step 2: Development of a hydraulic model of river and flood plain

For the transformation of river discharge under governing conditions of the water level at mouth to flood levels in the Nam Mae Kok backwater reach of the Mekong a hydraulic model is required, covering the river and flood plain of the last 40 km or so of the Nam Mae Kok comprising the full backwater zone. An adequate hydraulic model for the Nam Mae Kok is not yet available and reference is made to Sub-section 5.2 of Appendix 1 for details on development scheduling.

2.6.3 Step 3: Selection of flood combinations

To arrive at the 2, 10, 25 and 100 year flood levels in the Nam Mae Kok near the mouth model runs for a large number of scaled historical flood season hydrographs from the Mekong and from the Nam Mae Kok are required. The selection of hydrographs for the Mekong will include for each peak discharge level (T = 2, 5, 10, 25, 50 and 100 years) a very low, low, medium, high and very high flood volume. This leads to 30 combinations. In the selection of the flood volume use is made of the flood volume-peak discharge relation and the distribution of the residual (regression - 1.96, - 1.00, 0.00, +1.00, + 1.96 times the standard error are taken). The historical hydrographs with peak discharges and flood volumes which are nearest to the required ones will be selected for Chiang Saen. By scaling of the hydrograph ordinates the required peak value is obtained. The resulting hydrograph is then translated to a hydrograph at Sop Kok using the following stage-relation curve:

$$\begin{aligned} &h_{SopKok} = 0.594 + 0.878 h_{ChiangSaen} + 0.0186 h^2_{ChiangSaen} \qquad h\ in\ (m+GZ) \\ &H_{SopKok}(masl) = h_{SopKok}(m+GZ) + 355.31 \end{aligned} \tag{2.4}$$

with: h = gauge reading relative to gauge zero

H = water level relativ

For each combination of peak discharge-flood volume on the Mekong a very low, low, medium, high and very high peak discharge on the Nam Mae Kok is selected, to arrive at 6 x 5 x 5 = 150 combinations of hydrographs.

2.6.4 Step 4: Running of the hydraulic model for selected floods

The hydraulic model is subsequently run for the 150 different combinations of peak flow and flood volume at Chiang Saen (translated to a water level at Sop Kok) and peak discharge in the Nam Mae Kok near the mouth. The results of the simulations for each node in the model are stored in the database for use in the next step. In absence of an adequate hydraulic model these simulations could not yet be executed.

2.6.5 Step 5: Application of Monte Carlo technique to the simulations

Next the Monte Carlo technique is applied for relevant (hydraulic) features to interpolate between the results of the 150 combinations on basis of samples taken from the probability distribution functions of peak flow and flood volume at Chiang Saen and peak discharge in the Nam Mae Kok near the mouth, as explained in Sub-section 2.4.

2.6.6 Step 6: Determination of flooding extent, depth and duration

By comparing the water levels, derived in Step 5 for selected return periods, with the topography in the DEM of the flood prone areas the flooding extent, depth and duration can be established.

2.7 Final remarks and recommendations

Analysis of the hydrological data of the Nam Mae Kok further showed that:

1. Validation of hydrological data does not appear to be common practice according to sources at the data collecting agencies.
2. The applied stage-discharge relations for the stations on Nam Mae Kok and tributaries vary strongly from year to year. It is doubted that these variations can be attributed to morphological changes downstream of the gauging site alone. Re-settings of gauges to different gauge zeros seem to have occurred, but have not been recorded.
3. Whereas the rainfall records are mutually consistent, the discharge series are not. Distinct changes in the records are apparent in 1981 in the series of Ban Tha Sai and in 1995 in either the series of either Ban Tha Mai Liam or Ban Tha Ton.
4. The most recent flood of 2006 is not included in the available rainfall and discharge series.

To complete the flood hazard assessment it is first of all required that the existing 1D mathematical model of the Nam Mae Kok is upgraded using the latest bathymetric data and field information. But for the Chiang Rai region it would be better to replace the 1D hydraulic model by a 2D model in view of the complex flooding. For the river mouth a 1D model of river and floodplain of the ultimate 40 km is sufficient.

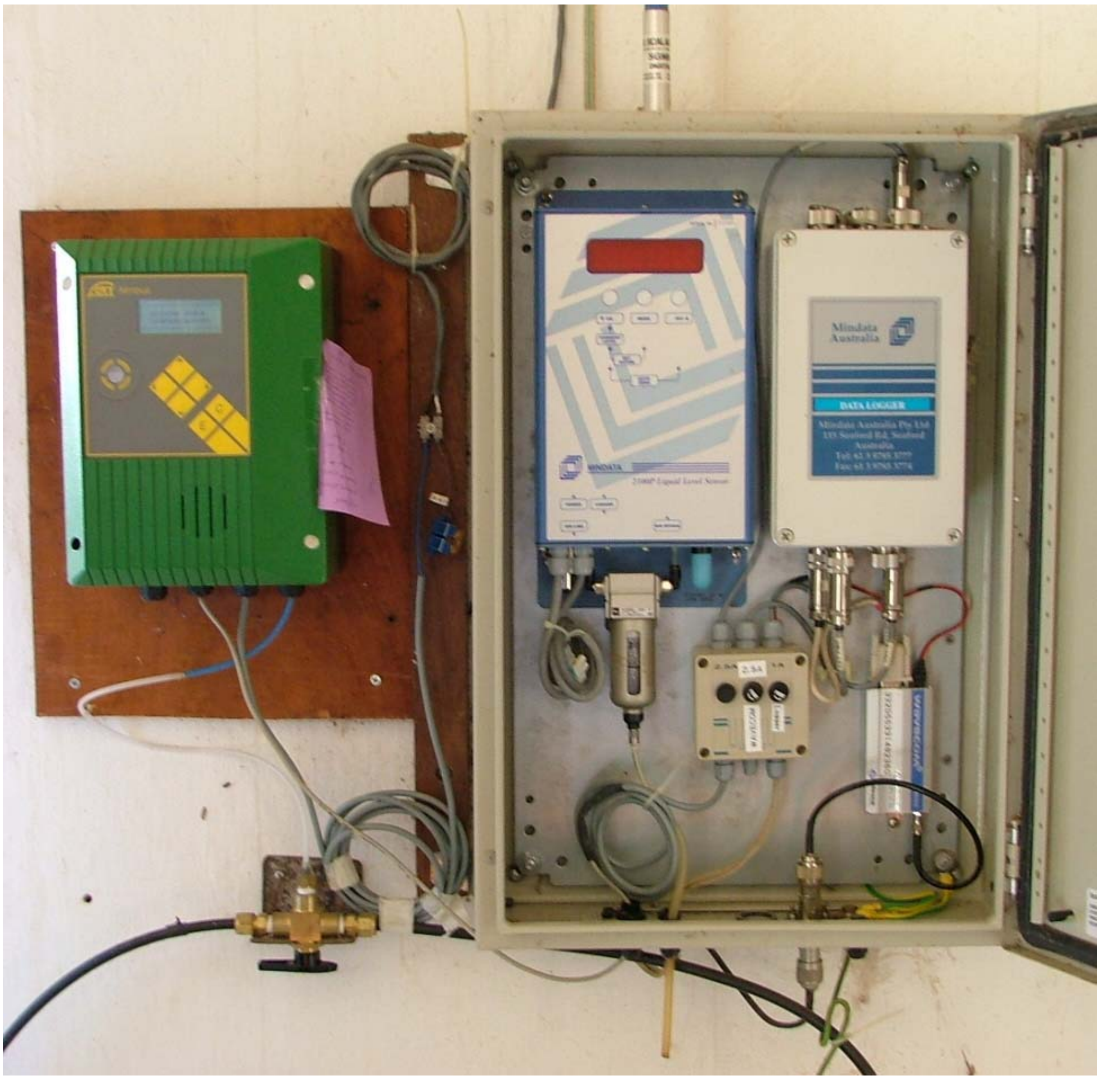
In addition, the following information for Nam Mae Kok is recommended for updating of the analysis to date:

1. Ban Tha Mai Liam, series 0502
2. Ban Tha Ton, series 0501
3. Ban Tha Sai ser
4. Hourly discharge values for the days of the annual peak value plus those of 1 day before and 1 day after the peak.
5. Level of the gauges in Chiang Rai and Ban Tha Ton on Nam Mae Kok, Ban Tha Mai Liam on Nam Mae Fang and Nam Mae Lao at Ban Tha Sai.
6. Full history of the gauging stations (gauge setting, leveling, repairs) and stage-discharge measurements to resolve the annual shifts in the stage-discharge relations.
7. Establishment, dimensions and operation of the weirs on Nam Mae Kok and Nam Mae Lao.

With the additional information the time series should be re-validated and homogenized prior to application of the statistical procedures. Next the hydrological hazard is to be updated and the procedures outlined above to be carried out with the hydraulic model.

CHAPTER 3

BOKEO



3 BOKEO

3.1 General

The LNMC has selected Bokeo Province along the Mekong River as focal area for river training works to protect the river banks and reduce erosion risk. The river stretches selected include the following locations along the river (chainage according to hydrographic atlas of MRC):

1. Ban Thon Peung at rkm 2367-2369
2. Ban Don Savan at rkm 2364
3. Ban Kouan at rkm 2359
4. Ban Simouangngam at rkm 2349
5. Ban Bokeo at rkm 2314.

The locations of the sections are presented in Figure 3.1.

6. 

Figure 3.1 Location of critical sections and water level gauging stations on Mekong

For the design water levels and flow velocities of selected frequencies are required. This chapter provides a summary of the hydraulic conditions in the Mekong in Bokeo Province. For details of the analyses reference is made to Appendix 2: “Hydraulic design conditions for Bokeo river bank protection”.

3.2 Methodology

3.2.1 Water levels

The following water level information is required to support the design:

- MHWL = maximum high water level
- AHWL = 95% not-exceeded water level
- MWL = median water level
- SLWL = 5% not-exceeded water level
- Minimum water level

The design water levels for the sections/locations defined in Sub-section 3.1 have been obtained by interpolation between the characteristic levels at gauging stations along the Mekong covering Bokeo Province: Sop Ruak (rkm 2370.4), Chiang Saen (rkm 2364.0), Sop Kok (rkm 2359.0) and Chiang Kong (rkm 2313.0). Linear interpolation has been applied in absence of the availability of a hydraulic model for this Mekong reach. The design water levels at the stations have been derived from average duration curves of daily water levels.

For Chiang Saen a daily water level record is available from 1960 till 2006 in the MRC HYMOS database. Shorter series are available for the other stations. The series of Sop Ruak and Sop Kok have been homogenized and completed based on stage relation curves with Chiang Saen. In the series the year 1966 has been excluded in view of its extremity (flood peak with a return period of 800-10,000 years, with 4 m higher water levels than observed in any other year on record). For Chiang Kong records are available since 1972.

3.2.2 Flow velocities

For design of river bank protection works and estimation of erosion rates detailed information on flow velocity field is required. This calls for the availability of 2D or 3D hydraulic models of the river stretches. Such models are not available for this reach. However, for a first inventory an indicative figure as an average flow velocity at maximum water level is considered sufficient.

The discharges at maximum water level are based on the flow record of Chiang Saen and further downstream augmented with the inflow from the Nam Mae Kok and the Nam Mae Ing. The maximum water level refers to the water level in the Mekong on 30 August 1971 (1966 excluded). The water level for that date at Chiang Kong (yet to be established) has been estimated by extrapolation from a linear stage-relation for high levels between Chiang Khong and Chiang Saen, established for the period 2002-2006.

The cross-sectional averaged flow velocities have been obtained from above discharges and the available cross-sectional area in the Mekong under the maximum water table for each of the selected river reaches. Cross-sections at the critical locations are available from the “Hydrographic Atlas Mekong River in the Lao PDR and Thailand”, April 1996. The bathymetry of the river refers to the situation in 1991/92. The river topography has been reduced to the Lowest Low Water Level taken from a length profile established in 1959/60 by Harza.

3.3 Results

3.3.1 Design water levels at the stations

The design water levels at the 4 gauging stations in Focal Area 2 as derived from the average duration curves of the daily water levels is presented in Table 3.1 and Figure 3.2. The variation of the water table through the year can be obtained from frequency curves of the water level, which are presented in Appendix 2.

Table 3.1 Design water levels at location of gauging stations

Station	Location (rkm)	Min (masl)	5% (masl)	50% (masl)	95% (masl)	Max (masl)
Sop Ruak	2370.4	360.12	360.64	362.13	366.14	369.89
Chiang Saen	2364.0	357.31	358.04	359.77	363.86	368.27
Sop Kok	2359.0	356.08	356.68	358.37	362.69	368.02
Chiang Kong	2313.0	342.18	342.77	344.29	349.51	355.53

In Figure 3.2 also the Lowest Low Water Level used as the reduction level for the cross-sectional profiles in the Hydrographic Atlas has been shown. It is observed that this level, apart from the reach Sop Ruak-Chiang Saen, is below the minimum water level as obtained from the gauge record. This may be due to inaccuracies in the Harza reference level, which has been developed before three out of four gauging stations were established.

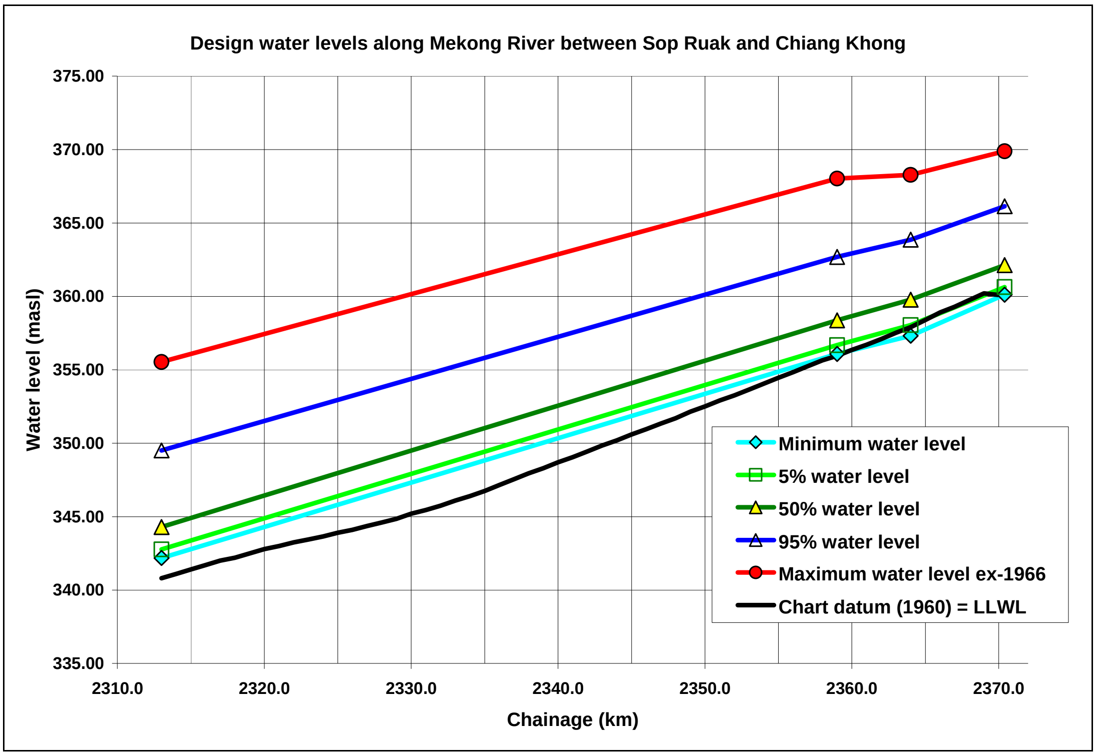


Figure 3.2 Design water levels in Bokeo Province on Mekong river.

3.3.2 Design water levels at the critical river stretches

The design water levels at the critical river stretches are obtained from the values at the stations by linear interpolation. The levels are presented in Table 3.2.

Table 3.2 Design water levels at bank protection sections in Bokeo Province

Location	Location (Rkm)	Min (masl)	5%-level (masl	50%-level (masl)	95%-level (masl)	Max (masl)
Ban Thon Peung	2369	359.51	360.07	361.61	365.64	369.54
	2368	359.07	359.67	361.25	365.29	369.28
	2367	358.63	359.26	360.88	364.93	369.03
Ban Don Savan	2364	357.31	358.04	359.77	363.86	368.27
Ban Kouan	2359	356.08	356.68	358.37	362.69	368.02
Ban Simouangngam	2349	353.06	353.66	355.31	359.83	365.31
Ban Bokeo	2314	342.49	343.08	344.60	349.80	355.80

3.3.3 Flow velocities

The cross-section average flow velocities at maximum water level at the critical locations along the Mekong in Bokeo Province are presented in Table 3.3.

Table 3.3 Cross-section average flow velocities at bank protection sections in Bokeo Province

Location	Location (Rkm)	Max (masl)	Q_{max} (m^3/s)	A (m^2)	v (m/s)
Ban Thon Peung	2369	369.54	15,400	7,570	2.03
	2368	369.28	15,400	8,488	1.81
	2367	369.03	15,400	6,325	2.44
Ban Don Savan	2364	368.27	15,400	7,930	1.94
Ban Kouan	2359	368.02	15,400	9,029	1.71
Ban Simouangngam	2349	365.31	17,100	8,443	2.03
Ban Bokeo	2314	355.80	17,100	10,097	1.70

CHAPTER 4

XE BANGFAI

4 XE BANGFAI

4.1 General

The Sebanfai basin has been selected by the LNMC as Focal Area for Integrated Flood Risk Management in Laos. The area concerns the lower Xe Bangfai river and flood plain from Sebanfai Highway Bridge to its confluence with the Mekong opposite That Phanom.

Floods on the lower Xe Bangfai are classified as combined floods. In this chapter the assessment of the hydrological and flood hazard in the lower Xe Bangfai basin are given. The effect of proposed flood mitigation measures have been analysed

This chapter provides a summary of the activities on flood hazard assessment for the Xe Bangfai. For details of the analyses reference is made to Appendix 3: “Flood hazard assessment for Xe Bangfai”.

4.2 Basin description and hydrological characteristics

4.2.1 Basin layout

The Xe Bangfai basin covers an area of 10,240 km^2. The river takes its rise in the Annamite mountain range and it debouches into the Mekong opposite That Phanom at rkm 1,166. The upper basin is steep, but below Mahaxai the river slopes are small and this reach is almost entirely affected by backwater from the Mekong, see Figure 4.1.

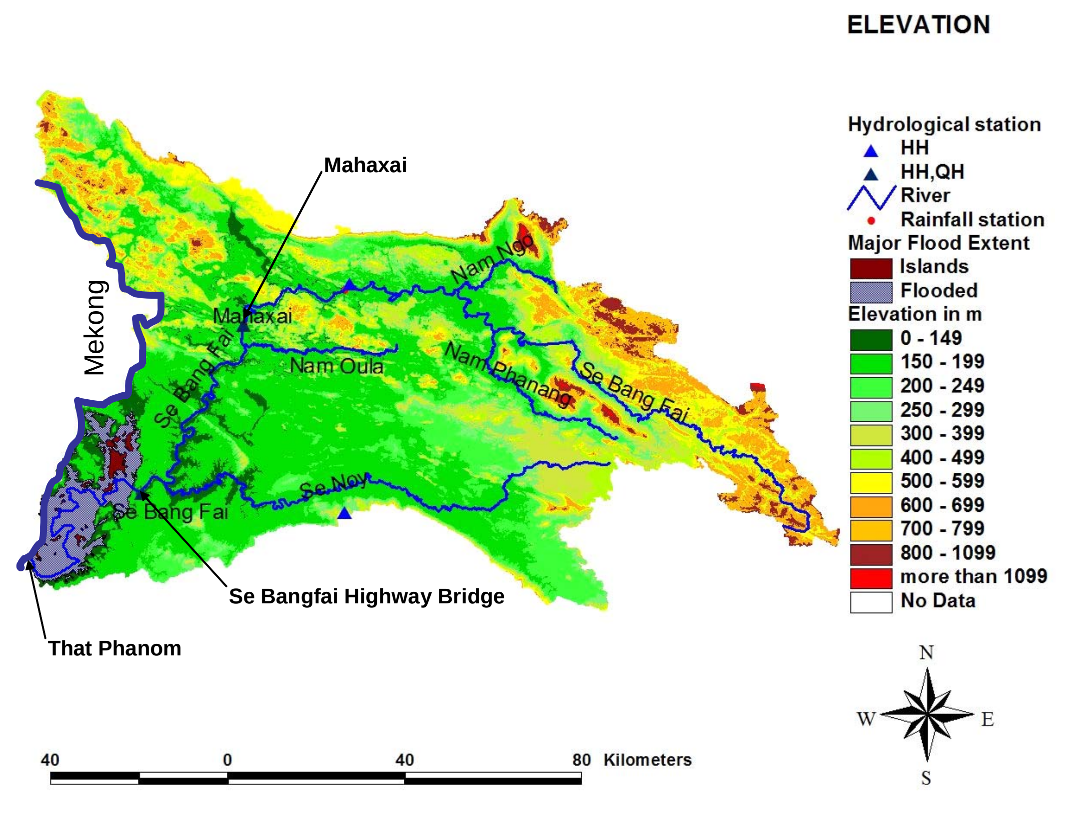


Figure 4.1 Elevation map of Xe Bangfai basin with location of major gauging stations

Downstream of Xe Bangfai Highway Bridge the river inundates a large flood plain enclosed by the Xe Bangfai and the Mekong; this comprises the Focal Area.

The key hydrological station on the Xe Bangfai is at Mahaxai, which monitors the flow of 4,520 km^2 or 44% of the basin. Major tributaries draining downstream of Mahaxai are the Nam Oula and particularly the Se Noy.

As from December 2009 onward the flow in the Sebanfai will be augmented with about 220 m^3/s diverted from the Nam Theun basin by the Nam Theun 2 Hydro-electric Project. This flow enters the Sebanfai shortly upstream of Mahaxai.

4.2.2 Rainfall and evaporation

The average annual rainfall in the Xe Bangfai ranges from 2,500 mm in the upper reaches to around 1,500 mm near the mouth. Representative for the rainfall in the lower Xe Bangfai is station That Phanom with an annual rainfall between 900 and 2,000 mm. On average about 87% of the annual total occurs during the South-West Monsoon from May to September, with the highest rainfall in August, see Figure 4.2.

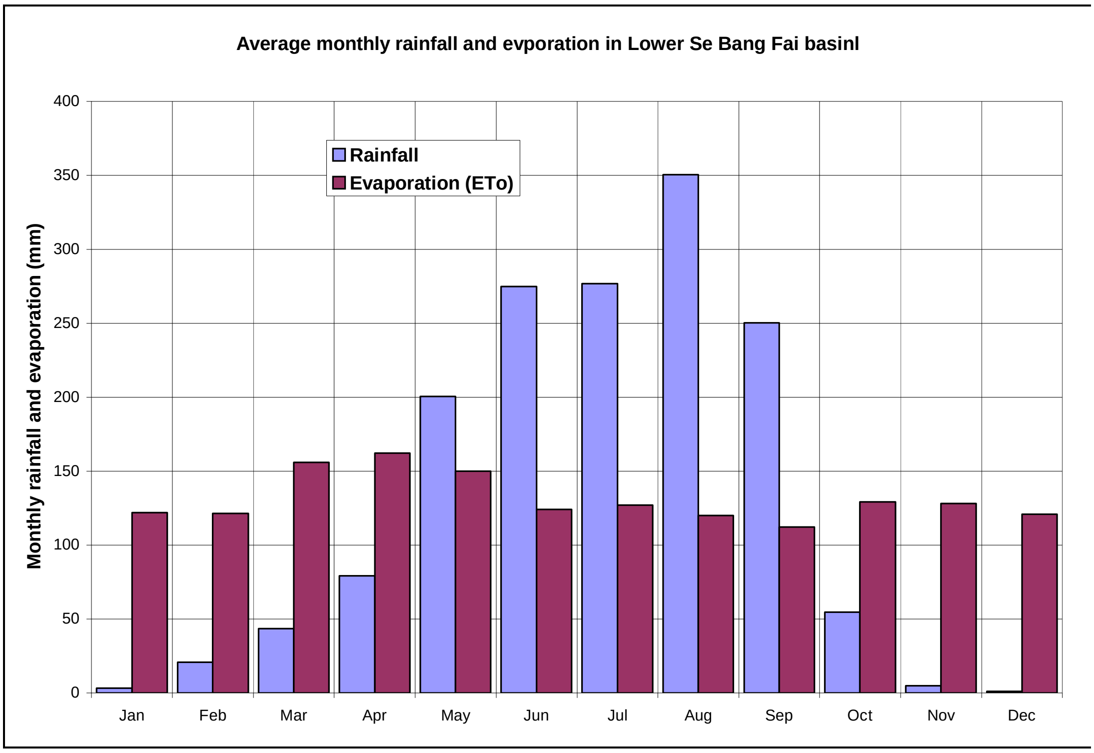


Figure 4.2 Monthly rainfall statistics of station That Phanom, Period 1966-2005

In the same figure also the variation of the reference evaporation ET$_0$ for the lower Xe Bangfai is presented. Its annual total is estimated at 1,570 mm with maximum values from March to May. In the period May-September rainfall exceeds the reference evaporation.

4.2.3 Runoff

A daily flow record is available of the Xe Bangfai at Mahaxai. This station, however, covers only some 44% of the basin. The flows are also measured further downstream at Xe Bangfai Highway Bridge, monitoring 8,560 km^2 or 84% of the area. Unfortunately, the available discharge series in the MRC database for this station is incorrect as no account is given to backwater effects of the Mekong on the water levels. A new series was established by making use of the fact that the observed flows at Highway Bridge correlate well with the discharge at Mahaxai. The monthly flows at Mahaxai and at Highway Bridge are presented in Table 4.1 and Figure 4.3. The highest flows are observed in the months July to September, with peak volumes generally in August. From a comparison of frequency curves of daily flows presented in Figure 4.4 it is observed that the occurrence of high flows on the Xe Bangfai are likely to coincide with those on the Mekong.

Table 4.1 Monthly flow volumes and depth in Xe Bangfai at Mahaxai and Highway Bridge

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mahaxai (MCM)	60	41	37	35	91	566	1,601	2,371	1,688	636	241	106	7,504
Mahaxai (mm)	13	9	8	8	20	125	354	524	373	141	53	23	1,653
Highway B (MCM)	71	48	42	39	121	892	2,778	4,232	2,961	998	340	133	12,721
Highway B (mm)	8	6	5	5	14	104	325	494	346	117	40	16	1,478

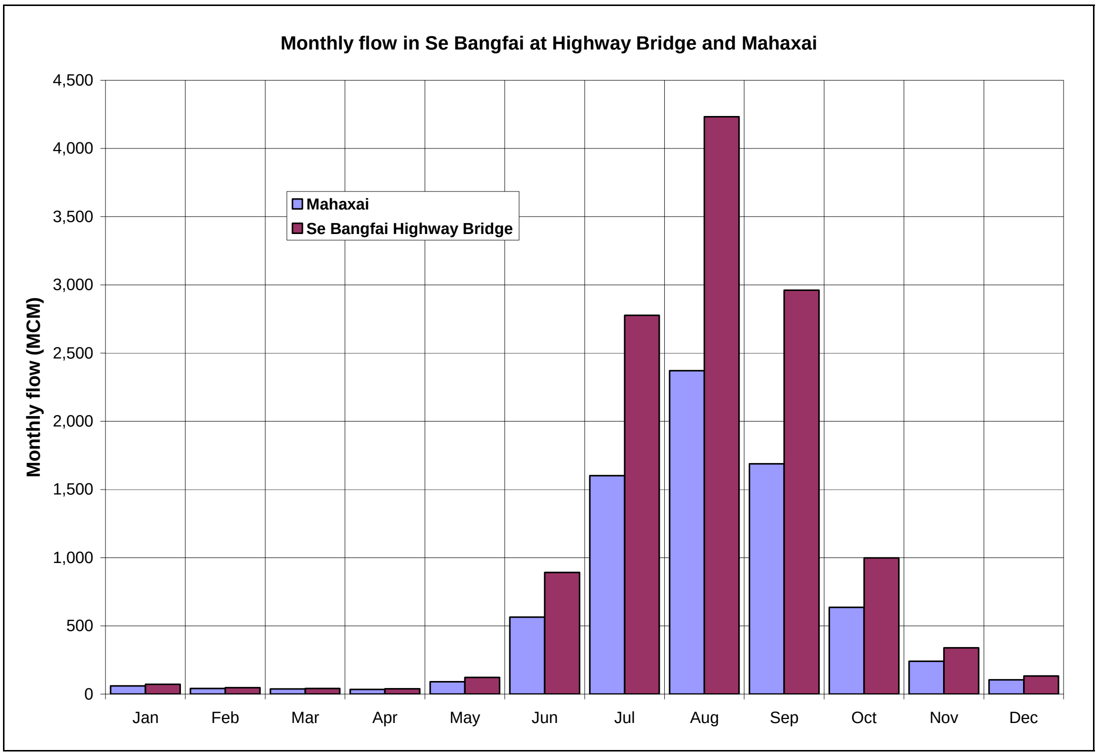


Figure 4.3 Monthly flows in Xe Bangfai at Mahaxai and Highway Bridge

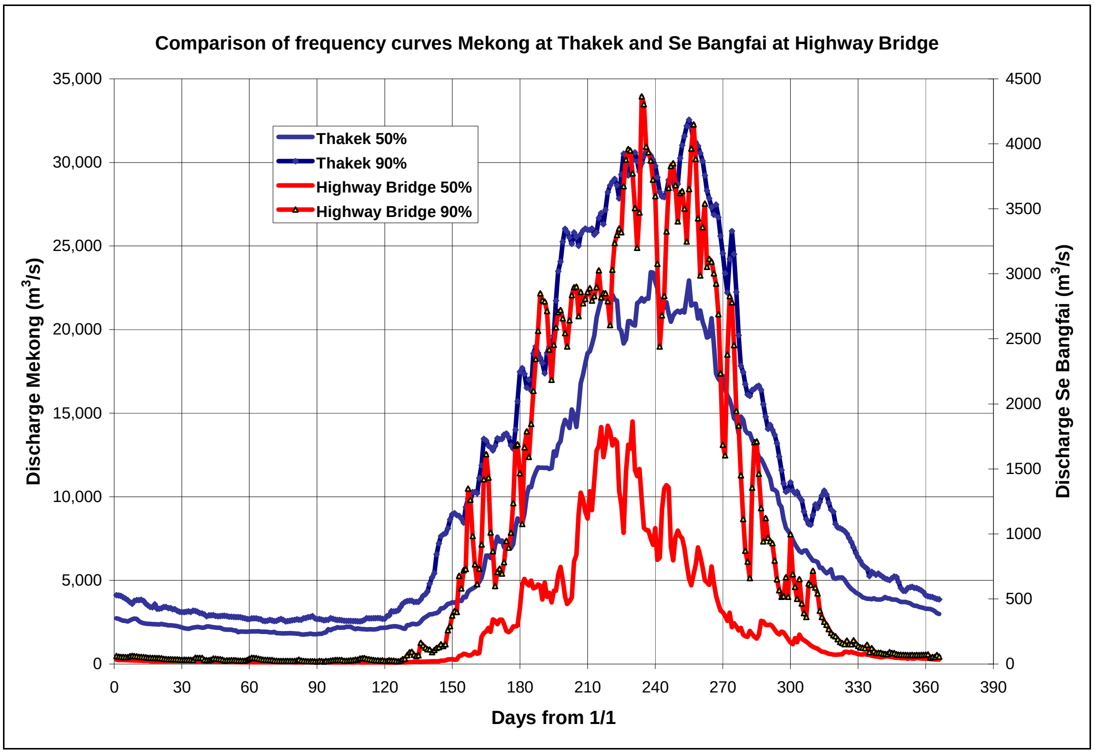


Figure 4.4 Comparison of discharge frequency curves of Mekong at Thakek and Xe Bangfai at Highway Bridge.

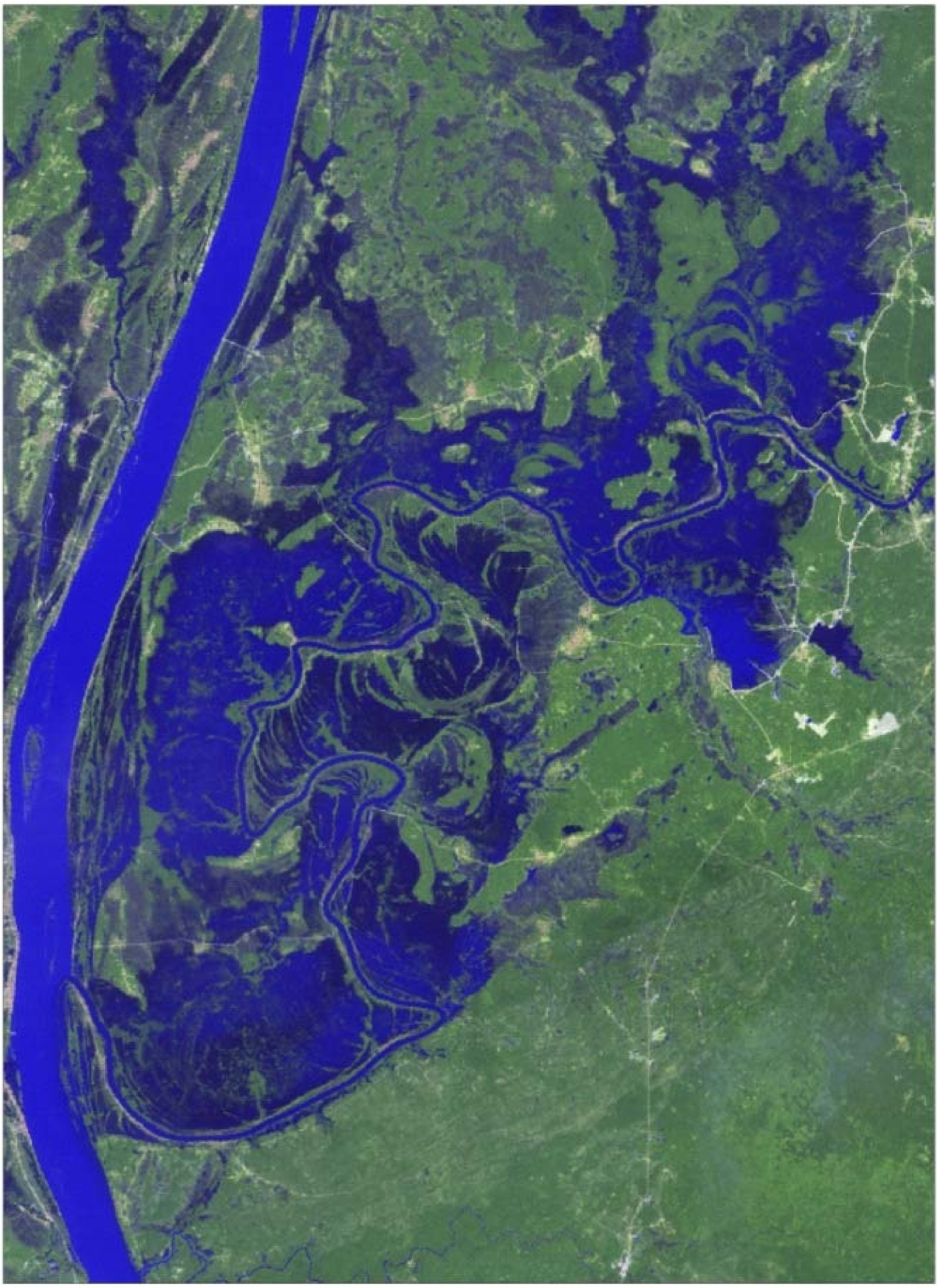
4.3 Type of floods and flooded area

Flooding takes place in the districts Thakek, Nong Bok, Xe Bangfai and Mahaxai. Major flooding takes place between the Mekong and Highway 13S, north of Xe Bangfai river (see Figure 4.5). Lowest areas are 140 masl whereas Nongbok village is flood free at an elevation of 150 masl. Flooding here last several months.

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

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

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



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

Figure 4.5 Extent of flooding along Lower Xe Bangfai and Mekong in the year 2000

4.

4.4 Flood hazard assessment procedure

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

1. The maximum discharge in the Mekong river at That Phanom;
2. The total volume of the flow in the Mekong river at That Phanom;
3. The total volume of the flow in the Xe Bangfai river at Mahaxai.

For each of the three random variables, samples are taken from their respective probability distribution functions. This procedure is repeated *N* times (with *N* sufficiently large) to obtain *N* combinations of possible realisations of the three random variables. This can be considered as a synthetic series of *N* years, where each sampled combination of random variables describes the main hydraulic features of the flood season in a single year. For each combination/year the hydraulic model of the lower Xe Bangfai is applied to derive the relevant hydraulic features like maximum water level at a number of locations in the Xe Bangfai area. Formally, this means the hydraulic model should be run *N* times, but since *N* is generally very large (in this case 100,000) that would require a long computation time. Instead, the hydraulic model is run for 90 different combinations of the three random variables that basically cover the whole spectre of possible outcomes. The results of the 90 simulations are stored in a database. The outcomes of the *N* Monte Carlo runs are then determined by interpolation of the results of the 90 simulations. Since 3 random variables are involved, the interpolation is 3-dimensional. The procedure needs to be applied separately for each location in the area in which one is interested, because the relation between the three random variables on the one hand and the resulting maximum water level or damage on the other hand may vary significantly from one location to the other.

4.5 Flood hazard assessment

The flood hazard assessment for the lower Xe Bangfai involves the following steps:
1. assessment of the hydrological hazard in the lower Xe Bangfai;
2. development of a hydraulic model of the river and flood plain to translate water levels and discharges into flood levels;
3. selection of 90 combinations of Mekong and Xe Bangfai floods;
4. running of the hydraulic model for 90 combinations of inflows (Mahaxai and lateral inflow) and downstream water levels (That Phanom);
5. application of Monte Carlo technique to simulations;
6. determination of flooding extent, depth and duration;
7. repeat the Steps 2, 4 to 6 for each development alternative.

These steps are shortly discussed below. For a detailed analysis reference is made to Appendix 3.

4.5.1 Step 1: Hydrological hazard assessment

The flood hazard in the lower Xe Bangfai is determined by peak discharges and flood volumes in the Xe Bangfai and water levels in the Mekong at the mouth of the Xe Bangfai at That Phanom. The frequency distributions of annual maximum discharge and flood volumes at the boundaries of the Focal Area are displayed in Table 4.2 and Figure 4.6 and Figure 4.7.

Table 4.2 GEV-parameters and peak-discharge and flood volumes (June-November) for distinct return periods in the Xe Bangfai at Mahaxai and the Mekong at Savannakhet

Parameters Return periods	Xe Bangfai at Mahaxai		Mekong at Savannakhet	
	Peak discharge (m^3/s)	Flood Volume (MCM)	Peak discharge (m^3/s)	Flood Volume (MCM)
k	0.341	0.221	0.245	0.370
α	498	2,304	4,785	37,064
u	1,614	6,105	26,946	207,874
T (years)				
2	1,757	6,916	28,623 32,950	220,577
5	2,177	9,045	35,220	250,532
10	2,398	10,188	37,550	264,469
25	2,626	11,386	38,961	277,351
50	2,765	12,126	40,139	284,374
100	2,881	12,755		289,752

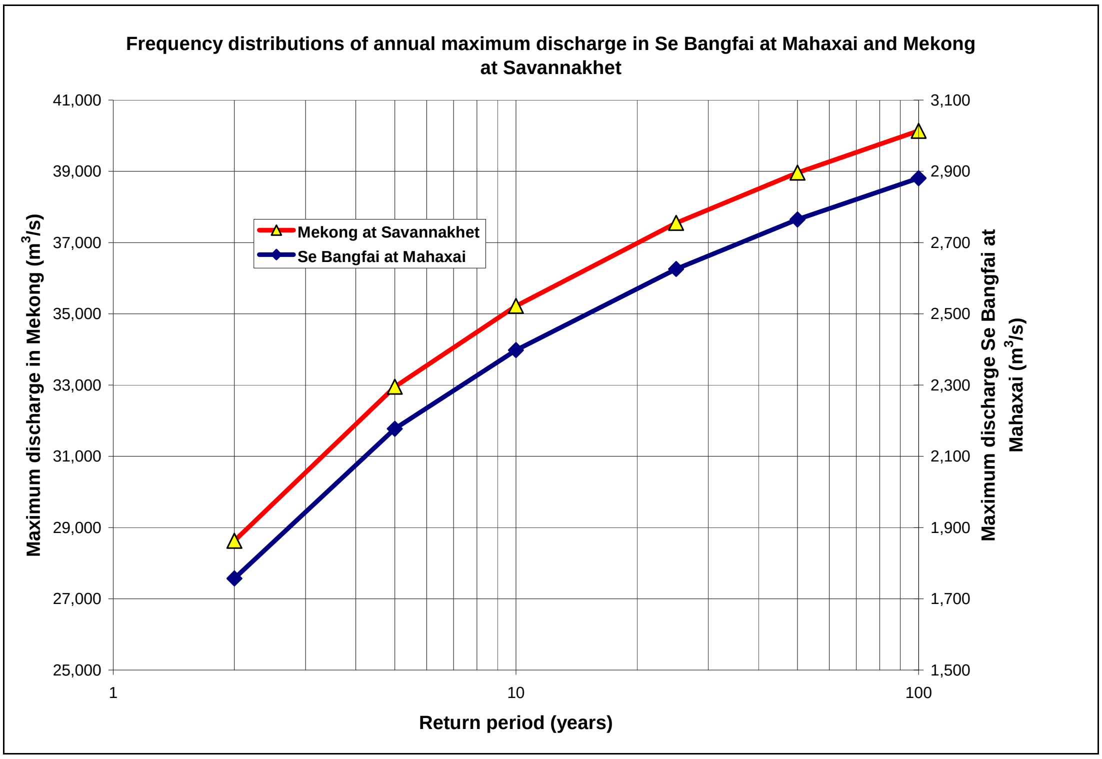


Figure 4.6 Frequency distributions of annual maximum discharge in Xe Bangfai at Mahaxai and Mekong at Savannakhet

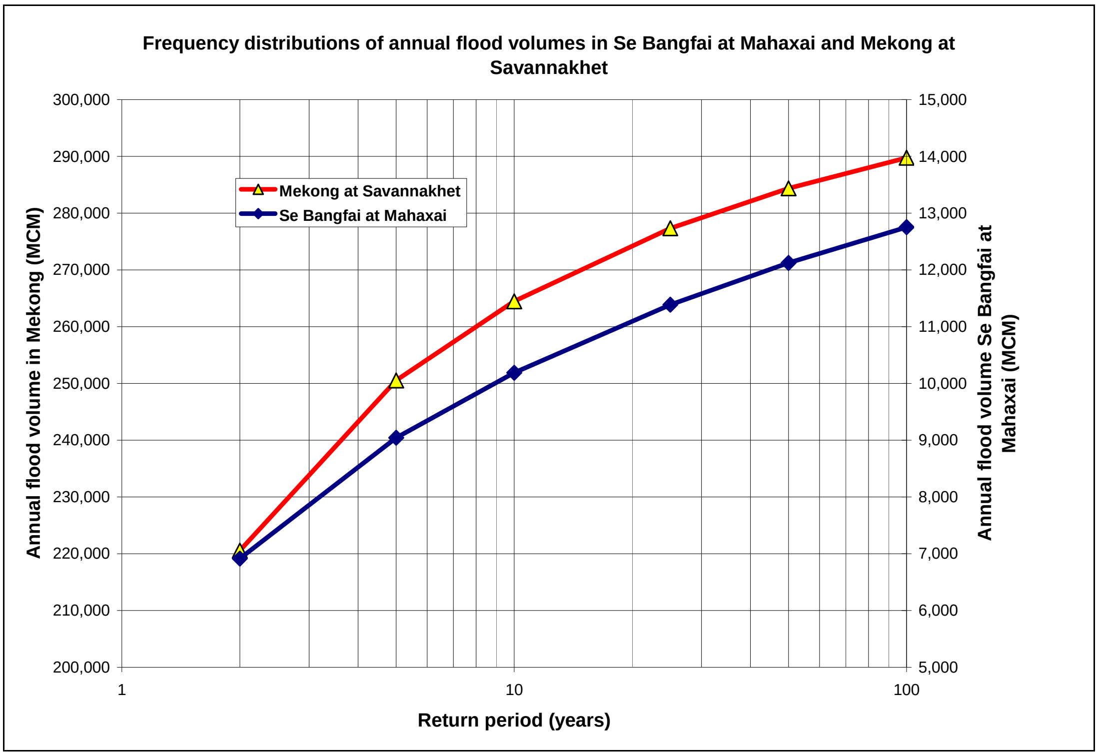


Figure 4.7 Frequency distributions of annual flood volume in Xe Bangfai at Mahaxai and Mekong at Savannakhet

Since That Phanom is a water level gauging station only, and henceforth not suitable for extrapolation of frequency distributions, the data of the nearest downstream discharge station on the Mekong at Savannakhet was taken instead. Both for annual maximum discharge and the flood volume (flow volume 1 June - 30 November) of the Xe Bangfai at Mahaxai and the Mekong at Savannakhet the observed frequencies are well fitted by the GEV-distribution (see equation 2.1).

The relations between the peak discharges and flood volumes required for the selection of combinations in the Monte Carlo procedure in Step 3 are:

$$\begin{aligned} V_{Savannakhet}(MCM) &= 5.66\,Q_{peak,Savannakhet}(m^3/s) + 56{,}173 && (R^2 = 0.61) \\ V_{Mahaxai}(MCM) &= 0.0431\,V_{Savannakhet}(MCM) - 2{,}268 && (R^2 = 0.70) \\ Q_{peak,Mahaxai}(m^3/s) &= 0.1734\,V_{Mahaxai}(MCM) + 556 && (R^2 = 0.78) \end{aligned} \qquad (4.1)$$

The lateral inflow to the Xe Bangfai downstream of Mahaxai has been derived from the difference between the flow at Xe Bangfai Highway Bridge and Mahaxai. The series of the Highway Bridge have been recomputed from the flow at Mahaxai using the following relationship (see also Figure 4.8):

$$Q_{BSBF} = 0.838\,Q_{Mahaxai}^{1.108}$$

with:

Q_{BSBF} = discharge at Xe Bangfai Highway Bridge
$Q_{Mahaxai}$ = discharge at Mahaxai

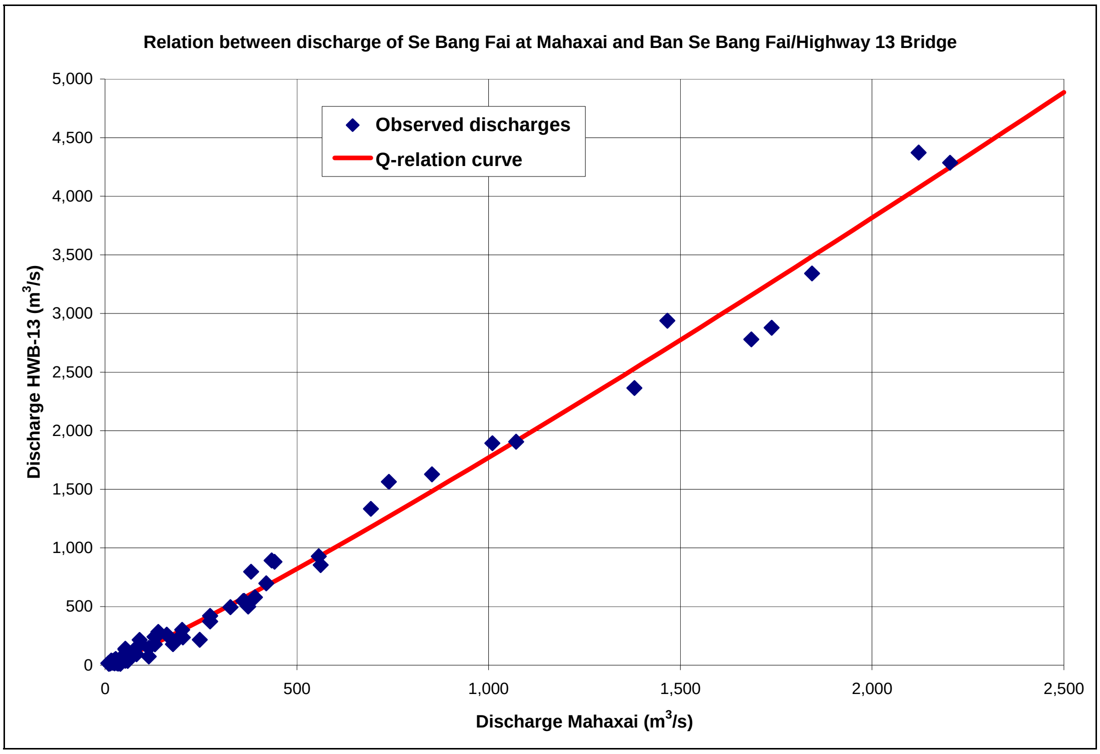


Figure 4.8 Discharge of Xe Bangfai at Highway Bridge as function of discharge at Mahaxai.

4.5.2 Step 2: Hydraulic model development

The flood levels in the lower Xe Bangfai are a function of the river discharge and the water levels in the Mekong. These flood levels are determined with a hydraulic model. A one-dimensional hydraulic model based on ISIS for the lower Xe Bangfai has been developed by the LNMC and MRC. It comprises the lower 158 km of the river from the mouth of the Nam Khatang, 15 km upstream of Mahaxai, to the confluence with the Mekong at That Phanom. The main tributary Se Noy is represented as lateral inflow at about 10 km upstream of Xe Bangfai Highway Bridge. The schematisation of the river is based on 49 cross-sections. The flood plains along the left and right banks are schematised as storages with a depth volume relation. The storages are connected to the main stream via spillways/two way weirs. The hydraulic roughness in the model, expressed as Manning-n, ranges from 0.05-0.07 in the upper part of the model near Mahaxai to 0.04-0.03 downstream of the Se Noy confluence. The layout of the model is shown in Figure 4.9.

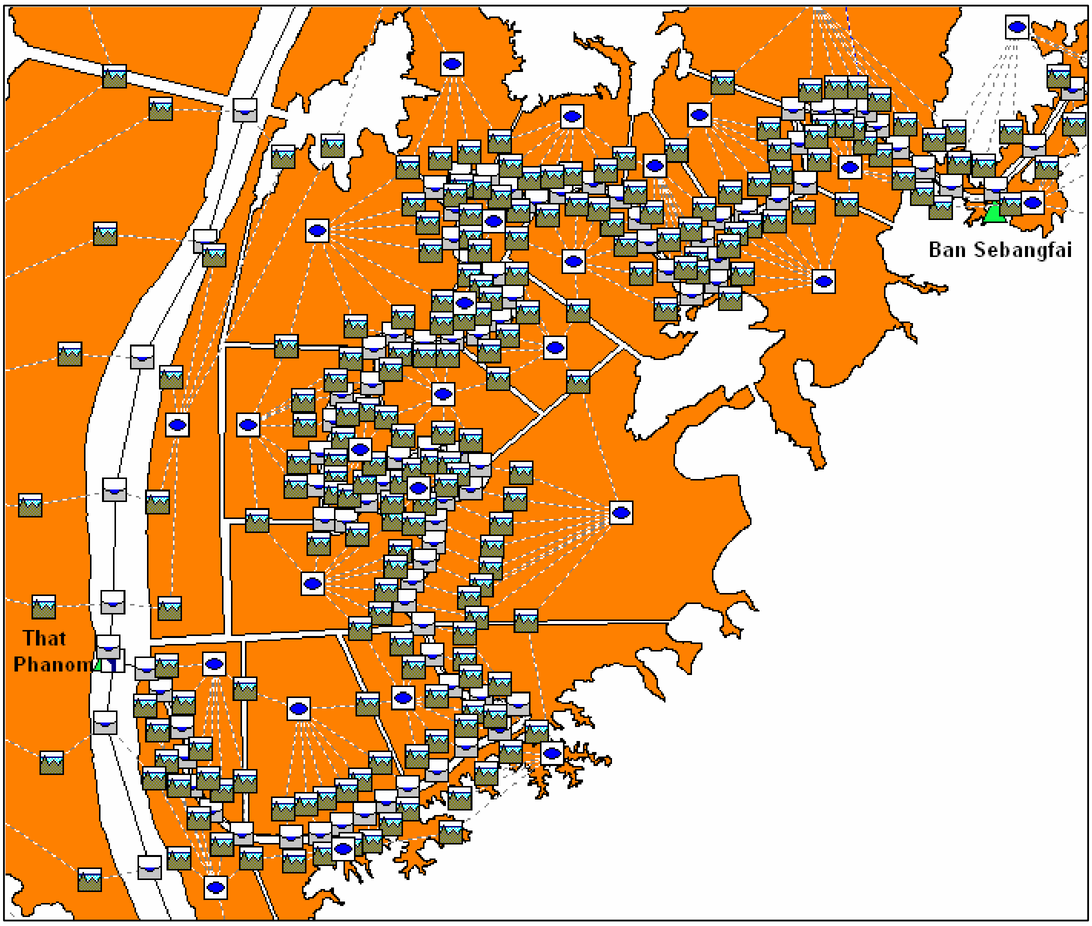


Figure 4.9 Schematization of Xe Bangfai in ISIS-hydraulic model.

The following boundary conditions are used in the hydraulic model:

1. discharge at Mahaxai as upstream inflow,
2. lateral inflow of Nam Oula and Se Noy concentrated at the Se Noy confluence, and
3. water level of the Mekong at That Phanom at the downstream end.

Reference is made to Appendix 3 for details of the boundary conditions. Performance tests have been carried out for the flood seasons of the years 1995 to 2000 to check the validity of the model. An example of the comparison between observed and computed water levels at Xe Bangfai Highway Bridge is shown in Figure 4.10 for the year 1995. The overall model performance is unbiased for water levels > 135 masl values. Individual values, however, may deviate +/- 1.5 m. These differences are partly due to small shifts in the quick rising and falling of the hydrograph and are due to inaccuracies in the supplied tributary discharge. In this respect it is noted that a very high accuracy is not to be expected because about 45% of the discharge at Ban Se Bangfai is estimated via an approximate regression equation from the flow difference between Ban Se Banfai and Mahaxai and not from a discharge rating curve.

The quality of the model to determine the inundation depth and extent in the flood is still uncertain as detailed information on the extent of the flooding phenomenon is not available. Hence, there remains doubt on the ability of the model to properly describe the interaction between river and flood plain. It is strongly advocated to use a 1D-2D model for the lower Se Bangfai for appropriate simulation of the river-floodplain inter-action. This also simplifies the model set-up and calibration!

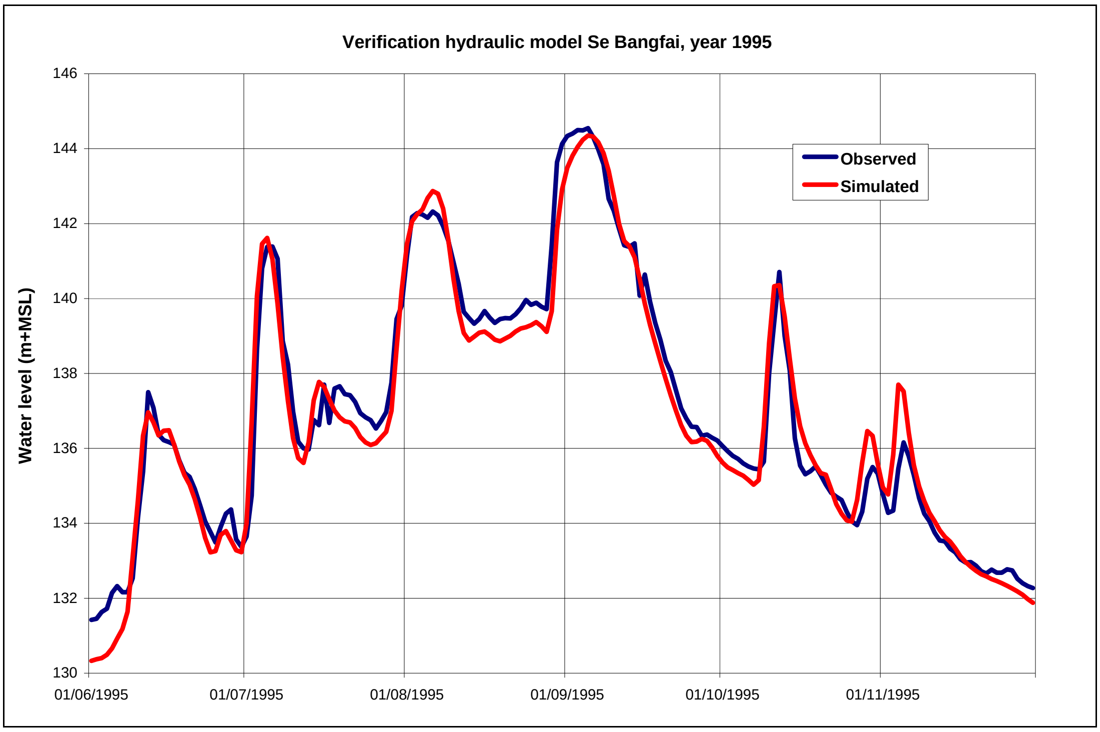


Figure 4.10 Model performance test, observed and simulated water level of 1995 at Xe Bangfai Highway Bridge.

4.5.3 Step 3: Selection of 90 combinations of Mekong and Xe Bangfai floods

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

1. Extension of the water level series at That Phanom with the period 1923-1971, using a stage-discharge relation for the stage at That Phanom and the discharge at Savannakhet.
2. Starting off from peak discharges at Savannakhet with return periods of 2, 5, 10, 25, 50 and 100 years (see Table 4.2) select for each peak discharge 5 flood volumes (very low, low, medium, high and very high) by using the regression relation between flood volume and peak flow (equation 4.1).
3. Selection of (adjusted) historical hydrographs at That Phanom of the years with flood volumes at Savannakhet according to the selection under 2.
4. Using equation (4.1), generation of 3 corresponding flood volumes in the Xe Bangfai for each selected flood volume at Savannakhet (low, medium and high).
5. Selection of hydrographs in the Xe Bangfai series with volumes close to those computed under 4, and subsequent scaling of hydrograph(s) to match with the required flood volume, and final adjustment based on peak discharges.
6. For the Nam Theun 2 scenario: add 220 m^3/s to the discharge at Mahaxai.
7. Finally, computation of lateral inflow from the difference of Highway Bridge derived according to equation (4.2) and Mahaxai.

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

4.5.4 Step 4: Application of the hydraulic model for 90 combinations

After selection of the 90 combinations of inflows (Mahaxai and lateral inflow) and downstream water levels (That Phanom) hydraulic model simulations for these combinations are made to derive water levels and flow velocities at all nodes and branches of the lower Xe Bangfai model. This step is to be repeated for each development scenario.

4.5.5 Step 5: Application of Monte Carlo procedure

Monte Carlo simulations have been executed to derive exceedance frequencies of water levels along the Xe Bangfai river. The error introduced by the Monte Carlo techniques decreases with increasing number of samples. Therefore, a relatively large amount of 100,000 samples was taken to make sure errors were small.

Tests on the accuracy have been executed by comparing the results of two successive Monte Carlo runs. It turned out that the absolute difference in resulting 100-year water levels between the two runs differed at maximum two centimetres for all locations in the river, which is negligible.

Furthermore, verifications on the selection of the boundary conditions have been made by comparison of the observed and computed frequency distributions:
For the water levels at That Phanom, and
For the discharge at Mahaxai.

For both boundaries the computed distributions showed close resemblance with the observed ones. The water levels derived with the procedure for Case 1: the Base Case, which covers the situation without embankments along the lower Xe Bangfai, are shown in Figure 4.11.

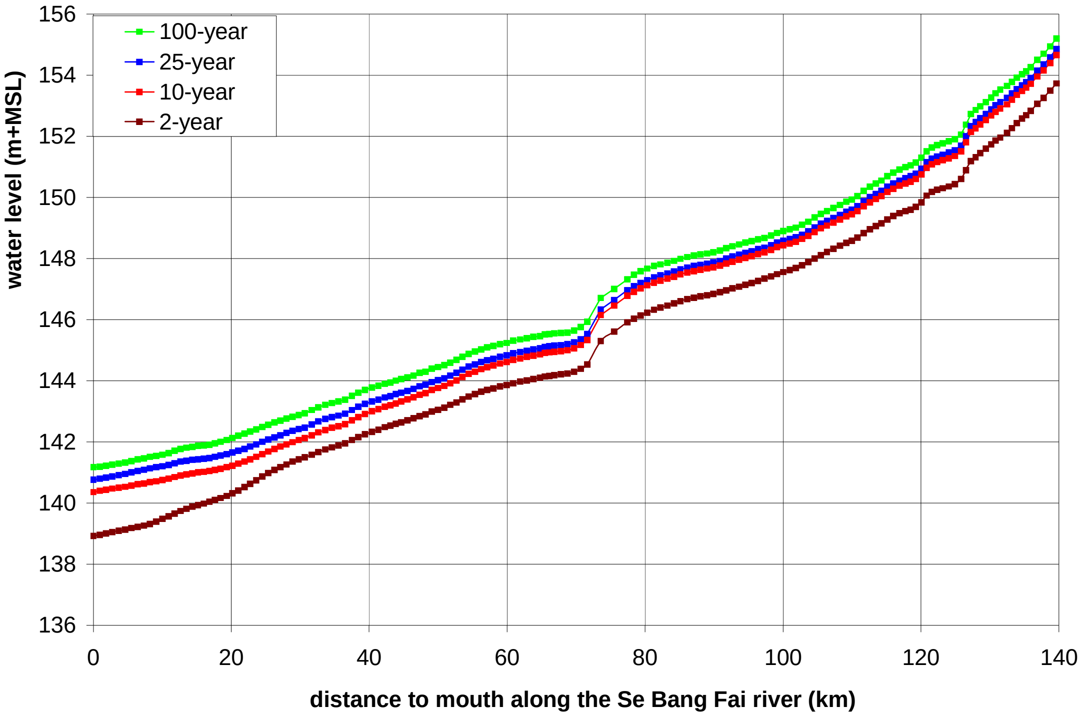


Figure 4.11 Computed 2, 10, 25 and 100-year flood level along the Xe Bangfai river for the case with no embankments.

4.5.6 Step 6: Determination of flood extent and depth

By comparing the computed water levels of selected return period with ground levels, available in a DEM, flood depth and extent can be obtained. For Case 1: the Base Case the flood depth and extent is presented in Figure 4.12. The figure shows flooding along both banks of the river up to 4-5 m depth. Reference is made to Appendix 3 for additional flood maps.

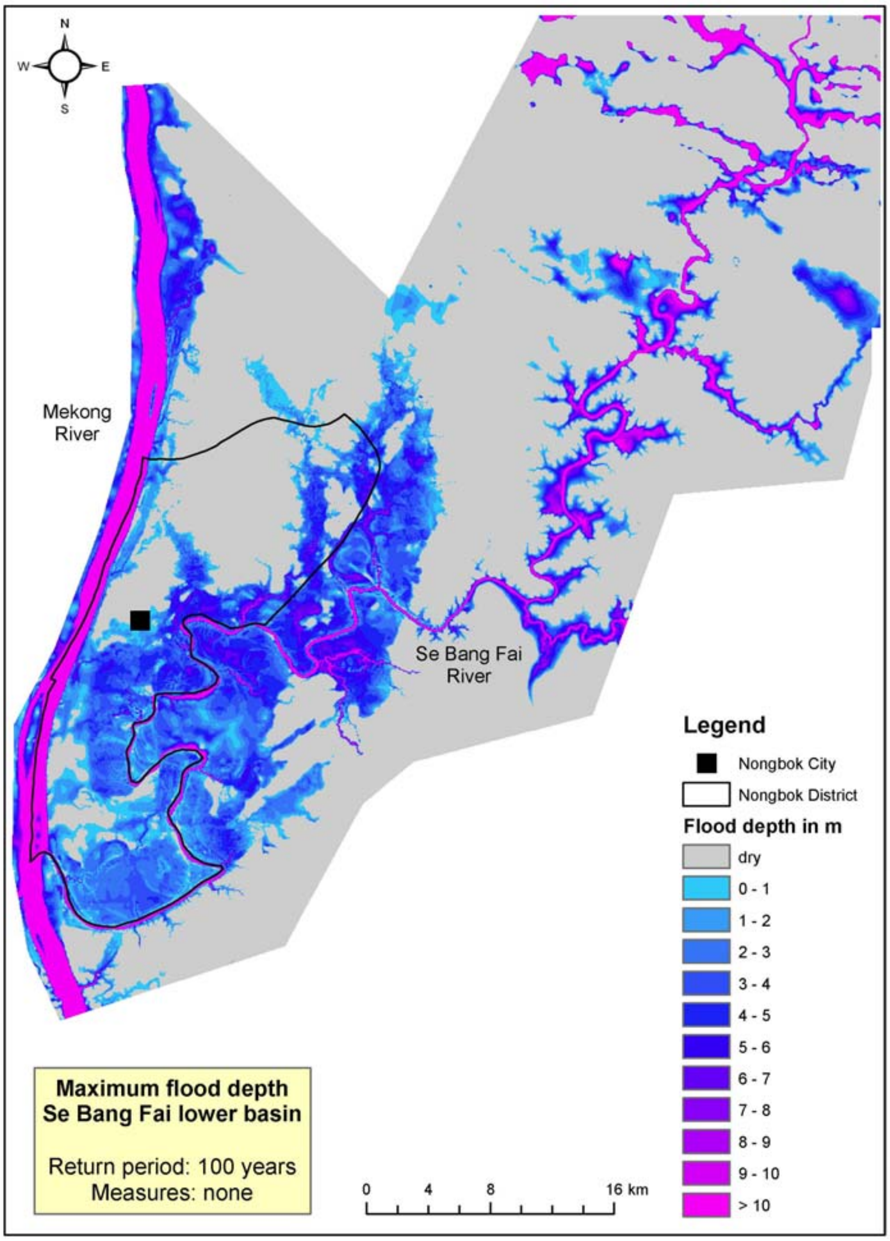


Figure 4.12 Flood depth and extent map lower Xe Bangfai, Case 1: Base case for T=100 years return period

4.5.7 Step 7: Analysis of development alternatives

To analyse effects of developments like the options mentioned in Sub-section 4.3 the Steps 2 and 4 to 6 have to be repeated. This has been carried out for Case 2: the case with dikes along the left bank (Savannakhet Province) of the lower Xe Bangfai (physically implemented around 2002) and for Case 3: the case that embankments are put in place on both banks of the Xe Bangfai downstream of the Highway Bridge (see Figure 4.13). The effect of these developments on the 100-year water levels along the river are presented in Figure 4.14. It shows that full embankment of the Xe Bangfai downstream of Highway Bridge will increase the water levels in the river locally with more than 1 m. The positive effect of course is that the water levels in the protected floodplains strongly decrease. The measure of decrease naturally depends on the magnitude of the increase in dike height. In the simulations as executed dikes were assumed to be high enough to provide full protection to the floodplains.

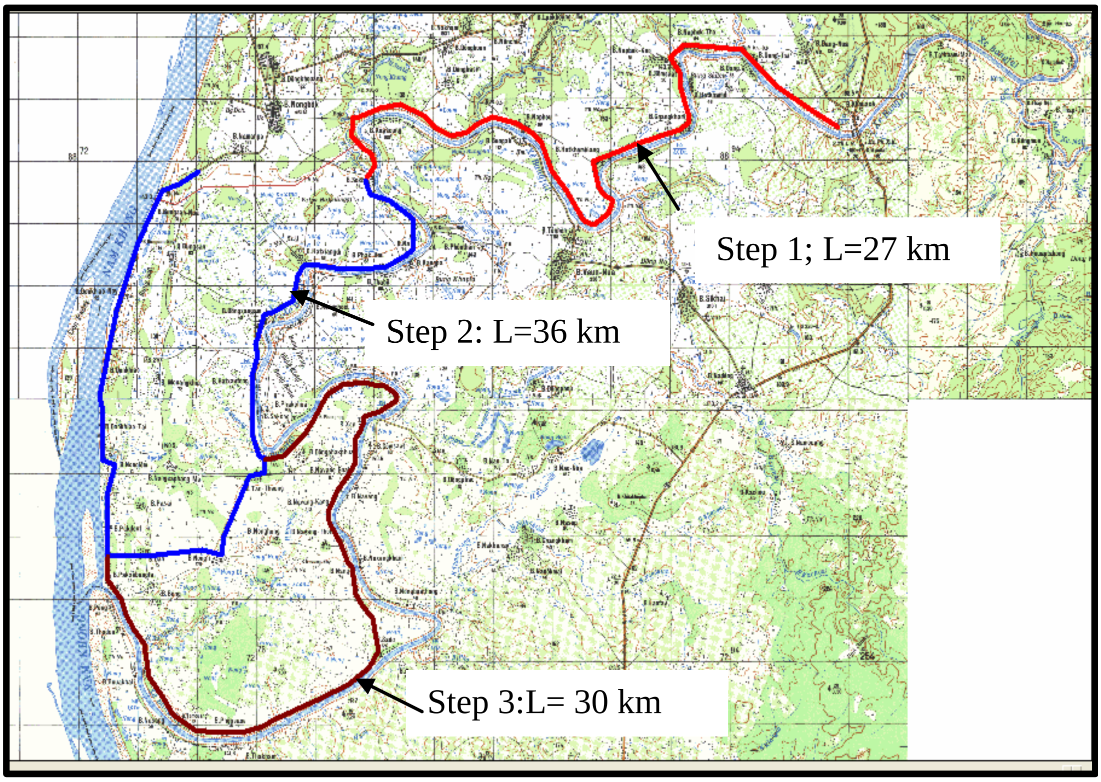


Figure 4.13 Construction of dikes along the right bank of the Xe Bangfai downstream of Highway Bridge

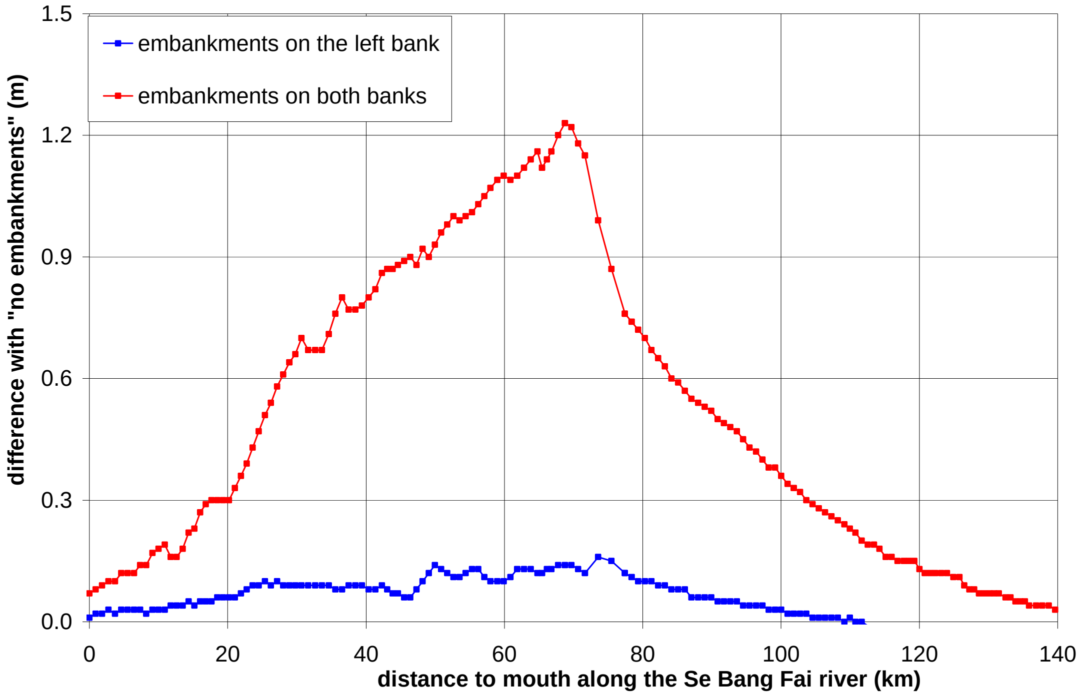


Figure 4.14 Differences in the computed 100-year flood level along the Xe Bangfai river for Cases 2 and 3 relative to case 1, the Base Case.

Another option that has been proposed is the construction of a bypass canal “Xelat” from the Xe Bangfai at Sokbo to the Mekong at Bungsan Nua upstream of That Phanom, see Figure 4.15. It involves an 8 km long canal with bed width of 200 m at an elevation of 138 masl. The effect of this bypass canal has been investigated with the hydraulic model applied with the flow conditions in the years 1995 to 2000. For this the hydraulic model of the lower Xe Bangfai has been extended with the Mekong from Thakek till That Phanom, to create a realistic boundary condition at the downstream end of the canal. Furthermore, the latest cross-sections available for the Xe Bangfai have been implemented in the model. Some results for the year 1996 are presented Figure 4.16 and Figure 4.17. The bypass conveyed for the selected years up to 500 to 1000 m^3/s, lowering the maximum water levels along the rivers near the off-take with about 0.5 to 1.0 m. Similar values are found for the flood plains with substantially reduced flood duration. For the 100-year water level a maximum reduction (near the off-take) of 1.83 m is observed

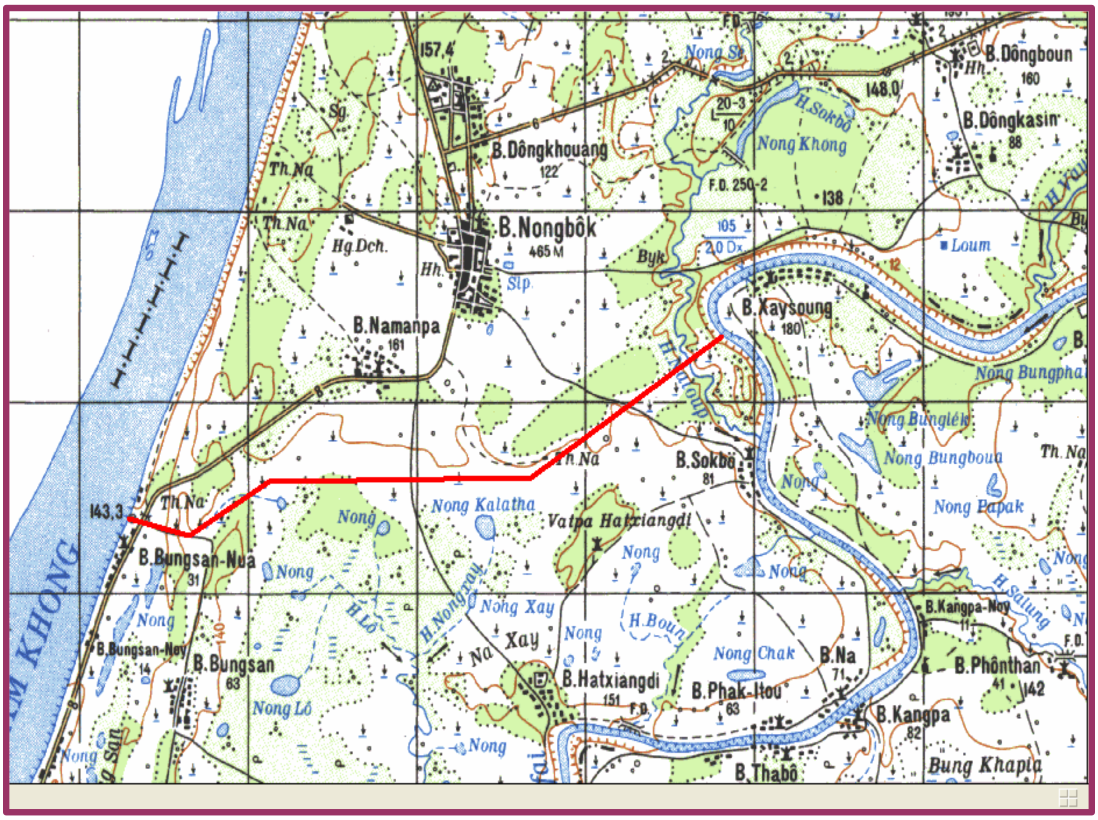


Figure 4.15 Canal “Xelat” from Sokbo to Bungsan Nua

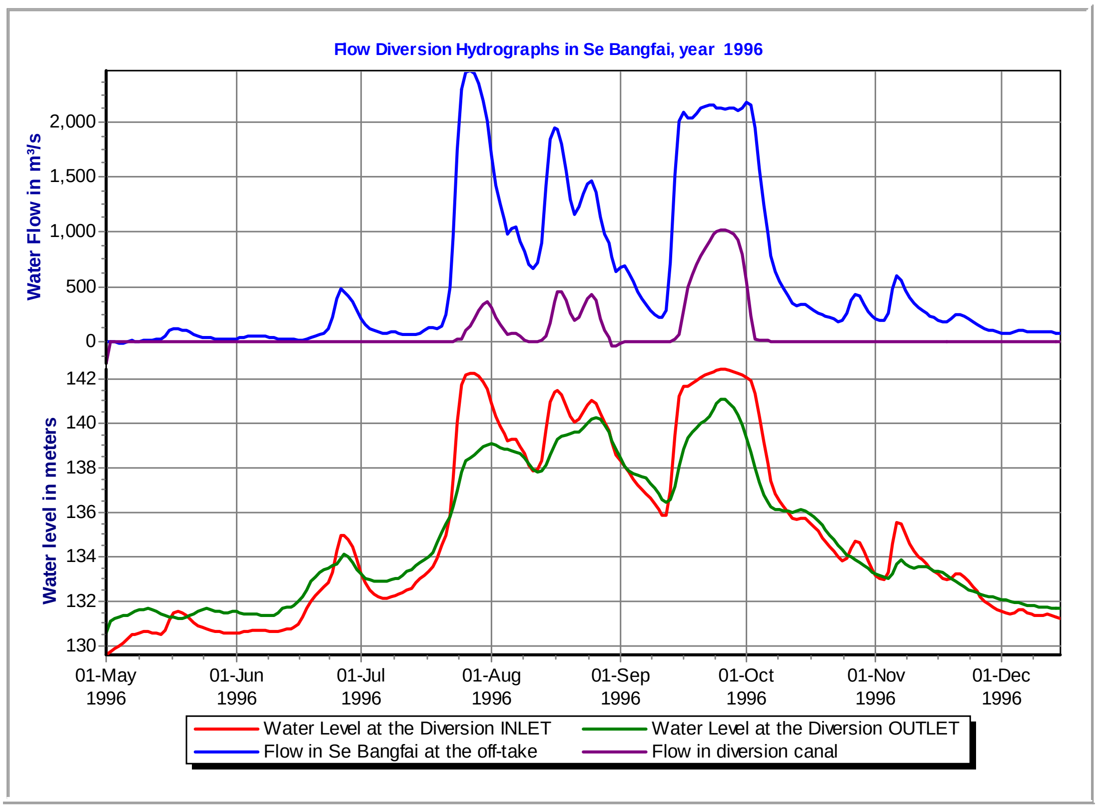


Figure 4.16 Water levels in Xe Bangfai and Mekong and discharge in canal and river (20 km d/s offtake) , Year 1996

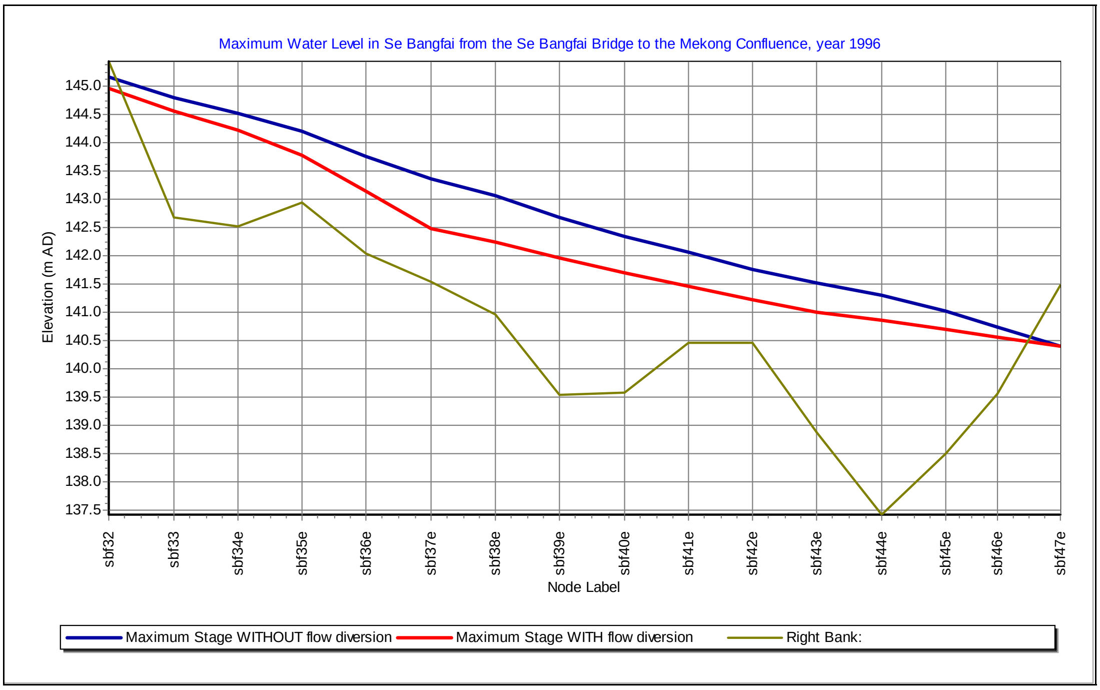


Figure 4.17 Maximum water level along Lower Sebanfai from Highway Bridge to mouth with and without bypass canal, Year 1996

4.6 Final remarks and recommendations

The flood hazard assessment procedure for combined flooding in the Xe Bangfai has been demonstrated. The Monte Carlo procedure was shown to be an effective technique to deal with flood frequencies determined by a number of variables. Unfortunately, the hydraulic model results showed to be biased and cannot be used for design. To improve the flood hazard assessment for the lower Xe Bangfai the following recommendations are made:

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

CHAPTER 5

UPPER SE SAN

5 UPPER SE SAN

5.1 General

In the provisional BDP list of projects for Vietnam the Project Drainage and Flood Control Kontum in Upper Se San is mentioned. The type of floods that creates damages here are flash floods. VNMC has proposed this area as focal area for flood risk assessment due to flash floods. From the Field Visit Consultants undertook to Kontum on 22 February, 2008, it was learned that the flooding problems are not around the city but rather in the uplands. Little data could be collected for these areas. Therefore, it was decided to focus in this Focal Area particularly on flood hazard assessment procedures for flash floods using generally applicable techniques.

5.2 Basin description and hydrological characteristics

The Focal Area covers the upper basin of the Se San in Vietnam in Kontum and Gia Lai Provinces, upstream of Yali reservoir. The headwaters of the Se San are formed by the Dak Bla and Krong Po Ko rivers, which join some 15 km downstream of the city of Kontum upstream of Yali (see Figure 5.1). The Dak Bla river has a basin area of 3,050 km^2 (IWRP, 2003). The river has its headwaters in the Ngoc Co Rinh range and joins the Krong Po Ko at Sa Binh. The latter has a basin area of 3,530 km^2.

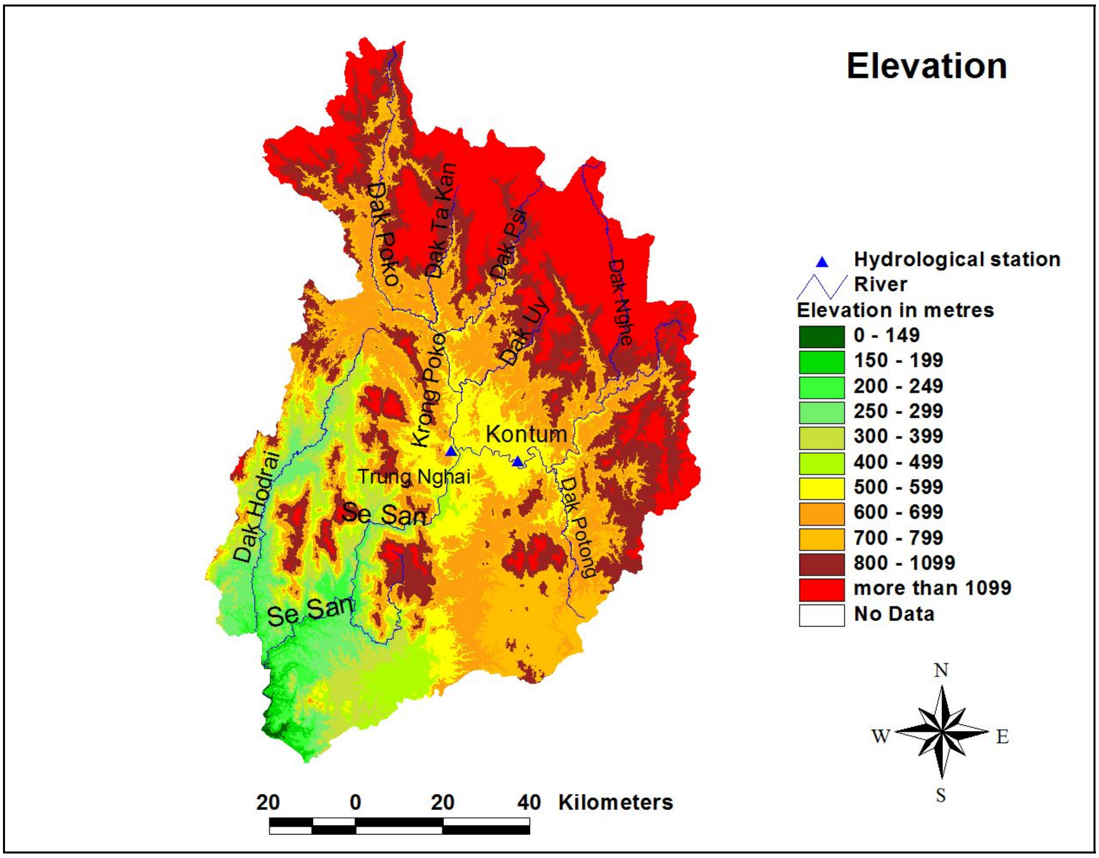


Figure 5.1 Elevation map of Upper Se San River Basin

Elevations range from 500 m to 2,500 m in the upper reaches with slopes of 10 -30% and locally even higher, typically the conditions for having flash floods. The levels drop to about 200 m at the border with Cambodia. At locations, as e.g. around Kontum, the slopes of the land reduce to about 1%. The mountain areas are covered with forest, whereas in the lower reaches along the rivers agriculture is practised.

5.3 Problem description

In the IWRP (2003) Report flash flood problems are mentioned for Upper Se San occurring particularly in areas where forest cover has largely been removed and flows have been obstructed by man-made interventions. The report states:

"Due to the fact that the watersheds have seriously destroyed and left barren, and during the dry season, droughts have caused the soil layers to become bare. As a result, these soils fail to keep moisture and are strongly eroded in the event of large rains. Moreover, the underground water penetrates into cracked and weathered soil and rock layers, causing land collapse. The streams themselves are flows of sand and mud, which wash many villages away. Flash floods often occur in high mountains and in remote areas in the Central Highlands, where most of the population are minor ethnic groups. In recent years there are more flash floods which are followed by great damages in terms of property and people."

Implementation of early warning systems is considered as a measure to reduce flash flood damage. Pilot projects for flash flood warning systems are underway.

5.4 Hydrological characteristics

5.4.1 Rainfall and evaporation

Average annual rainfall in the Se San varies from 1600 mm in the western part to 2,500 mm in the upper Se San. Annual variation for Pleiku ranges between 1,200 mm and 3,200 mm. The seasonal variation can be observed from Figure 5.2. Some 90 % of the rainfall occurs between May and October, with August generally the wettest month.

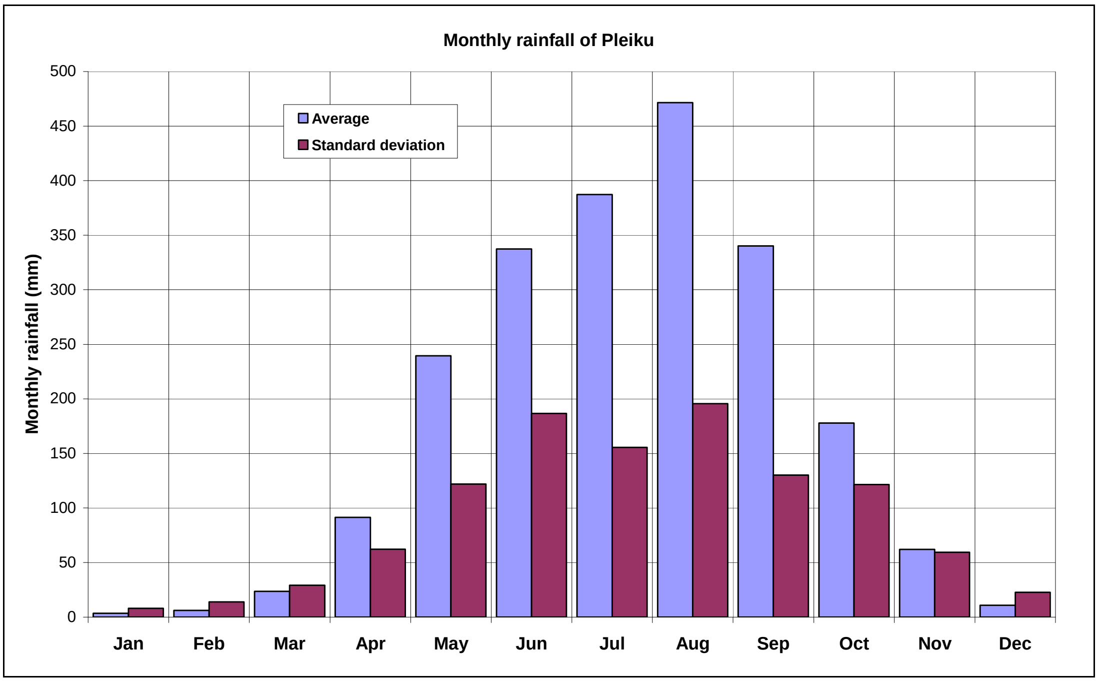


Figure 5.2 Monthly rainfall characteristics of Pleiku

With respect to the occurrence of extreme floods the landfall of cyclones is of importance. For central and southern Vietnam particularly during the months September to November, those events can be expected as can be observed from Figure 5.3.

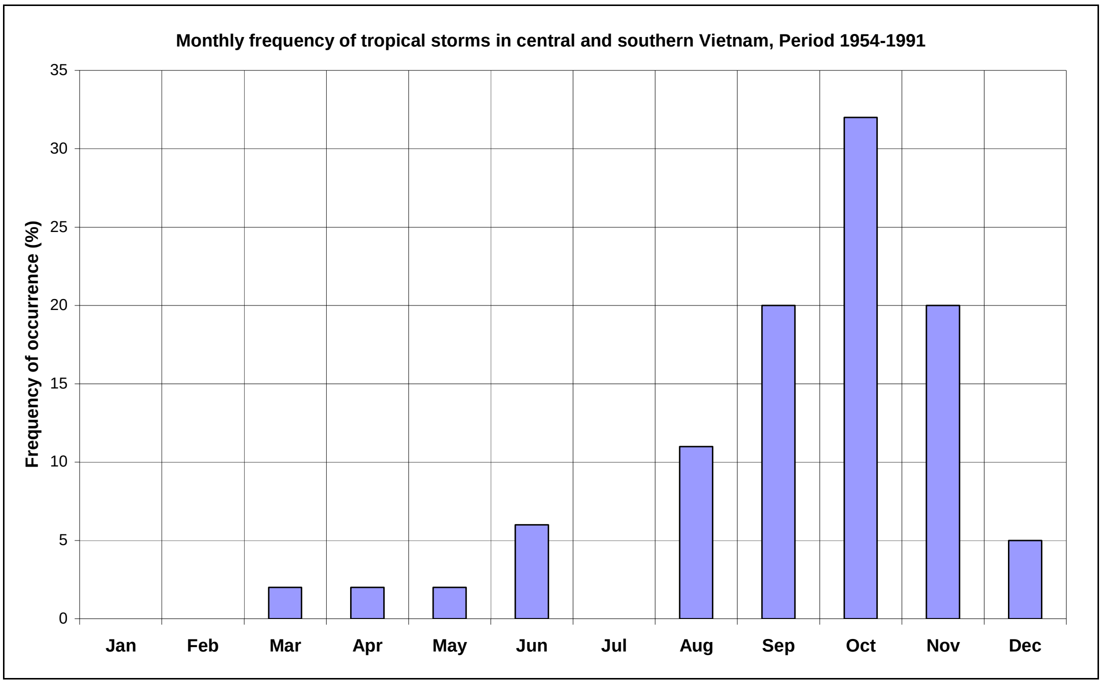


Figure 5.3 Monthly frequency of tropical storms and cyclones in central and southern Vietnam, Period 1954-1991 (ADPC, 2000)

Annual evaporation amounts range from 900 to 1500 mm in the Upper Se San. Maximum values are observed in December-April and the evaporation is minimal in June-September.

5.4.2 Runoff

The average monthly flow for the Upper Se San at Kontum and Trung Nghia is presented in Figure 5.4. The largest flows occur in August-October. From an analysis of the hydrographs it appears that the base-flow component for the Se San is quite important. The runoff depth from Krong Po Ko (1,200 mm) is larger than that from the Dak Bla (975 mm).

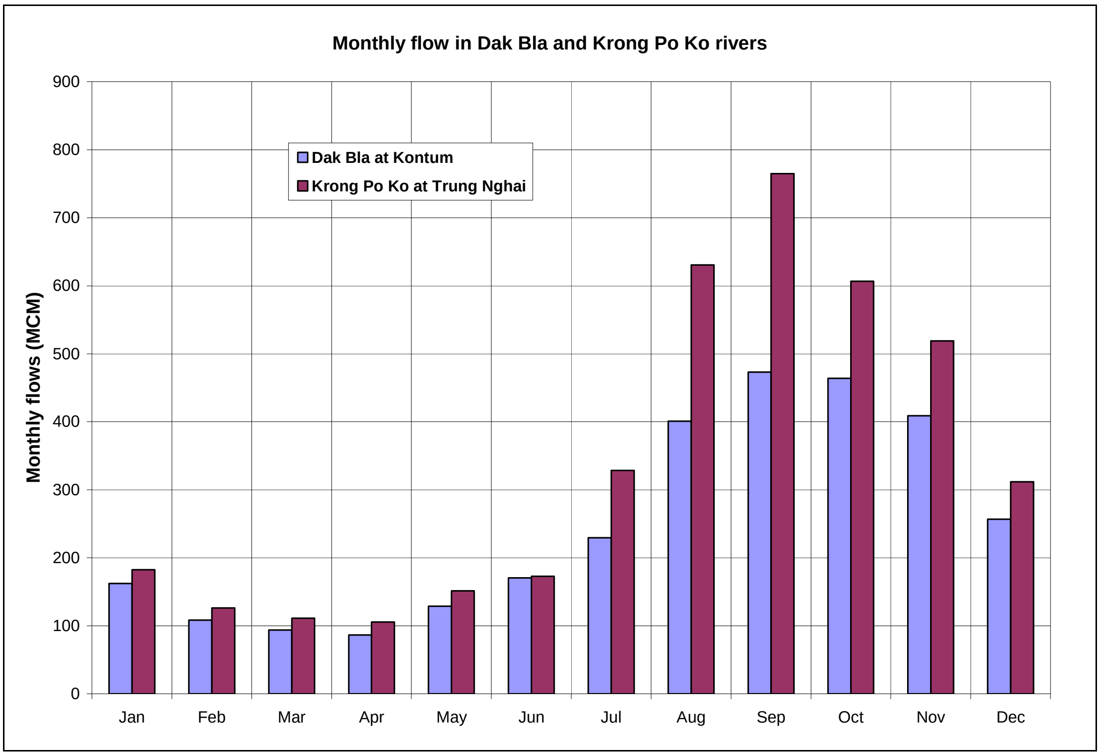


Figure 5.4 Monthly flows of Dak Bla at Kontum and Krong Po Ko at Trung Nghia (Upper Se San)

- Hydrographs of the Dak Bla at Kontum clearly show that floods on this river can be very flashy. The flood of 1996 is shown in Figure 5.5. Peak values from one year to another may differ by a factor 5.

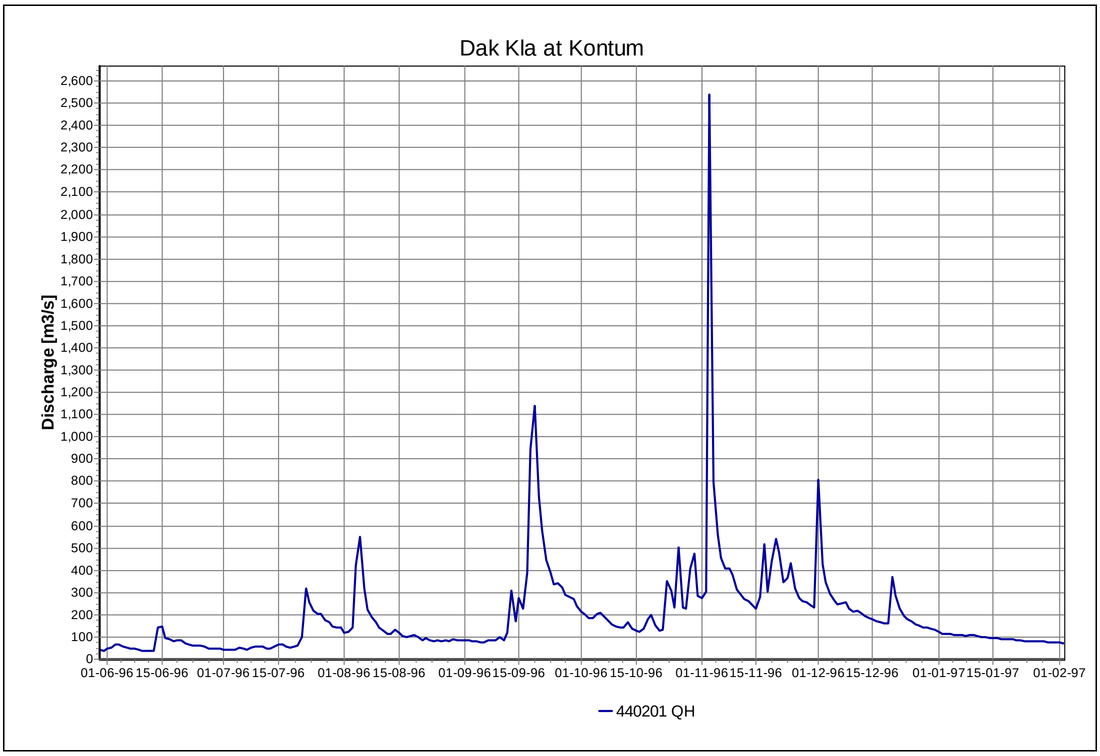


Figure 5.5 Discharge hydrograph of the Dak Bla at Kontum, year 1996

5.5 Type of floods

Flash floods occur in the steep sloped upper reaches of the Upper SE San due to intense rainfall after a long rainy period forcing the catchment to respond quickly to the rainfall. Flash floods are short lived, typically in the order of hours, rise and fall rapidly and the flow velocities are very high. Effects of flash floods, when accompanied with landslides, are equivalent to dam break waves.

5.6 Flood hazard assessment procedures

The hydrological monitoring infrastructure in the Lower Mekong basin is such that only a limited number of basins are equipped with rainfall and water level recorders. For most locations only daily rainfall is available. The water level gauging network is generally less dense and the monitoring interval is often too large to properly describe flash flood. Very often only daily water levels are available, which is fully unsuitable for analyses of flash floods. With respect to flow, discharge measurements usually cover only the lower stages and occasionally include flood data. These conditions have to be taken into account when flood hazard assessment procedures are developed. The following procedures are proposed:

1. Flood hazard derived from rainfall extremes
2. Flood hazard derived from observed flows

Flood hazard determined from regional flood statistics

When using rainfall extremes for the assessment of the flood hazard the following main steps are involved:

1. Collection of relevant information,
2. Database development and field visit,
3. Determination of design rainstorms for different return periods,
4. Transformation of design rainstorms into design hydrographs,
5. Transformation of design hydrographs into design levels.
6. Starting off from daily rainfall values first a distribution function is fitted to the observed annual maximum values. Next, with the Rainfall-Ratio method these statistics are transformed to extreme values for shorter durations, to complete the intensity-duration-frequency curves. Then incremental intensities are derived sorted around the peak value to get the design hyetograph. An example is given for Pleiku, see Figure 5.6 and Figure 5.7. Subsequently, rainfall losses are determined based on e.g. the Curve Number Method and the excess hyetographs are transformed into design hydrographs by a unit hydrograph. For this the Clark Method is recommended. These design hydrographs are finally transformed into flood levels using a hydraulic model of the river reach of concern.

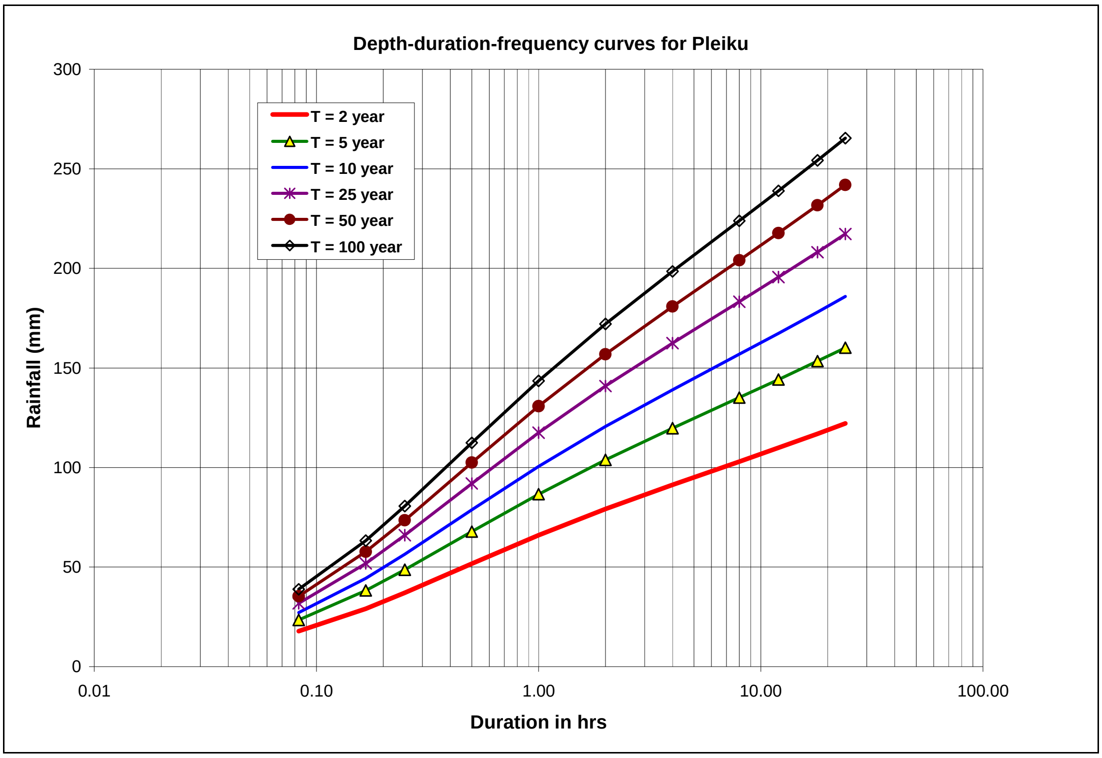


Figure 5.6 Depth-duration-frequency curves for Pleiku using Phnom Penh RR-values.

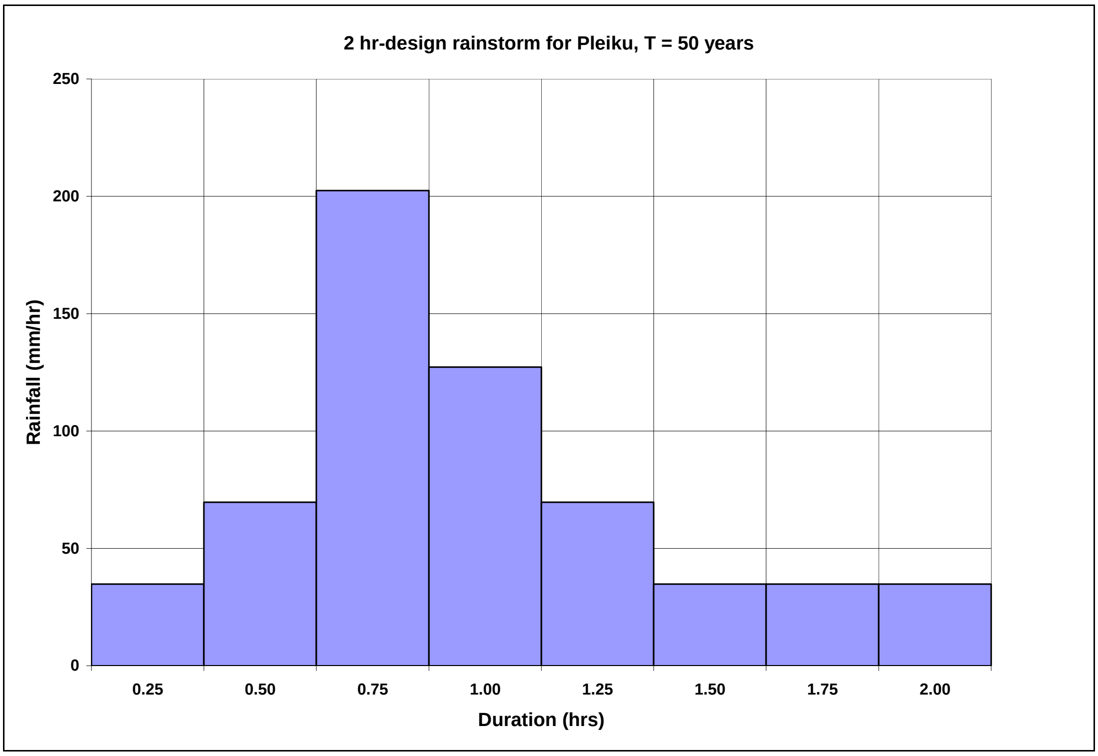


Figure 5.7 2hr-Design Rainstorm for Pleiku, Return Period = 50 years

In case a discharge series of sufficient length (≥ 15 years) is available then the procedure outlined for the hazard assessment for the city of Chiang Rai for tributary floods (see Chapter 2) is also applicable:

1. creation of a homogeneous series of annual maximum flows of sufficient length
2. application of extreme value analysis to the annual maximum series to derive frequency distribution of flow extremes
3. derivation of representative dimensionless flood hydrographs from 20 largest flood hydrographs in the series
4. scaling of the representative flood hydrographs to the flood peak of selected return periods
5. routing of the hydrograph through the river section of interest to derive the associated flood levels.

Note that this procedure is only applicable for flash floods if hourly (or smaller interval) discharge series is available or can be created.

Adamson (2007) proposed the use of a regional approach. This has been developed for the upper part of the LMB. It involves the following steps:

6. Creation of a regional sample of annual maximum flood peaks by pooling the individual annual maximum values scaled to their individual mean annual flood value.

Subsequently, a TCEV (Two Component Extreme Value) distribution is fit to the observed frequency distribution of pooled values. The TCEV-distribution is chosen to account for the different phenomena creating the discharge extremes, monsoon and monsoon and typhoons, where the latter causes extremes far beyond the monsoon range.

7. To apply the TCEV-values to ungauged sites a regional relationship between the mean annual maximum flood discharge and one or more climatic and/or basin characteristics has been developed. For the upper part of the LMB Adamson (2007) found a relation with drainage area. Since the error about regression is considerable it is advised to enter more characteristics in the relation.

To make the latter procedure applicable to the Upper Se San, regional values will have to be collected. Furthermore, corrections have to be made for daily average values to peak values, which in the case of flash floods may be a considerable adjustment in view of the short duration.

5.7 Final remarks and recommendations

Floods in the upper reaches of the Se San are very flashy, creating considerable damage. The areas are increasingly sensitive to flash floods due to deforestation. But around Kontum city no flooding problems exist anymore. Three methods have been identified to assess the flash flood hazard:

1.a Flood hazard derived from rainfall extremes
1.b Flood hazard derived from observed flows
1.c Flood hazard derived from regional statistics

In the absence of flow series the flood hazard assessment procedure starting off from rainfall extremes is promising, as it makes use of the physical characteristics of the basin and easily accessible meteorological data. Focal Areas have to be selected to test the method. It is recommended to use pilot areas where verifiable flood levels are available. A review of short duration rainfall relative to daily rainfall statistics for the Se San region is advocated with due attention to orographic effects and effects of orientation of the mountain ranges.

The flood hazard derived from regional statistics of the Upper LMB is not applicable in the Upper Se San. Values in Upper Se San seem to be higher. To make the procedure applicable to the Upper Se San regional values will have to be collected, with corrections for daily average values to peak values.

CHAPTER 6

KRATIE

6 KRATIE

6.1 General

The CNMC has selected Kratie Province along the Mekong River as focal area for river training works to protect the river banks. This includes the following locations along the river (chainage according to hydrographic atlas of MRC):

• Pu. Sambok	at rkm 573.4
• Pum Thmar Krae Kroam	at rkm 568.7
• Pum Peam Te	at rkm 557.2

The locations are shown in Figure 6.1. For the design, water levels and flow velocities of selected frequencies are required. These data are elaborated in this report.

Figure 6.1 Layout of bank protection sites on Mekong near Kratie

For the design water levels and flow velocities of selected frequencies are required. This chapter provides a summary of the hydraulic conditions in the Mekong in Kratie Province. For details of the analyses reference is made to Appendix 5: “Hydraulic design conditions for Kratie river bank protection”.

6.2 Methodology

6.2.1 Water levels

Similar to Bokeo, the following water level information is required to support the design at Kratie:

- MHWL = maximum high water level
- AHWL = 95% not-exceeded water level
- MWL = median water level
- SLWL = 5% not-exceeded water level
- Minimum water level

The design water levels for the sections/locations defined in Sub-section 6.1 have been based on the characteristic levels derived for station Kratie (rkm 560.3). The Kratie levels have been translated to the critical sections upstream and downstream of the station by application of the water level slope between Kratie and Kampong Cham, located 113 km downstream of Kratie. The slope of the water table varies from 4.5×10^{-5} for low and medium flows till 7.0×10^{-5} for high flows. Linear interpolation has been applied in absence of the availability of a hydraulic model for the Mekong reach upstream of Kratie. The design water levels as described above have been derived from an average duration curve of homogenized water level series for Kratie, derived from Stung Treng. This simply means that for the range of possible water levels the number of days are counted during which the water level is not exceeded. Subsequently, the three water levels that are not exceeded on 5%, 50% and 95% of the days respectively are taken as design water levels, together with the observed minimum and maximum water level. The applied stage relation between the Kratie, derived from Stung Treng is valid for the 2000-2006 hydraulic conditions. The historical water level record of Kratie shows an upward trend due to downstream developments, including land fills. For Stung Treng a completed homogeneous stage record is available for the period 1910-2006.

6.2.2 Flow velocities

For design of river bank protection works and estimation of erosion rates detailed information on flow velocity field is needed. This requires the availability of 2D or 3D hydraulic models of the river stretch around Kratie. Such models are not available for this reach. However, for a first inventory an indicative figure as an average flow velocity at maximum water level is considered sufficient. The discharge at maximum water level is based on the latest discharge rating curve flow at record of Kratie, based on ADCP-measurements, (see Appendix 8). The cross-sectional averaged flow velocities have been obtained from above discharge and the available cross-sectional area in the Mekong under the maximum water table for each of the selected river reaches. Cross-sections at the critical locations are available from the “Hydrographic Atlas Mekong River in Cambodia”, June, 1999. The bathymetry of the river refers to the situation in 1997/98. The river topography has been reduced to the Low Water Level taken from a length profile established in 1960 by Harza.

6.3 Results

6.3.1 Water levels

The design water levels as defined in Sub-section 6.2 have been derived from the average duration curve of the homogenized water levels at Kratie. The values are displayed in Table 6.1 and Figure 6.2.

Table 6.1 Design water levels around Kratie

Erosion sites/Gauging station	Location (Rkm)	Design water levels (masl)				
		MinWL	SLWL	MWL	AHWL	MHWL
Sambok	573.4	5.84	6.86	10.24	21.93	24.66
TK Kroam	568.7	5.63	6.65	10.00	21.60	24.33
Kratie	560.3	5.25	6.27	9.58	21.01	23.74
Peam Te	557.2	5.11	6.13	9.43	20.79	23.52

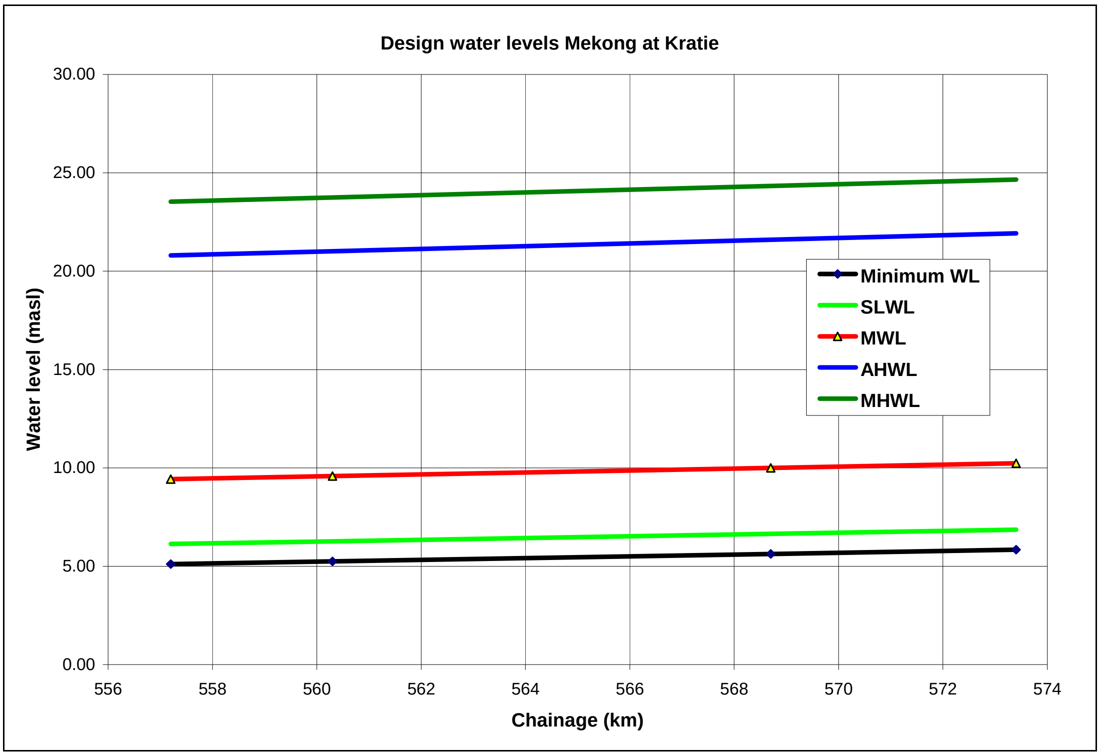


Figure 6.2 Design water levels around Kratie

6.3.2 Flow velocities

The discharge at Kratie at the maximum water level presented in Table 6.1 of 23.74 (masl) is estimated at 64,200 m^3/s. The cross-section average flow velocities at maximum water level at the critical locations along the Mekong in Kratie Province are presented in Table 6.2.

Table 6.2 Flow area and velocities at MHWL for a discharge of 64,200 m^3/s at Kratie

Erosion sites/Gauging station	Location Rkm	MHWL (masl)	Cross-sectional area (m^2)	Cross-section average flow velocity (m/s)
Sambok	573.4	24.66	13,640	4.7
TK Kroam	568.7	24.33	17,000	3.8
Kratie	560.3	23.74	gauging station	
Peam Te	557.2	23.52	19,200	3.3

The average flow velocities in the reaches appear to vary from 3.3 to 4.7 m/s. These are unrealistically high values, probably due to wrong referencing of the bathymetry to the LLWL. To properly estimate the flow velocities in this case the use of 2D or 3D models is recommended.

CHAPTER 7

MEKONG DELTA

7 MEKONG DELTA

7.1 General

In the Mekong Delta 4 Focal Areas have been selected by the CNMC and the VNMC concentrated along the border between Cambodia and Vietnam, including:

1. Takeo, west of Bassac in Cambodia
2. Prey Veng, east of Mekong in Cambodia
3. Long Xuyen Quadrangle, west of Bassac in Vietnam, and
4. Plain of Reeds, east of Mekong in Vietnam

Flood hazard assessment in these Focal Areas involves the determination of flood levels for distinct return period from 2 to 100 years with the duration and time of occurrence of the flood. The latter is particularly of importance in relation to the timing of harvest of the crop.

This chapter provides a summary of the activities on flood hazard assessment for the Focal Areas in the Mekong delta and the development scenarios analysed. For details of the analyses reference is made to Appendix 6: “Flood hazard assessment for Mekong Delta” and related Appendices 7 to 11.

7.2 Basin description and hydrological characteristics

The Mekong Delta covers the Mekong river basin from Kratie to the river mouth in the South China Sea, see Figure 7.1. The total area amounts about 144,500 km^2 of which 105,100 km^2 is in Cambodia, 4,200 km^2 in Thailand and 35,200 km^2, the Cuu Long Delta, is located in the southern part of Vietnam. A number of river reaches can be distinguished:

1. From Kratie via Kampong Cham to Chroy Changvar (Phnom Penh), just upstream where the Tonle Sap River joins the Mekong and the Bassac branches off at Chaktomouk Junction to discharge part of the total Mekong flow to the sea;
2. The Tonle Sap River and Lake with its large number of tributaries covering a drainage area of nearly 86,000 km^2.
3. Mekong from Phnom Penh to the North Vam Nao River junction, with discharge stations Neak Leung in Cambodia and Tan Chau in Vietnam. The North Vam Nao River diverts part of the Mekong flow to the Bassac;
4. Mekong downstream of North Vam Nao River, discharging its water to the South China Sea via a number of branches: Co Chien, Ham Luong, Cua Dai, and Cua Tieu. The total Mekong flow is measured in this reach at My Thuan;
5. Bassac from Chaktomouk Junction to the junction with North Vam Nao River, with stream gauging stations Chaktomouk in Cambodia and Chau Doc in Vietnam. Downstream of Chaktomouk the basin of the Prek Thnot discharges to the Bassac;
6. Bassac downstream of the junction with North Vam Nao River to the South China Sea with the flow measured at Can Tho. Part of the flow from the right bank of the Bassac drains via the Cai Lon River to the Gulf of Thailand.

The Tonle Sap Lake, the flood plains and the road infrastructure play an important role in storing and conveying of the floodwaters, flattening and delaying the flood waves.

Figure 7.1 Layout of the Mekong Delta covering the Focal Areas

The land use in the delta is heavily dominated by paddy land, with some forest in the upper parts. Soils in the delta are the most fertile of the LMB, brought in by the floods. Large quantities of gleysols exist suitable for rice farming. In the lower part of the delta intrusion of saline water affects the quality of the soils. Infertile acid sulphate soils are found in the Plain of Reeds.

Reference is made to Volume 2A for a full description of the characteristics of the Mekong Delta.

The Focal Areas around the Cambodian-Vietnamese border two are west of the Bassac (Takeo and Long Xuyen Qadrangle) and two east of the Mekong (Prey Veng and Plain of Reeds).

7.2.1 Rainfall and evaporation

The average annual rainfall in the delta varies from 1,200 to 2,000 mm and around Tonle Sap from 1,300 to 1,600 mm. The rainfall is seen to be distributed into two seasons, see also Figure 1.2.

- the dry season from November to April receives some 10% of the annual rainfall, while
- the rainy season from May to November receives the remaining 90%.

Characteristic for the rainfall in the delta is - different from the upper part of the Mekong basin – that also October is a wet month.

Annual (pan)-evaporation in the Mekong basin in Cambodia ranges from 1300 to 1900 mm. For the Mekong Delta in Vietnam annual totals between 900 and 1300 mm are reported. Monthly pan-evaporation data generally are highest in the March-April and lowest in July-September/October.

7.2.2 Upstream inflow to the delta

The inflow to the delta is to a large extent determined by the discharge in the Mekong at Kratie. In Phase 1 the flow at Stung Treng is taken, which is approximately equal to the flow at Kratie. The Stung Treng series was considered to be more reliable and available for a longer period (1910-2006), see Appendix 8.

The monthly flow statistics of the Mekong at Stung Treng for the Period 1910-2006 is presented in Table 7.1 and Figure 7.2. Largest flows are observed in the months August and September and lowest in March-April.

Table 7.1 Monthly flow statistics (MCM) of the Mekong at Stung Treng, Period 1910-2006

Var	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
mean	10,879	7,315	6,114	5,573	10,131	28,918	61,130	99,625	100,254	61,855	29,066	16,622	437,480
stdev	1,779	1,155	1,097	1,368	3,407	11,029	16,277	21,651	18,043	14,036	6,564	3,186	60,258
cv	0.164	0.158	0.179	0.245	0.336	0.381	0.266	0.217	0.180	0.227	0.226	0.192	0.138
min	7,205	4,780	3,426	1,931	3,391	9,922	26,355	52,390	51,462	31,474	16,788	9,945	285,292
max	15,596	9,740	8,957	9,329	23,141	67,019	102,090	160,875	147,218	101,193	46,386	23,618	553,923

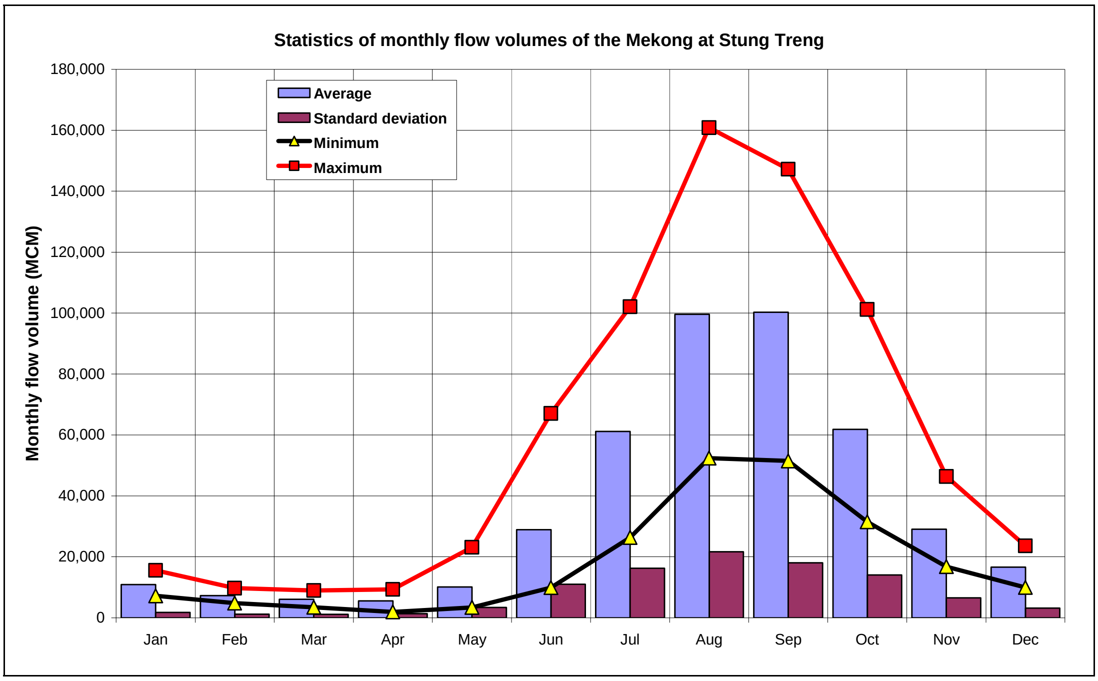


Figure 7.2 Monthly flow statistics of the Mekong at Stung Treng, Period 1910-2006

7.2.3 Lateral inflow

Downstream of Kratie the inflow to the Mekong is from the 13 Stungs draining to the Tonle Sap Lake and the Mekong tributaries Prek Te, Prek Chhlong, Prek Thnot. Their monthly averages are presented in Table 7.2.

Table 7.2 Average monthly tributary inflow (MCM) to the Tonle Sap (observations of years 1997-2004) and to the Mekong downstream of Kratie (SWAT series 1985-2006)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Tonle Sap	487	271	271	312	783	1,616	2,783	4,740	5,581	6,638	2,947	926	27,354
Prek Te	114	60	34	27	42	87	160	369	633	587	358	201	2,671
P. Chhlong	84	44	32	26	43	79	84	163	278	340	228	133	1,533
P. Thnot	77	58	40	88	192	236	337	395	505	675	299	153	3,054

From the table it is observed that on average the inflow to Tonle sap is largest in October, in response to the rainfall. In comparison with the Mekong, see Figure 7.2, it follows that the inflow regime to the Tonle Sap is shifted by about one month. This gives excellent opportunities to use the Tonle Sap Lake for temporary storage of the early flood of the Mekong to reshape the regime downstream of Phnom Penh for harvesting in late August.

7.2.4 Tidal boundary

The downstream boundary of the Mekong Delta is formed by the Gulf of Thailand in the west and the South China Sea in the south:

- The tide in the Gulf of Thailand varies from semi-diurnal to diurnal. The tidal range is in the order of 1.5 m. Levels are highest in October and November.
- In the South China Sea the tide is basically semi-diurnal, but becomes at times almost diurnal. The daily range is generally in the order of 1.5 to 2.5m; the maximum range is about 4 m. The tidal averages show a sharp increase in September-October coinciding with highest flows in the Mekong.

The tidal levels do not show clear effects of wind set up in the mouth of the Mekong. The annual maximum values during the available 22 years at the near coastal station only varied from 1.58 to 1.82 masl.

7.2.5 Delta floods

The floods in the Mekong Delta are classified as a special type of flood in the Lower Mekong Basin due to their special external and internal boundary conditions and the delta's unique hydraulic infrastructure. The flood levels in the Mekong Delta in its downstream part are essentially the result of upstream and lateral inflow, local rainfall and downstream water levels at sea. The flood in the Mekong delta is conveyed via the Mekong and Bassac Rivers and via their flood plains, including the colmatage canal system which diverts and controls the flow from and to the River. In the delta the river regime is modified by to the temporary storage in Tonle Sap Lake and in the Mekong flood plains, creating slowly rising and falling water levels.

7.3 Flood hazard assessment procedure

For the Mekong delta downstream of Kratie for flood hazard assessment use is made of the fact that a relatively long historical discharge series at the upstream boundary (Kratie or equivalently Stung Treng) is available. Furthermore, for the tributary inflow further downstream and to the Tonle Sap Lake long representative series have been created preserving the serial and cross-correlation with the Mekong flow. The series, which cover the period 1910-2006, are used as boundary conditions for a hydrodynamic model (based on ISIS-modelling package) to derive a 97-year series of water levels in the flood-prone areas. Further input to the model is formed by local rainfall, evaporation, water use and the year 2000 tidal conditions at the Gulf of Thailand and the South China Sea.

The relevant statistics, including the probabilities of flooding and related damages for return periods from 2 to 100 years, can be derived directly from the series of water levels and depths computed with the model. From the model results for each year maximum water levels and flood damages are derived for all model nodes to estimate the exceedance probabilities. The probability estimates are obtained with Gringortens formula:

$$p_i = \frac{r_i - 0.44}{N + 0.12}$$

where:

p_i = probability of exceedance of the annual maximum water level in year *i*

N = total number of years

r_i = rank number of the maximum water in year *i* (1 = highest, n = lowest)

Since the series of annual maxima is close to 100 years, the estimated 100-year water level is by definition approximately the same as the maximum observed water level.

7.4 Hydraulic model of the delta and boundary conditions

7.4.1 Hydraulic model

For the flood hazard assessment use is made a hydraulic model of the Mekong Delta. The model is used to compute flood levels for distinct return period from 2 to 100 years with the duration and time of occurrence of the flood, based on 97 years of historical floods from 1910 to 2006. The hydraulic model of the Mekong Delta is based on the ISIS modelling system for the simulation of unsteady flow in channel networks. The system was introduced to the MRC under the WUP-A programme and now serves as part of the Decision Support Framework (DSF).The model covers the Mekong Basin from Kratie to the South China Sea, including the Tonle Sap Lake and Floodplain, the Cambodian floodplains and the Vietnamese Mekong Delta. Recently, this model has been recalibrated (see Appendix 7), but it was concluded, that further improvements are needed before it can be used as a reliable instrument in the study of flood management scenarios. Currently, it does not satisfy the criteria that have been set by MRCS for acceptance of the model. Apart from differences in peak levels, errors in the celerity of flood wave propagation are observed. Consultants concluded that the current model will be acceptable for demonstration purposes to study the selected focal areas in the border area between Cambodia and Vietnam. For a final analysis the ISIS model has to be further improved.

For the simulation of structural measures to change the nature of the floods in the project areas, adaptations in the model schematization are required. Particularly the Cambodian part of the delta requires a denser network.

7.4.2 Boundary conditions

The boundary conditions of the hydraulic , including:
- upstream boundary condition at Kratie,
- tributary inflow to Tonle Sap Lake,
- tributary inflow to Mekong,
- rainfall,
- evaporation,
- water use, and

downstream boundary condition at Gulf of Thailand and South China Sea.

7.4.3 Upstream boundary at Kratie

The upstream boundary at Kratie is derived from the discharge series available for Stung Treng for the period 1910-2006, shifted with one day to account for the travel time between Stung Treng and Kratie.

Extreme value analysis has been carried out on the annual maximum peak flows and flood volumes at Stung Treng using GEV-distributions. Particularly the flood volumes are of importance for the Mekong Delta as these create the highest water levels and flood damages.

The results of the extreme value analyses are shown in Table 7.3 and Figure 7.3. The correlation between the peak flows and flood volumes is included in the bivariate extreme value distribution on peak flows and flood volume. For its establishment reference is made to Appendix 9 for the details.

Table 7.3 Annual maximum discharge and flood volume in the Mekong at Stung Treng, period 1910-2006

T	Peak flow (m^3/s)	Flood volume (MCM)
2	54,400	331,000
5	62,600	389,000
10	66,600	416,000
25	70,600	440,000
50	72,900	453,000
100	74,800	463,000

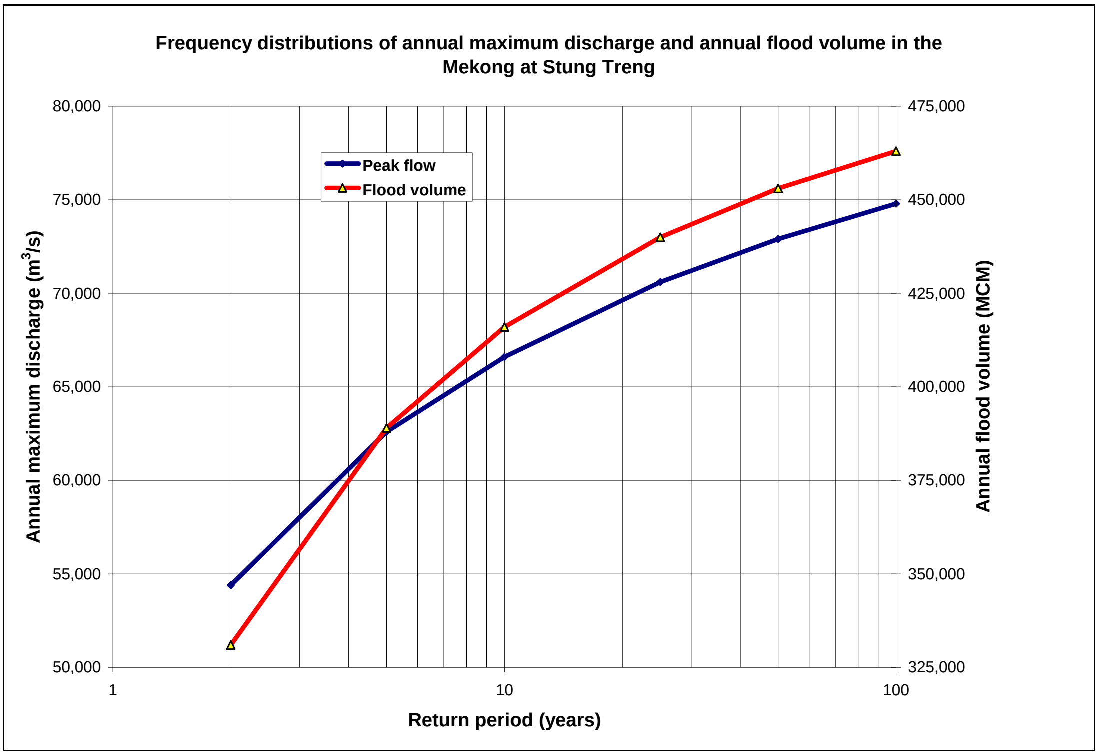


Figure 7.3 Frequency distributions of annual maximum discharge and flood volume in the Mekong at Stung Treng, Period 1910-2006

7.4.4 Tributary inflow to Tonle Sap

The area draining to Tonle Sap up to the highways 5 and 6 amounts 68,830 km^2. It comprises the drainage areas of 13 Stungs. Inflow series of daily discharges are available for the years 1997-2004. A multiple regression equation has been used for the generation of monthly tributary flow of month *i* as a function of the tributary flow in month i-1 (to preserve the serial correlation) and the flow at Stung Treng in the same month (to preserve the cross-correlation). A normally distributed random number was added to preserve the variance. Monthly values have been disaggregated to daily sequences by scaling historical series; series were selected on their resemblance with the generated flood volumes.

7.4.5 Tributary inflow to Mekong

Apart from the inflow to the Tonle Sap Lake the Delta Model also requires inflow series for the tributaries Prek Te, Prek Chhlong, Prek Thnot, East Vaico River, and West Vaico River. The daily flow series for the period 1985-2006 are available from the DSF files created by the SWAT model. Since the SWAT-series show no correlation with the flow in the Mekong a pragmatic approach was used to extend the series by applying a block-wise repetition of the series 1985-2006 for the years 1910-1984.

7.4.6 Rainfall and evaporation

Daily series of 9 locations in Cambodia and of 5 locations in Vietnam are required as input to the hydraulic model of the Mekong Delta. Data is available for the locations for the period 1985-2006. Analysis showed that seasonal rainfall at the selected locations hardly correlated with Tonle Sap inflow and not at all with the flow in the Mekong. Hence, a block-wise repetition of the series 1985-2006 was applied for the period 1910-1984. For the same locations as rainfall is input into the model also evaporation data is required. Historical records have been used and when not available monthly averages have been applied. The latter is justified in view of the limited variability from year to year of potential evaporation in a particular month.

7.4.7 Water use

At 128 nodes in the network of the Delta model water is abstracted for agriculture, domestic and industrial use. The total annual abstraction amounts 16.5 BCM. During the flood season the demand is about 4.4 BCM in total.

7.4.8 Sea boundary

In total at In total at 19 nodes water level boundaries are defined in the Delta Model. These boundaries are taken from hourly observations made at 2 stations in the Gulf of Thailand and 4 stations in the South China Sea. The hourly observations used in the Delta Model are records of the year 2000. It appears that the year 2000 slightly underestimates the range of water levels at the sea boundary, but this effect is practically vanished in the reach of the Focal Areas.

7.5 Flood hazard assessment

For the management of floods and related risks in the Focal Areas in the Mekong Delta the following development scenarios have been considered:

[1] Base Case
- The existing condition of land use and flood control levels in Cambodia and Vietnam.

[2] Scenario Cam0: flood protection in Cambodia
This scenario comprises of early flood protection and full flood protection in Cambodia according to recommendation in Stage 1, while no development in Vietnam is assumed. The protection in Cambodia is as follows:

- Takeo
  - Zones 1 and 3: full protection
  - Zone 2: early flood protection
- Prey Veng
  - Zone 1: early flood protection
  - Zones 2 and 3: 1: 10 year flood protection (+free board)
  - Zone 4: no protection.

Early flood protection is defined as follows: based on the model simulation of the base case the annual maximum water level of the early flood season, which ends on August 1, is derived for the series of 97 years (1910-2006). Subsequently, the water level with a return period of 10 years, $h_{1Aug;\ 10}$, is derived from this series. So $h_{1Aug;\ 10}$, is the water level that is exceeded on average once in every 10 early flood seasons (1 May – 1 August). Early flood protection means that the crest height of the dikes are raised to the level of $h_{1Aug;\ 10}$. This means the probability of flooding in the early flood season is equal to 1/10 (10%).

[3] Scenario Vna flood protection in Vietnam, variant a
This scenario comprises of early flood protection and full flood protection in Vietnam.

- Long Xuyen Quidrangle
  - enlargement of canals,
  - no sluices along Bassac,
  - rubber dams open on the 15th of August
- Trans Bassac: full protection as at present
- Plain of Reeds: Canal enlargement

[4] Scenario Vnd flood protection in Vietnam, variant d
This scenario comprises of full flood protection in the largest part of the Mekong Delta in Vietnam. It is explicitly noted that this scenario is not in accordance with the current policy of Vietnam for flood protection of the delta. However, it provides an outlook in the far future, say 2060 in case that the socio-economic situation might have changed so much that full flood protection would be an option.

[5] Scenario Cam0Vna: flood protection in Cambodia and Vietnam
This is the combination of scenarios Cam0 and Vna

[6] Scenario diversion:
This is the scenario in which a Diversion to the Tonle Sap lake is built for early flood control.

The results are summarised below. The results for the development scenarios are compared with the Base Case for selected locations in the Focal Areas and along the rivers (see Figure 7.4), to assess the effect of the measures. Also, the effect of sea level rise is analysed.

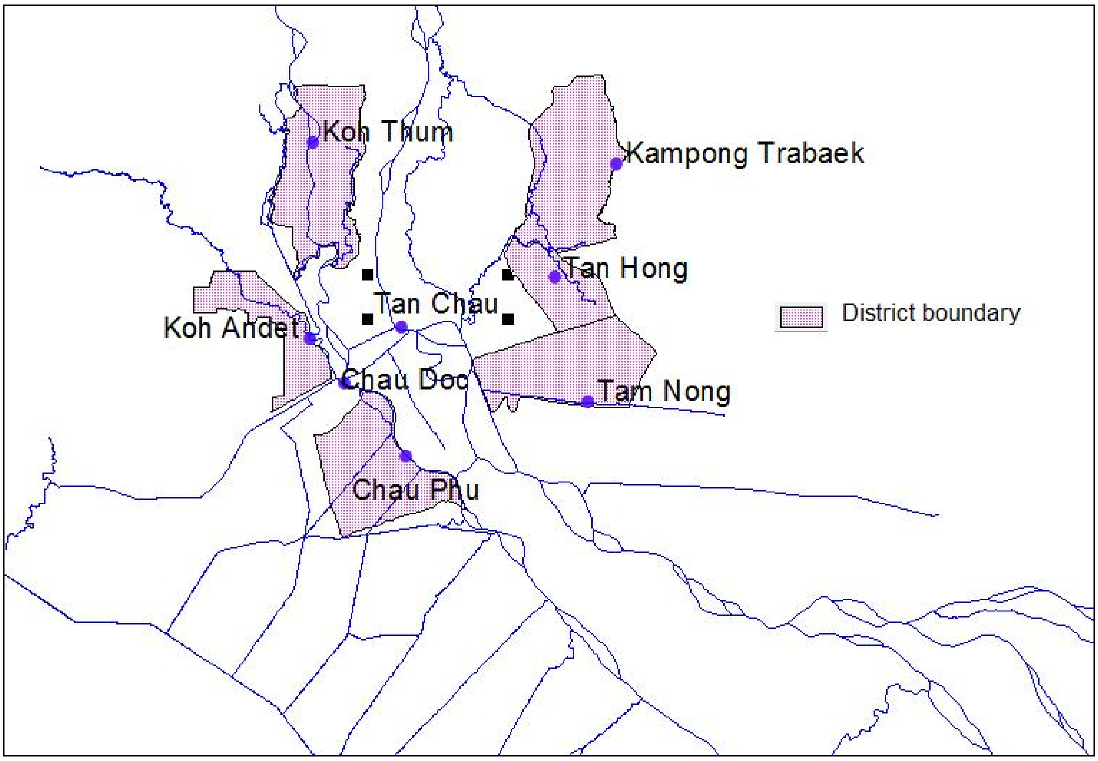


Figure 7.4 Selected locations for flood damage assessment.

7.5.1 Base Case

For the Base Case the hydraulic model was run for the 97 historical flood seasons (May to December) of upstream and tributary inflow from 1910 to 2006. Per year the annual maximum water levels were abstracted and subjected to a frequency analysis per node. The water levels for 2, 5, 10, 25 and 100 years were subsequently compared with ground elevation to determine flood depth and extent. The results for the 100 years return period are shown in Figure 7.5. By comparing these maps with land use, basic information for damage assessment is obtained. Instead of selecting the maximum water levels per year one can also select other characteristics for specific seasons as the full details of the hydrographs of 97 years are available in the database for any location in the model, including also flow velocities.

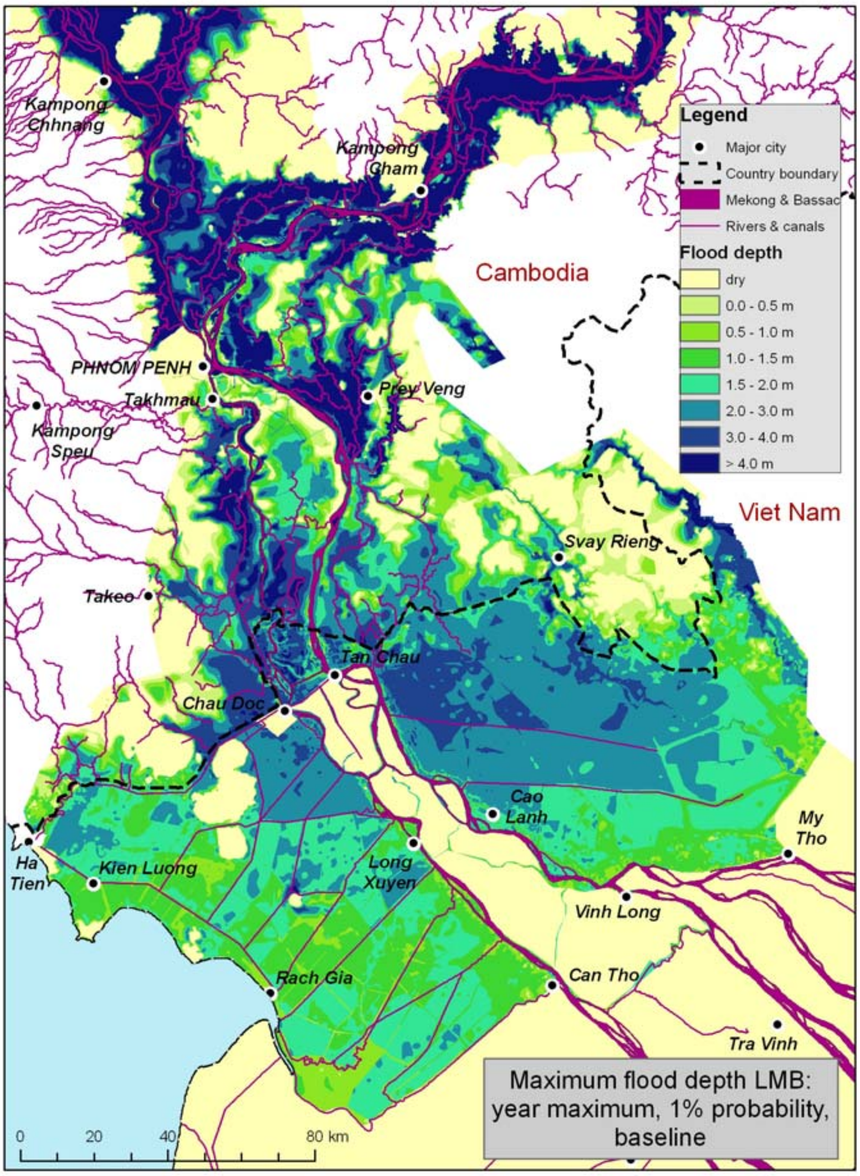


Figure 7.5 100 year flood map for entire Mekong Delta.

7.5.2 Development scenarios

Instead of running the hydraulic model for the above scenarios for the full 97 flood seasons, only 11 selected years (1918, 1923, 1927, 1929, 1939, 1940, 1971, 1994, 1996, 2000 and 2001) were simulated in order to save valuable computation time. The years were selected in such a way that they represent the range from moderate to extreme years in terms of Mekong flows and, consequently, flood depths.

7.5.3 Results for scenario [2] – Cam0

The water levels with probability of exceedance of 50%, 20%, 10%, 4%, 2% and 1% for this scenario are compared with the corresponding water levels for the base case. Figure 7.6 and

Figure 7.7 show the differences with the base case for the 25 locations in Cambodia and 34 locations in Vietnam respectively. As can be seen there is no consistent pattern. For 16 out of 25 locations in Cambodia the water level decreases as a result of the measures of scenario Cam0, for 8 locations the water levels increases and for one location (Preah Sdech) both increases and decreases are observed. Of the 34 Vietnamese locations, 11 show an increase in water levels, 13 show a decrease in water levels and 10 show hardly any change at all. So for some locations the annual expected damages will increase as a result of the measures of scenario Cam0 and for some locations the water levels will decrease. This will be quantified in Volume 6E.

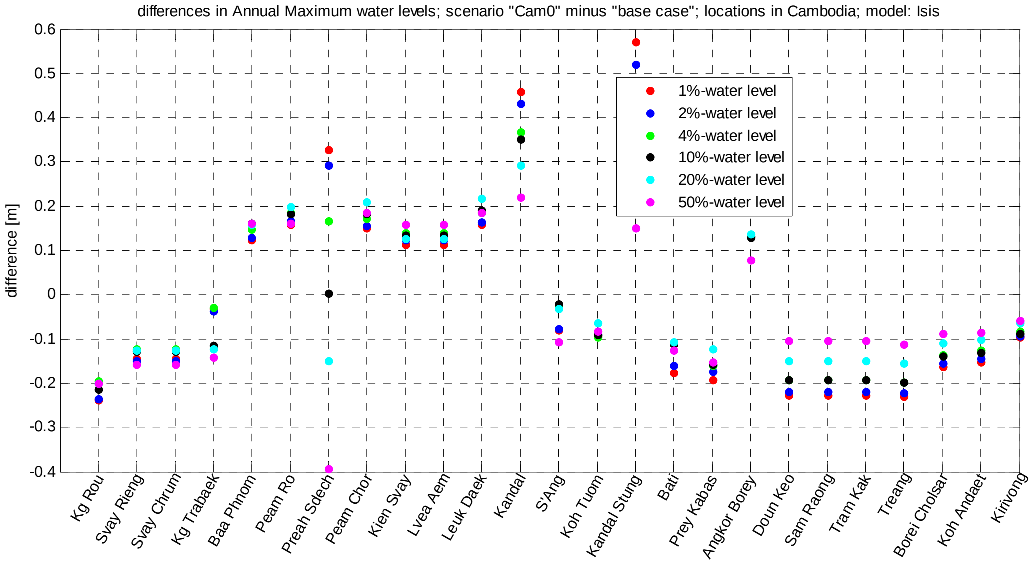


Figure 7.6 Change in the p-percent annual maximum water level (p=1, 2, 4, 10, 20 and 50) for 25 locations in **Cambodia**; comparison of scenario **Cam0** with the base case. Positive values indicate an increase in water level.

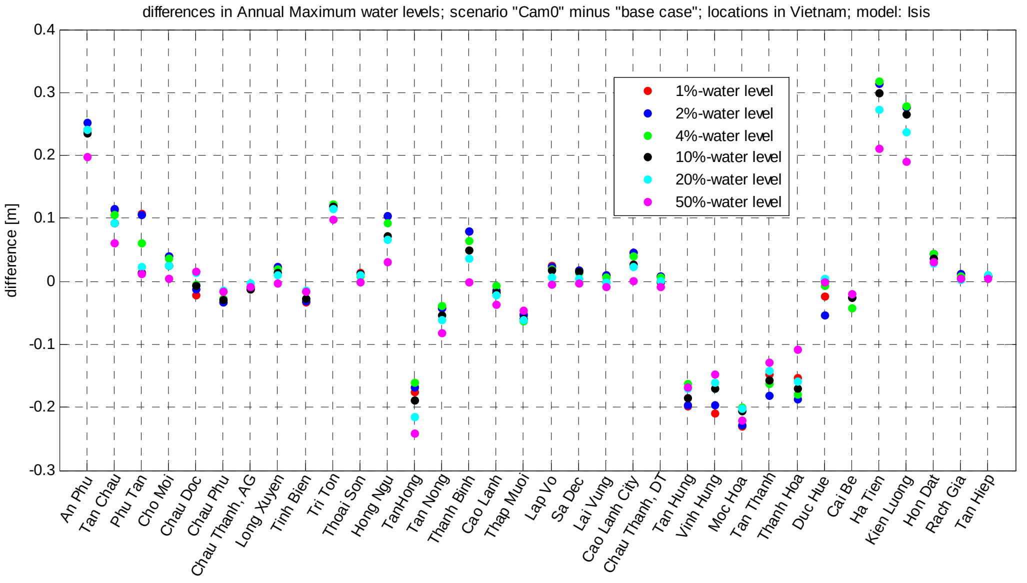


Figure 7.7 Change in the p-percent annual maximum water level (p=1, 2, 4, 10, 20 and 50) for 34 locations in **Vietnam**; comparison of scenario **Cam0** with the base case. Positive values indicate an increase in water level.

Figure 7.8 - Figure 7.11 compare water levels in the Mekong and Bassac rivers for the base case and scenario Cam0. Most noteworthy is the fact that the scenario leads to a reduction in water levels over some stretches of the Bassac river.

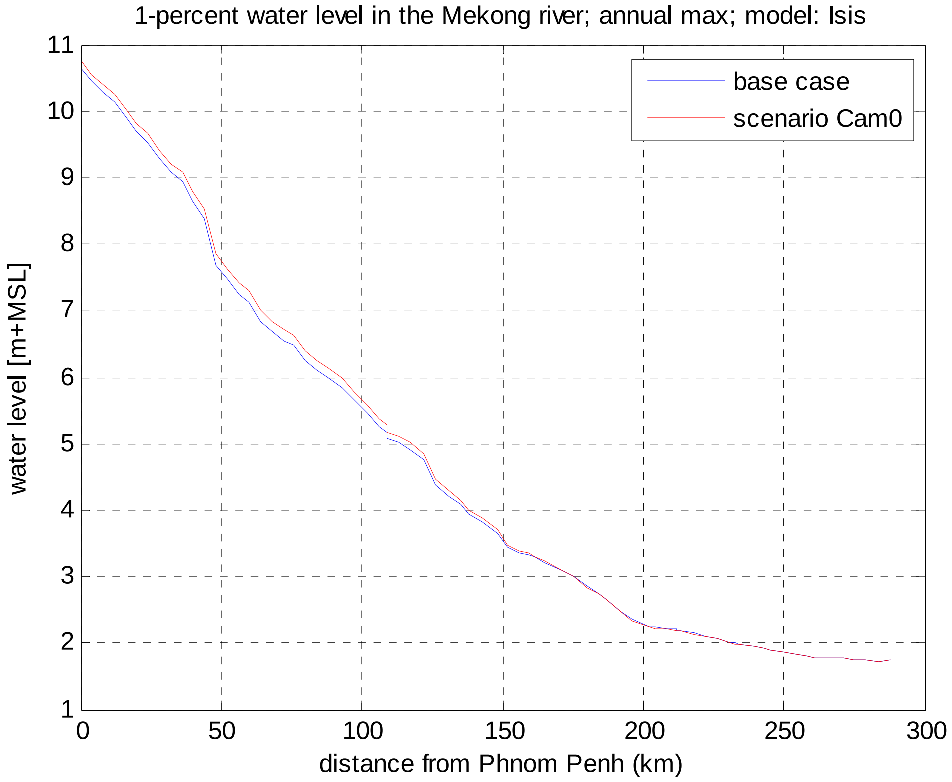


Figure 7.8 Water levels in the **Mekong** river downstream of Phnom Penh; comparison between the base case and scenario **Cam0**.

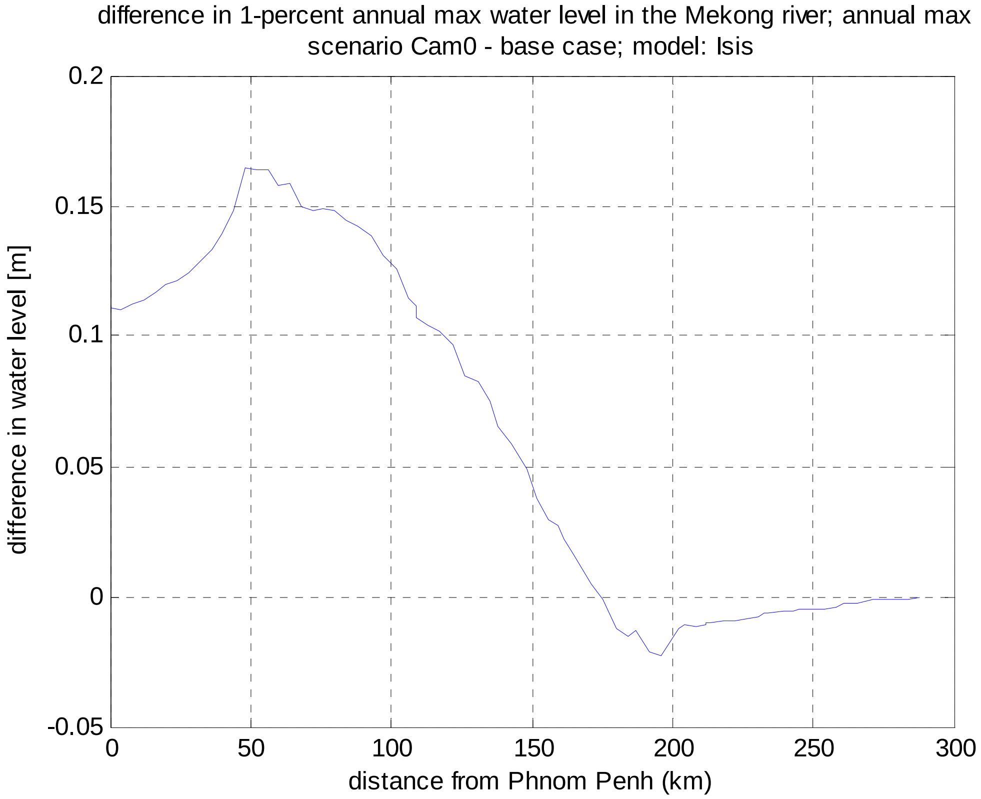


Figure 7.9 Increase in water level in the **Mekong** river downstream of Phnom Penh as a result of scenario **Cam0** (differences between the two cases of Figure 7.8).

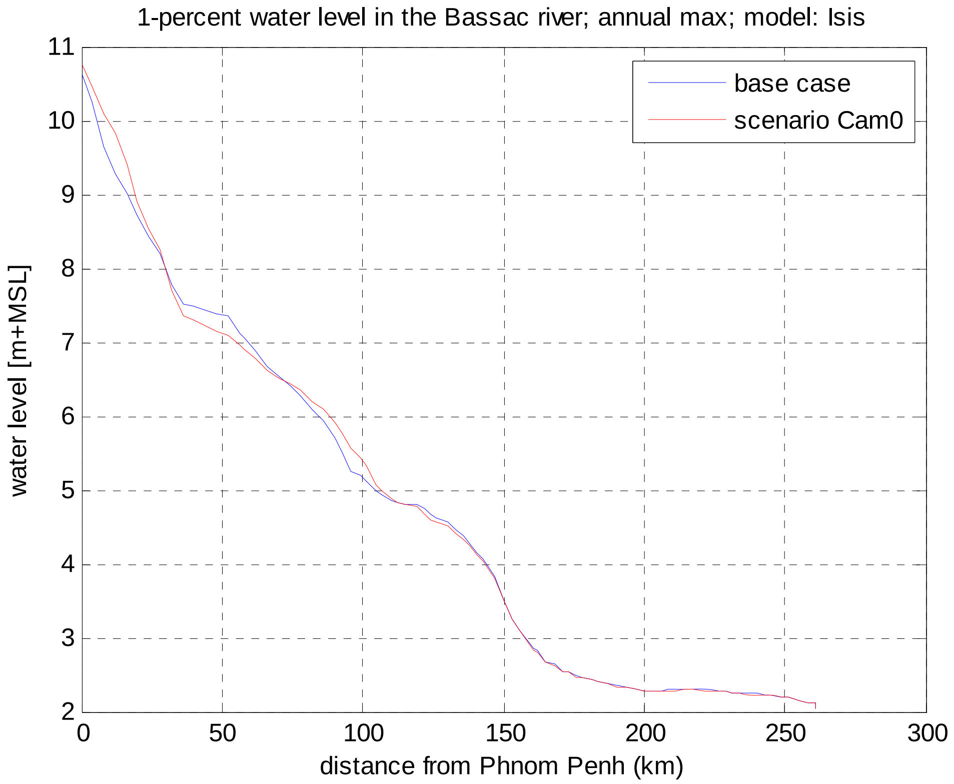


Figure 7.10 Water levels in the **Bassac** river downstream of Phnom Penh; comparison between the base case and scenario **Cam0**.

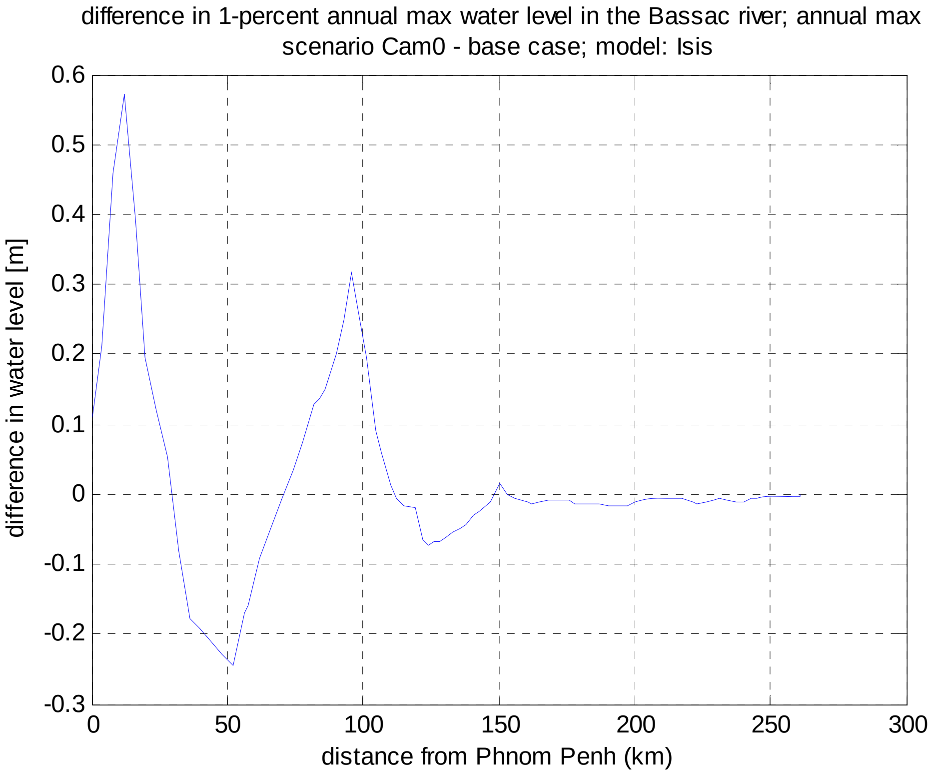


Figure 7.11 Increase in water level in the **Bassac** river downstream of Phnom Penh as a result of scenario **Cam0** (differences between the two cases of Figure 7.10).

7.5.4 Results for Scenario [3] – Vna

Figure 7.12 and Figure 7.13 show the differences in water levels between scenario Vna and base case for the 25 locations in Cambodia and 34 locations in Vietnam respectively. Again, for some locations the water levels increase as a result of the measures of scenario Vna, while for other locations the water levels decrease. All Cambodian locations show an increase in water level. Figure 7.14 - Figure 7.17. compare water levels with probabilities of exceedance of 1% in the Mekong and Bassac rivers for the base case and scenario Vna

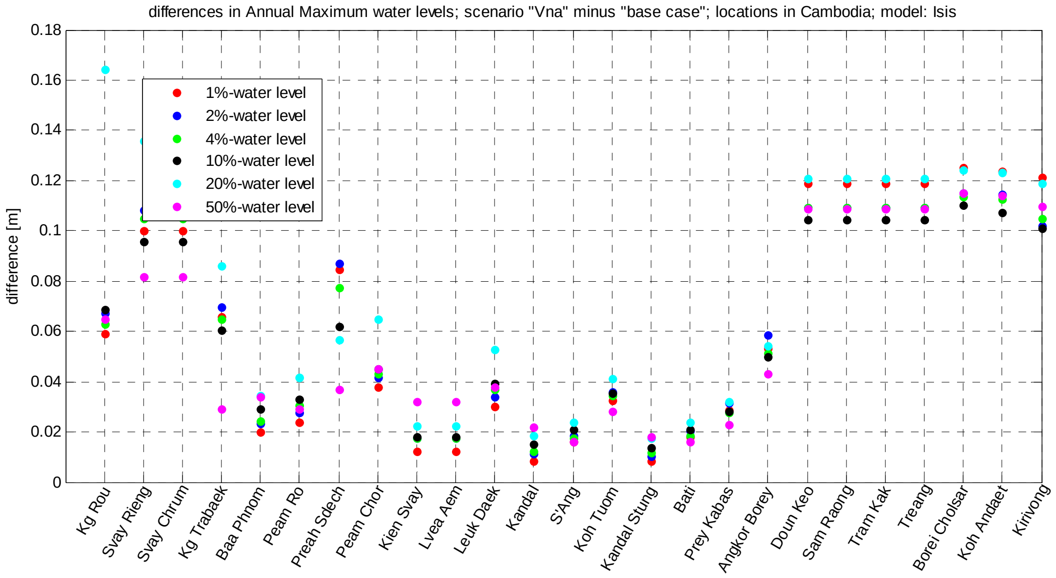


Figure 7.12 Change in the p-percent annual maximum water level (p=1, 2, 4, 10, 20 and 50) for 25 locations in **Cambodia**; comparison of scenario **Vna** with the base case. Positive values indicate an increase in water level.

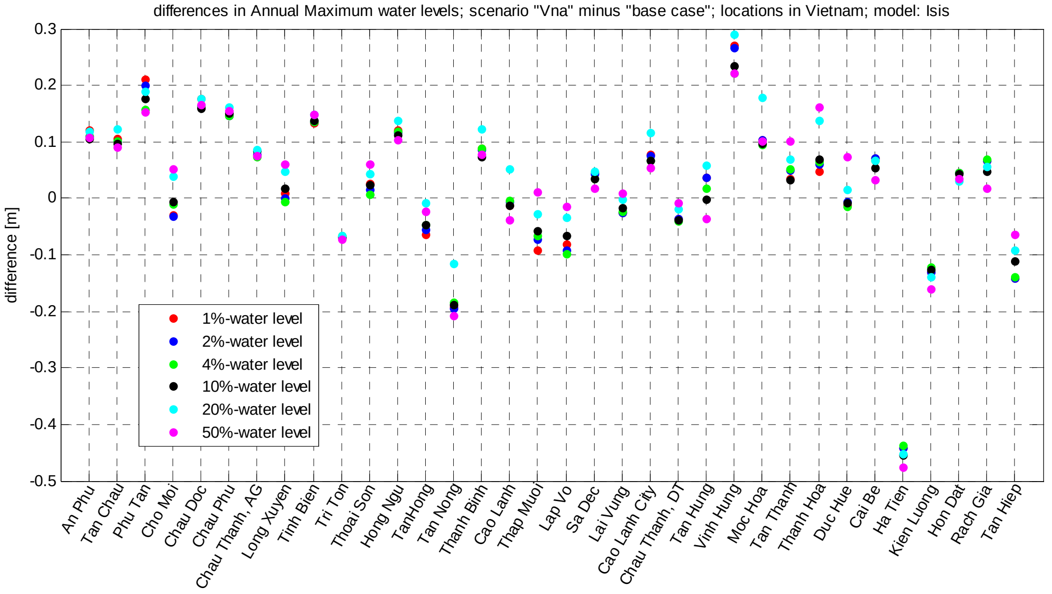


Figure 7.13 Change in the p-percent annual maximum water level (p=1, 2, 4, 10, 20 and 50) for 34 locations in **Vietnam**; comparison of scenario **Vna** with the base case. Positive values indicate an increase in water level.

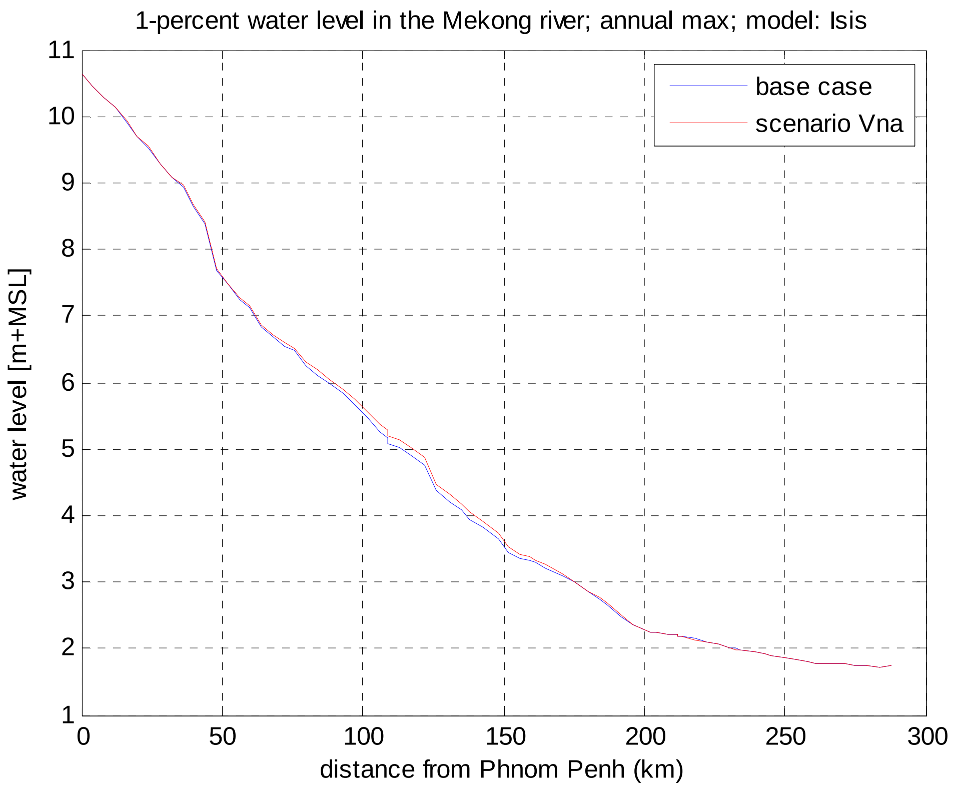


Figure 7.14 Water levels in the **Mekong** river downstream of Phnom Penh; comparison between the base case and scenario **Vna**.

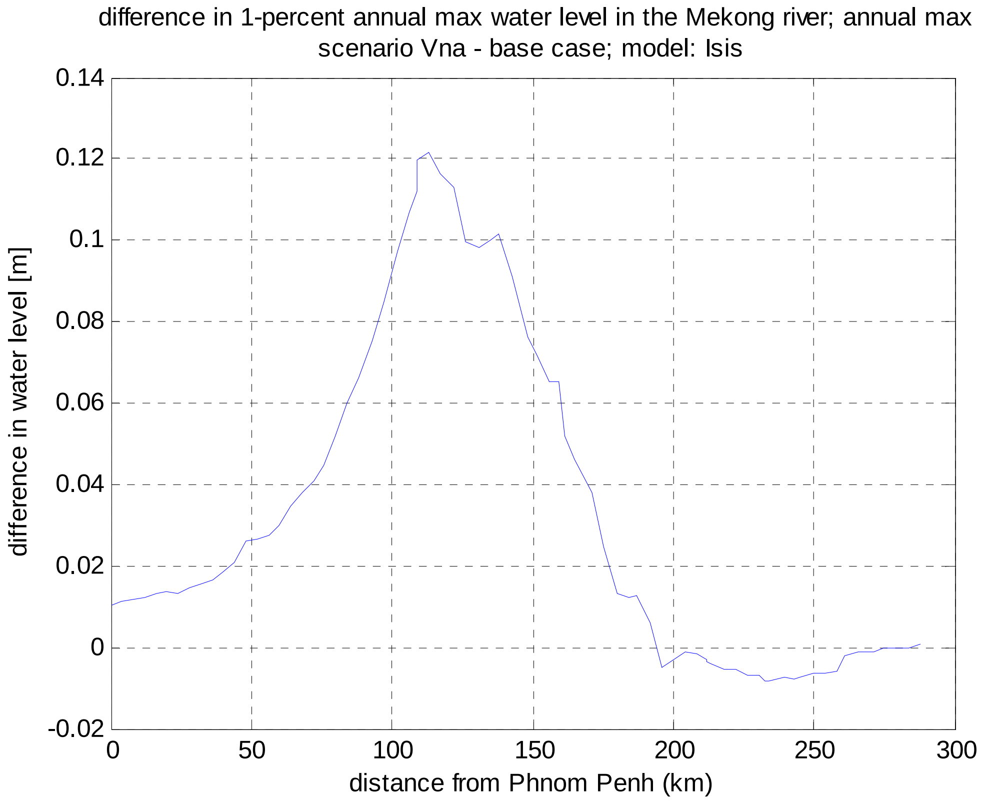


Figure 7.15 Increase in water level in the **Mekong** river downstream of Phnom Penh as a result of scenario **Vna**.

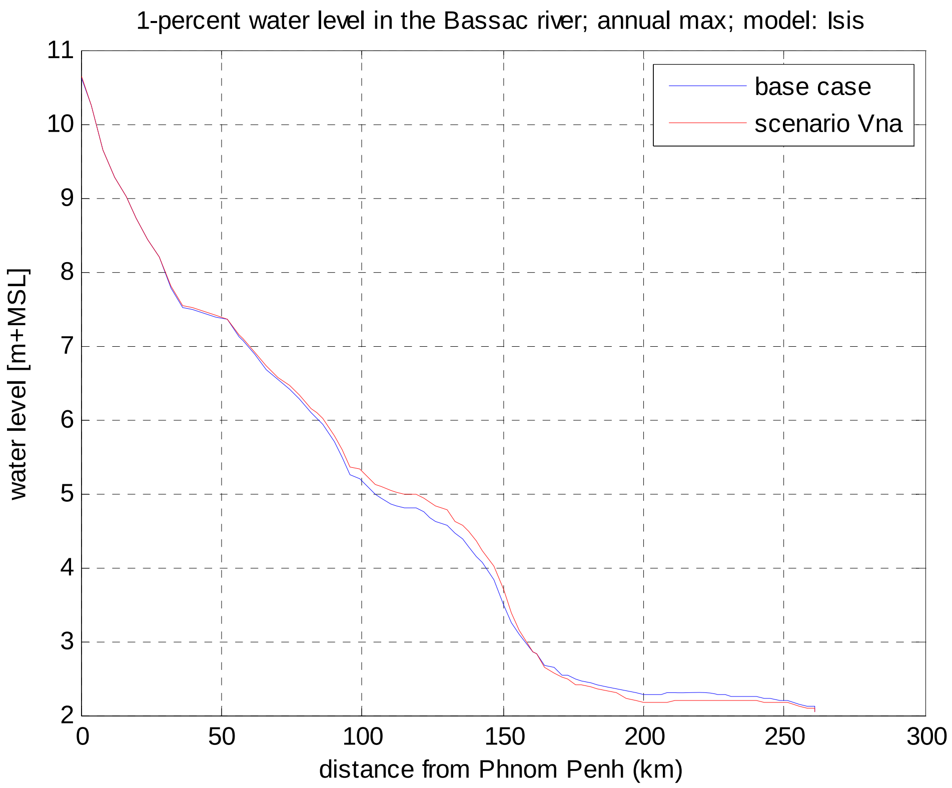


Figure 7.16 Water levels in the **Bassac** river downstream of Phnom Penh; comparison between the base case and scenario **Vna**.

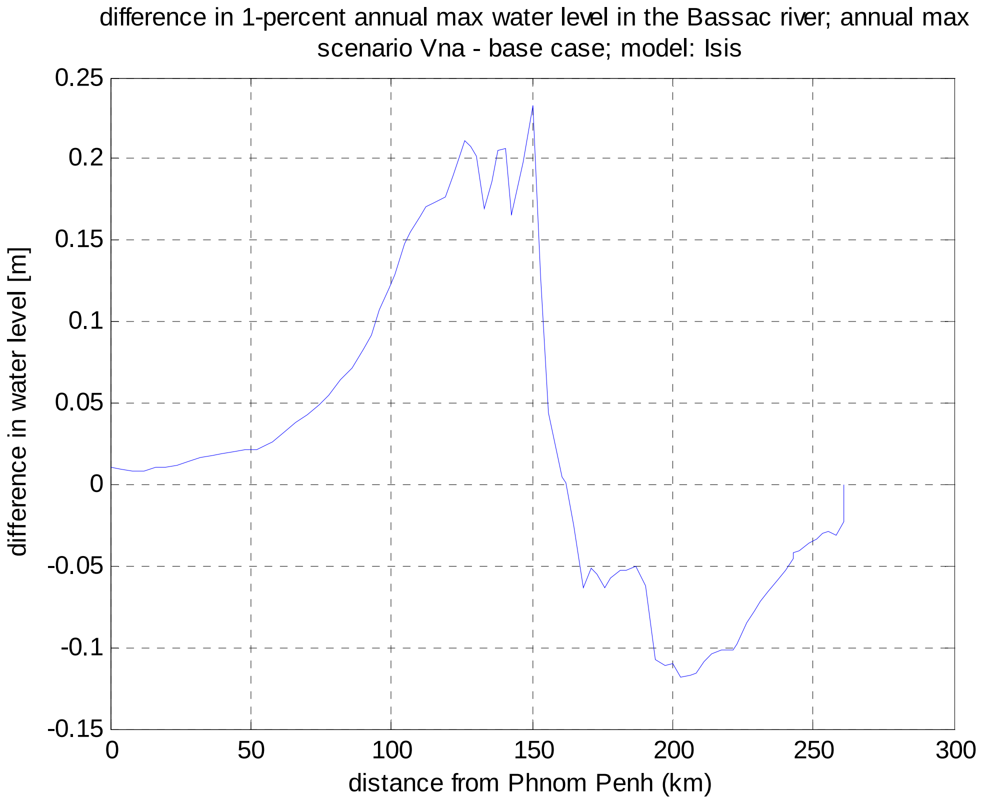


Figure 7.17 Increase in water level in the **Bassac** river downstream of Phnom Penh as a result of scenario **Vna**.

7.5.5 Results for Scenario [4] – Vnd

Figure 7.18 and Figure 7.19 show the differences in water levels between scenario Vnd and base case for the 25 locations in Cambodia and 34 locations in Vietnam respectively. Again, for all locations in Cambodia the water levels increase as a result of the measures of scenario Vnd. For locations in Vietnam the effects of changes are mixed. Figure 7.20 - Figure 7.23. compare water levels with probabilities of exceedance of 1% in the Mekong and Bassac rivers for the base case and scenario Vnd.

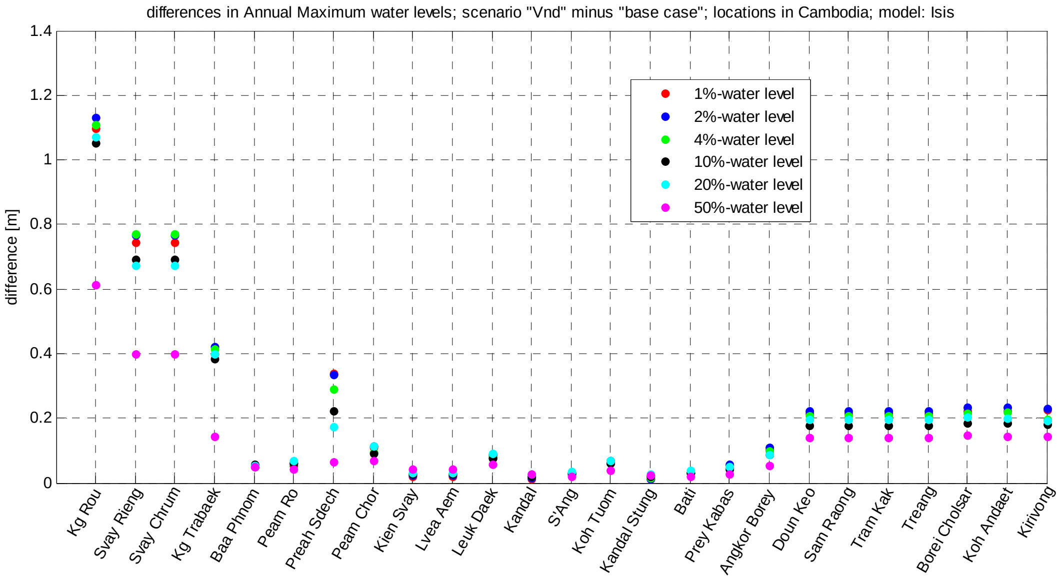


Figure 7.18 Change in the p-percent annual maximum water level (p=1, 2, 4, 10, 20 and 50) for 25 locations in **Cambodia**; comparison of scenario **Vnd** with the base case. Positive values indicate an increase in water level.

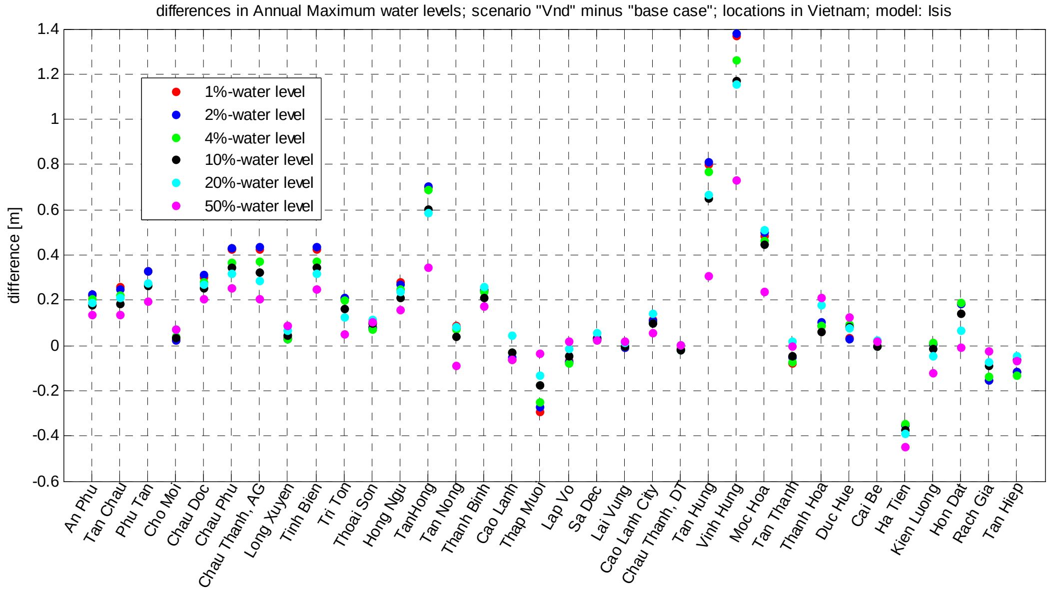


Figure 7.19 Change in the p-percent annual maximum water level (p=1, 2, 4, 10, 20 and 50) for 34 locations in **Vietnam**; comparison of scenario **Vnd** with the base case. Positive values indicate an increase in water level.

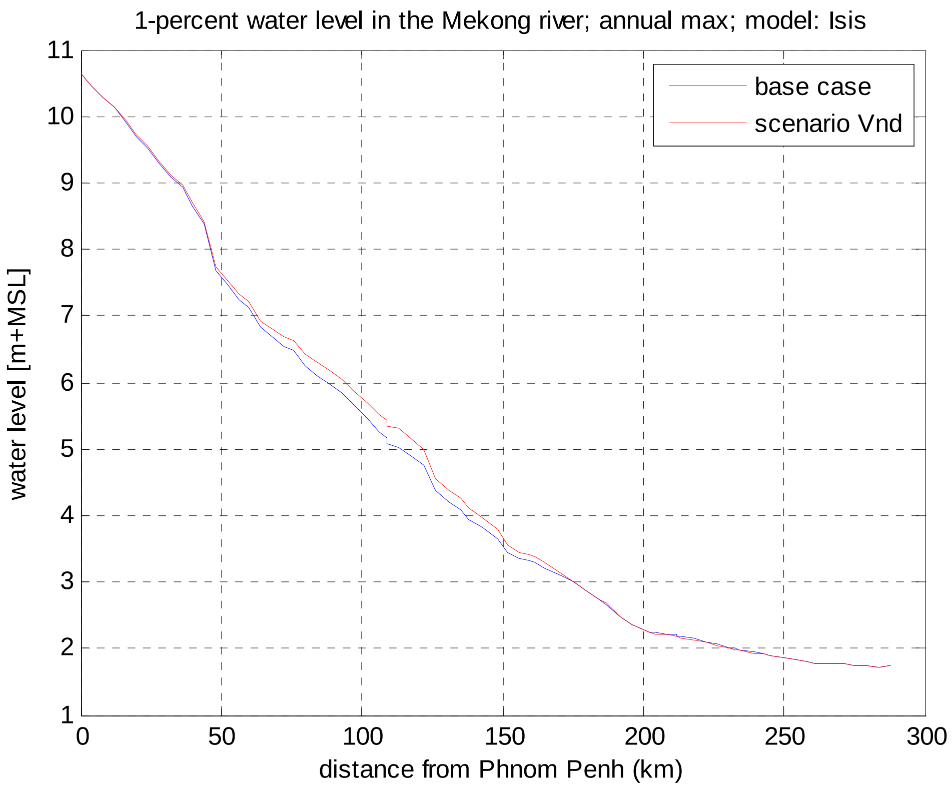


Figure 7.20 Water levels in the **Mekong** river downstream of Phnom Penh; comparison between the base case and scenario **Vnd**.

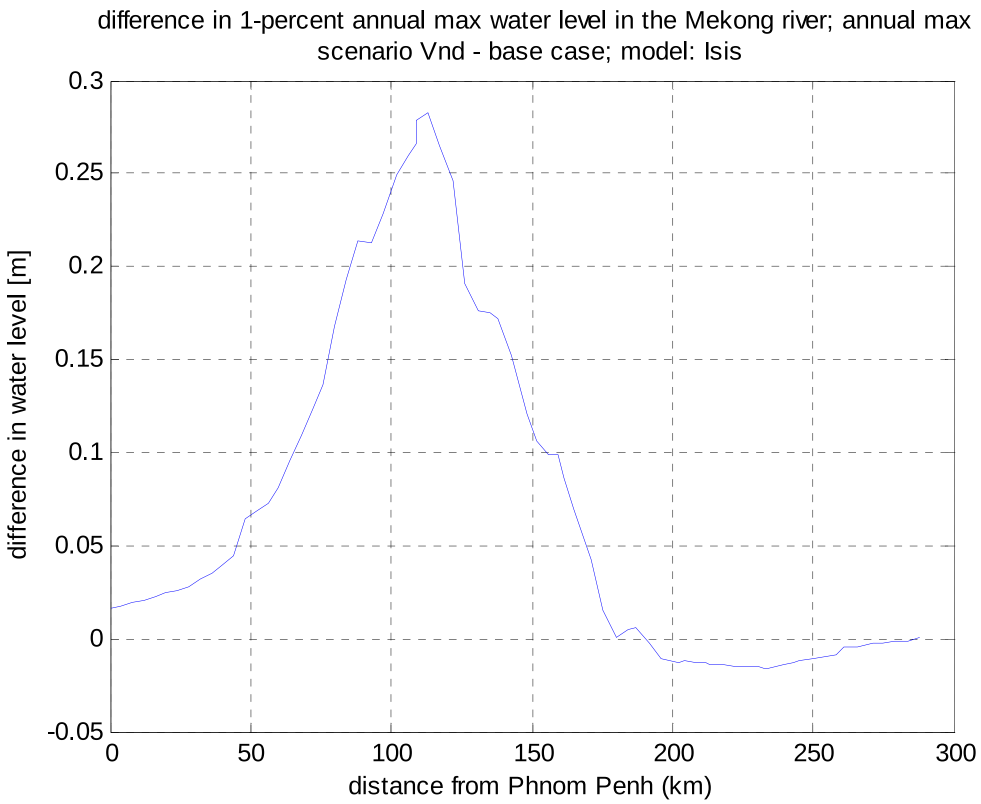


Figure 7.21 Increase in water level in the **Mekong** river downstream of Phnom Penh as a result of scenario **Vnd**.

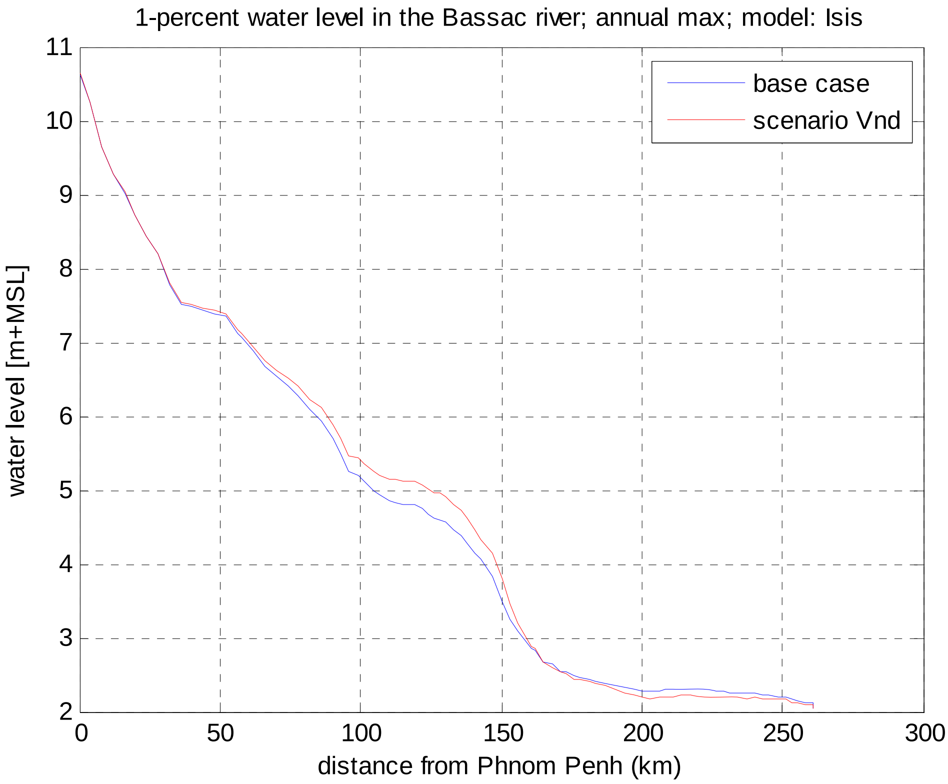


Figure 7.22 Water levels in the **Bassac** river downstream of Phnom Penh; comparison between the base case and scenario **Vnd**.

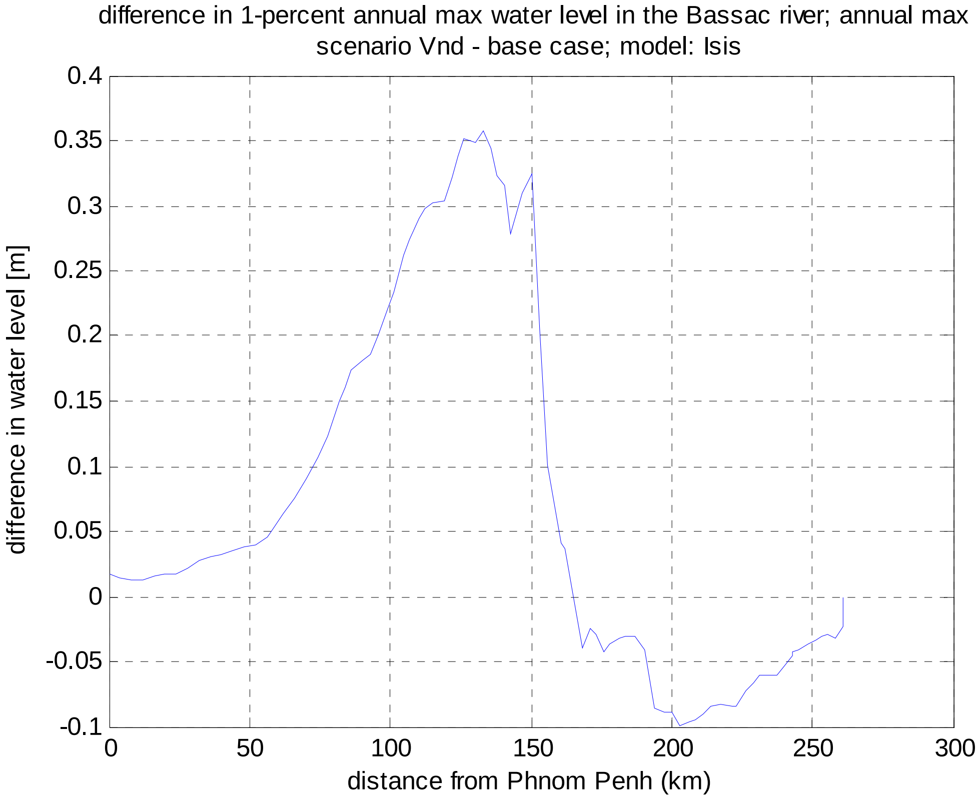


Figure 7.23 Increase in water level in the **Bassac** river downstream of Phnom Penh as a result of scenario **Vnd**.

7.5.6 Results for Scenario [5] – Cam0Vna

Figure 7.24 and Figure 7.25 show the differences in water levels between scenario Cam0Vna and base case for the 25 locations in Cambodia and 34 locations in Vietnam respectively. Again, for some locations the water levels increase as a result of the measures of scenario Cam0Vna, while for other locations the water levels decrease. Figure 7.26 - Figure 7.29 compare water levels with probabilities of exceedance of 1% in the Mekong and Bassac rivers for the base case and scenario Cam0Vna.

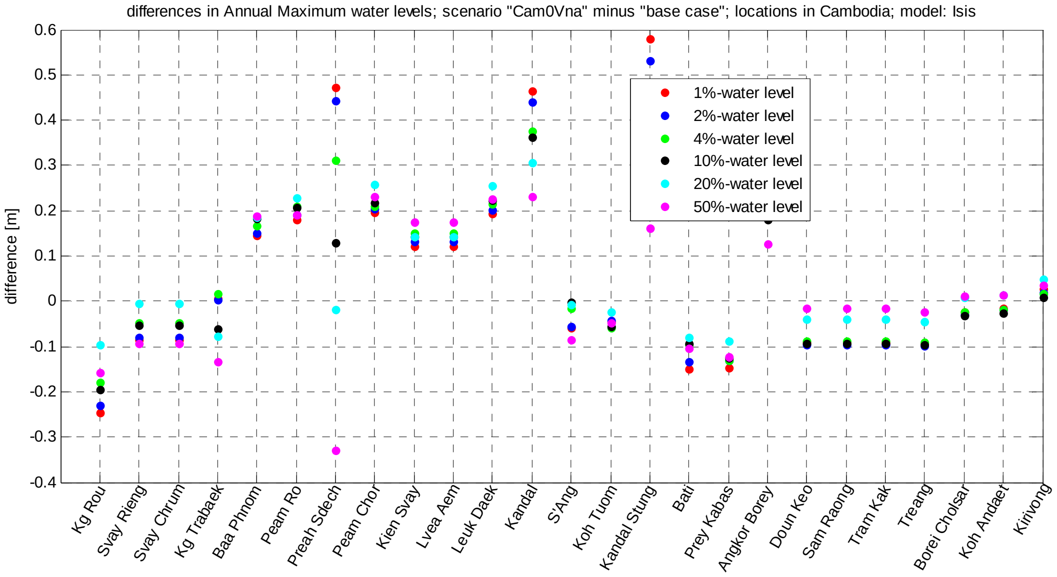


Figure 7.24 Change in the p-percent annual maximum water level (p=1, 2, 4, 10, 20 and 50) for 25 locations in **Cambodia**; comparison of scenario **Cam0Vna** with the base case. Positive values indicate an increase in water level.

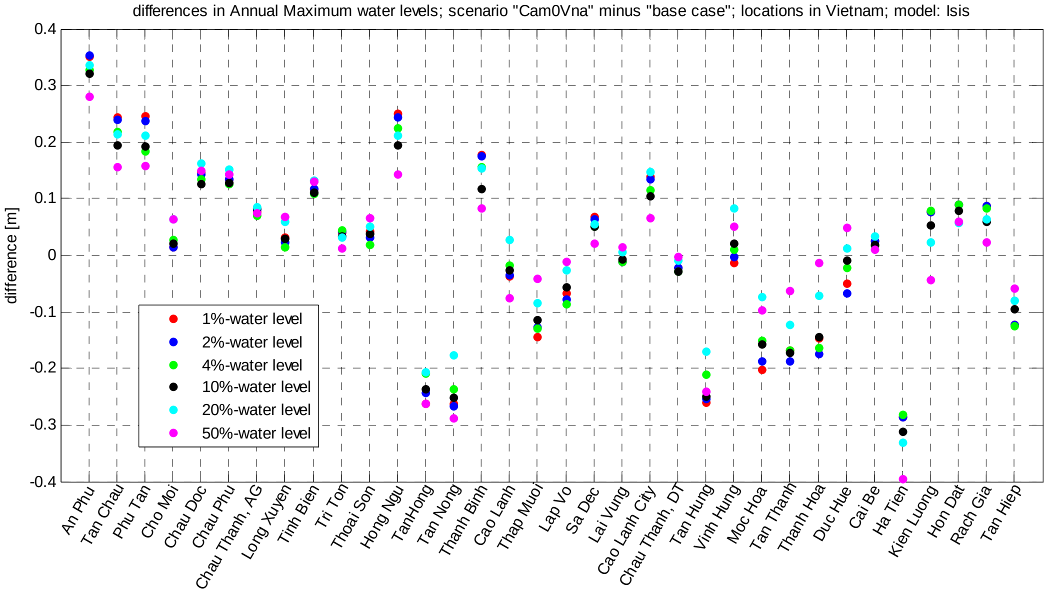


Figure 7.25 Change in the p-percent annual maximum water level (p=1, 2, 4, 10, 20 and 50) for 34 locations in **Vietnam**; comparison of scenario **Cam0Vna** with the base case. Positive values indicate an increase in water level.

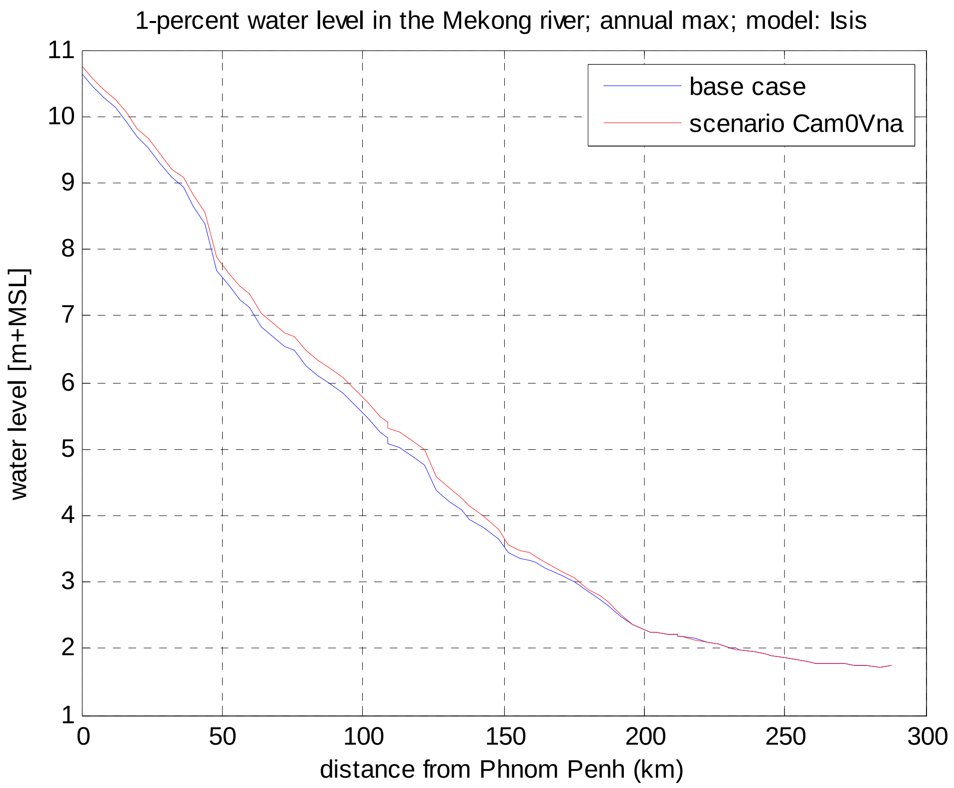


Figure 7.26 Water levels in the **Mekong** river downstream of Phnom Penh; comparison between the base case and scenario **Cam0Vna**.

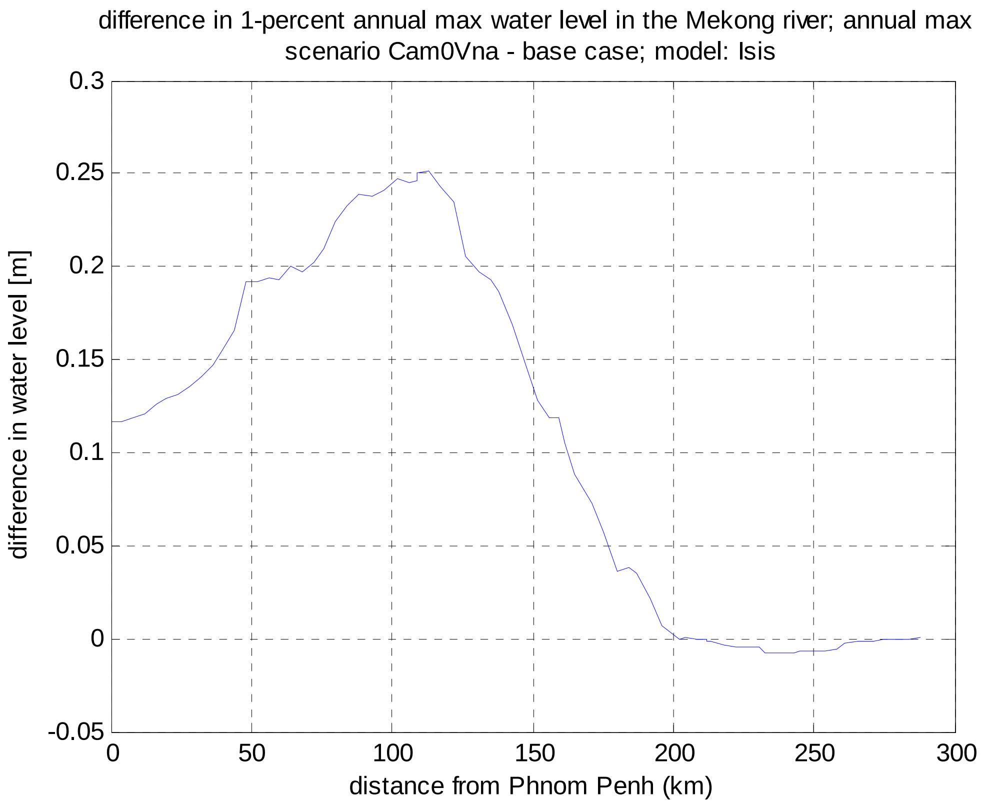


Figure 7.27 Increase in water level in the **Mekong** river downstream of Phnom Penh as a result of scenario **Cam0Vna**.

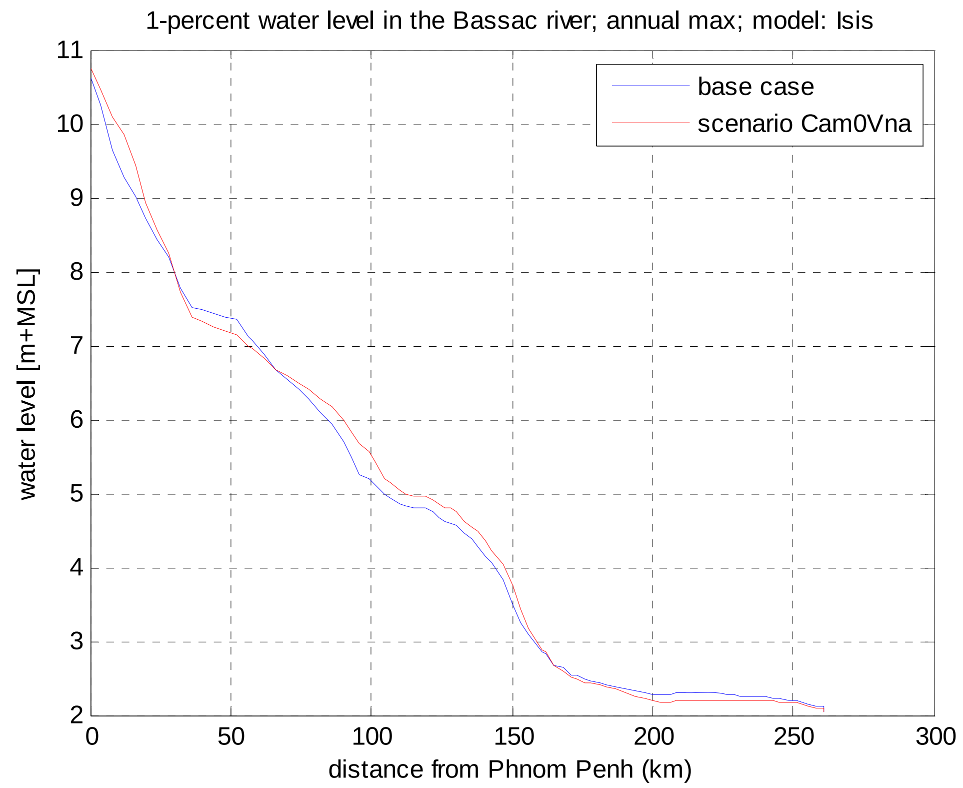


Figure 7.28 Water levels in the **Bassac** river downstream of Phnom Penh; comparison between the base case and scenario **Cam0Vna**.

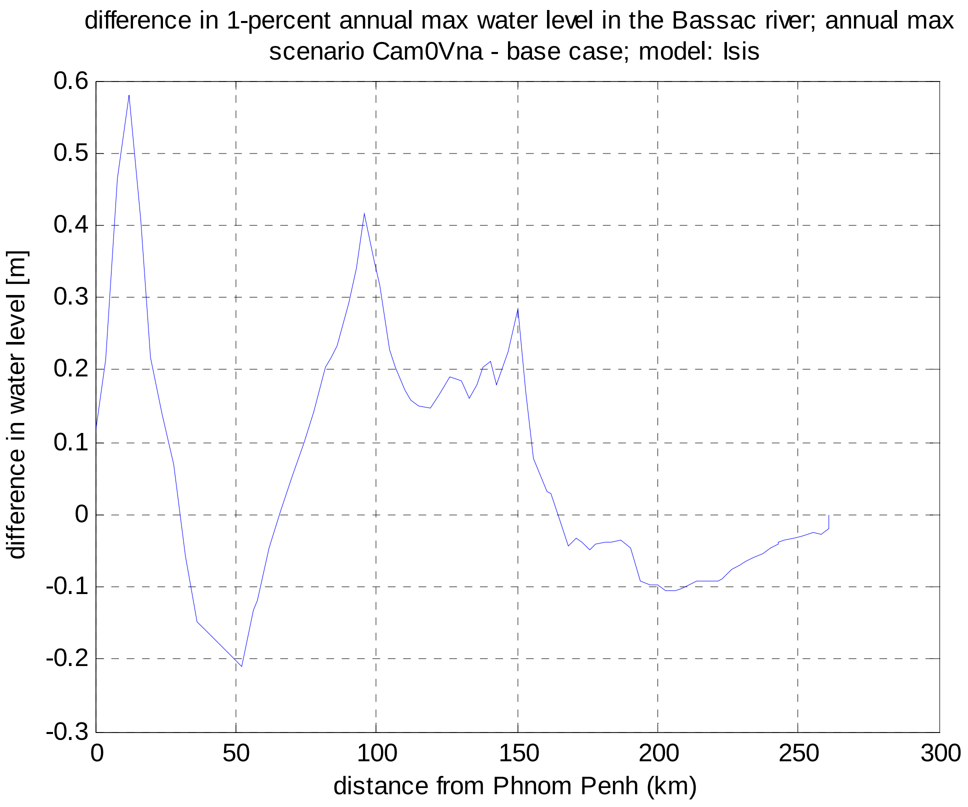


Figure 7.29 Increase in water level in the **Bassac** river downstream of Phnom Penh as a result of scenario **Cam0Vna**.

7.6 Scenario [6] – flood diversion to the Tonle Sap lake

In Cambodia the paddy is harvested before 1 August each year according to the crop calendar. In Vietnam the crop is harvested before the third week of August. When floods occur before the date of harvest it will create damage to the crop. Hence, if the floods can be limited till after the date of harvest up to the capacity of the Mekong and Bassac downstream of Phnom Penh, then benefits are generated for the farmers. In Scenario_4 this is achieved by diversion of flood water to the Tonle Sap for early flood control. Additional benefits of such option is generated for fish farming in the Lake as the Tonle Sap Lake level will be higher than normal. Furthermore, if the outflow from the Lake is controlled the water availability for the dry season increases, which provides options to reduce salinity problems in the delta.

The effectiveness of flow diversion to Tonle Sap from midway Kampong Cham-Phnom Penh to the Lake has been investigated for two variants:

1. a fully controlled diversion, and
2. an uncontrolled diversion.

For this a water balance model of the Mekong between Kampong Cham and Phnom Penh has been developed, including Tonle sap River and Lake and a diversion canal from the Mekong to the Lake, see Figure 7.30. In the controlled mode, the diversion is operated such that the flow downstream of Phnom Penh does not exceed the capacity of the rivers Mekong and Bassac, set to 30,000 m3/s. Limits are further set to the diversion capacity, and Tonle Sap River capacity (10,000 m3/s) and Tonle Sap Lake volume (85.86 BCM i.e. equivalent to a Lake level of 11.0 masl). The model is run for the 97 historical flood seasons, see Chapter 4.

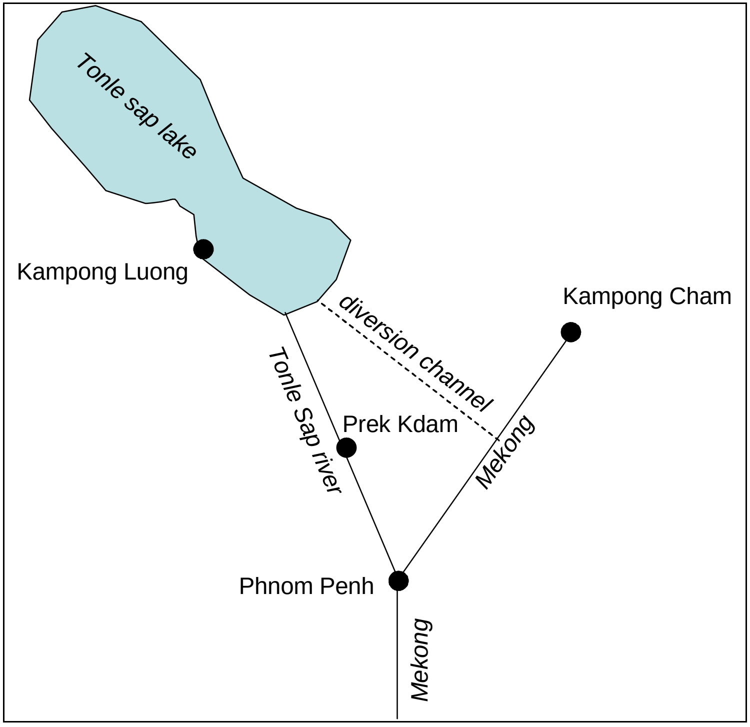


Figure 7.30 Structure of water balance model of Mekong and Tonle Sap

Controlled diversion

For the controlled diversion the effectiveness of the measure for different diversion capacities can be read from Figure 7.31.

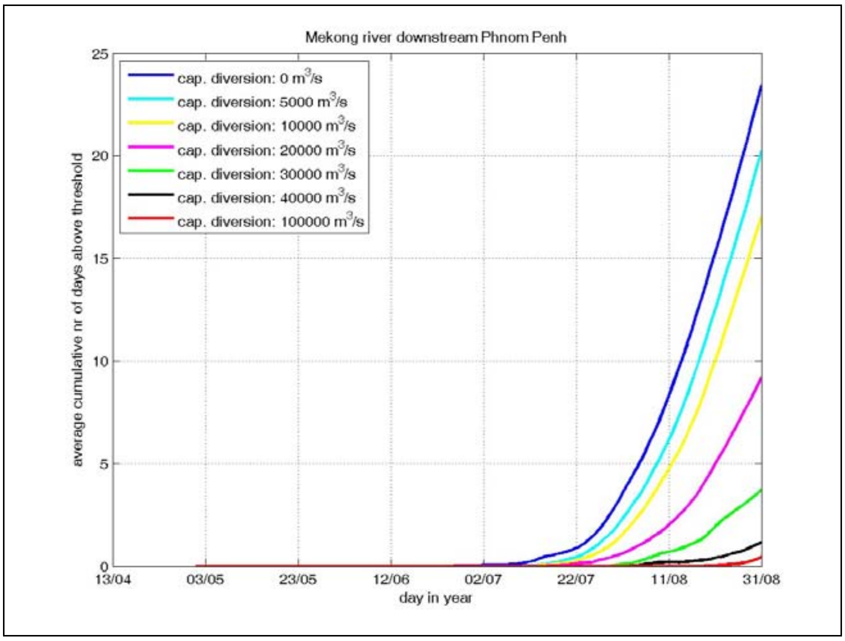


Figure 7.31 Average cumulative number of days (up to the date shown on the horizontal axis) in the simulated period 1910-2006 during which the flow downstream of Phnom Penh exceeded 30,000 m^3/s; depending on the available flow capacity of the diversion channel

The graph shows that under present conditions the number of days that flooding takes place downstream of Phnom Penh before 1 August is about 3 days on average each year. This would reduce to 1 day with a diversion canal with a capacity of 20,000 m^3/s. before the third week of August on average during 16 days flooding occurs, whereas with a diversion canal of the same capacity this would reduce to about 5. Figure 7.32 shows the mean wet surface area of the lake for different values of the flow capacity of the diversion channel. It shows the area increases with increasing capacity. Generally, an increase in the wet surface area has a positive effect on the fish population.

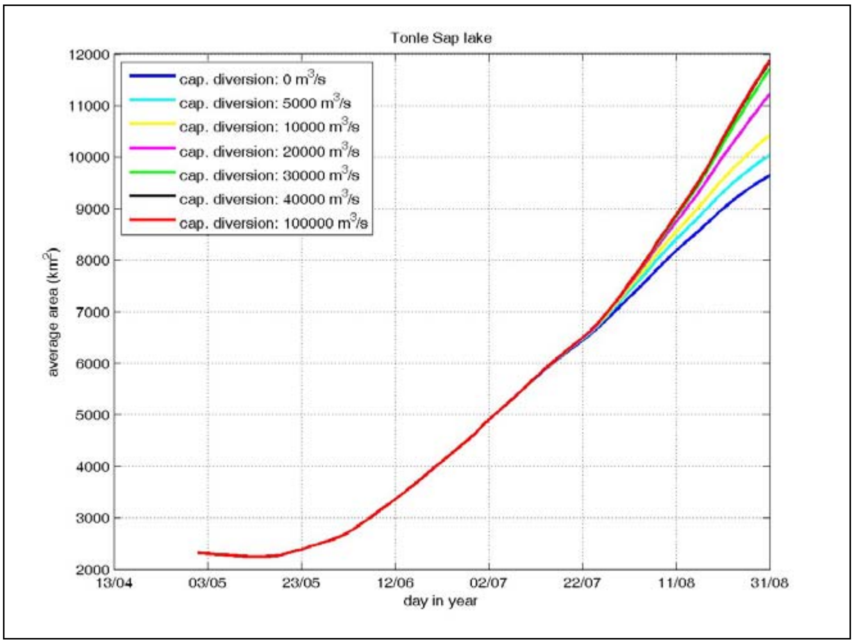


Figure 7.32 Mean wet surface area of the lake for different values of the flow capacity of the diversion.

Uncontrolled diversion

For the uncontrolled diversion a 2,500 m wide diversion canal is assumed with a weir at the off-take having a fixed level of 8.0 masl. The effectiveness of this measure seems to be limited as is observed from Figure 7.33 at first glance. However, this is mainly due to the fact that this option cannot control the flow downstream of Phnom Penh not to exceed exactly 30,000 m^3/s. The flood volume, though, will reduce substantially.

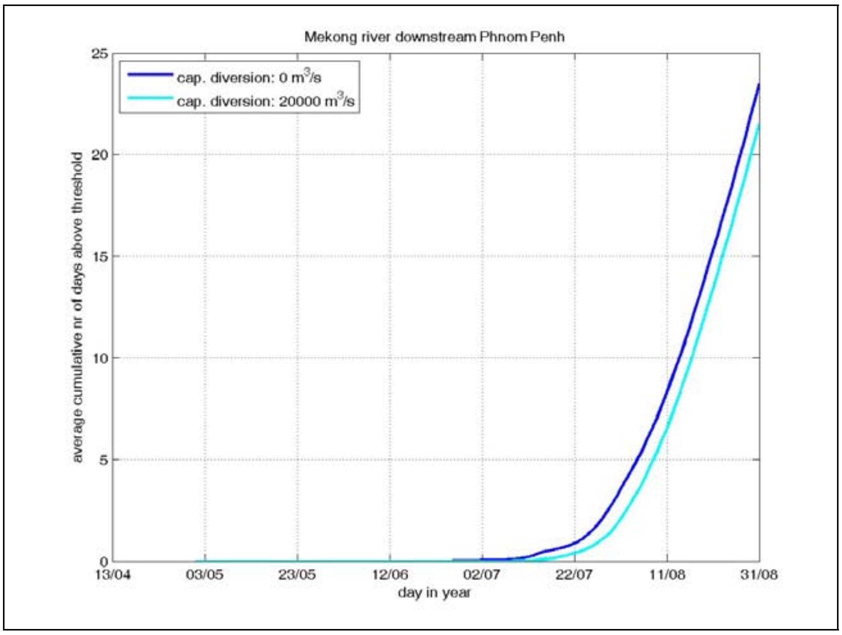


Figure 7.33 Average cumulative number of days (up to the date shown on the horizontal axis) in the simulated period 1910-2006 during which the flow downstream of Phnom Penh exceeded 30,000 m^3/s; depending on the available flow capacity of the diversion channel.

So the benefit of the uncontrolled channel can be found in the volume of water that fills the flood plain. This volume will be reduced each year the water flows into the diversion channel. For each year in the simulation period 1910-2006 the volume above the threshold of 30,000 m^3/s was derived. Figure 7.34 and Figure 7.35 show the frequency distributions of these volumes as derived on August 1st and August 21st each year. It shows that especially at August 1 there is a large percentage-wise reduction of flood volume, indicating that the diversion channel prevents significant areas of farmland from flooding before the end of the growing season.

The uncontrolled diversion has also been simulated with the hydraulic model for the same flood seasons as selected for the Scenarios_1 to 3. An unregulated diversion canal diverting Mekong water into the Lake from an off-take at Khchau village was implemented. It turned out the maximum flood water levels are only slightly reduced by this Scenario, as its function has finished before the peak passes. The reduction on the early flood levels is somewhat larger but still very limited. By blocking the early return flow from the Tonle Sap the diversion channel option can be made more effective.

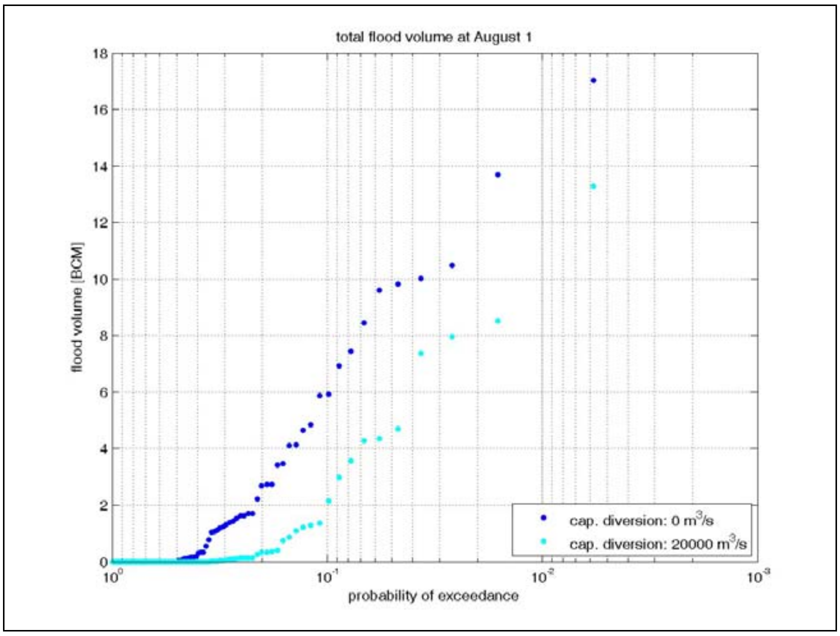


Figure 7.34 Frequency distribution of the total volume above a threshold of 30,000 m^3/s in the Mekong downstream of Phnom Penh until August 1, depending on the available flow capacity of the diversion channel.

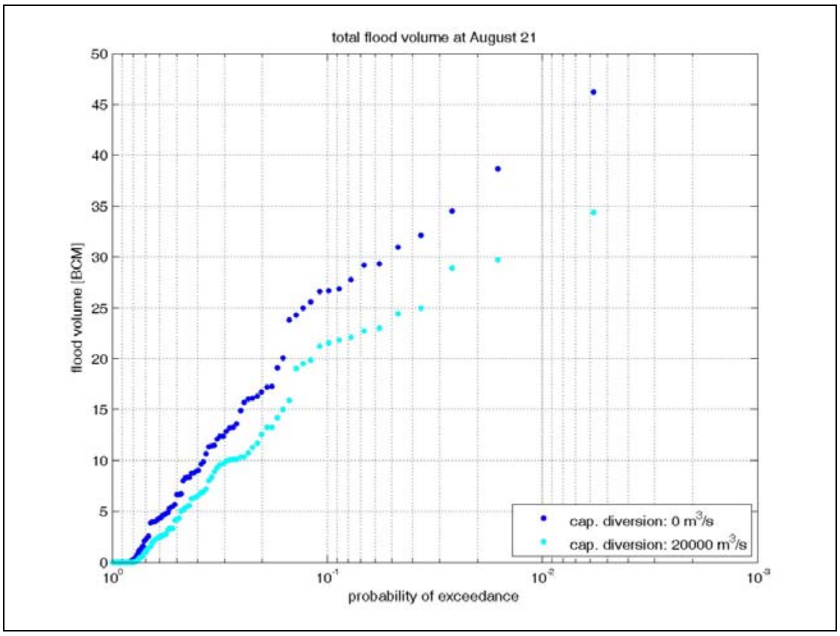


Figure 7.35 Frequency distribution of the total volume above a threshold of 30,000 m^3/s in the Mekong downstream of Phnom Penh until August 21, depending on the available flow capacity of the diversion channel.

7.7 Final remarks and recommendations

The use of the hydraulic model of the Mekong Delta ran for 97 historical flood seasons forms an excellent base for flood hazard assessment in the Mekong Delta to arrive at flood levels and related parameters of selected return periods. Since serial and cross-correlations between the influencing variables is fully taken into account use of complicated multi-variate distribution functions is avoided.

Based on the analyses it is strongly recommended to improve on the computational tools available at the MRC. The recalibration of the Mekong Delta hydraulic model is to be undertaken with priority including an extension of the computational network in the Focal Areas in Cambodia. Prior to the recalibration, during the 2010 flood season concurrent current meter and ADCP discharge measurements have to be made at Kratie to resolve in-homogeneities in the inflow series of the Mekong Delta.

The effects of the development alternatives are recommended to be repeated with the hydraulic model using the updated schematisation of the Focal Areas in Cambodia. Then also controlled diversion of flood water to the Tonle Sap, including an outflow control structure in the Tonle Sap River, to maximise the benefits of extra storage of water within the basin is recommended to be evaluated.

Finally, reference is made to the conclusions and recommendations given in the Appendices 6 to 11.

CHAPTER 8

SUMMARY

8 SUMMARY

Assessment of flood damage risks involves the estimation and linkage of flood hazards (probability of flooding) and flood vulnerability (extent of damage that can result from flooding). Flood hazard assessment involves analysis of the type of flooding, flood frequencies, duration, extent, inundation depths and flow velocities. The flood hazard (probability of high water levels) results from hydrological hazard (probability of high discharges/flood volumes), which is determined by the meteorological boundary conditions and the drainage characteristics of the watershed.

Representative areas, called Focal Areas, have been selected by the National Mekong Committees for demonstration of integrated flood risk management in the Lower Mekong Basin (LMB), covering various types of floods. This report comprises the assessment of the flood hazard and boundary conditions for river bank protections in the selected Focal Areas, which include:

1. Nam Mae Kok, flood hazard from tributary and combined floods
2. Bokeo, boundary conditions for river bank protections
3. Xe Bangfai, flood hazard from combined floods
4. Upper Se San, flood hazard from flash floods
5. Kratie, boundary conditions for river bank protections, and
6. Mekong Delta, i.e. flood hazard from delta flooding in:
   1.d West of Bassac: Takeo and Long Xuyen Quadrangle
   1.e East of Mekong: Prey Veng and Plain of Reeds.

Differences in characteristics and available series between the areas made it necessary that individual, i.e. “taylor-made”, methods for flood hazard assessment were developed and applied for each focal area. Despite the differences in approach, in general the following steps were executed for each area:

1. initial assessment of flood types in the area;
2. data collection;
3. data storage;
4. data validation;
5. data analysis to derive statistics of rainfall and flow characteristics;
6. set-up and application of a hydraulic model;
7. probabilistic flood frequency analysis in which the statistics of step 5 and the hydraulic model of step 6 are combined to derive statistics of water levels and water depths at (ungauged) locations of interest in the focal areas;
8. flood hazard mapping based on the results in step 7 for all locations

Steps 6-8 were generally repeated a couple of times to assess the effect of potential measures on probabilities of flooding. Each potential measure is implemented in the hydraulic model to quantify the effect of this measure on water levels and water depths. Combined with damage analysis (as described in Volume 2C and Volume 3A) this enables the direct comparison between the cost of a certain measure and the benefit in terms of reduced expected annual flood damage. Measures can then be ranked in terms of cost-effectiveness.

The quality of the results of the above described flood hazard analysis depend to a large extent on the quality of the hydraulic models. Unfortunately, the hydraulic models for the selected areas had the tendency to produce biased results, i.e. results that are on average significantly higher or lower than observed discharges. This makes that these models are acceptable for demonstration purposes but unsuitable for planning or design.

CHAPTER 9

REFERENCES

9 REFERENCES

Adamson, P.T. (2007). An assessment of the Statistical Nature of the IBFM Flow Seasons and Indicators and their Potential Vulnerability to Regional Water Resources Development.
Draft Final Report Integrated Basin Flow Management, MRC

Adamason, P.T. (2007). Strengthening of the Flood Management Capacity for 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-areas 1 to 10. MRC (June 2006)

Beecham, R and H. Cross (2005). Modelled Impacts of Scoping Development Scenarios in the Lower Mekong Basin. MRC, May 2005

CTI & DHI (2003). Consolidation of Hydro-meteorological data and multifunctional hydrologic roles of Tonle Sap Lake and its vicinities (Basinwide). Main Report. MRC, March 2003

EGAT (2007). Design data of reservoirs in Mun-Chi basin. EGAT, Bangkok

Forsius, J. (2007). Monitoring the reverse flow at Prek Kdam. MRC

Halcrow (2001). Water Utilisation Project Component A: Development of Basin Modelling Package and Knowledge Base (WUP-A). Working Paper No 1-Hydrological Review, MRC

JICA (2004). The study on Hydro-Meteorological Monitoring for water Quantity Rules in Mekong River Basin. Volume-I, Main Report and annexes. CTI Engineering International Co., Ltd. and Nippon Koei., Ltd

MRC (2005). Hydrological, Environmental and Socio-Economic Modelling Tools for the Lower Mekong Basin Impact Assessment. Water Utilisation Programme. WUP-FIN Phase II; Working Paper No 8-Chaktomuk model application

MRC (2005). Overview of the Hydrology of the Mekong Basin. Mekong river Commission, November 2005

MRC (2006). Framework for the Development of Best Practice IFRM Guidelines for BDP. Volume 2: Backgound Information. Draft 7. 4 May 2006

MRC (2006). Annual Flood Report 2005. Flood Management and Mitigation Programme, July 2006

MRC (2007). Annual Mekong Flood Report 2006. Mekong River Commission, March 2007

MRC (2009a). Guidelines for flood risk assessment. Mekong River Commission, April 2007

NORPLAN (2004). Cumulative Impact Analysis and Nam Theun II Contributions. Final Report to ADB and the Government of Lao PDR.

Ogink H.J.M. (2005). Hydrologic modelling for the Cau basin. 2nd RRBSP, Hanoi (2005)

Sweco/Groner (2006). Environmental Impact Assessment on the Cambodian part of the Se San River, due to hydropower development in Vietnam. Electricity of Vietnam.

WUP-FIN (2003). Modelling Tonle Sap for Environmental Impact Assessment and Management Support. MRCS/WUP-FIN Project Report

VNMC (2007). Report on Identification of Transboundary Flood Issues at National Level in Cuu Long Delta. Prepared by Pham Xuan Phuong