THE MEKONG RIVER COMMISSION SECRETARIAT

Hydrological and Flood Hazards in the Lower Mekong Basin

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

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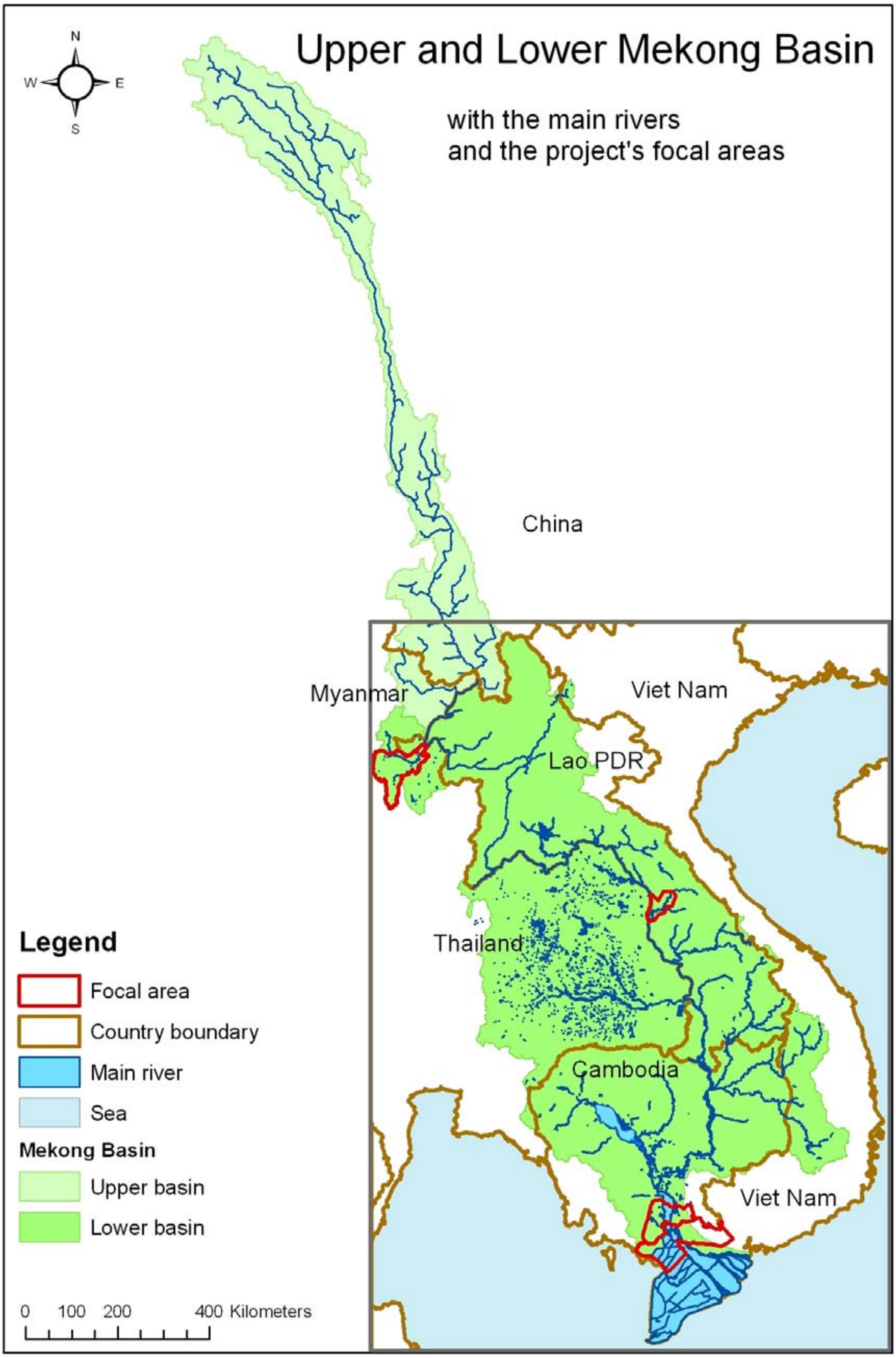
Upper and Lower Mekong Basin
with the main rivers
and the project's focal areas
N
W
E
S
China
Myanmar
Viet Nam
Lao PDR
Thailand
Cambodia
Viet Nam
Legend
Focal area
Country boundary
Main river
Sea
Mekong Basin
Upper basin
Lower basin
0 100 200 400 Kilometers

GLOSSARY

Damage curve	The functional relation between inundation characteristics (depth, duration, flow velocity) and damage for a certain category of elements at risk.
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 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.

ADCP	Acoustic Doppler Current Profiler (Acoustic Doppler Profiler); instrument to measure how fast water is moving across an entire water column
ARF	Area Reduction Factor (hydrology)
BCM	Billion Cubic Meters
BDP	Basin Development Planning
BPG	Best Practise Guidelines
CBA	Cost Benefit Analysis
d/s	downstream
DACA	Damage and Casualties Assessment project for the Lower Mekong Basin based on HIS-SSM
DEM	Digital Elevation Model (see also DTM)
DSF	Decision Support Framework
DTM	Digital Terrain Model (see also DEM)
EC	European Commission
EU	European Union
EV1	Extreme Value type 1 distribution (hydrology)
EXCIMAP	European Exchange Circle on Flood Mapping
FEMA	Federal Emergency Management Agency
FHA	Flood Hazard Assessment
FMM	Flood Management and Mitigation
FMMP-C2	Flood Management and Mitigation Programme, Component 2
FN curve	Curves relating the probability per year of causing N or more fatalities (F) to N
FRA	Flood Risk Assessment
FV	Future Value (economic analysis)

GEV	Generalised Extreme Value distribution (hydrology)
GIS	Geographic Information System
HAZUS	Software for risk assessment analysis of potential losses from floods, hurricane winds and earthquakes (by FEMA)
HH	Household(s)
HIS-SSM	Hydrological Information System - damages and casualties assessment module
HYMOS	Information system for water resources management
IDW	Inverse Distance Weighting method: an interpolation method to obtain a continuous GIS-raster on the basis of data points (nodes), assigning most weight to nearby points by using their distance to the point to calculate(see also NN)
IFRM	Integrated Flood Risk Management
ISIS	Hydrodynamic simulator for modelling flows and levels in open channels and estuaries
IUH	Instantaneous Unit Hydrograph (hydrology)
JICA	Japan International Cooperation Agency
LMB	Lower Mekong Basin
LMD	Lower Mekong Delta
LXQ	Long Xuyen Quadrangle (Vietnam)
MCM	Million Cubic Meters
MRC(S)	Mekong River Commission (Secretariat)
MSL	Mean sea level, the average (mean) height of the sea, with reference to a suitable reference surface
NN	Natural Neighbours method: an interpolation method to obtain a continuous GIS-raster on the basis of data points (nodes), assigning most weight to nearby points by calculating overlapping areas in Voronoi/ Thiessen polygons (see also IDW)
NPV	Net Present Value (economic analysis)
PDR (Lao)	(Lao) People’s Democratic Republic
PoR	Plain of Reeds (Vietnam)
PV	Present Value (economic analysis)
RFMMP	Regional Flood Management and Mitigation Programme
RID	Royal Department of Irrigation
RR	Rainfall Ratio (hydrology)
SBF	Se Bang Fai (Lao PDR)
SCS-CN	Soil Conservation Service (USA) Curve Number method (hydrology)
SWAT	River basin scale model quantifying the impact of land management practices in large, complex watersheds
TCEV	Two Component Extreme Value (hydrology)
u/s	upstream
UH	Unit Hydrograph (hydrology)
UK	United Kingdom
UNESCO-IHE	Institute for Water Education (IHE) of the United Nations Educational, Scientific and Cultural Organization
USA	United States of America
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 3A** of the above series.

[1] Developed by the Delft Cluster

1.2 Hydrological and Flood Hazards in the Lower Mekong Basin

The Terms of Reference of the FMMP-C2 project call among others for an assessment of flood damage risks in the Lower Mekong Basin (LMB). This involves (see Figure 1.1):

- assessment of flood hazards in the LMB Sub-Areas, i.e. type of flooding, frequencies, duration, inundation depths, flow velocities, etc.
- assessment of flood vulnerability in the LMB Sub-Areas, i.e. the extent of damage that can result from floods, and
- assessment of flood damage risk, i.e. the link between the extent of damage and the probability of occurrence of a flood event.

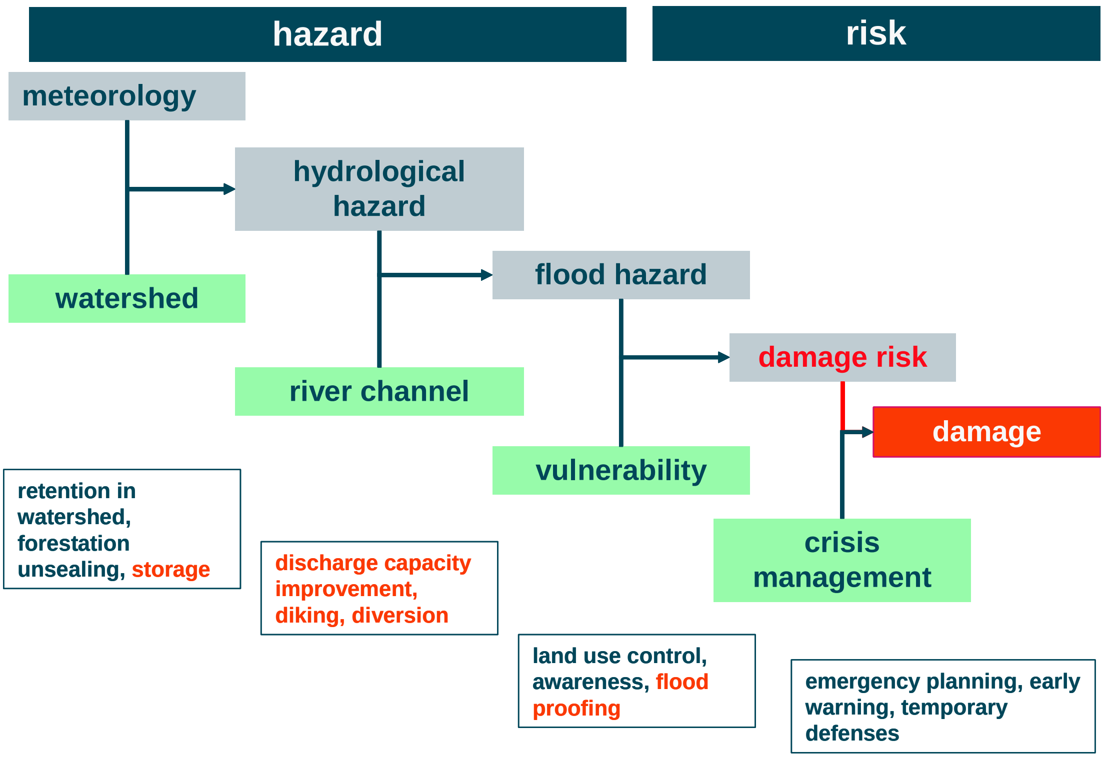

Figure 1.1 Structured damage risk assessment and effective measures.

Flood hazards (probability of high water levels) result from hydrological hazards (probability of high discharges), which are determined by the meteorological boundary conditions and the drainage characteristics of the watershed. To tranform hydrological hazards into flood hazards the discharge hydrograph is to be translated into a water level hydrograph. The flood volume also plays a role as this affects the duration of flooding. Measures to reduce the hydrological hazard include creation of extra retention in the upper reaches of the basin, reservoirs, forestation, improvement of the infiltration capacity and flow diversion. The flood hazard can be reduced by increasing the conveyance capacity of the river/canal or by diking.

In this report the character and nature of flooding in the different LMB sub-areas is given and an overview is made of available flood data in the LMB regarding hydrological and flood hazards. Recent studies and investigations regarding the hydrology of the Mekong basin have been reviewed. The final objective of this document is to propose for each sub-area and type of flood a procedure to determine the hydrological and flood hazard with the means available.

The structure of this document is as follows. In Chapter 2 a short overview is given of the climatic and hydrological conditions is given, followed by the distinguished types of floods in the analysis per sub-basin. The review of the hydrological and flood hazard in the sub-areas is presented in the Chapter 4 to 13 and includes the following elements:

- basin description;
- hydro-meteorological data availability in the HYMOS database of MRC, including rainfall, water level and discharge data;
- rainfall and runoff characteristics of the tributaries and main stream in the sub-area
- developments in the sub-area that may affect the flow regime
- tributary, main stream and combined floods in the sub-area and means to determine the hydrological and flood hazards.

In Chapter 14 an overview is presented of the stage-discharge data of the streamflow stations available in the MRC HYMOS database. The conclusions of the analyses per sub-area is presented in Chapter 0, and using these conclusions a procedure is proposed in Chapter 16 to implement the hydrological and flood hazard mapping per sub-area.

The ten sub-areas of the lower Mekong Basin are presented in Figure 1.2. This division is in accordance with the areas defined for the Basin Development Plan of MRC, (BDP, 2006).

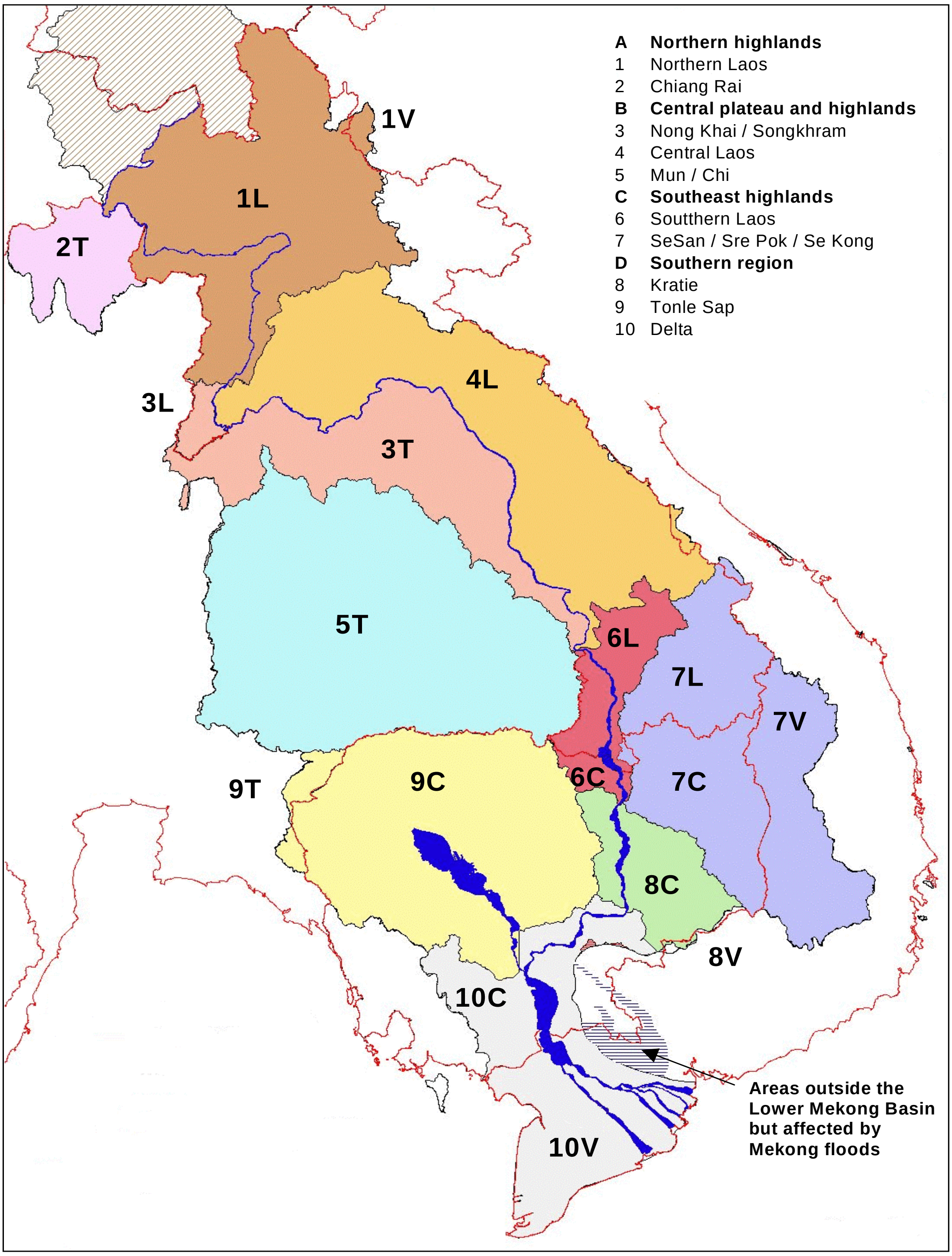

Figure 1.2 Overview of sub-areas in the Lower Mekong Basin.

CHAPTER 2

HYDROLOGICAL CHARACTERISTICS OF THE MEKONG BASIN

2 HYDROLOGICAL CHARACTERISTICS OF THE MEKONG BASIN

2.1 General

In this chapter a summary is given of the hydrological characteristics of the Mekong Basin as far as relevant for providing background information to the description of the character and nature of flooding. For detailed descriptions reference is made to MRC (2005) and the 2005 and 2006 Annual flood reports (MRC, 2006 and 2007).

2.2 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 arounf 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, 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 Floodplains of Cambodia and the Cuu Long Delta in Vietnam, which covers the Mekong, Bassac and their flood plains.

The hydraulic infrastructure in the basin and land use is presented in detail in the Chapters 4 to 13.

2.3 Hydro-meteorological monitoring network

The hydro-meteorological monitoring network in the Lower Mekong basin is dealt with in the Chapters 4 to 13 for each of the sub-areas separately. An overview of the main stations and their location along the Mekong and the outflow of the major tributaries is presented as reference in Table 2.1.

Table 2.1 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			

2.4 Climatic conditions

The climate in the Mekong basin is described in an 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 monsoons, the Southwest Monsoon, which brings rains in the period from May till September-October. During the Northeast Monsoon when the winds blow from China mainland temperatures drop and rainfal becomes low. For the floods the Southwest Monsoon is of importance as well as the occurrence of tropical cycloons, which landfall in the period from June to December, where the occurrence in the upper LMB is predominatly in the beginnning of the cycloon 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. The mean annual rainfall in the LMB is presented in Figure 2.2.

It is observed that from west to east the rainfall increases from about 1100 mm to some 2500 mm due to orographical effects as the Laotian mountains lift the moist air masses entering from the southwest. The monthly distribution of the rainfall follows closely the monsoons, with rainfall mainly from May to September in the North, and May to October in the South.

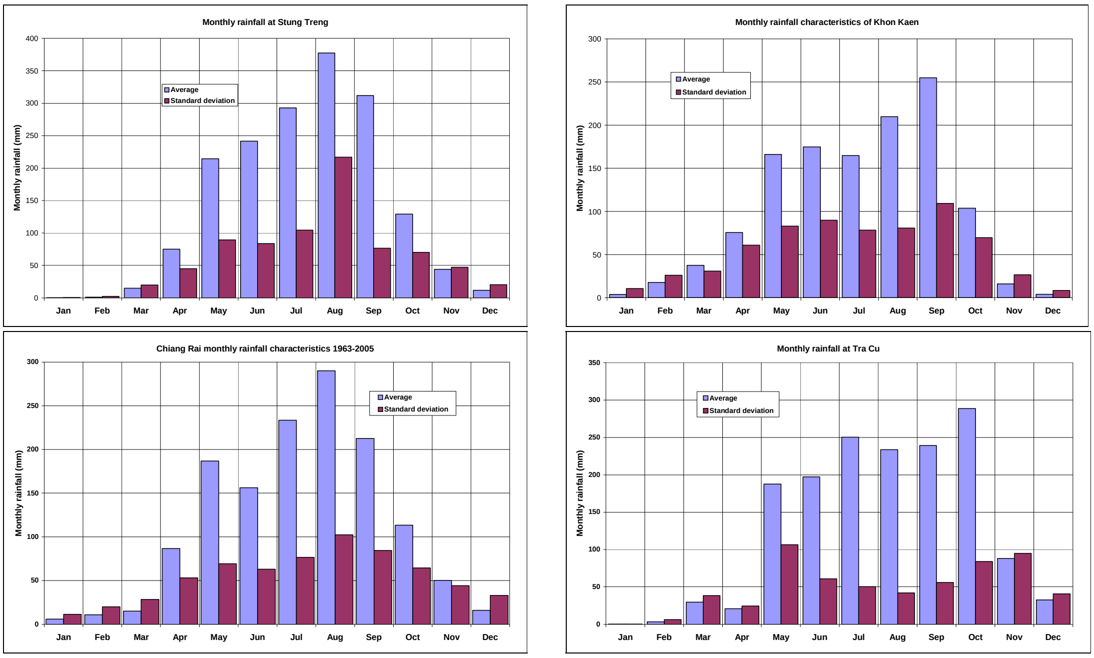

Figure 2.1 Monthly rainfall characteristics of Chiang Rai (SA2), Khon Kaen (SA5), Stung Treng (SA8) and Tra Cu (SA10).

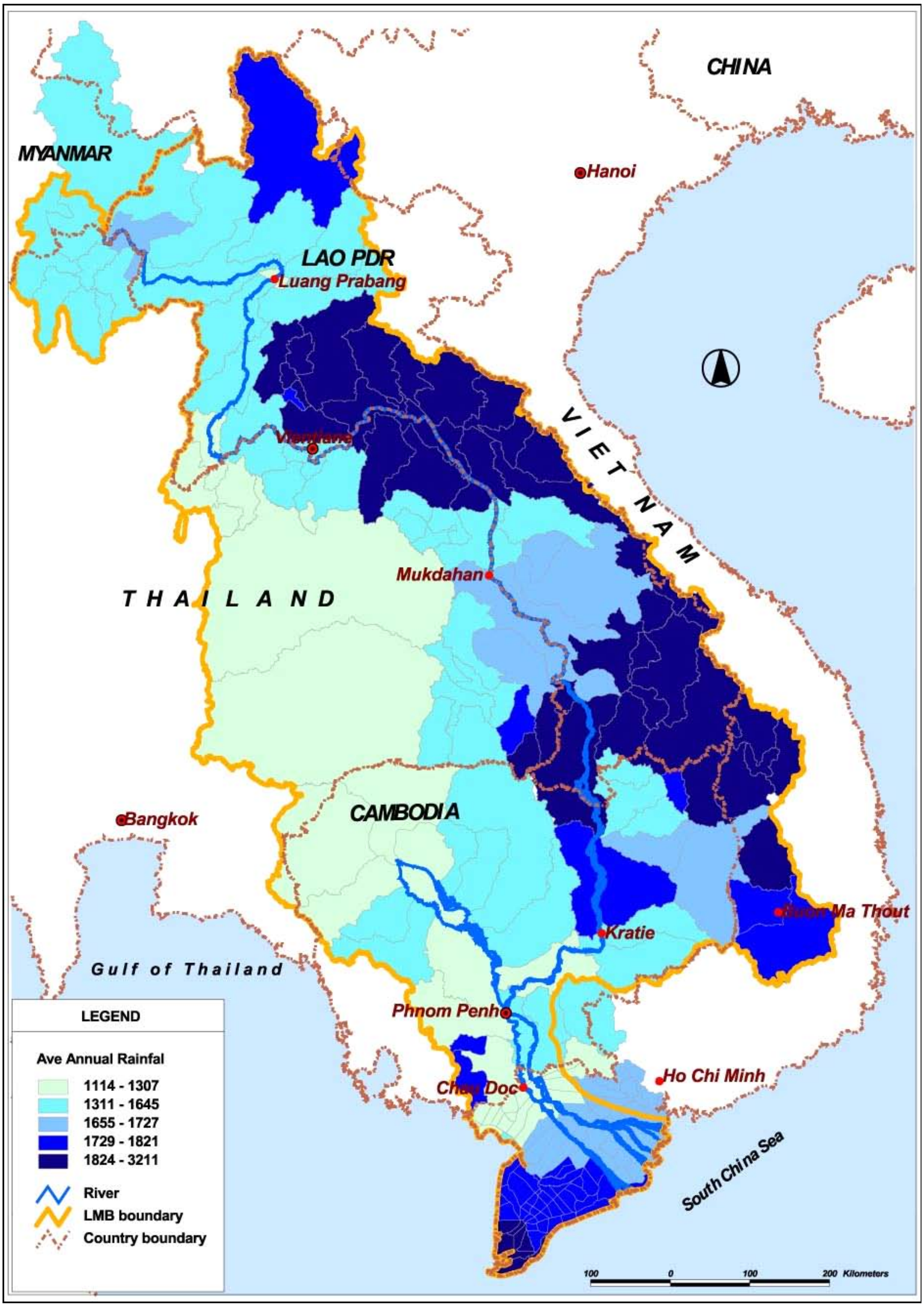

Figure 2.2 Mean annual rainfall in LMB (BDP, 2006).

2.5 River flows

The annual river flows at key locations along the Mekong river are presented in Figure 2.3. It is observed that the annual 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.

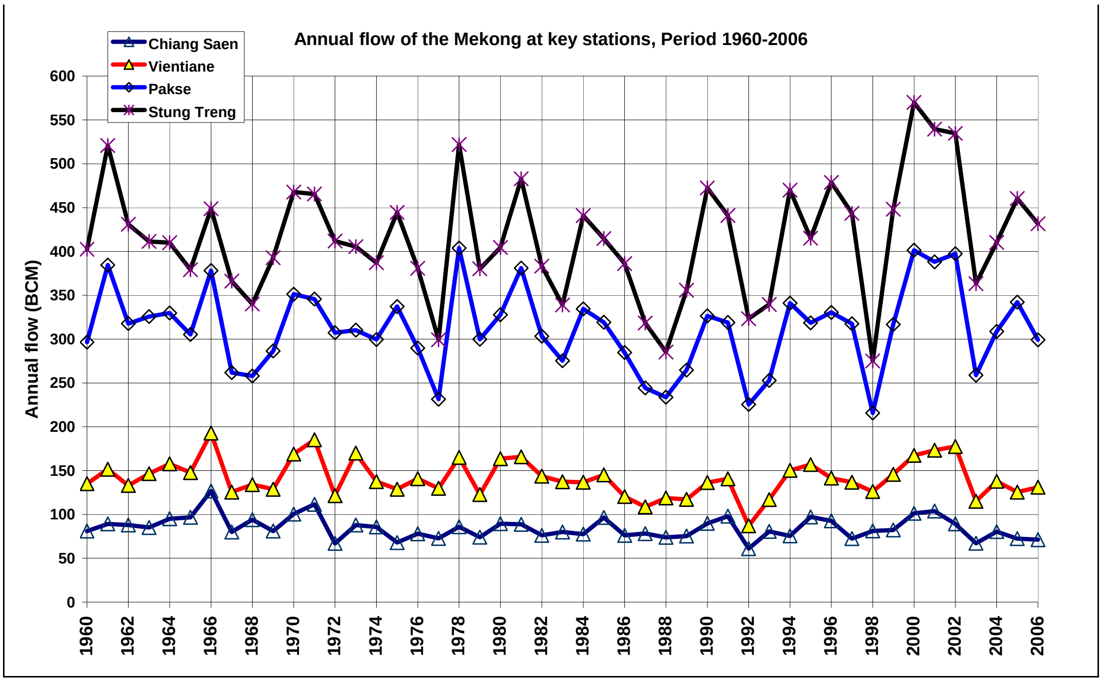

Figure 2.3 Annual flow of the Mekong at key stations, Period 19560-2006.

The seasonal variation of the flow is presented in Figure 2.4. 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, which is important in the upper reaches of the LMB, but its importance gradually diminishes further downstream.

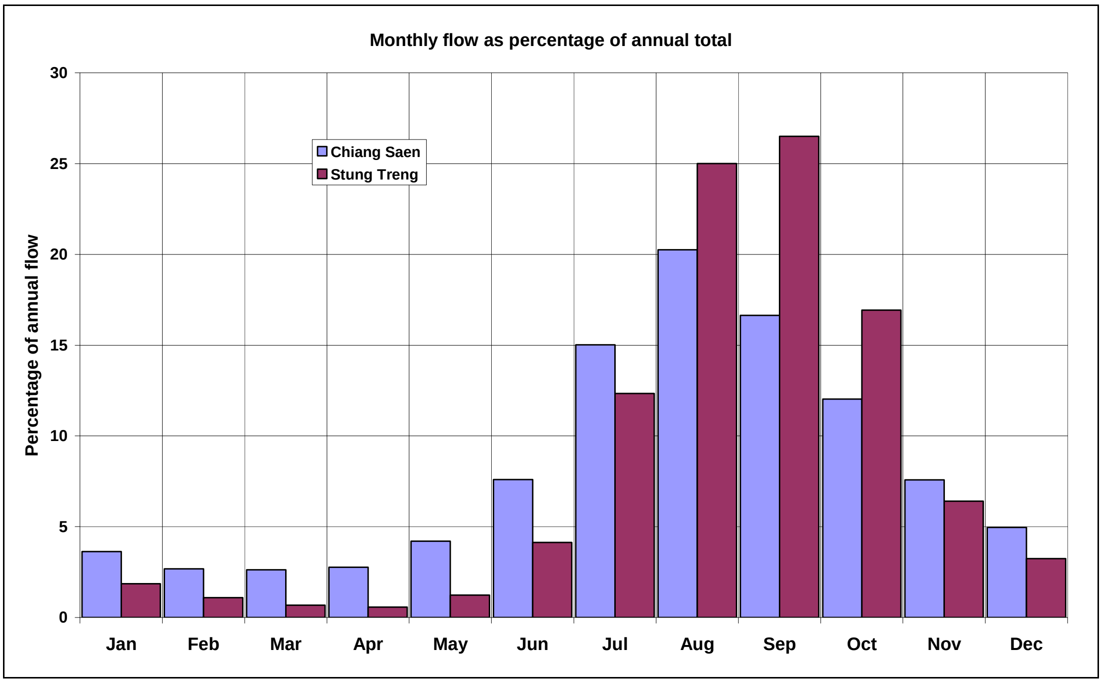

Figure 2.4 Monthly flows at Chiang Saen and at Stung Treng as percentage of annual total.

This may be observed from the contributions of the various Mekong reaches to the flow at Stung Treng, depicted in relative and absolute sense in Figure 2.5 and Figure 2.6.

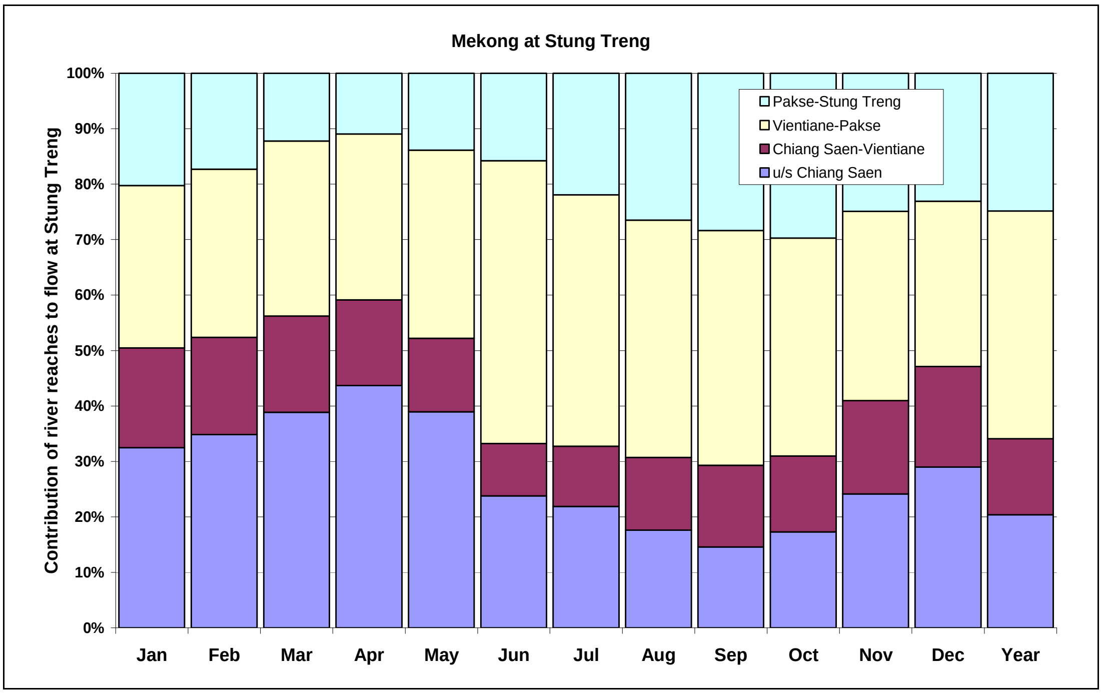

Figure 2.5 Relative weight of contributions of river reaches to the flow at Stung Treng.

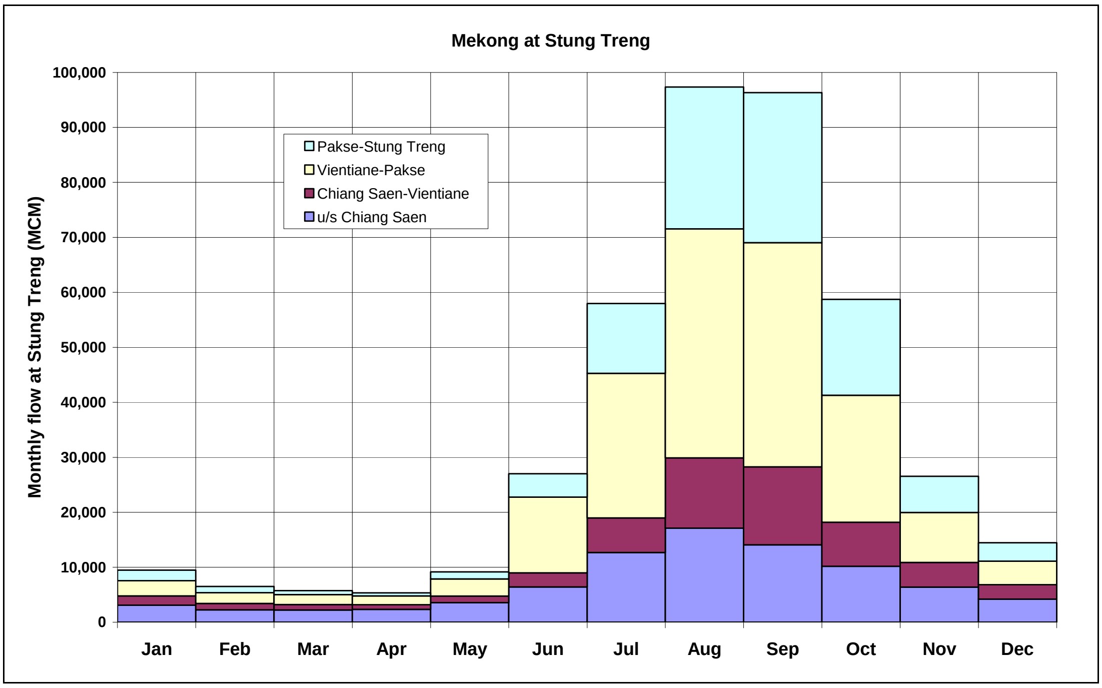

Figure 2.6 Contribution of river reaches to the flow at Stung Treng.

From above figure 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.

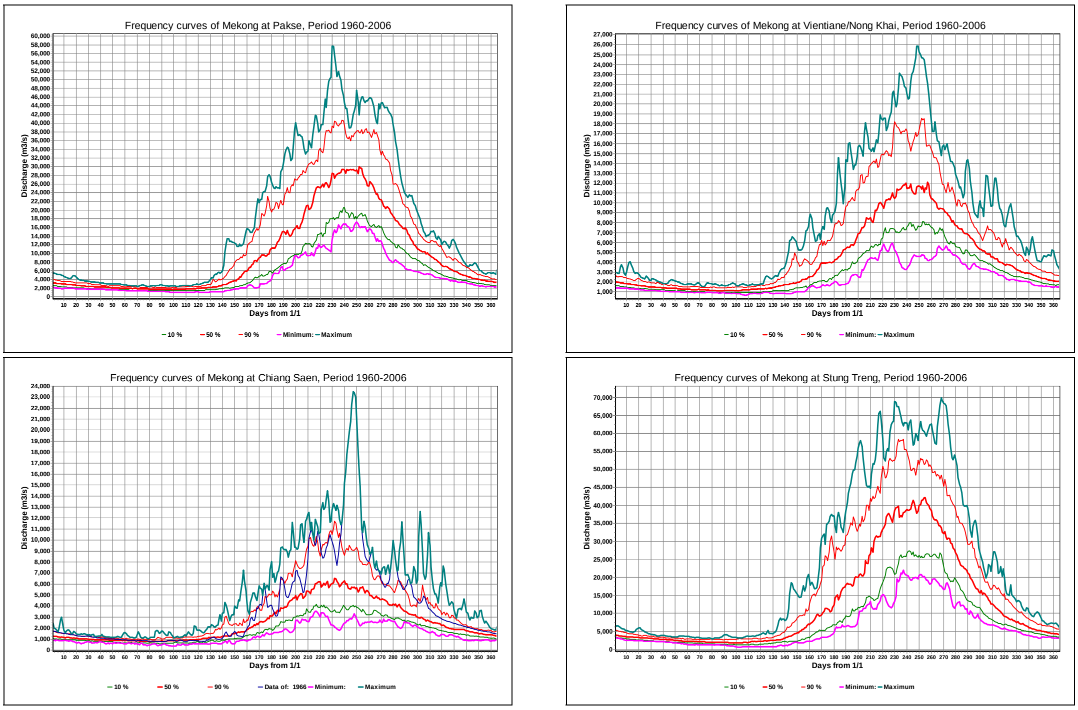

Figure 2.7 Frequency curves of daily flows for the Mekong at Chiang Saen, Vientiane, Pakse and Stung Treng.

The development of the flow along the river, the variation through the year and the occurrence of floods can be read from **Error! Reference source not found.**. It is observed that the period in which extreme flows may occur gradually increases, also due to the fact that peak rainfall shifts from July-August in the north to September-October in the south.

The distributions of annual maximum discharges of key stations on the Mekong are presented in Figure 2.8. The 100-year flood is seen to increase from 20,000 m3/s at Chiang Saen to almost 80,000 m3/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. Besides level and extent also the duration of the flood is of importance for damage estimation. The exceedance duration is beside of flood discharge also a function of the flood volume, which is defined for the Mekong as the flow volume between 1 June and 30 November. The flood as characterised by peak discharge and volume have been modelled by Adamson, P.T. (see MRC, 2005) by a joint distribution. An example is given in Figure 2.9 for Vientiane. It is observed that for the same peak discharge the flood volume can vary considerably.

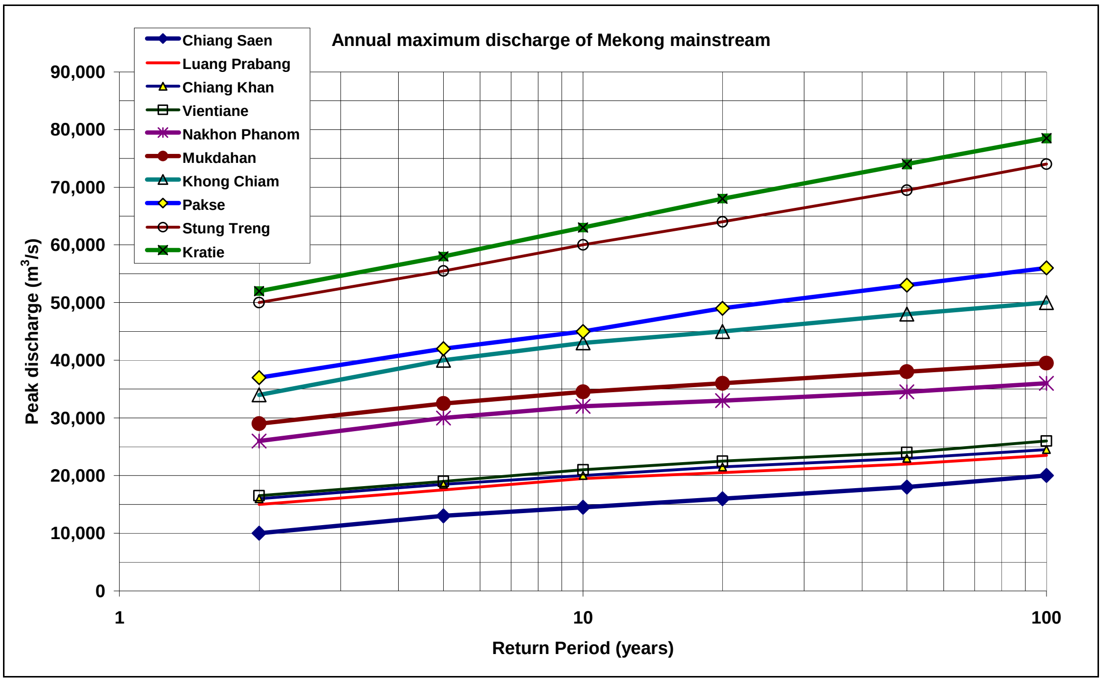

Figure 2.8 Distribution of annual maximum discharge of Mekong at key stations.

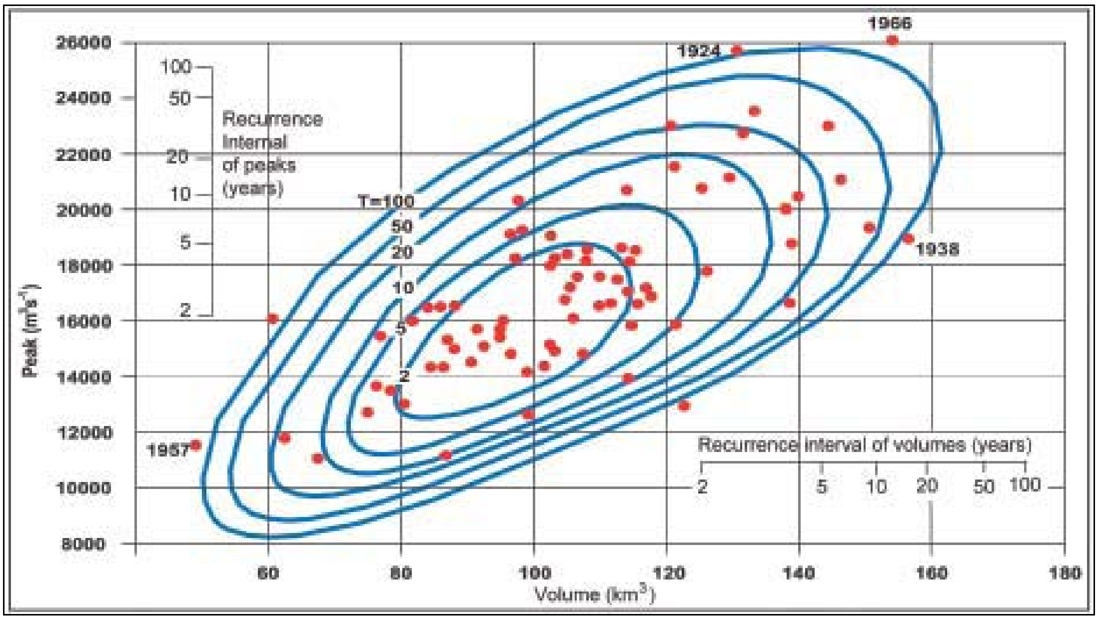

Figure 2.9 Joint statistical distribution of the peak and volume of the annual flood hydrograph on the Mekong at Vientiane (MRC, 2005).

2.6 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.

Hydropower development

The existing effective storage capacity of man made reservoirs in the Mekong basin is about 11 BCM. Large scale hydropower development is planned on the Mekong mainstream in China, 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 2.2. The size of the developments vary from one publication to another. Our data is based on consultation visits to the relevant ministries in the LMB-countries, see next chapters. Other recent sources are NORPLAN (2004) and Beecham and Cross (2005). 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 of developments on floods have been investigated by Beecham and Cross (2005) and Adamson (2007). In the former study the effect of the Chinese dams and various development scenarios have been investigated. Some results are presented in Figure 2.10. From this it is observed that the Chinese dams (assumed active storage 28.5 BCM) have a high potential to reduce flood peaks in the upper part of the LMB. The effect, 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 1 to 2 dm, but for the extreme flood of the year 2000 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. It is noted, however, that these effects required an active storage capacity equal to roughly the annual amount of Mekong flood volume stored temporarily in the Tonle Sap. Hence, retention as a flood mitigating measure for the delta is not a realistic option.

Table 2.2 Existing and planned reservoir capacity in Mekong basin (various sources) and effect on mean annual maximum.

Section	**Mean annual flow (BCM)**	**Total (BCM)**	**Existing and planned reservoir capacity (BCM)**	**MAF-red (%) China dams**	**MAF-red (%) China dams + LMB**
u/s Chiang Saen	84.5	84.5	32.2 (active)	-28	-28
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	-5	-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	0	-18
Total	457.3	457.3	98.0 + 35.55 (active)		

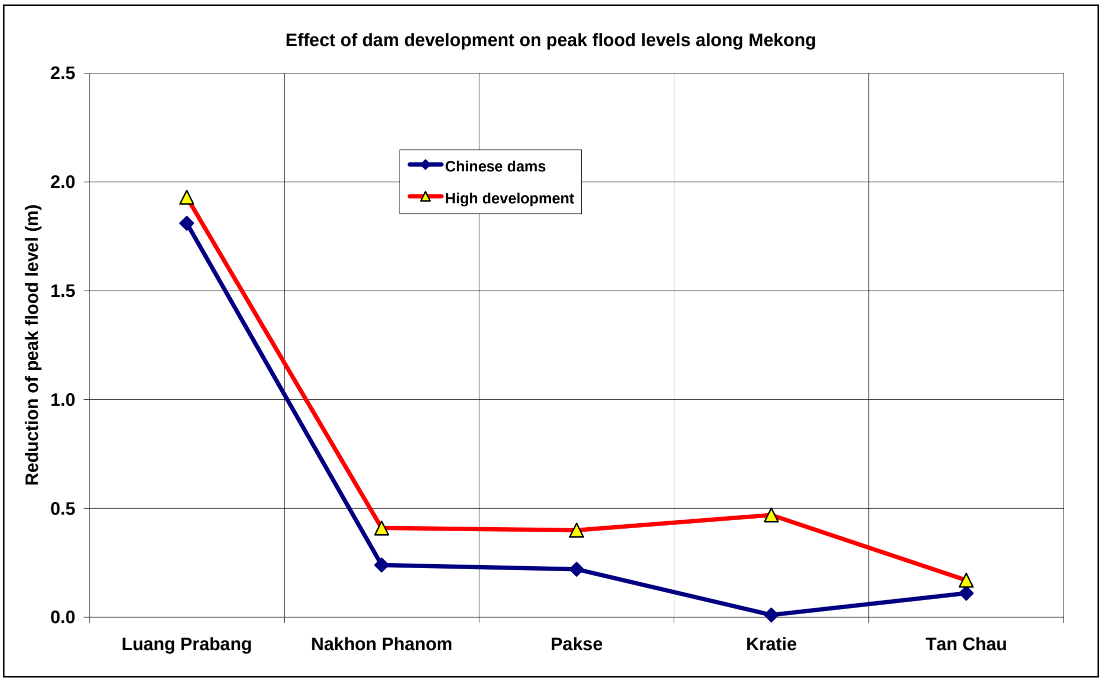

Figure 2.10 Effect of development scenarios on peak flood levels at selected locations along the Mekong River.

Some results of the study by Adamson (2007) have been presented in the last two columns of Table 2.2. It shows the reduction of the mean annual maximum flood for 20 % regulation (degree of regulation refers to the percentage flood season flows that are reallocated to the dry season) of the Chinese dams alone (32.2 BCM) and in combination with a high development of hydropower in the LMB (25.7 BCM). Similar trends as presented in Figure 2.10 are observed.

It is noted that the results should be considered as indicative as neither the reservoir operation rules for the planned dams are known nor the actual implementation. Nevertheless, the 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.

Land use changes

The effect of land use changes in the Mekong basin on the 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 is found on any systematic change in frequency and magnitude of the annual flood or hydrological conditions in general. In MRC (2006) results of a study by Cluis are presented for annual average monthly flows and annual maximum monthly flows at Mukdahan for the perod 1925-1991. Here a monotonic decrease was found, but the outcome is questioned as this may have been due to errors in the rating curves.

Climate change

Also changes in the rainfall climate from the fifties till present has been investigated by Adamson (2007). Based on analysis of the annual maximum 1 and 10 day storm rainfall for 5 locations in the upper reach of the LMB it is concluded that there is no evidence that the incidence of extreme storms has 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. It is not clear whether this statement is valid for peaks over threshold as well, also in line with the finding in the previous pragraph.

In the same study by Adamson (2007) regional floods have been analysed. Here the conclusion is made that there is sufficient evidence 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/LaNina 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 iinfluence of climate change on the flooding regimes of the Mekong is very uncertain. Regarding sea level rise there is concensus: the level will rise with some 2 to 5 dm in the next century (IPCC, 2007).

CHAPTER 3

CLASSIFICATION OF FLOODS IN THE LOWER MEKONG BASIN

3 CLASSIFICATION OF FLOODS IN THE LOWER MEKONG BASIN

3.1 General

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

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

In the (draft) document “Framework for the Development of Best Practice Guidelines for BDP”, Volume 2: “Background Information” another classification is given, which reads:

1. Mainstrean Floods
2. Tributary Floods
3. Local Floods
4. Dam Release Floods
5. Dambreak Floods
6. Storm Surge Floods, and
7. Tsunami Floods

It is noted that only the mainstream and tributary floods are equivalent to the above typology. Local floods and tributary floods do not differ much. Both result from heavy rainfall resulting in flows exceeding the drainage capacity and do not require extra attention. Dam release floods do not require structural measures, but need an appropriate flow release procedure, with advance warning in case of excessive discharges to avoid calamities as with Yali dam releases. Dambreak floods computations are standard procedures in dam design and if measures are required this will be part of the design. Storm surge floods are caused by typhoons and set up the water levels near the coast. These are implicitly included in the boundary conditions for defining floods in the Mekong Delta, and do not require special attention. Tsunami Floods require advance warning, which is not part of structural measures as envisaged to be developed under this Project. The first classification as presented in the Annual Flood Report 2005 (MRC, 2006) can shown to be sufficient to describe the natural floods in the LMB for which structural measures can be designed to reduce hydrological or flood hazards.

3.2 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 land slides, 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.

3.3 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.

3.4 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 are not flashy; they may stay for weeks. In view of the shallow areas along the Mekong downstream of Vientiane a lare 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).

3.5 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 existance and dimensions of embankments. Flow diversion and diking are options to reduce the hydrological and flood hazard.

3.6 Flood in the Mekong delta

The flood in the Mekong delta deals with the conveyance of flood water 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.

CHAPTER 4 TO 13

HYDROLOGICAL AND FLOOD HAZARDS IN THE SUB-AREAS

4 HYDROLOGICAL AND FLOOD HAZARDS IN SUB-AREA 1

4.1 Basin characteristics

Sub-area 1 (SA1), see Figure 4.1, covers the mountainous areas of northern Laos and Vietnam draining to the Mekong between the Chinese border some 210 km upstream of Chiang Saen to the mouth of the Nam Nhiam, just upstream of Chiang Khan. The right bank tributaries of the Mekong draining the area in Thailand around Chiang Saen and Chiang Rai are included in Sub-area 2.

SA1 measures 80,469 km^2 of which 1,396 km^2 is located in Vietnam. The major rivers in the sub-area (> 1,000 km^2), all left bank tributaries of the Mekong draining between Chiang Saen (rkm 2,363) and Luang Prabang (rkm 2,010), include from upstream to downstream:

- Nam Tha (drainage area 8,690 km^2, mouth at rkm 2,271),
- Nam Beng (drainage area 2,500 km^2, mouth at rkm 2,169),
- Nam Ou (drainage area 25,810 km^2, mouth at 2,035), covering also the Vietnamese contribution of the Nam Yom and Nam Nua, draining the area around Dien Bien Phu),
- Nam Suong (drainage area 6,670 km^2, mouth at rkm 2,025), and
- Nam Khan (drainage area 7,400 km^2, mouth at rkm 2,011).

Some 90 % of SA1 is hilly and mountainous with elevations mostly between 500 and 2,500 masl (see Figure 4.2) and a highest peak of 2,819 masl.

The basin areas are characterised by steep inclines and narrow river valleys, running predominatly SW. From Figure 4.3 it is observed that the slopes vary mainly between 10-30% though near the divides steeper slopes are observed. Only in the lower reaches of the Nam Ou and around the Mekong river the 500 m countour is not exceeded; the Mekong in SA1 runs at an elevation between 400 and 200 masl.

The land cover of SA1 is presented in Figure 4.4. Forest was the main soil cover in SA1 but large scale deforestation, shifting cultivation and fires reduced its area to 20-25% of the total surface (BDP, 2006). The dominant land-cover now is short forest re-growth, scrub, bamboo and temporary cropping. Tall forests in varying stages of re-growth are mainly confined to small borderline areas. Only some 4% of the land is suitable for upland agriculture.

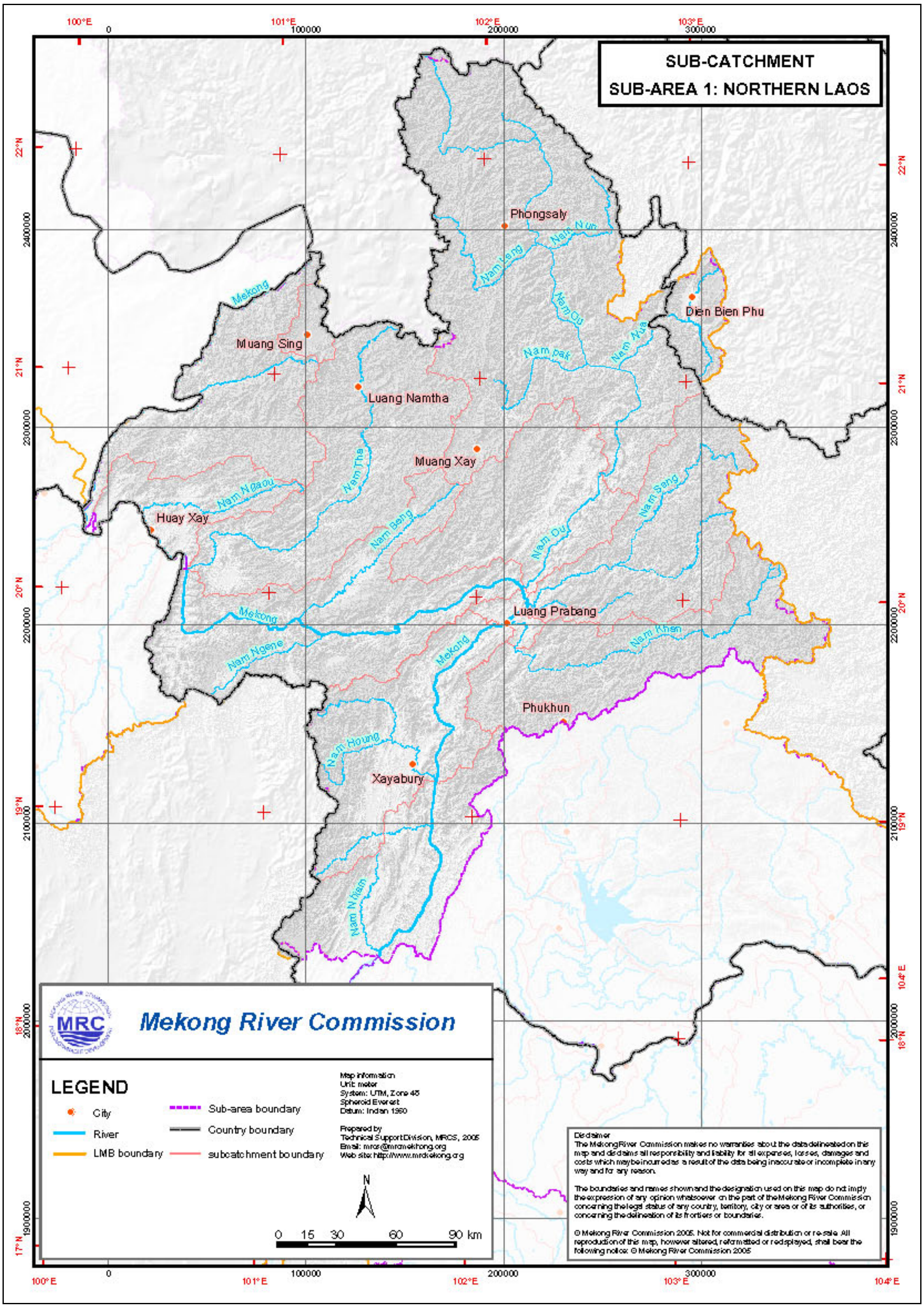

Figure 4.1 Layout of river basins in SA1 (BDP, 2006).

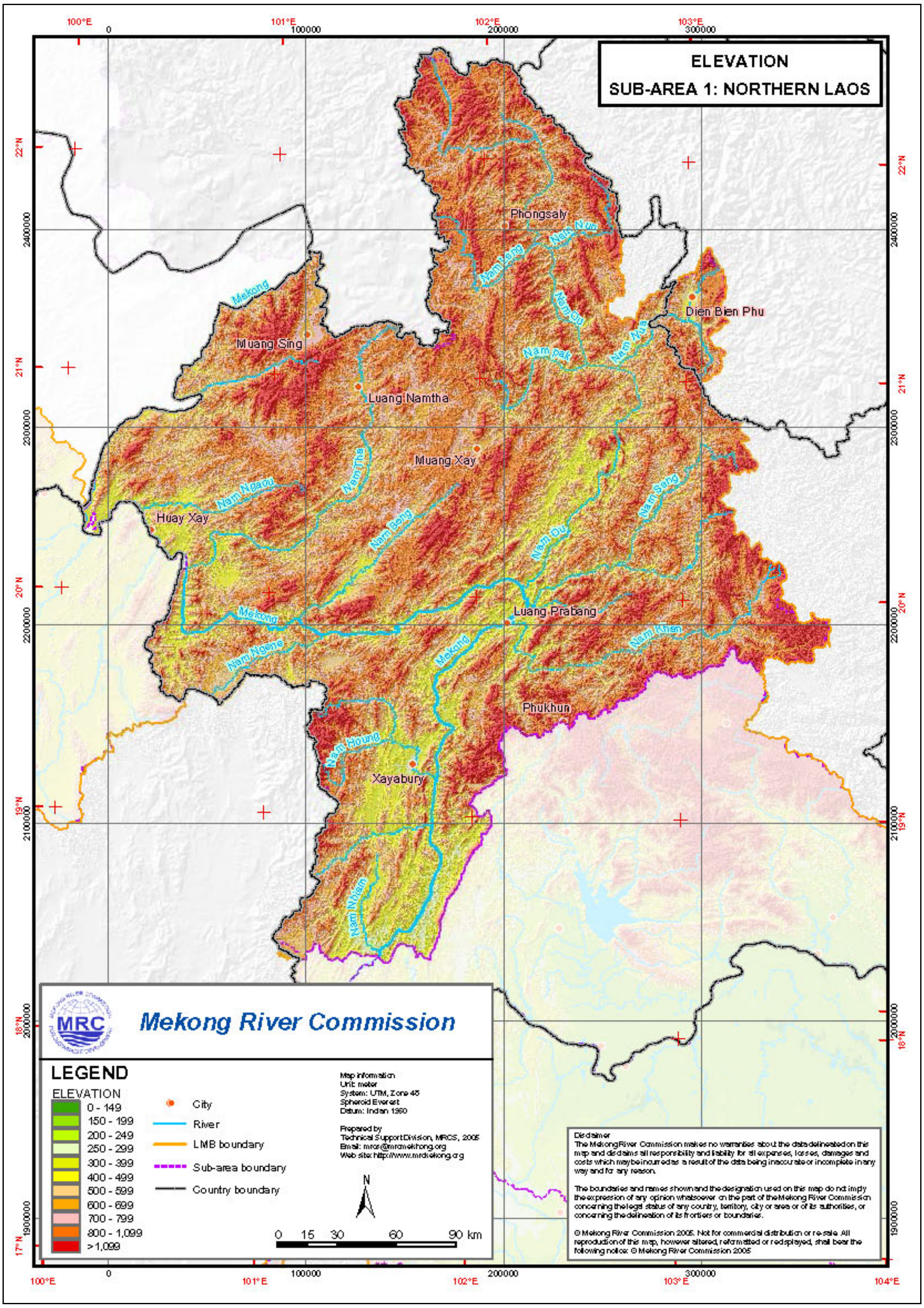

Figure 4.2 Topographical map of SA1 (BDP, 206).

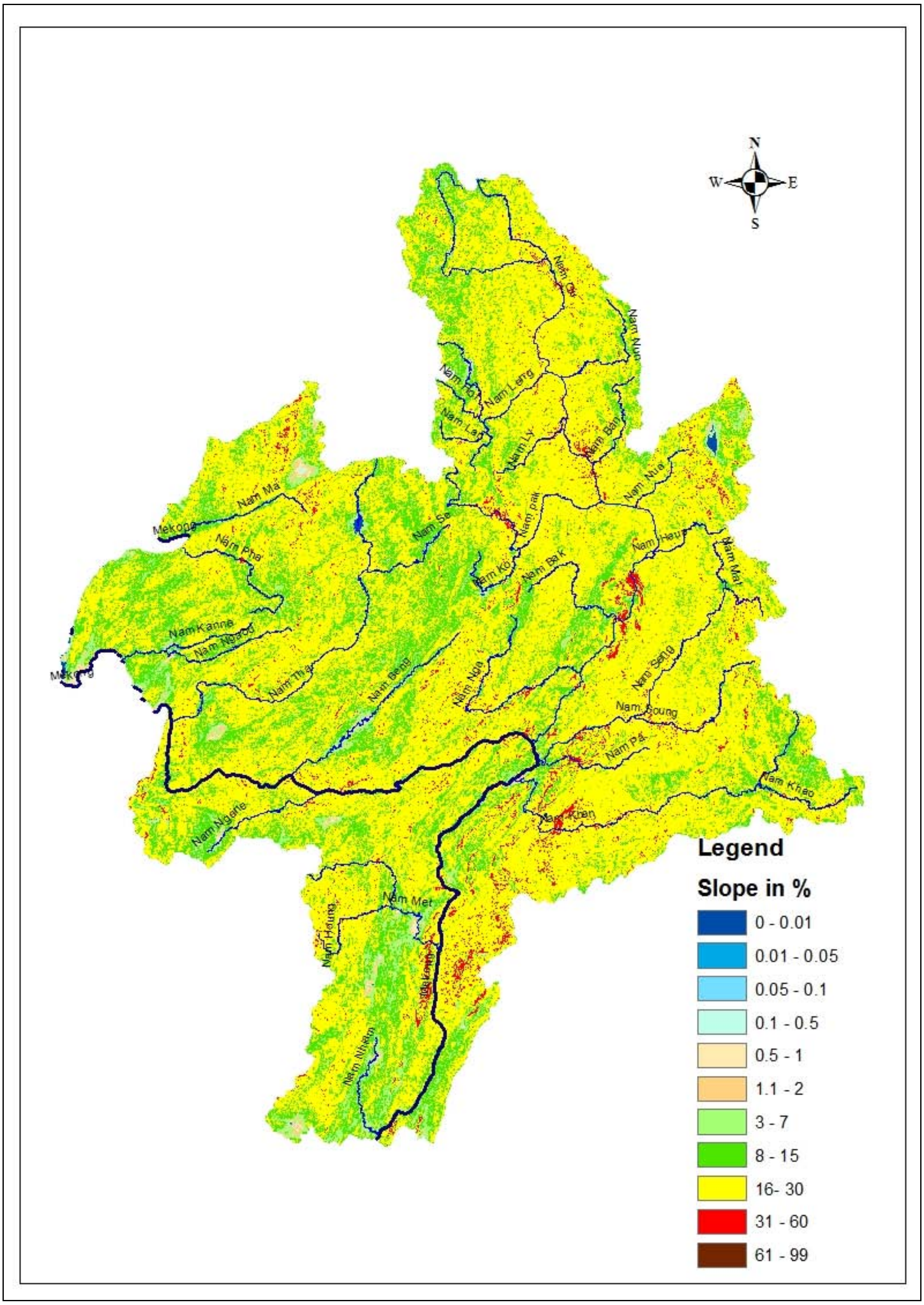

Figure 4.3 Slope map of SA1.

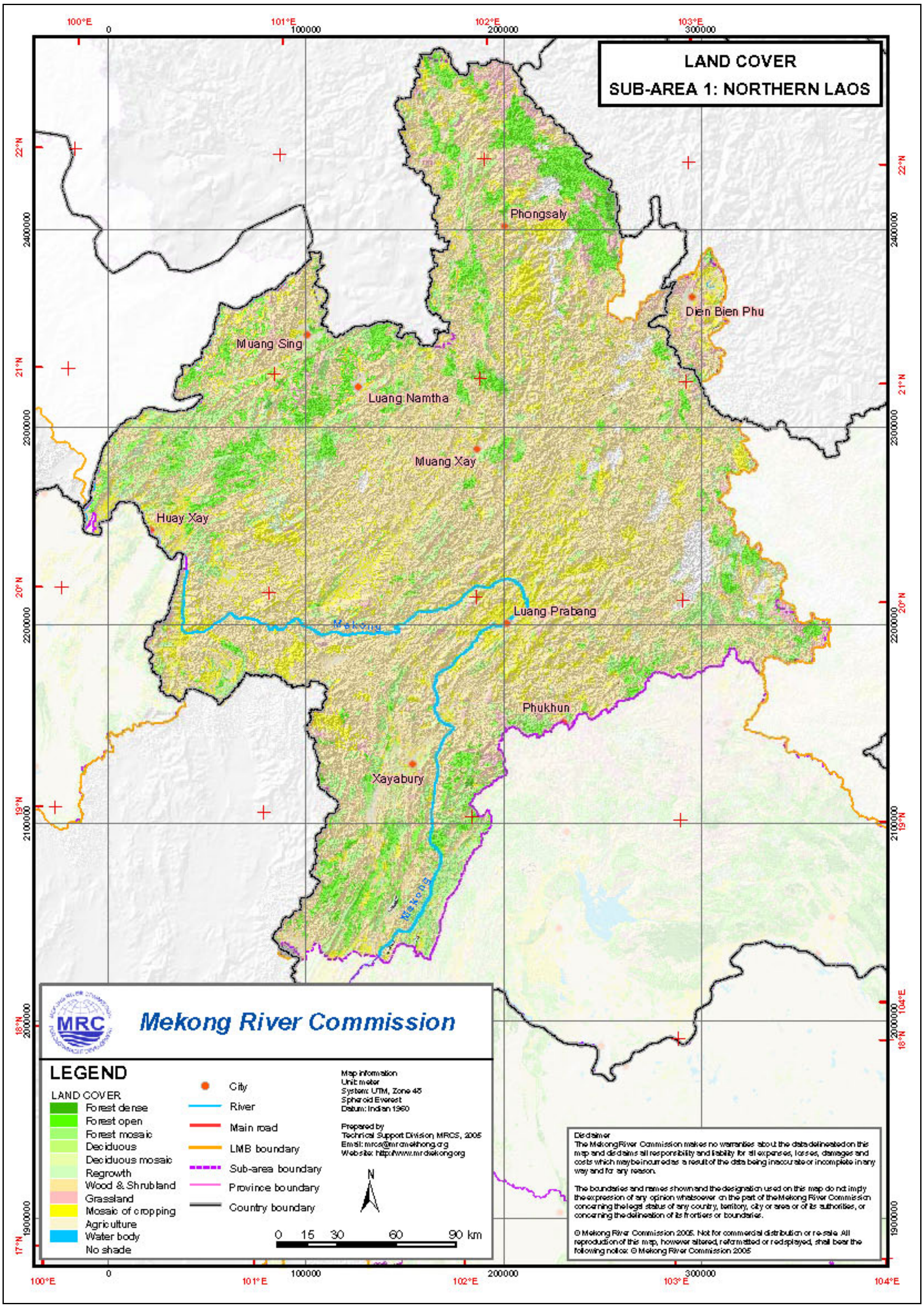

Figure 4.4 Land cover in SA1.

4.2 Hydrological characteristics

4.2.1 Data availability

The location and availability of the rainfall, water level and discharge data in SA1 as available in the HYMOS database at MRC is presented in Table 4.1 to Table 4.5 and Figure 4.5.

The total number of rainfall stations in the database is 16. However, for a particular year data is only available for at maximum 11 stations, which implies a density of 1 per 7,300 km^2. To assess the total availability of rainfall stations Consultants visited the Department of Meteorology and Hydrology of Laos. Unfortunately, the Department appeared to be very reluctant to provide any information on the layout of their network. Only a list of names of stations without co-ordinates and elevation could be obtained. From this list it has been deduced that the actual number of stations is larger than those available in the MRC database. The total number of rainfall stations in Laos is 147, of which of 67 stations MRC received data in 2005.

The number of water level gauging stations on the tributaries amounts 10, of which only at 5 discharges are measured as well. The flow records are available as from the early ninties onward, with the exception of the longer records for Nam Suong at Ban Sibounhom and Nam Khan at Ban Mout. Although some of the stations have records prior to 1990 it is noted that no discharge measurements are available prior to this year, which makes validation of the available data impossible. Inspection of the record of Ban Sibounhom learned that the flow record of this station is likely of doubtfull quality.

At 4 locations along the left bank of the Mekong River in SA1 water levels are gauged, which figure becomes higher if also the right bank stations are included (see SA2). At Chiang Saen (see SA2) and Luang Prabang the discharge is measured.

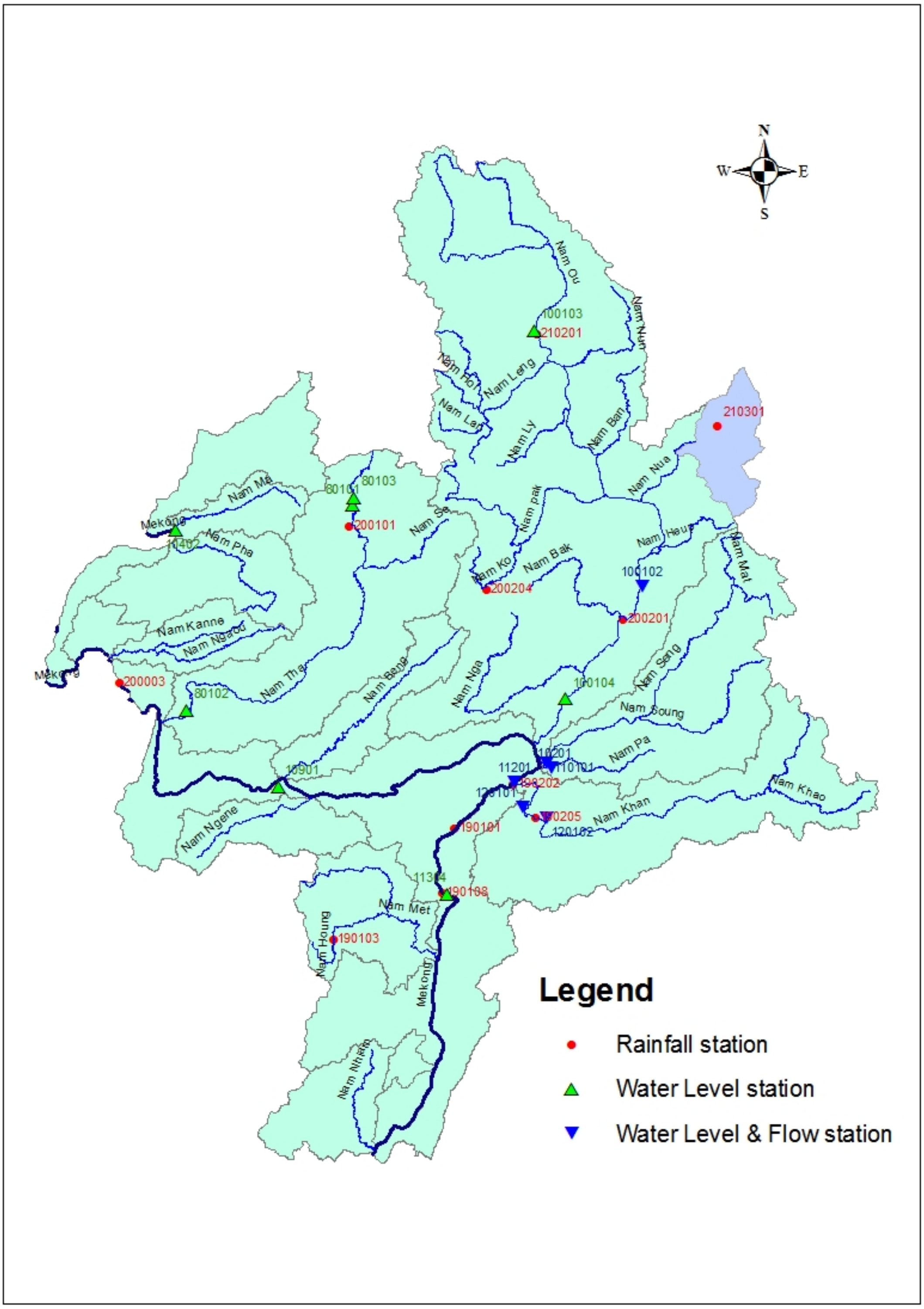

Figure 4.5 Network of rainfall, water level and stream gauging stations in SA1.

Table 4.1 Overview of rainfall, water level and stream gauging stations and their locations in SA1.

Station Location

Rainfall

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
010402	Xieng Kok	Mekong	20.8967	100.6417
010901	Pak Beng	Mekong	19.8583	101.1150
011201	Luang Prabang	Mekong	19.8917	102.1367
080101	Muong Nam Tha	Nam Tha	21.0167	101.4133
110101	Ban Sibounhom	Nam Suong	19.9700	102.2733
190101	Sengkhalok	Mekong	19.7000	101.8833
190103	Sayaboury	Nam Huong	19.2333	101.3667
190108	Thadeua(Sayaboury)	Mekong	19.4340	101.8340
190202	Luang Prabang	Mekong	19.8833	102.1333
190205	Xieng Ngeun	Nam Khan	19.7500	102.2333
200003	Houei Sai	Mekong	20.2667	100.4167
200101	Muong Namtha	Nam Mun	20.9300	101.4000
200201	Muong Ngoy	Nam Ou	20.5667	102.6000
200204	Oudomxay	Nam Ou	20.6800	102.0000
210201	Phongsaly	Nam Ou	21.7333	102.2000

Water Level

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
010402	Xieng Kok	Mekong	20.8967	100.6417
010901	Pak Beng	Mekong	19.8583	101.1150
011201	Luang Prabang	Mekong	19.8917	102.1367
011304	Ban Pakkhone	Mekong	19.4300	101.8550
080101	Muong Nam Tha	Nam Tha	21.0167	101.4133
080103	Ban Hong Leuay	Nam Tha	21.0500	101.4183
100102	Muong Ngoy	Nam Ou	20.7017	102.7583
100103	Ban Hatsa	Nam Ou	21.7389	102.0321
100104	B.Fay	Nam Ou	20.2417	102.3550
110101	Ban Sibounhom	Nam Suong	19.9700	102.2733
110201	Ban Kok Van	Nam Pa	19.9533	102.2983
120101	Ban Mixay (Ban Mout)	Nam Khan	19.7867	102.1767
120102	Ban Pak Bak (downstream)	Nam Khan	19.7433	102.2800
210301	Dien Bien	Nam Ou	21.37	103

Flow

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)		
			Latitude	Longitude	Catchment Area, km²
011201	Luang Prabang	Mekong	19.8917	102.1367	268000
100102	Muong Ngoy	Nam Ou	20.7017	102.7583	19700
110101	Ban Sibounhom	Nam Suong	19.9700	102.2733	5800
110201	Ban Kok Van	Nam Pa	19.9533	102.2983	700
120101	Ban Mixay (Ban Mout)	Nam Khan	19.7867	102.1767	6100
120102	Ban Pak Bak (downstream)	Nam Khan	19.7433	102.2800	5800

Table 4.2 Availability of rainfall stations in SA1.

Daily Data Availability of BDP Sub-Area 1L (before 1960)

Rainfall

Station ID	Station Name	River	1910										1920										1930										1940										1950									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
190202	Luang Prabang	Mekong											+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+							+	+	+	+	+	+	+	+	+	+
200003	Houei Sai	Mekong			+	+	+	+	+	+	+	+	+	+	+	+	+	245		92	+	+	+	+	+	+	92	+	+	+	+	+	+		+	+	+	31														
200101	Muong Namtha	Nam Mun																				+	+	+	+	+			+	+	+		153	+	+	+																
210201	Phongsaly	Nam Ou													+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	31															

Daily Data Availability of BDP Sub-Area 1L (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
010402	Xieng Kok	Mekong																																													+	+	
010901	Pak Beng	Mekong																																									327	+	59	+	182	330	194
011201	Luang Prabang	Mekong																																									264	+	+	+	+	+	+
080101	Muong Nam Tha	Nam Tha																																				+											
110101	Ban Sibounhom	Nam Suong																																															
190101	Sengkhalok	Mekong							+		184			+	+	+	+	+													+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
190103	Sayaboury	Nam Huong					+	+	+	+	+	+	+	+	+	+	+	185			+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
190108	Thadeua(Sayaboury)	Mekong																																	+	+			+	+	+	+	+	+					
190202	Luang Prabang	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
190205	Xieng Ngeun	Nam Khan																+													+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
200003	Houei Sai	Mekong															+																																+
200101	Muong Namtha	Nam Mun																																334	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
200201	Muong Ngoy	Nam Ou																																					+	+	+	+	+	+	+	+	+	+	+
200204	Oudomxay	Nam Ou																																+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
210201	Phongsaly	Nam Ou																													+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
210301	Dien Bien	Nam Ou																																										+	+	+	+	+	+

Table 4.3 Availability of water level data in SA1.

Water Level

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
010402	Xieng Kok	Mekong													91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+														+	77	+	
010901	Pak Beng	Mekong																	115	3	65	36	21	38	125	288	90	137				68	20		109	174			123	93	108	148	219	17	63	+	159		194
011201	Luang Prabang	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
011304	Ban Pakkhone	Mekong																																										31	12	+	213	121	63
080101	Muong Nam Tha	Nam Tha																		31	12	10	+	41	43	53	28	131	63	+																			
080103	Ban Hong Leuay	Nam Tha																																												1	+	+	
100102	Muong Ngoy	Nam Ou																			98	4	4	117	311			152	313	92	70	44	+	+	+	304	+	120	+	+	+	+	+	+	12	+		214	181
100103	Ban Hatsa	Nam Ou																			142	116	156																										
100104	B.Fay	Nam Ou	45	288																																						81	127	+	+	31	274	127	+
110101	Ban Sibounhom	Nam Suong						4	13	+	+	+	+	259	34		90	+	+	+	+	+	+	+	59	+	+	+	+	+	+	+	+	+	+	243	+	+	+	+	+	+	+	+	+	+	+	+	+
110201	Ban Kok Van	Nam Pa																						121	137	31	41	138		59	+	+	+	+	122	243	+	+	+	+	+	+	+	+	+	+	153		
120101	Ban Mixay (Ban Mout)	Nam Khan	39	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	92	+	+	+	+	+	+	+	+	273	+	+	+	+	+	+	+	+	+	+	+	+	+
120102	Ban Pak Bak (downstream)	Nam Khan																										99	218	229	216	+	+	+	+	212	+	+	+	+	+	+	+	1	+	+	122		

Table 4.4 Availability of streamflow stations in SA1.

Flow

Station ID	Station Name	River	1910										1920										1930										1940										1950									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
011201	Luang Prabang	Mekong																														+					+						+	+	+	+	+	+	+	+	+	+

Flow

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
011201	Luang Prabang	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
100102	Muong Ngoy	Nam Ou																												92	70	44	+	+	+	304	121	31	+	+	+	+	+	+	12	+		364	
110101	Ban Sibounhom	Nam Suong								90	+	+	+	259	34		90	+	+	+	+	+	275							+	+	+	+	+	+	243	+	+	+	+	+	+	+	+	+	+	+		
110201	Ban Kok Van	Nam Pa																													+	+	+	+	122	243	+	+	+	+	+	+	+	+	+	+	153		
120101	Ban Mixay (Ban Mout)	Nam Khan	39	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	92	+	+	+	+	+	+	+	+	273	+	+	+	+	+	+	+	+	+	+	+	+	
120102	Ban Pak Bak (downstream)	Nam Khan																										99	218	229	217	+	+	+	+	216	+	+	+	+	+	+	+	1	+	+	122		

Notes: + = no missing

blank = missing

90 = number of missing days in a year

Table 4.5 Availability of stage-discharge data.

Measured Flow Data Availability of BDP Sub-Area 1L (1960-2006)

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
011201	Luang Prabang	Mekong	8	105						31	84			15	8	2													12	28			45	34	27			28	46	41	40	36	29	33	25				
100102	Muong Ngoy	Nam Ou																															51	42	67			39	63	72	80	40	38	46	33				
110101	Ban Sibounhom	Nam Suong																															19		12			14	21	15	30	28	14	7	17				
110201	Ban Kok Van	Nam Pa																															13		11			9	17	17	25	21	8	13	11				
120101	Ban Mixay (Ban Mout)	Nam Khan																																				8	19		30	28	21	21	18				
120102	Ban Pak Bak (downstream)	Nam Khan																															47	32	39			31	44	29	30	23	22	20	18				

Notes:

blank = no measured flow

105 = number of measured flows in a year

4.2.2 Rainfall

The climate in SA1 is determined by the monsoons. During the occurrence of the SW-Monsoon from May to October moist air from the Indian Ocean is brought into the Mekong Basin creating long periods with extensive rain, occasionally further aggravated by incursions of typhoons from the east. The tropical storms are most frequent in this area during the months June and July. The areal distribution of the rainfall is influenced by orographical effects dependent on the heigth and orientation of the mountain ranges. In winter time when the NE Monsoon winds bring cold dry air from the China mainland the rainfall amounts are low as was described in the discussion on the typical climatic features of the LMB in Chapter 2.

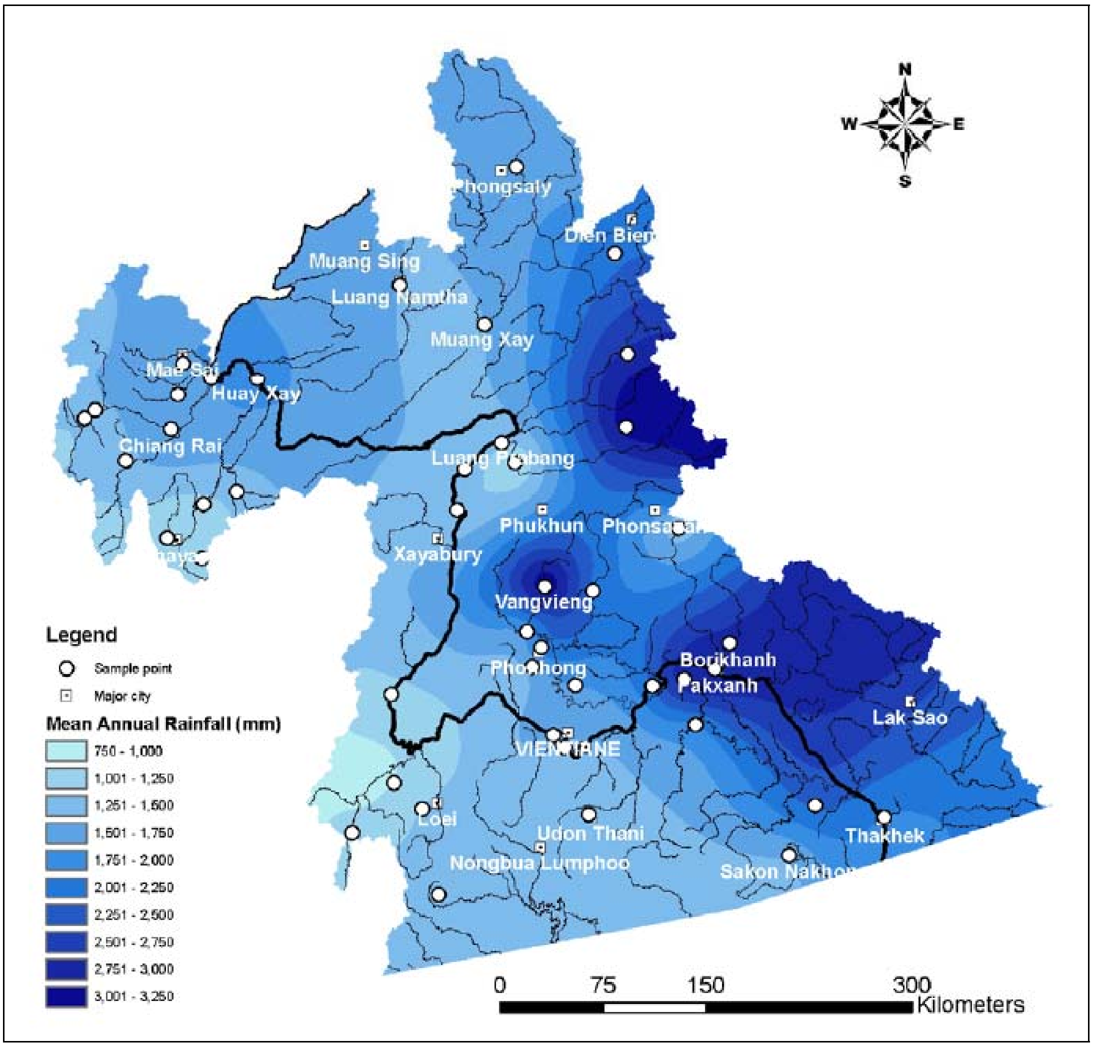

Figure 4.6 Mean annual rainfall in norther region of the LMB (Adamson, 2007).

The areal variation of the mean annual rainfall in SA1 is depicted in Figure 4.6. A varying pattern from west to east is observed. Starting from the west the annual rainfall is seen to first reduce from 1,600 mm to about 1,000 mm north of Luang Prabang to increase then sharply to about 3,000 mm towards the eastern mountain ranges.

The variation of the annual rainfall is considerable as shown for Luang Prabang in Figure 4.7, which indicates a range of 800 to 1,800 mm around a mean value of 1,260 mm.

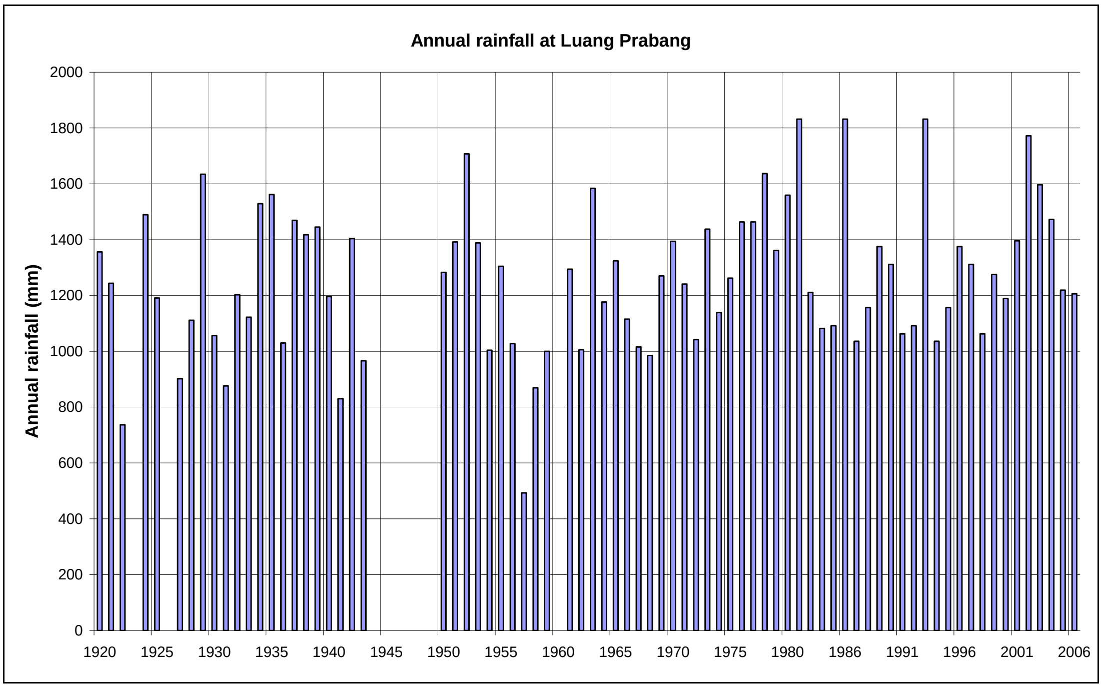

Figure 4.7 Annual rainfall at Luang Prabang, Period 1920-2006.

The seasonal variation of the rainfall in SA1 represented by Luang Prabang in shown in Figure 4.8. Rainfall is largest on average in the months July and August.

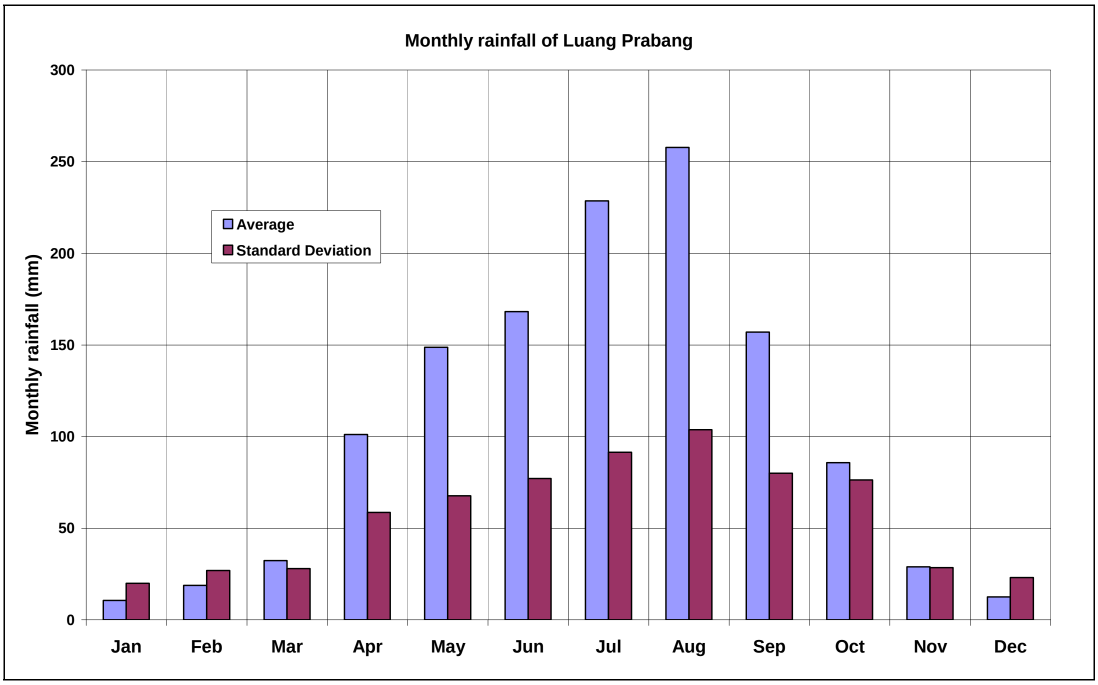

Figure 4.8 Monthly rainfall characteristics of Luang Prabang.

4.2.3 Runoff

Tributaries

Discharge data are only available for a limited number of tributaries. The discharge hydrographs and frequency curves of daily discharge for the Nam Ou at Muong Ngoy (drainage area is 19,700 km^2) are shown in Figure 4.9 and Figure 4.10. The graphs show clearly the seasonal pattern following the variation in the rainfall. The figures also show the occasional very high extreme values far beyond the average annual maximum. Peaks above the mean annual flood for this site (3,500 m^3/s according to Adamson, 2007) occurred in the months July to September as can be observed from Figure 4.10. The monthly flow characteristics are presented in Figure 4.11, showing the highest volumes in July-August.

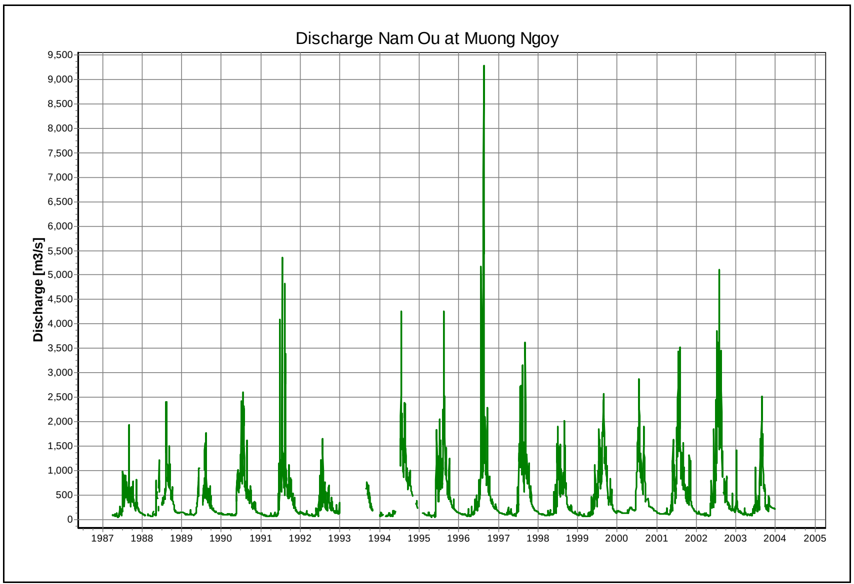

Figure 4.9 Discharge hydrograph of Nam Ou at Muong Ngoy, Period 1987-2003.

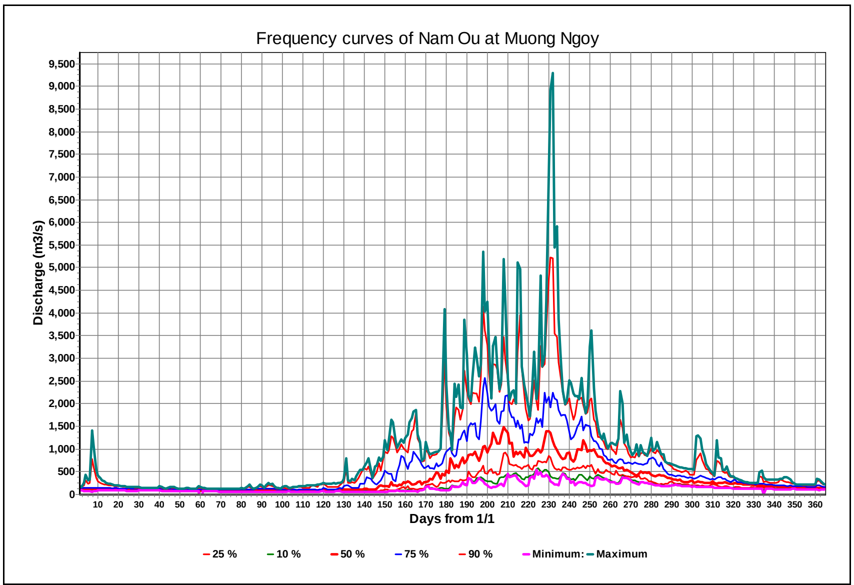

Figure 4.10 Frequency curves of the Nam Ou at Muong Ngoy.

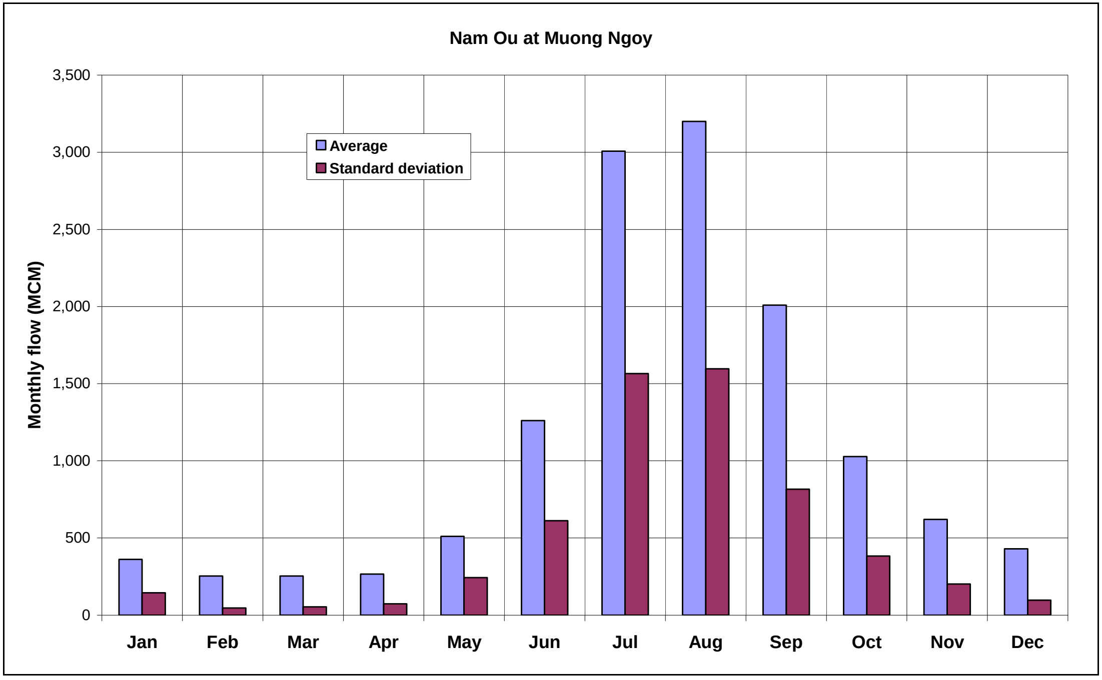

Figure 4.11 Monthly flow charcateristics of Nam Ou at Muong Ngoy, 1988-1992 & 1996-2003.

Similarly, the hydrographs and frequency curves of daily discharges for Nam Khan at Ban Mout or Ban Mixay (drainage area is 6,100 km^2) are presented in Figure 4.12 and Figure 4.13. The seasonal pattern is also observed from these figures. Peak values exceeding the mean annual flood value for Ban Mout (1,000 m^3/s according to Adamson, 2007) occurred in the period June to September. The monthly flow characteristics are presented in Figure 4.14. It is observed that in Nam Khan, in comparison with Nam Ou, the highest flows have shifted with one month, to occur in the months August and September.

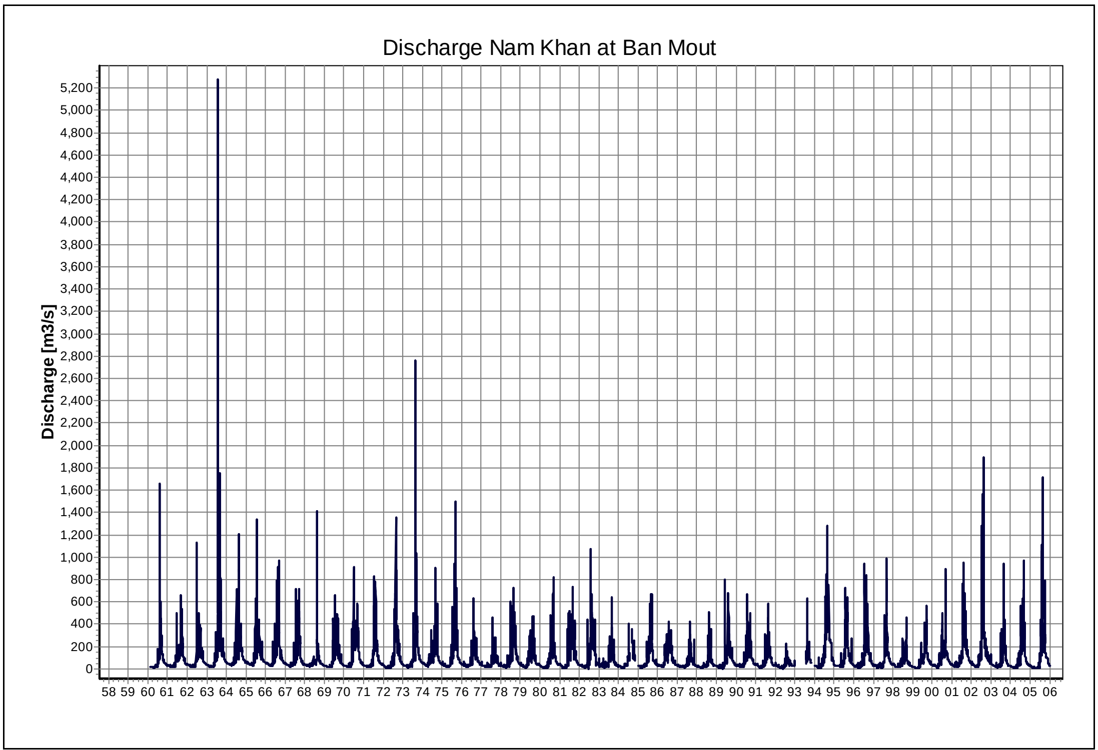

Figure 4.12 Discharge hydrograph of Nam Khan at Ban Mout, Period 1960-2005.

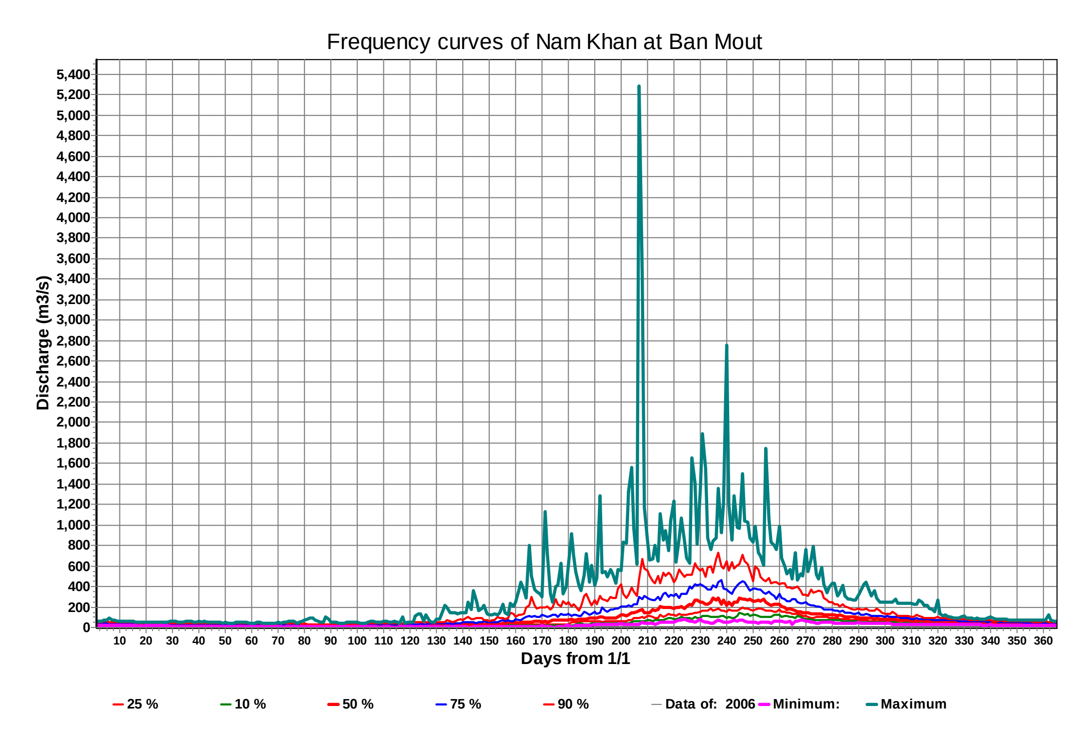

Figure 4.13 Frequency curves of Nam Khan at Ban Mout (Ban Mixay).

Since only a part of the tributaries are gauged a first estimate of the total runoff from SA1 was determined from the records of Chiang Saen and Luang Prabang by correcting for area and assuming spatial homogeneity. The results are presented in Table 4.6 and Figure 4.15.

Annually the average contribution of SA1 amounts some 39 BCM, which is 31% of the flow at Luang Prabang. Mean annual runoff values given by Adamson (2007) for stations on Nam Ou, Nam Suong, Nam Pa and Nam Khan add up to a runoff of 20 MCM/year for a total area covered by the stations of 32,300 km^2 i.e. 40% of the total area of SA1. Hence the remaining 60% in the lower reaches would produce some 19 BCM/year, which is consistent with the lower rainfall values towards the Mekong.

Table 4.6 Average monthly and annual runoff (MCM) from SA1 and at key stations in the Mekong in SA1, Period 1960-2006.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Luang Prabang	4,452	3,062	2,798	2,793	4,225	8,021	17,301	26,464	22,844	15,159	9,632	6,275	122,501
Chiang Saen	3,072	2,264	2,227	2,342	3,558	6,425	12,693	17,124	14,066	10,170	6,407	4,192	84,178
Difference	1,380	798	570	452	667	1,596	4,608	9,340	8,778	4,989	3,225	2,083	38,323
Runoff SA1	1,405	813	581	460	679	1,626	4,694	9,514	8,942	5,082	3,285	2,121	39,036

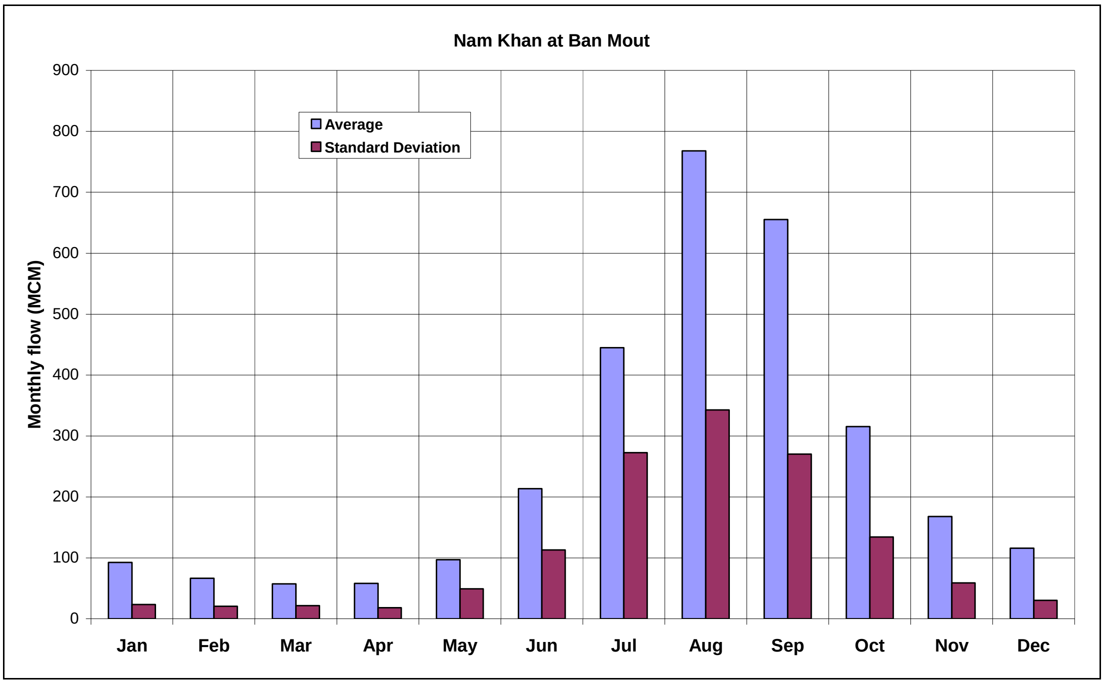

Figure 4.14 Monthly flow characteristics of Nam Khan at Ban Mout or Ban Mixay, 1961-2005.

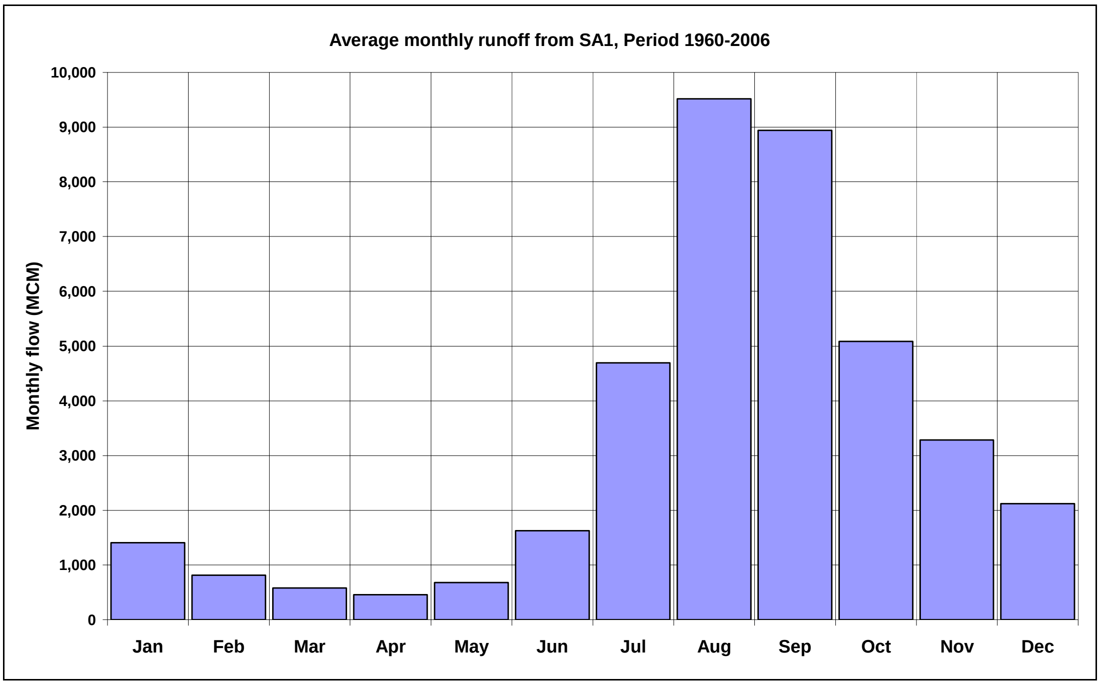

Figure 4.15 Average monthly runoff from SA1, Period 1960-2005.

Main stream

The daily discharge records and their frequency curves for the mainstream stations in SA1 viz.: Chiang Saen and Luang Prabang are shown in Figure 4.16 to Figure 4.19. It is observed that the flows are generally maximum in August, following the rainfall pattern. In both records the largest flood occurred in September 1966, as a result of heavy rains when Cycloon Phyllis struck the basin. The mean annual flood value at the two stations is respectively 10,500 m^3/s at Chiang Saen and 15,100 m^3/s at Luang Prabang (period 1960-2006). It is observed that for Chiang Saen this values have been exceeded in the months July through early November. For Luang Prabang this average flood window extends from July till mid September, hence about 50 days shorter than at Chiang Saen. This can be explained by the shorter time window for floods in SA1 and SA2.

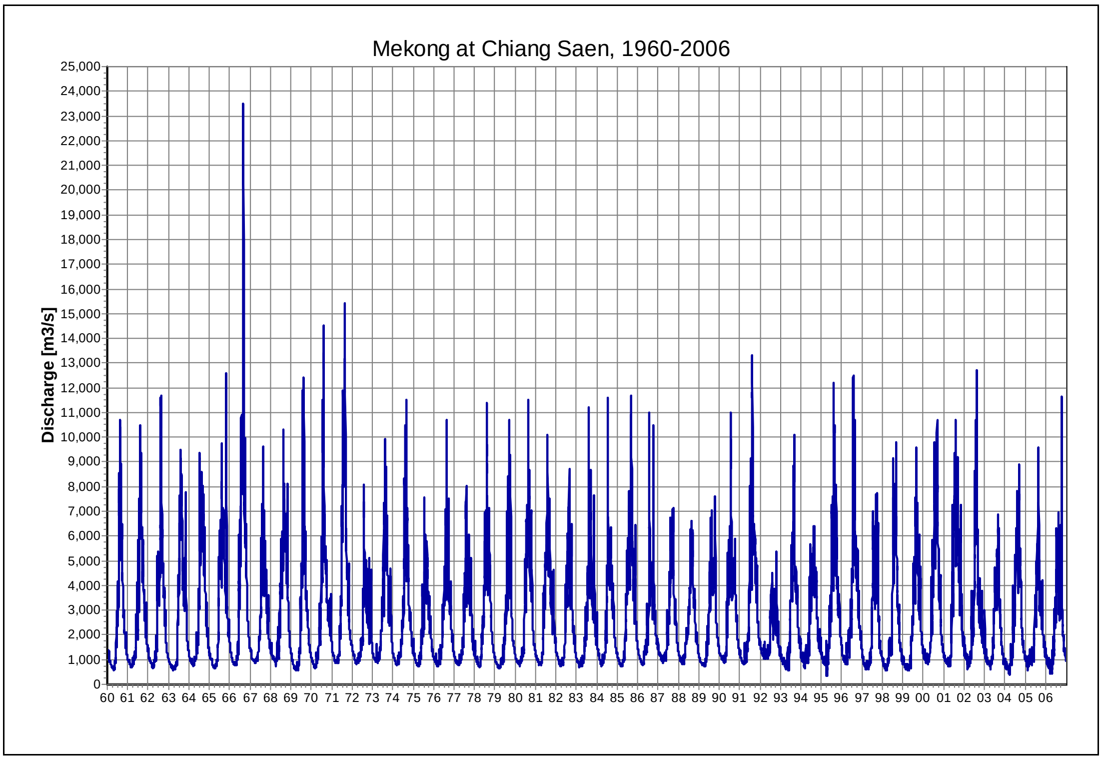

Figure 4.16 Mekong at Chaing Saen, 1960-2006.

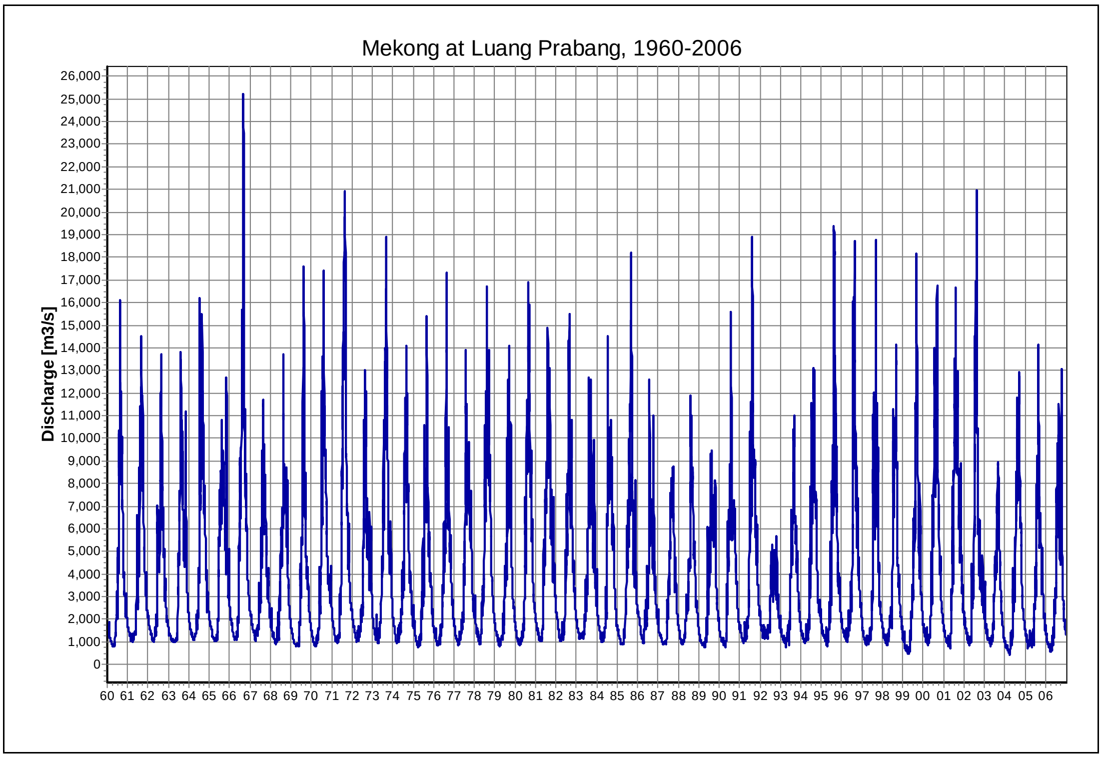

Figure 4.17 Discharge hydrograph of Mekong river at Luang Prabang, 1960-2006.

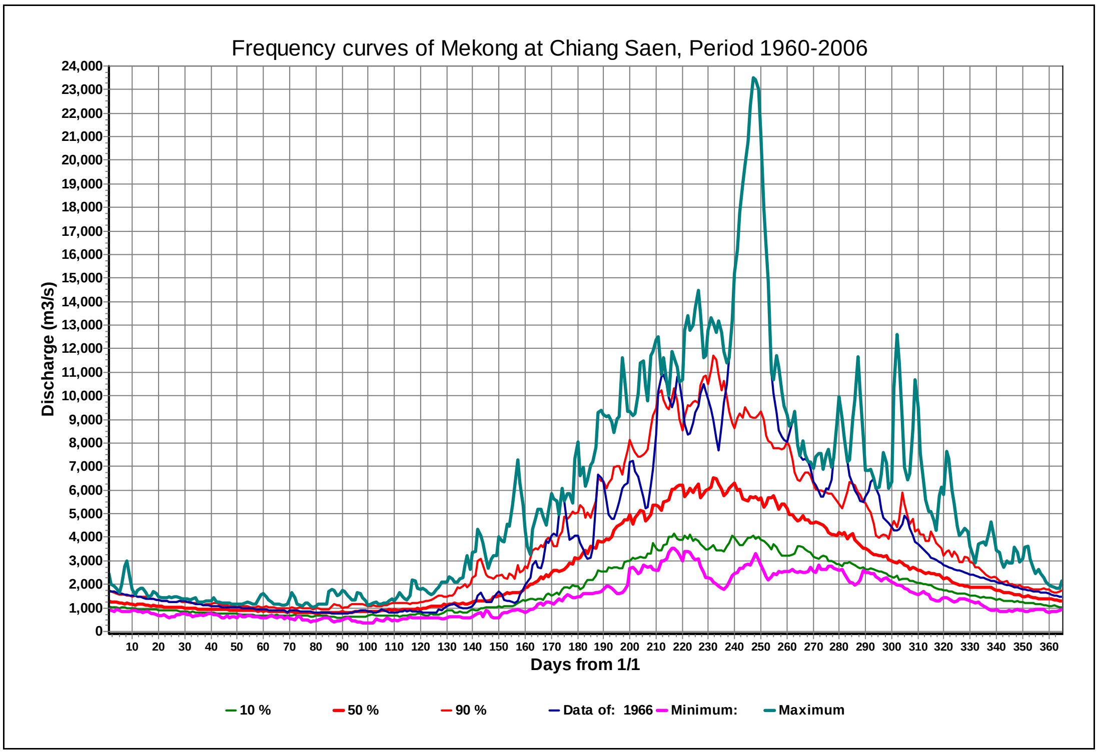

Figure 4.18 Frequency curves of the Mekong at Chaing Saen, period 1960-2006, with year 1966 shown.

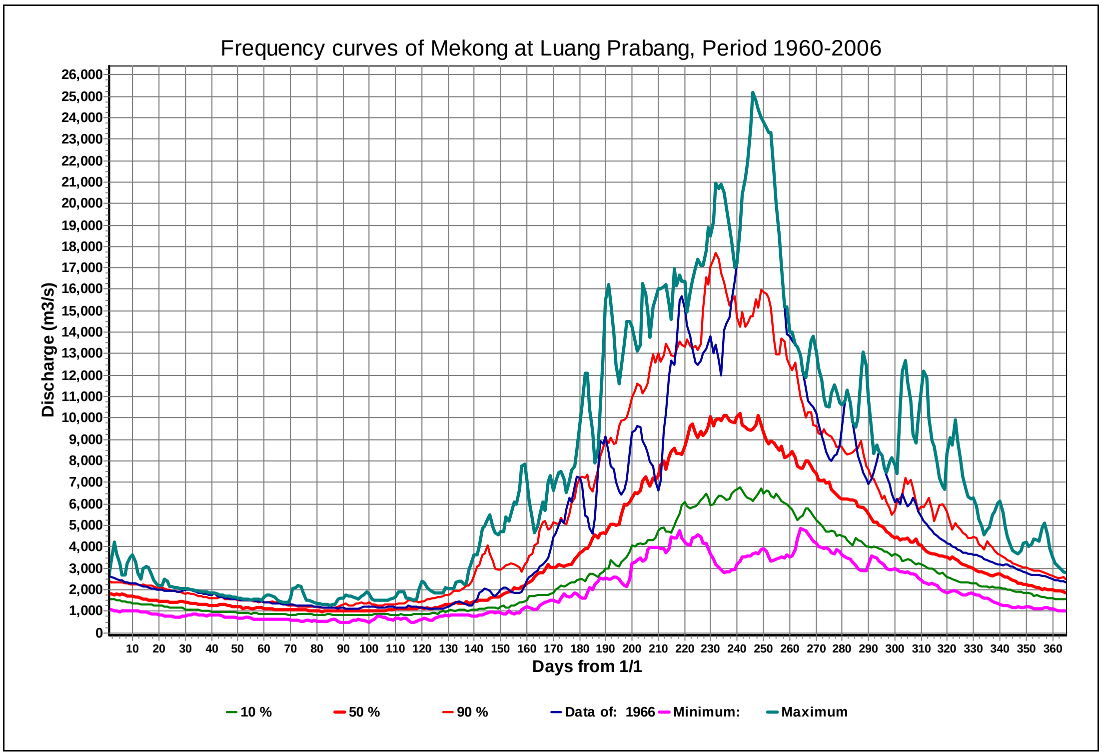

Figure 4.19 Frequency curves of the Mekong at Luang Prabang, period 196-2006, with year 1966 shown

The monthly flows at Chiang Saen and Luang Prabang are presented in Figure 4.20 and Table 4.6. Largest flows are generally observed in July-October. Monthly runoff expressed in mm is presented in Figure 4.21. From this figure it is observed that the runoff from SA1 is during the monsoon period larger than the runoff from China per unit area, as reflected in the runoff at Chiang Saen, whereas in spring the opposite is true. The latter is caused by melting of snow in Yunnan province, which creates extra runoff from the upper basin.

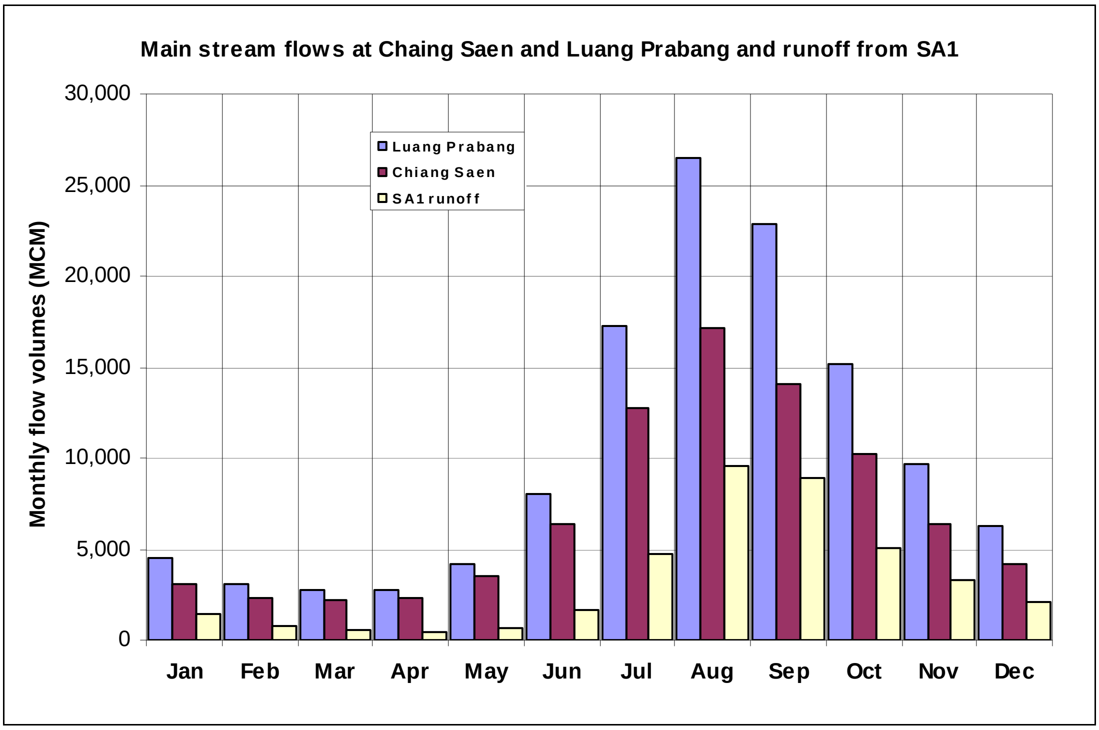

Figure 4.20 Monthly flow characteristics of the Mekong at Chiang Saen and Luang Prabang, with the estimated runoff from SA1.

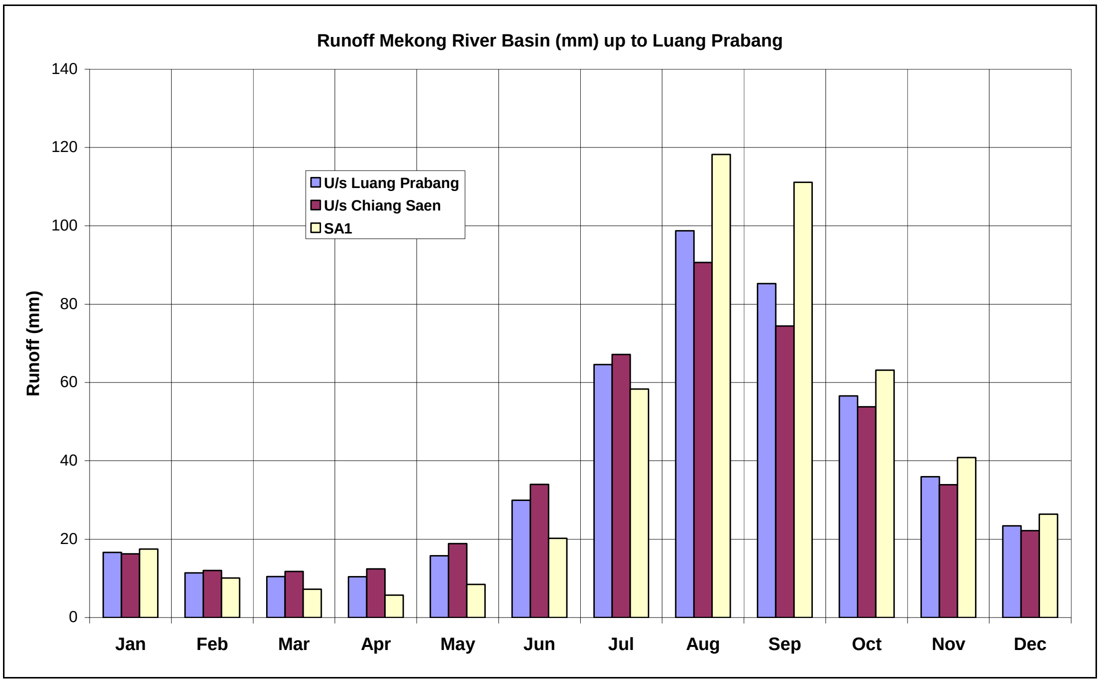

Figure 4.21 Monthly runoff in mm of Mekong at Chiang Saen and Luang Prabang and of SA1.

4.3 Developments in SA1 affecting the flow regime

Factors affecting the flow regime include land use changes and hydropower development. Large scale deforestation has taken place in SA1, which reduced the forestcover to a present value of 20-25% of the land area. The effects on the flow regime in SA1 are difficult to assess in absence of long reliable series. Theoretically, reducing the depth over which plants can take up water from the soil profile will decrease evaporation losses and hence increase the annual flow. Such conditions could be proven in the Cau basin in northern Vietnam, where deforestation has led to an increase in the annual flow volume (Ogink, 2005).

In SA1 at present hydropower is only developed at a small scale (see Table 4.7), though a number micro-hydro power schemes exist. The present development has no effect on the river regime. This will change in the future, as presented in Table 4.8, which shows the list of proposed hydropower projects that reached the MOU-level.

Table 4.7 Existing hydropower in SA1, exclusive of micro-hydro schemes (BDP,2003).

Province	**River/Stream**	**Installed Capacity**
Oudomxay	Nam Ko	1.5
Luang Prabang	Nam Dong	1

Table 4.8 Hydropower project at MOU status (MIME, 2007).

Project	**River/Stream**	**Installed capacity (MW)**	**Storage capacity (MCM)**	**Area (km^2)**
Nam Ou 2	Nam Ou	600	7,248	147
Nam Tha 1	Nam Tha	153	945	38
Nam Fa	Nam Fa	80	2,330	72
Nam Beng	Nam Beng	33	101	12
Nam Suong 1	Nam Suang	39	140	11
Nam Suong 2	Nam Suang	134	3,908	105
Nam Khan 2	Nam Khan	145	1,217	30
Nam Khan 3	Nam Khan	59	3,249	90

With all existing plans with MOU status implemented the total reservoir storage capacity in the basin will amount 19.1 BCM, which is about 50% of the average annual runoff. Under such circumstances the river regime can potentially be considerably adapted, of course dependent on the applied operation strategy.

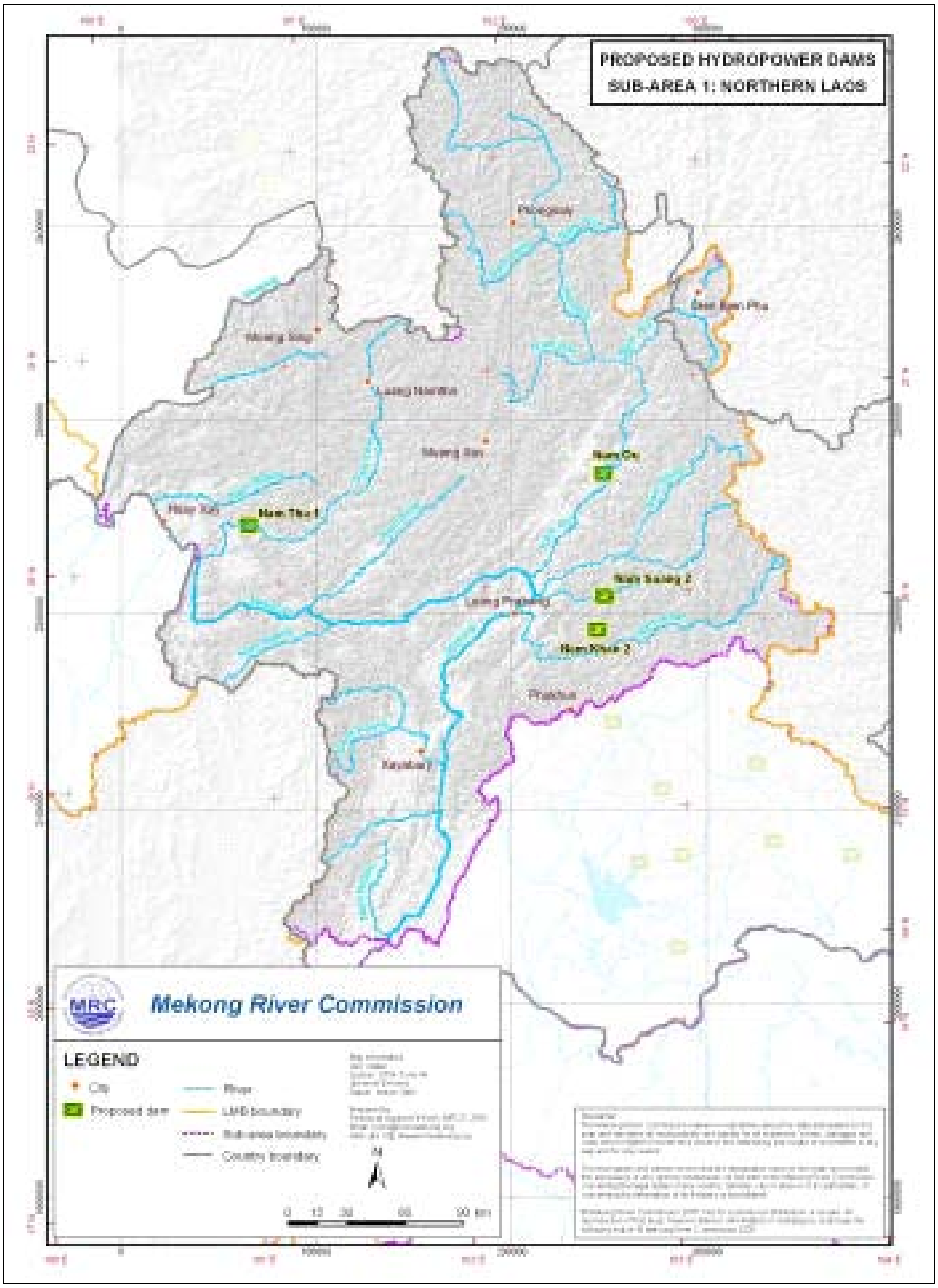

Figure 4.22 Overview of locations of planned hydropower projects in SA1.

4.4 Floods

4.4.1 Tributary floods

The line agencies in Loas have stated that the type of floods that is most important in SA1 is the flash flood. A typical example of a flash flood is presented in Figure 4.24, where a sharply rising and falling discharge hydrograph of the Nam Khan at Ban Mout (area 6,100 km^2) is shown, lasting only a few days. Even for larger basins like the Nam Ou at Muong Ngoy, with a catchment area of 19,700 km^2, the floods still may have a flashy character as can be observed from Figure 4.24. It shows the Nam Ou flood hydrograph of August 1996, which rose very rapidly to a peak value over 9,000 m^3/s, to last only a few days.

Limited data (small number of stations, short records and too large an interval) was shown to be available, too small to make a thorough overview of the extent of the phenomenon. Extension of the available records based on rainfall-runoff simulation is not feasible in view of the very local scale of the flash flood phenomenon and the low density of the rainfall network. Furthermore, the quality of the extremes are difficult to assess as, generally, only the lower discharges have been observed and hence considerable extrapolation has taken place to cover the extreme events.

A statistical analysis of the measured tributaries in the northern part of the MRB was carried out by Adamson (2007). With respect to SA1 it covered the Nam Ou, Nam Suong, Nam Pa and Nam Khan (at two locations). In view of the different origins of the extremes (more frequently monsoon rainfall and exceptionally occurrence of typhoons under wet monsoon soil conditions) a Two Component Extreme Value (TCEV) distribution was considered most suitable to match the observed annual extremes. The flexibility of such a distribution, also due to the large number of parameters, was shown to be sufficient to match the observed set of extremes. Reference is made to the study for computational details and values.

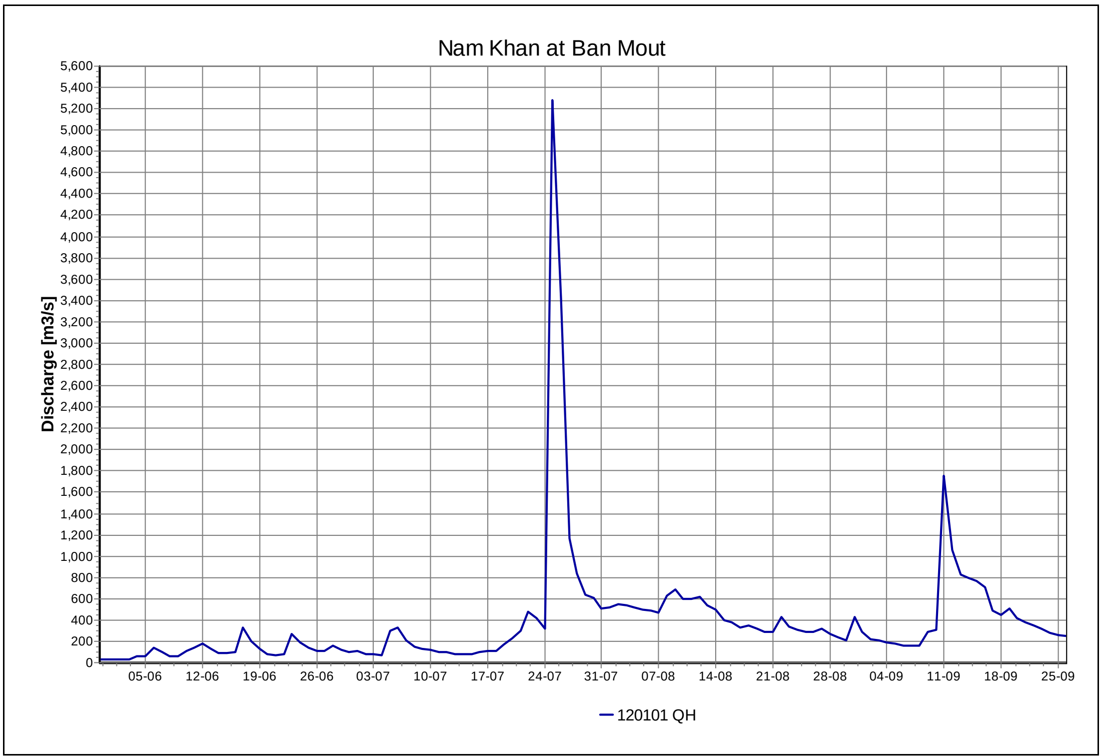

Figure 4.23 Flash flood on Nam Khan at Ban Mout in July 1963.

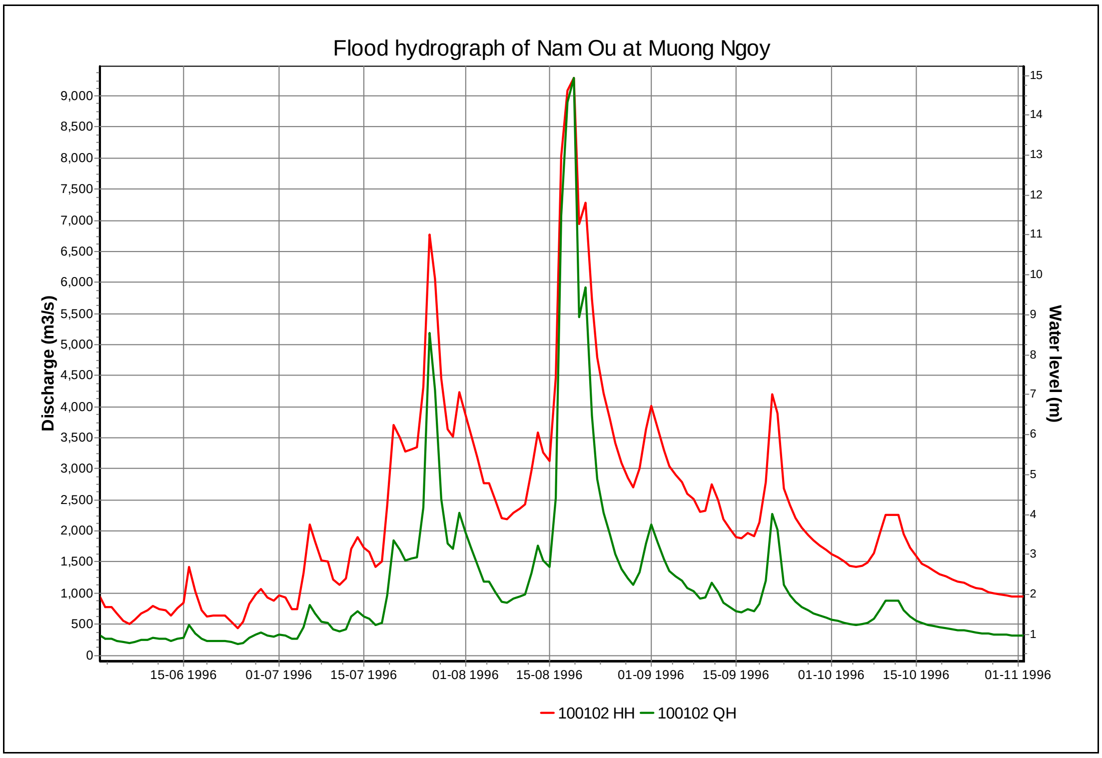

Figure 4.24 Characteristic flashy flood hydrograph on Nam Ou in August 1996.

A regional set of annual extreme discharge data was created in the cited study of Adamson, by scaling the extremes by the mean annual flood. It was shown that a TCEV distribution fitted well to these pooled data set. To estimate extremes for ungauged areas the mean annual flood have subsequently been described as a function of basin area, with a large unexplained part in the relationship. This might be improved by introducing into regression rainfall and basin characteristics. With respect to rainfall it was also shown that 1 -10 day rainfall extremes could well be classified according to annual totals. For basin characteristics physically based estimates of concentration time could possibly improve the mean annual flood-area relation.

Using the flood statistics as derived by Adamson (2007) an assessment was made of the return period of recent floods (2000-2006), for Nam Ou, Nam Pa and Nam Khan. The data in the HYMOS database for Nam Suong did not match with the presented statistics and have therefore been omitted.

Table 4.9 Return period of annual extremes on tributaries of SA1 since 2000.

Year	Nam Ou	T (years)	Nam Pa	T (years)	Nam Khan	T (years)
2000	2,868	2	75	2-5	894	2
2001	3,522	2-5	108	5-10	950	2-5
2002	-	-	166	25	1,894	10-20
2003	2,515	<2	59	<2	946	2-5
2004	-	-	-	-	974	2-5
2005	-	-	-	-	1,717	10-20
2006	-	-	-	-	-	-

From the table it is observed that of the presented/available years most severe has been the floods in 2002 (Nam Pa, Nam Khan) and in 2005 in Nam Khan. According to BDP (2006) the losses in 2002 amounted US$ 1,200,000, though the number of people affected in 2001 was higher, (over 100,00 people affected in Xayyabouly Province). The severeness of the 2001 flood is not observed from the above table and indicates that the flash flood phenomenon can be very local. The Annual Flood Report of 2005 (MRC, 2006) indicates little damages in SA1 though the peak on the Nam Khan was significant. In 2006 from 7-10 August locally flash floods occurred in Luang Namtha in response to orographycally induced monsoon rains (MRC, 2007). This area is not covered by one of the measured tributaries. This illustrates that a much larger network (rainfall and discharge) would be required to get a reliable picture of the hydrological hazards in SA1. An option could be a combination of ground stations with radar/satellite rainfall estimates. To translate the hydrological hazard into flood hazard details of the conveyance capacities of the tributaries have to be known. At present such information is not available.

The BDP-atlas (2006) states that watershed degradation has worsened local flooding, though Adamson (2007) finds no ground for such statement based on available rainfall and runoff data and literature.

With the planned hydropower projects implemented, one might expect a reduced flooding problem for areas (partly) controlled by a reservoir. However, then flood mitigation should become an objective in the operation of the reservoirs. Sofar however, in the feasibility studies this aspect has not been taken into consideration.

4.4.2 Main stream floods

For assessing flood hazard along the main stream the peak discharge rather then the flood volume is of importance as the maximum water level relative to the protection level determines whether areas are being flooded or not, despite the large attention flood volumes have obtained in the documentation by MRC. An overview of the annual maximum discharges is presented in Figure 4.25.

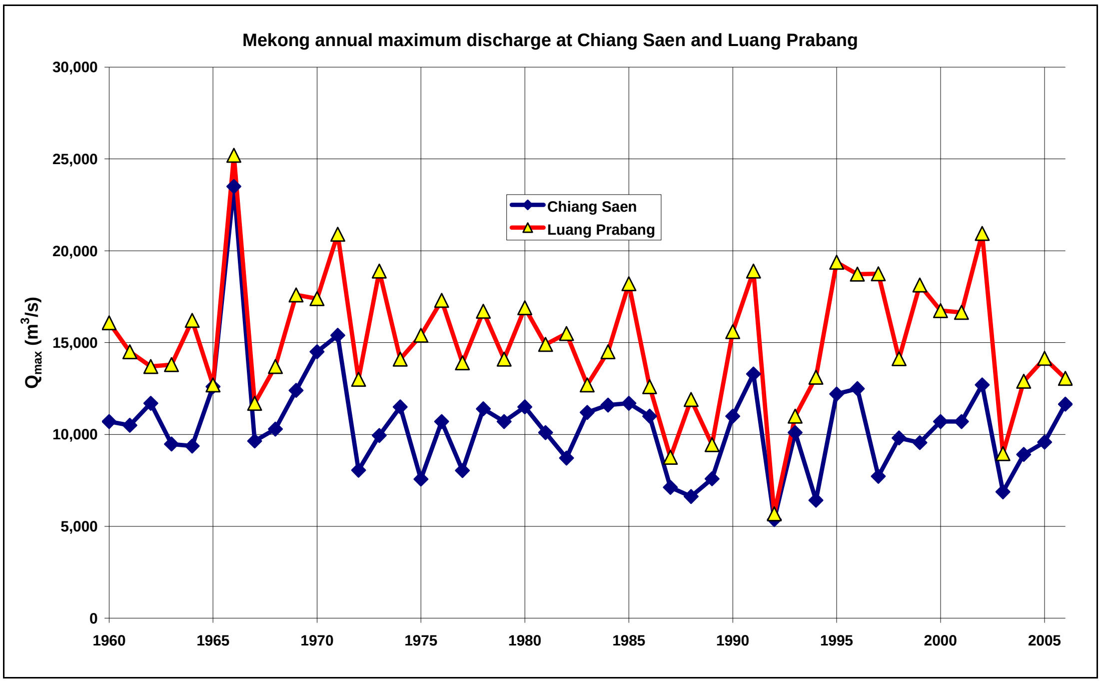

Figure 4.25 Annual maximum discharge in Mekong at Chainang saen and Luang Prabang, Period 1960-2006.

It is observed that since 1960 the peak discharge of 1966 has been highest. The return period of this flood, using the flood statistics presented in the Annual Flood Report of 2006 (MRC, 2007) is estimated at 400 years for Chaing Saen and 200 years for Luang Prabang. An overview of recent peak flows and exceedance durations is given in Table 4.10, Table 4.11 and Table 4.12.

Table 4.10 Peak flows in Mekong at Chaing Saen and Luang Prabang, period 2000-2006.

Year	Chiang Saen		Luang Prabang	
	Q_{Peak} (m^3/s)	T (years)	Q_{Peak} (m^3/s)	T (years)
1966	**23,500**	**400**	**25,200**	**200**
2000	10,700	2	16,700	4
2001	10,700	2	16,600	3
2002	12,700	5	20,900	26
2003	6880	<2	8,960	<2
2004	8910	<2	12,900	<2
2005	9580	<2	14,100	<2
2006	11,700	3	13,100	<2

Table 4.11 Exceedances (days) of Mekong discharges with distinct return period at Chiang Saen for period 2000-2006.

T (Years)	**2**	**5**	**10**	**20**	**50**	**100**
Q (m^3/s)	**10,000**	**13,000**	**14,500**	**16,000**	**18,000**	**20,000**
2000	3	0	0	0	0	0
2001	2	0	0	0	0	0
2002	10	0	0	0	0	0
2003	0	0	0	0	0	0
2004	0	0	0	0	0	0
2005	0	0	0	0	0	0
2006	1	0	0	0	0	0

Table 4.12 Exceedances (days) of Mekong discharges with distinct return period at Luang Prabang for period 2000-2006.

T (Years)	**2**	**5**	**10**	**20**	**50**	**100**
Q (m^3/s)	**15,000**	**17,500**	**19,500**	**20,500**	**22,000**	**23,500**
2000	5	0	0	0	0	0
2001	4	0	0	0	0	0
2002	16	5	2	1	0	0
2003	0	0	0	0	0	0
2004	0	0	0	0	0	0
2005	0	0	0	0	0	0
2006	0	0	0	0	0	0

It is observed that only in the year 2002 a significant flood occurred at Luang Prabang and less at Chiang Saen, which is consistent with the reported high values on the tributaries draining between the two sites for that year.

The flood level at Chiang Saen and Luang Prabang is reached when the discharge is resp. 16,000 and 18,000 m^3/s. This level was exceeded at Luang Prabang in the year 2002. To assess the extent of the flooding a hydraulic model coupled to a DEM is required. The ISIS-model for the reach Chiang Saen to Pakse would have been a candidate to carry out such an analysis. However, cross-sectional profiles above bankfull level are not incorporated in the model, which makes such an assessment with this model not possible at this moment. If, however, sufficient satellite images for different stages of the flood would be available, the extend and depth of flooding could be obtained from analysis of such images.

With respect to the assessment of the extent of the flooding when a certain discharge is exceeded also the river morphological development is to be taken into consideration. For a morphologically active river, a particular discharge will create different water levels, dependent on the conveyance capacity of the control reach downstream. For Chiang Saen and Luang Prabang variation of flood discharge levels have been investigated. The 10,000 m^3/s discharge level at Chiang Saen varied between 1960 and 2007 with 1.4 m, whereas the highest discharge frequently measured at Luang Prabang of 14,000 m^3/s varied with 1.5 m. This additional uncertainly will have to be taken into consideration when assessing the flood extent for a particular flood discharge.

Future flood levels will be affected by upstream dams. The planned development in SA1 was discussed above. The existing and planned development of hydropower in China till 2025 is presented in Table 4.13 (Adamson, 2007).

Table 4.13 Existing and planned hydropower projects in Upper Mekong Basin as collected by NORPLAN, 2004 (See Adamson, 2007).

Projects from u/s to d/s	**Year of Commissioning**	**Installed capacity (MW)**	**Active storage (BCM**
Gonguoqiao	2012	750	1.2
Xiaowan	2010-2014	4200	9.9
Manwan	existing	1500	2.6
Dachaoshan	existing	1350	3.7
Nuozhadu	2014	5500	12.3
Jinhong	2013	1500	2.5
Ganlaba	before 2015	150	-
Mengson	before 2015	600	-
Total		**15550**	**32.2**

It is observed that the active storage will grow from a present 6.3 BCM to 32.2 BCM in 2025, i.e. nearly 40% of the mean annual flow at Chaing Saen. Dependent on the degree of regulation (10 or 20%) the flood season flows will reduce by 10 to 20% at Chaing Saen and 2 to 11% at Luang Prabang. For Luang Prabang the overall effect will further increase when the plans for hydropower development in SA1 (and SA2) are implemented. The flood season lateral inflow reduction is estimated at 5 to 10%, adding up to a total reduction at Luang Prabang of some 11 and 16%. Note, that the effect of the dams on the lean season flows is relatively much larger.

4.4.3 Combined floods

Combined floods, created by high flows on the main stream and on the tributary at the same time, where the main stream backs up the water levels near the mouth of the tributary is not an issue in SA1 as the tributary valleys do not appear to be shallow upon entering the Mekong.

4.4.4 Summing up

For the 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 the procedure proposed by Adamson (2007) could be applied provided that a suitable relationship can be developed between the average annual flood and 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.

The hydrological hazard for the Mekong 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.

Combined floods have not reported to be an issue in SA1.

5 HYDROLOGICAL AND FLOOD HAZARDS IN SUB-AREA 2

5.1 Basin characteristics

Sub-area 2 (SA2), see Figure 5.1, covers the area around Chiang Rai and Chiang Saen draining to the right bank of the Mekong in northern Thailand from Chiang Saen (rkm 2363) to 100 km d/s until both banks of the river are controlled by Laos. The area is bordered by Myanmar to the north and Laos to the east. It covers areas of the provinces Chiang Rai (99%), Phayao (59%) and a small portion of Chiang Mai (10%). The total area of SA2 amounts 17,333 km^2. It covers the basins of:

- Nam Mae Kham (drainage area 4,095 km^2, mouth at rkm 2,360), with Nam Mae Cham
- Nam Mae Kok (drainage area 10,870 km^2, mouth at rkm 2,356, 55% of it located in Myanmar), with Nam Mae Fang and Nam Mae Lao
- Nam Mae Ing (drainage area 7,180 km^2, mouth at rkm 2,297)
- Some smaller basins draining directly to the Mekong with drainage areas < 1,000 km^2
- Kwan Phayao Lake a fresh water lake on the Nam Mae Ing

The basin is mountainous on the divides with elevations up to 2,000 m, particularly the areas west and south-west of Chiang Rai. But the major part of SA2 is fairly flat. The valley floor levels generally vary between 300 and 500 m, as can be observed from Figure 5.2.

The steepness of the terrain is shown in Figure 5.3. Particular attention is to be given to the areas with slopes of < 1% adjacent to steep grounds, like the Nam Mae Fang.

Soils in SA2 are composed mainly of alluvial deposits or flood plain alluvium, with moderate fertility. Soils on irrigable lands in SA2 are for about 40% comprised of acrisols, acidic, strongly leached tropical soils with low fertility. Some 35 % consists of clay-enriched luvisols. Most of SA2 is under forest cover on more than 10,000 km^2 in the basins of the Nam Mae Kok and Nam Mae Ing, mainly concentrated on steep terrain. It has the highest forest cover ratio of the Thai-areas draining to the Mekong. Due to expansion of agriculture the total area reduced considerable until a general ban was put on logging in 1989. Almost 20% of SA2 is covered by protected areas, including the Luang National Park. Another 20% of the area is used for lowland paddy with upland agriculture in smaller pockets over the region.

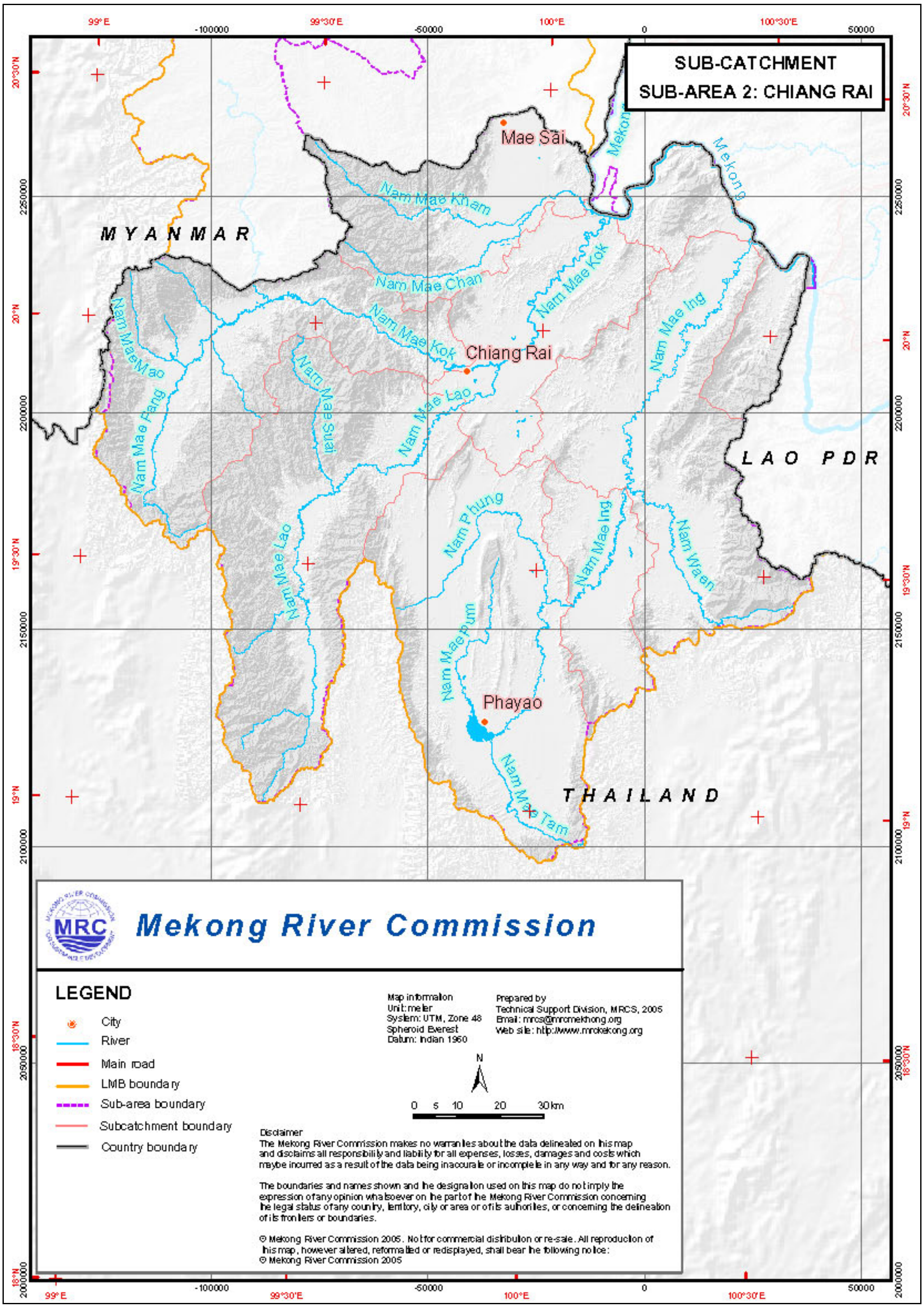

Figure 5.1 Layout of river basins in SA2 (BDP, 2006).

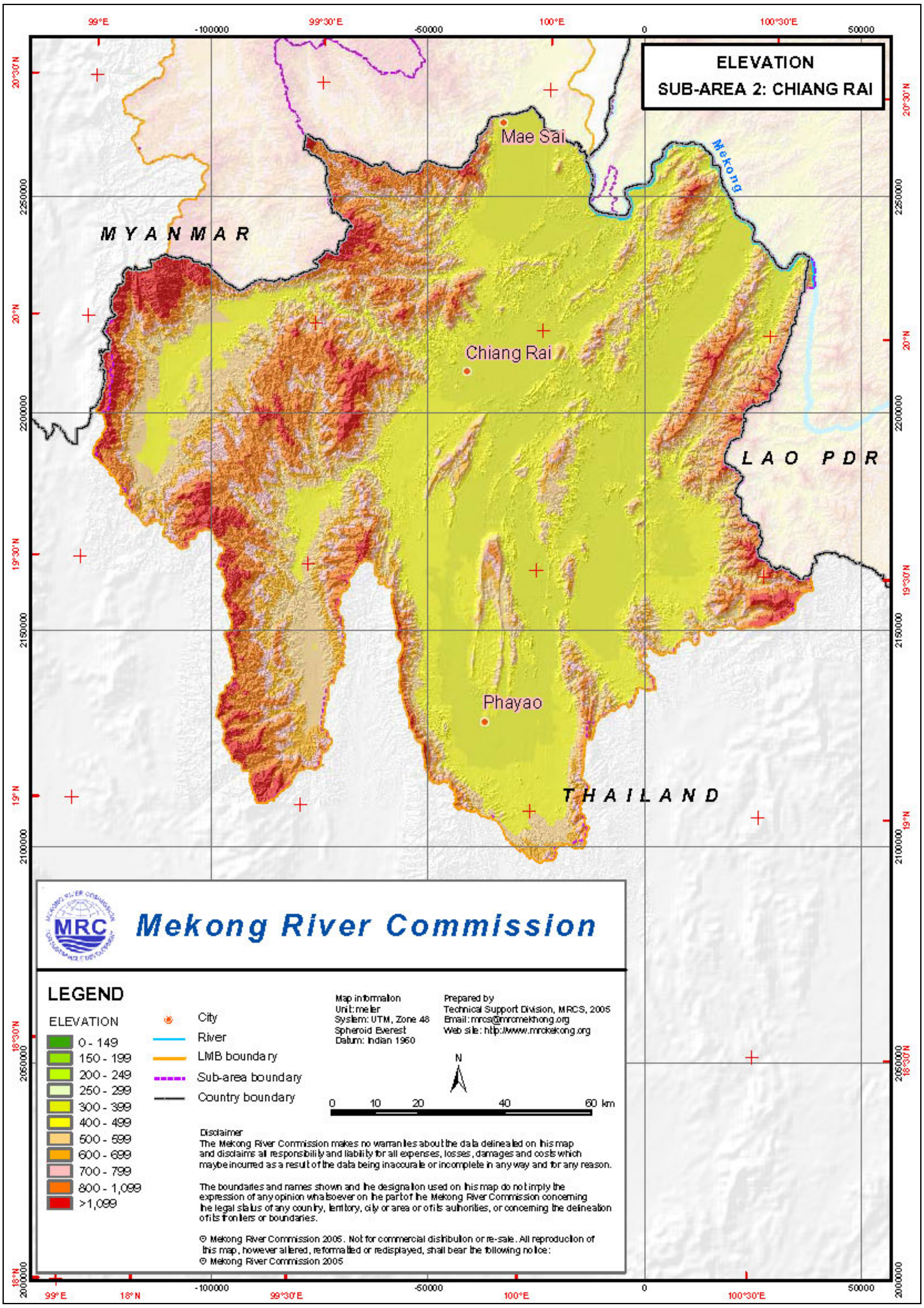

Figure 5.2 Topographical map of SA2 (BDP, 2006).

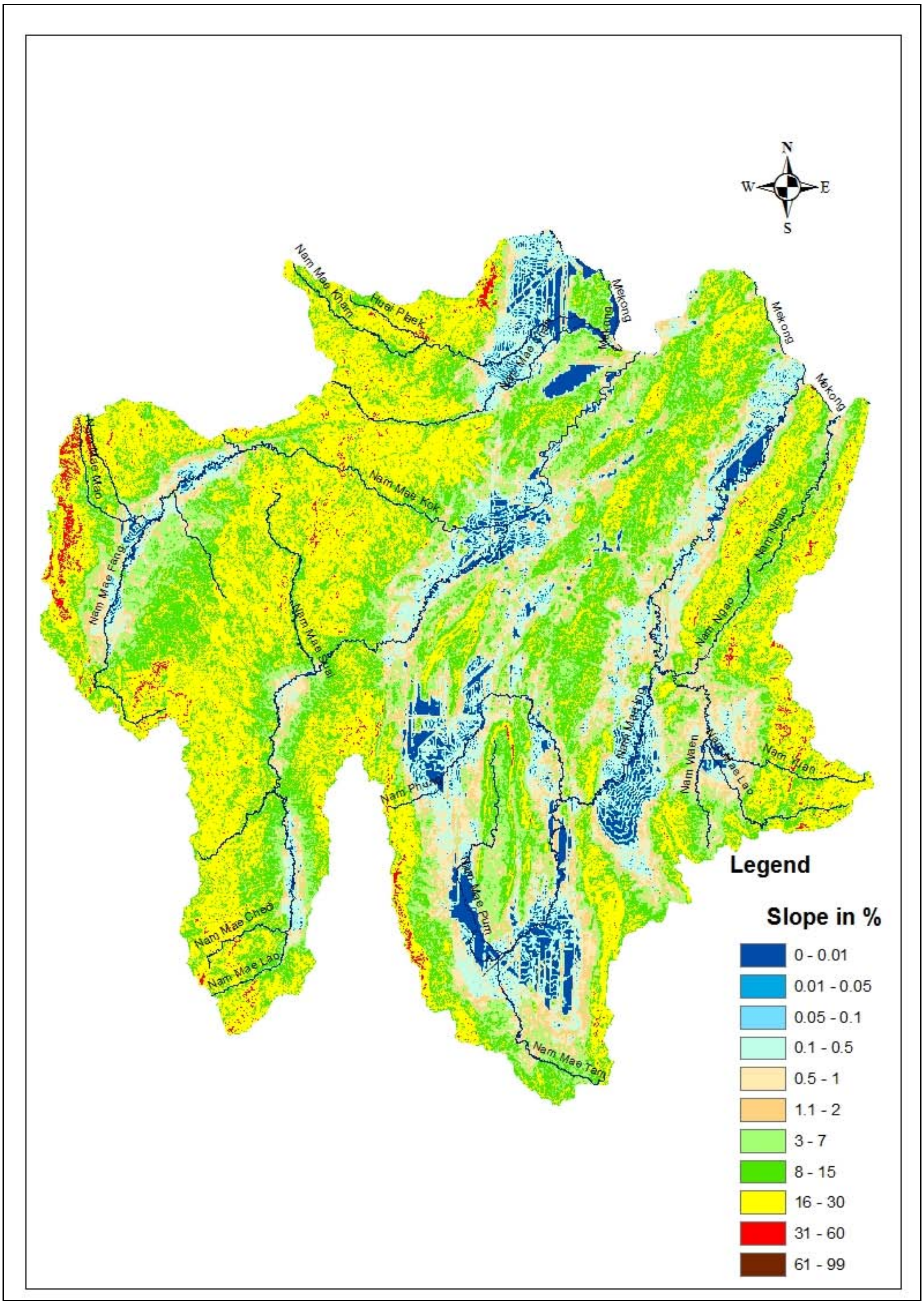

Figure 5.3 Slope map of SA2.

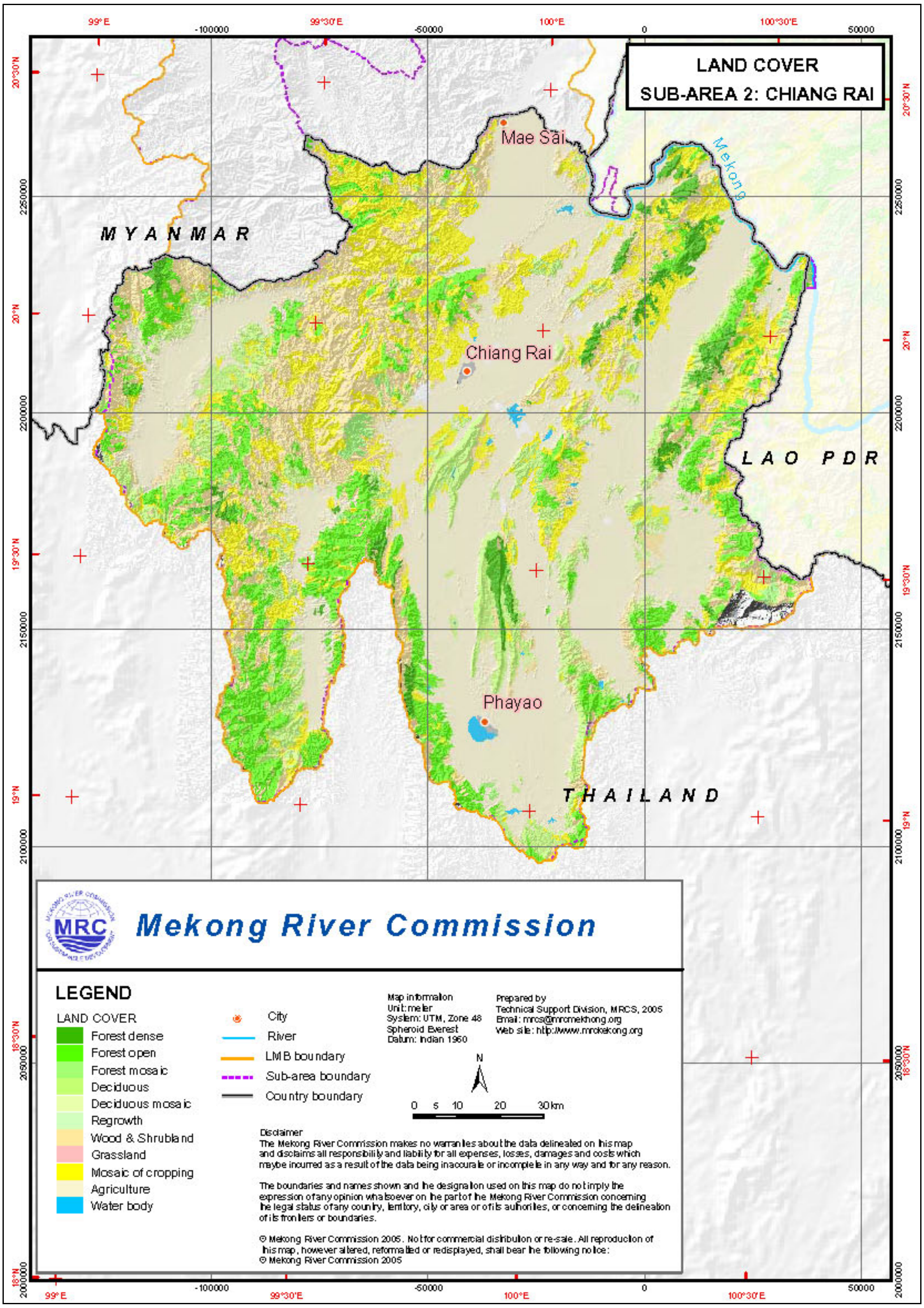

Figure 5.4 Land cover in SA2 (BDP, 2006).

5.2 Hydrological characteristics

5.2.1 Data availability

The location and availability of the rainfall, water level and discharge data in SA1 as available in the HYMOS database at MRC is presented in Table 5.1 and Table 5.2 and Figure 5.5.

The total number of rainfall stations in the database is 12 of which 4 are located in the Nam Mae Kok basin, 4 in the Nam Mae Ing basin, 2 in the Nam Mae Kham and 2 on the Mekong. Two series start in 1953, a number in the sixties, whereas basically all have data as from the early eighties onward.

Table 5.1 Overview of rainfall, water level and stream gauging stations and their locations in SA2.

Station Location

Rainfall

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
190002	CHIANG KHAM	Nam Mae Ing	19.5167	100.3000
190008	KHAO ING ROD	Nam Mae Ing	19.4334	100.0667
190009	BAN HUAI THAM	Nam Mae Ing	19.0667	100.0667
199901	FANG	Nam Mae Kok	19.9667	99.2334
199904	PHAYAO	Nam Mae Ing	19.2000	99.9834
199907	CHIANG RAI	Nam Mae Kok	19.9167	99.8334
199913	MAE SUAI DAM SITE	Nam Mae Kok	19.7000	99.5167
200001	CHIANG KHONG	Mekong	20.2667	100.4167
200002	CHIANG SAEN	Mekong	20.2667	100.1000
209901	MAE CHAN	Nam Mae Kham	20.1500	99.8667
209902	BAN MAE AI	Nam Mae Kok	20.0334	99.3000
209903	MAE SAI	Nam Mae Kham	20.3667	99.9000

Water level

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
010401	Sop Ruak	Mekong	20.3484	100.0867
010501	Chiang Sean	Mekong	20.2734	100.0834
010801	Chiang Khong	Mekong	20.2684	100.4100
040101	Ban Pa Yang	Nam Mae Kham	20.2334	99.8067
040201	Ban Huai Yano Mai	Nam Mae Chan	20.1117	99.7850
050104	Chiang Rai	Nam Mae Kok	19.9184	99.8500
050105	Ban Tha Ton	Nam Mae Kok	20.0600	99.3634
050201	Ban Tha Mai Liam	Nam Mae Fang	20.0200	99.3584
050301	Ban Tha Sai	Nam Mae Lao	19.8534	99.8434
051001	Dam Site	Nam Mae Suai	19.7000	99.5200
051101	Dam Site	Nam Mae Pun Luang	19.4334	99.4584
070103	Thoeng	Nam Mae Ing	19.6867	100.1917

Discharge

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)		Catchment Area, km²
			Latitude	Longitude	
010501	Chiang Sean	Mekong	20.2734	100.0834	189000
040101	Ban Pa Yang	Nam Mae Kham	20.2334	99.8067	518
040201	Ban Huai Yano Mai	Nam Mae Chan	20.1117	99.7850	203
050104	Chiang Rai	Nam Mae Kok	19.9184	99.8500	6060
050105	Ban Tha Ton	Nam Mae Kok	20.0600	99.3634	2980
050201	Ban Tha Mai Liam	Nam Mae Fang	20.0200	99.3584	1800
050301	Ban Tha Sai	Nam Mae Lao	19.8534	99.8434	3080
051001	Dam Site	Nam Mae Suai	19.7000	99.5200	426
051101	Dam Site	Nam Mae Pun Luang	19.4334	99.4584	258
070103	Thoeng	Nam Mae Ing	19.6867	100.1917	5700

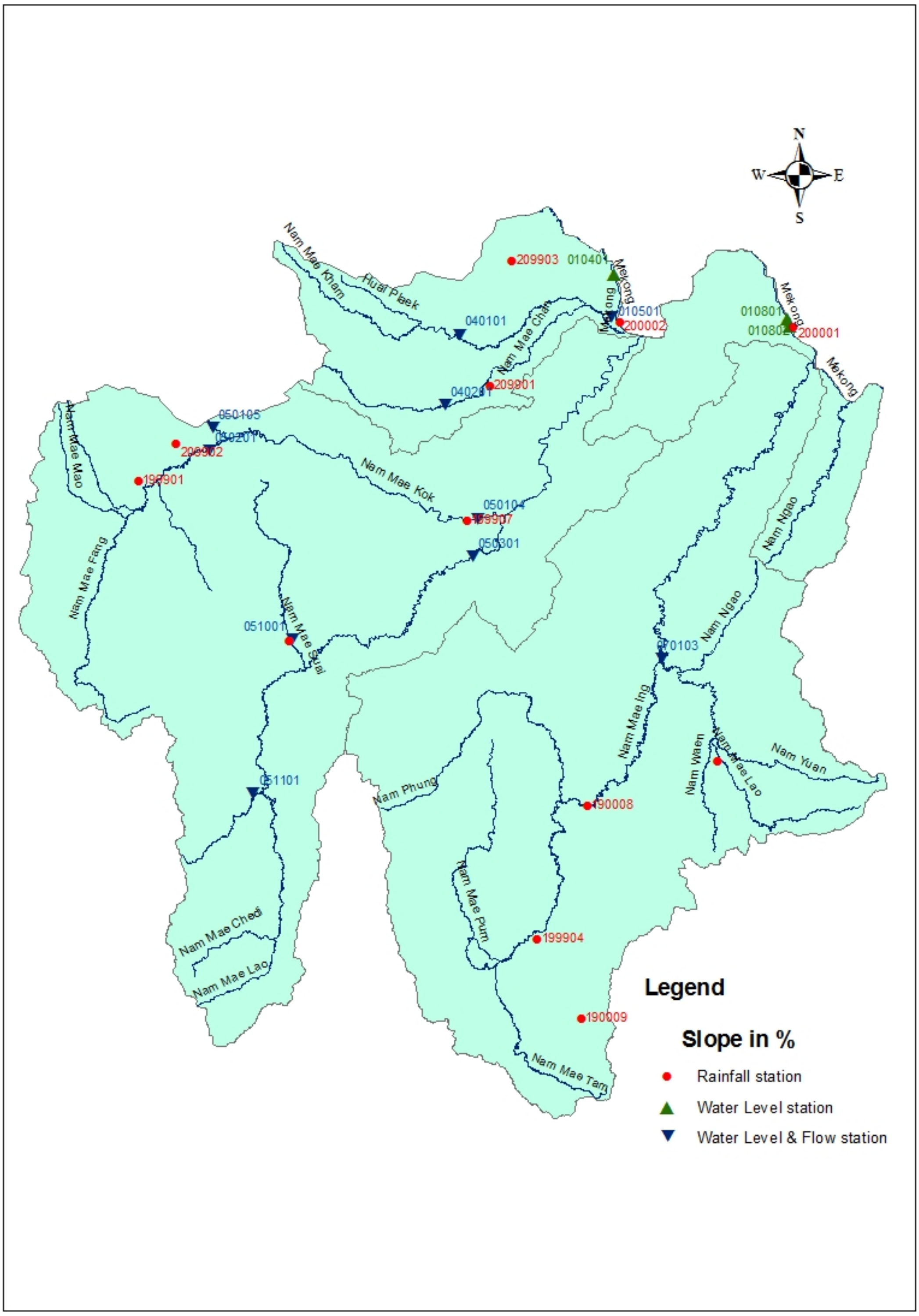

Figure 5.5 Layout of hydro-metorological network of SA2 as available in MRC database.

Table 5.2 Availability of rainfall, water level and discharge data in SA2.

Daily Data Availability of BDP Sub-Area 2T (1953-59)

Rainfall

Station ID	Station Name	River	1950						
			3	4	5	6	7	8	9
10801	Chiang Khong	Mekong	+	+	+	+	+	+	+
40101	Ban Pa Yang	Nam Mae Kham	+	+	+	+	+	+	+

Daily Data Availability of BDP Sub-Area 2T (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
190002	CHIANG KHAM	Nam Mae Ing																				
190008	KHAO ING ROD	Nam Mae Ing																	+	+	+	+
190009	BAN HUAI THAM	Nam Mae Ing																				
199901	FANG	Nam Mae Kok	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	+
199904	PHAYAO	Nam Mae Ing	+	+	+	+	+	+	+	+	+	+	+	+	+							
199907	CHIANG RAI	Nam Mae Kok				+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
199913	MAE SUAI DAM SITE	Nam Mae Kok																				
200001	CHIANG KHONG	Mekong							+	+	+	+	+	+	+	+	+	+	+	+	+	+
200002	CHIANG SAEN	Mekong							+	+	+	+	+	+	+	+	+	+	+	+	+	+
209901	MAE CHAN	Nam Mae Kham																				
209902	BAN MAE AI	Nam Mae Kok											+	+	+	+	+	+	+	+	+	+
209903	MAE SAI	Nam Mae Kham																				

Station ID	Station Name	River	1980										1990										2000					
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
190002	CHIANG KHAM	Nam Mae Ing				+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
190008	KHAO ING ROD	Nam Mae Ing	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+				
190009	BAN HUAI THAM	Nam Mae Ing	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
199901	FANG	Nam Mae Kok	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
199904	PHAYAO	Nam Mae Ing		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
199907	CHIANG RAI	Nam Mae Kok	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
199913	MAE SUAI DAM SITE	Nam Mae Kok	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+				
200001	CHIANG KHONG	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
200002	CHIANG SAEN	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
209901	MAE CHAN	Nam Mae Kham			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	212		+	122	122	+	+	
209902	BAN MAE AI	Nam Mae Kok	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
209903	MAE SAI	Nam Mae Kham				+	+	+	+	+	+	+		+		+	+	+	+	+	+	+	+	+	+	+	+	+

Water level

Station ID	Station Name	River	1960										1970									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
10401	Sop Ruak	Mekong													91	+	+	+	+	+	+	+
10501	Chiang Sean	Mekong	120	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
10801	Chiang Khong	Mekong													91	+	+	+	+	9	+	+
40101	Ban Pa Yang	Nam Mae Kham																				
40201	Ban Huai Yano Mai	Nam Mae Chan																90	+	+	+	+
50104	Chiang Rai	Nam Mae Kok																		90	+	+
50105	Ban Tha Ton	Nam Mae Kok										+	+	+	+	+	+	+	+	+	+	+
50201	Ban Tha Mai Liam	Nam Mae Fang										+	+	+	+	+	+	+	+	+	+	+
50301	Ban Tha Sai	Nam Mae Lao											24	+	+	+	+	+	+	+	+	+
51001	Dam Site	Nam Mae Suai												205	+	+	+	+	+	+	+	+
51101	Dam Site	Nam Mae Pun Luang																	91	+	+	+
70103	Thoeng	Nam Mae Ing										91	+	+	+	+	+	+	+	+	+	+

Station ID	Station Name	River	1980										1990										2000					
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
10401	Sop Ruak	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	14	+	+	+	+	+	+	+	+	+	+	+	+	+
10501	Chiang Sean	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
10801	Chiang Khong	Mekong	7	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	6	+	+	+	+	+	+	+
40101	Ban Pa Yang	Nam Mae Kham	207	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
40201	Ban Huai Yano Mai	Nam Mae Chan	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
50104	Chiang Rai	Nam Mae Kok	+	+	+	+	+	+	+	+	+	+	+	+	5	+	21	+	+	+	+	+	+	+	+	+	+	+
50105	Ban Tha Ton	Nam Mae Kok	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
50201	Ban Tha Mai Liam	Nam Mae Fang	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
50301	Ban Tha Sai	Nam Mae Lao	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
51001	Dam Site	Nam Mae Suai	+	+	+	+	+	+	+	+	+	+	+	+	6	+	5	+	+	+	+	+	+	+				
51101	Dam Site	Nam Mae Pun Luang	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
70103	Thoeng	Nam Mae Ing	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		

Discharge

Station ID	Station Name	River	1960										1970									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
10501	Chiang Sean	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
40101	Ban Pa Yang	Nam Mae Kham																				
40201	Ban Huai Yano Mai	Nam Mae Chan																90	+	+	+	+
50104	Chiang Rai	Nam Mae Kok																		90	+	+
50105	Ban Tha Ton	Nam Mae Kok										121	+	+	+	+	+	+	+	+	+	+
50201	Ban Tha Mai Liam	Nam Mae Fang										90	+	+	+	+	+	+	+	+	+	+
50301	Ban Tha Sai	Nam Mae Lao													91	+	+	+	+	+	+	+
51001	Dam Site	Nam Mae Suai																90	+	+	+	+
51101	Dam Site	Nam Mae Pun Luang																	91	+	+	+
70103	Thoeng	Nam Mae Ing										90	+	+	+	+	+	+	+	+	+	+

Station ID	Station Name	River	1980										1990										2000					
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
10501	Chiang Sean	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
40101	Ban Pa Yang	Nam Mae Kham	207	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
40201	Ban Huai Yano Mai	Nam Mae Chan	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
50104	Chiang Rai	Nam Mae Kok	+	+	+	+	+	+	+	+	+	+	+	+	5	41												
50105	Ban Tha Ton	Nam Mae Kok	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+
50201	Ban Tha Mai Liam	Nam Mae Fang	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
50301	Ban Tha Sai	Nam Mae Lao	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	+	+			
51001	Dam Site	Nam Mae Suai	+	+	+	+	+	+	+	+	+	+	+	+	6	+	5		+	+	+	+		+				
51101	Dam Site	Nam Mae Pun Luang	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
70103	Thoeng	Nam Mae Ing	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	1	+		

Notes: + = no missing
blank = missing
90 = number of missing days in a year

There are 12 water level stations in SA2 of which at 10 discharges have been measured. The series generally start in the seventies and appear to be fairly complete thereafter up to 2003. The most recent years appear not to have been entered in the HYMOS database yet.

5.2.2 Rainfall

Like for the rest of the Mekong Basin the climate in SA2 is determined by the monsoons. During the occurrence of the SW-Monsoon from May to October moist air from the Indian Ocean is brought into the Mekong Basin creating long periods with extensive rain, occasionally further aggravated by incursions of typhoons from the east. The tropical storms are most frequent in this area during the months June and July.

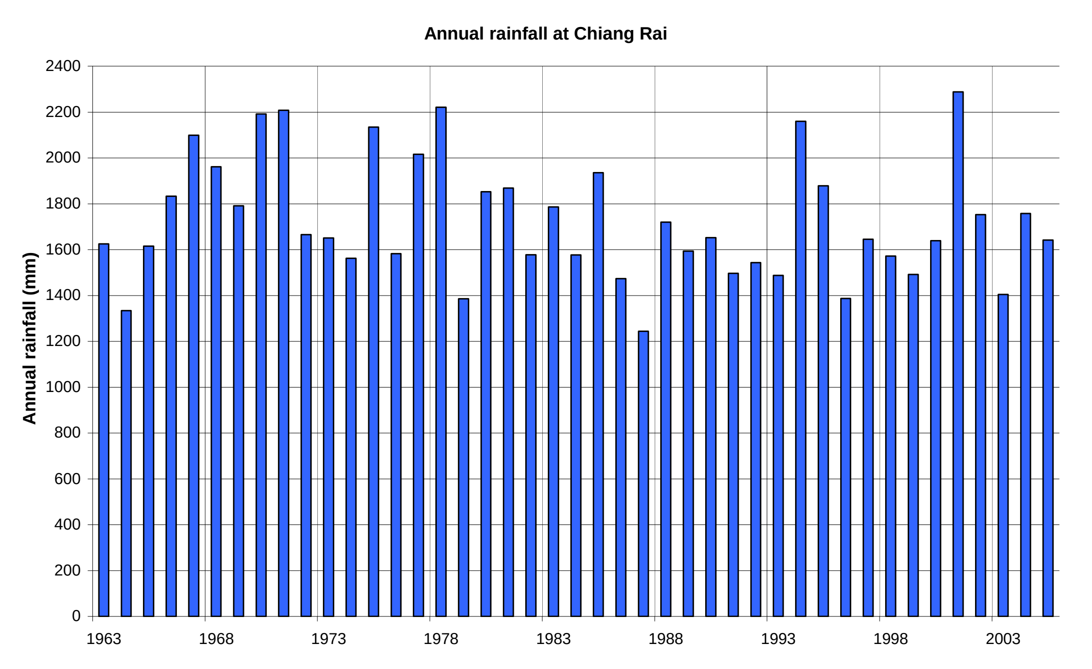

Figure 5.6 Annual rainfall at Chaing Rai, Period 1963-2005.

The average annual rainfall in SA2 varies from 1,000 to 2,000 mm, with the largest values in the north of the area towards the Mekong River (see Figure 4.6). An example of the variation of the annual rainfall in SA2 is presented in Figure 5.6 for Chiang Rai. The annual rainfall varies here from 1,200 to 2,300 mm with an average value of 1,700 mm.

The seasonal variation for the same station is presented in Figure 5.7. A double peak is observed; the first peak occurs generally in May and the second and largest peak in August with July and September also exceeding the value of May.

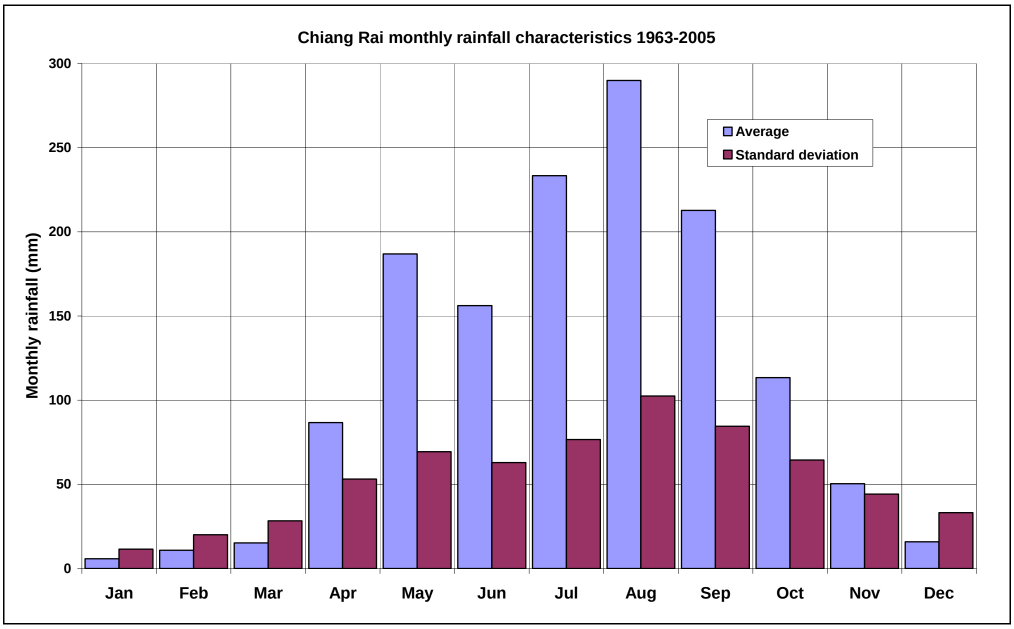

Figure 5.7 Monthly rainfall statistics of Chaing Rai, Period 1963-2005.

5.2.3 Runoff

Tributaries

The conditions regarding discharge data availability in SA2 is much more favourable than in SA1. In SA2 all major tributaries are covered by the hydrological network. To show the characteristics of the flow regime in these tributaries the daily flow records and frequency curves of the Nam Mae Kham at Ban Pa Yang (drainage area 200 km^2, mean annual flood 50 m^3/s (data by Adamson, 2007)), the Nam Mae Kok at Ban Tha Ton (drainage area 2,980 km^2, mean annual flood 350 m^3/s) and the Nam Mae Ing at Theong (drainage area 5,700 km2, mean annual flood 390 m^3/s) are presented in Figure 5.8 to Figure 5.13.

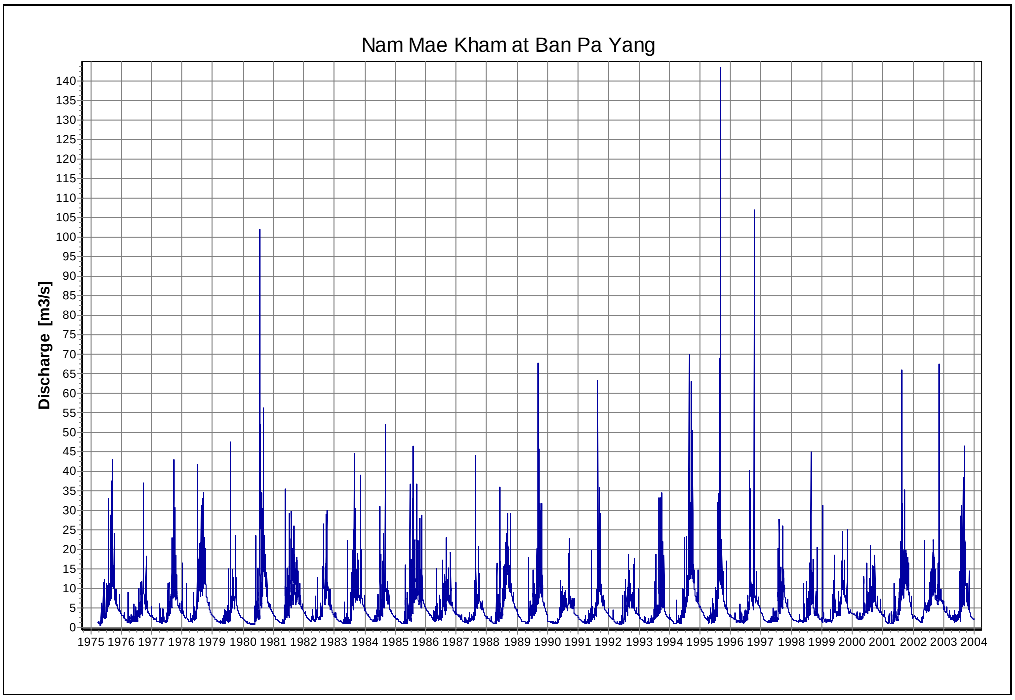

Figure 5.8 Discharge hydrograph of Nam Mae Kham at Ban Pa Yang.

The record for the Nam Mae Kham shows large variations from year to year, particularly in the peak values. The mean annual flood of 50 m^3/s has been exceeded according to the record from late July to mid November. Compared to the occurrence of peaks on the Kok and Ing floods on this river are about one month late. Difference between successive peak ratios can be as large as 7.

The record of the Nam Mae Kok at Ban Tha Ton shows less variation then the series of Ban Pa Yang above, though from one year to another the variation can still be a factor 3. The mean annual flood value has been exceeded in the past in the period between July and mid September, which is quite different from the Nam Mae Kham.

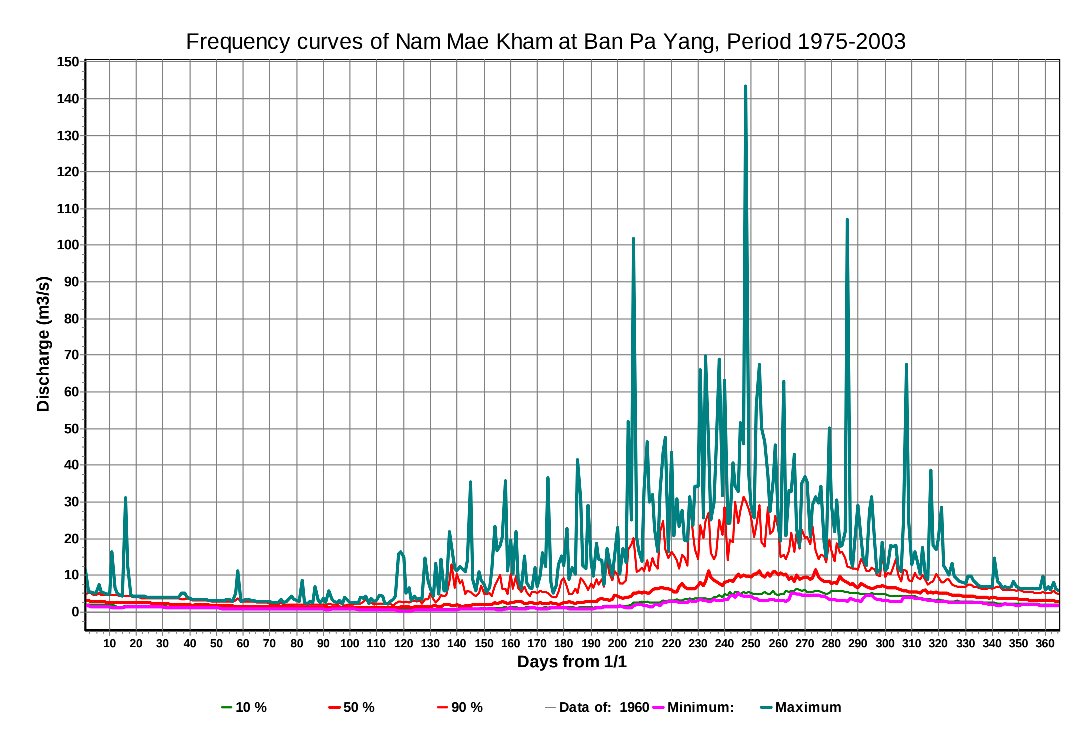

Figure 5.9 Frequency curves of the Nam Mae Kham at Ban Pa Yang.

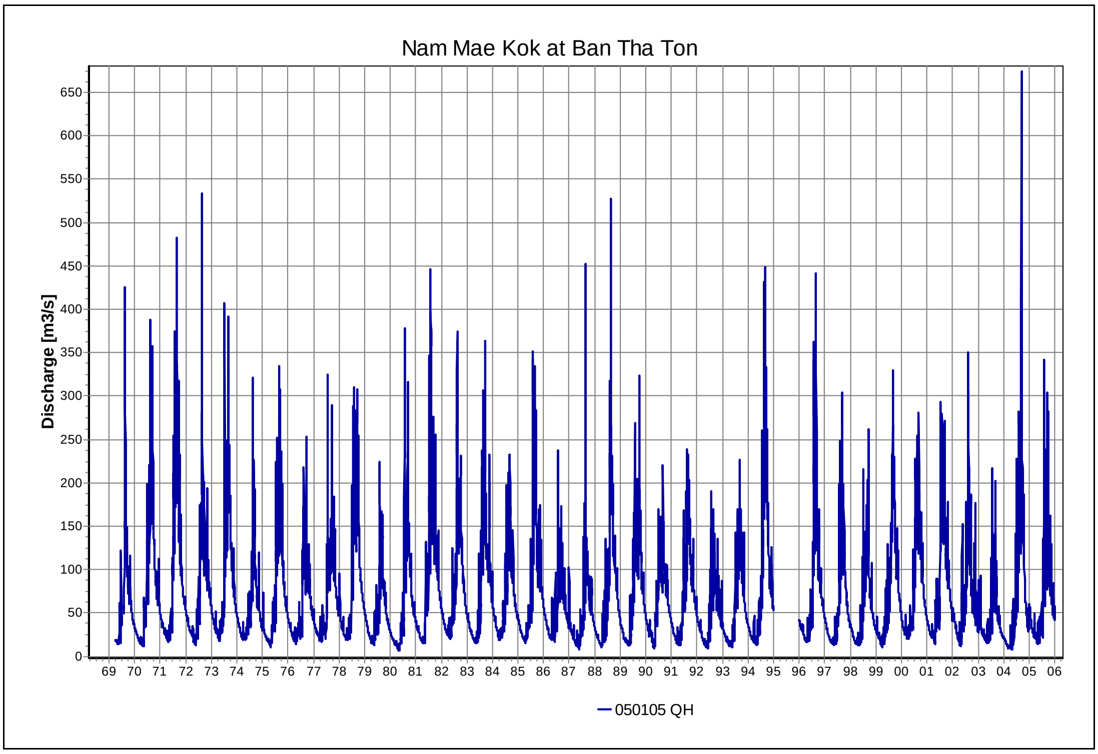

Figure 5.10 Discharge hydrograph of the Nam Mae Kok at Ban Tha Ton.

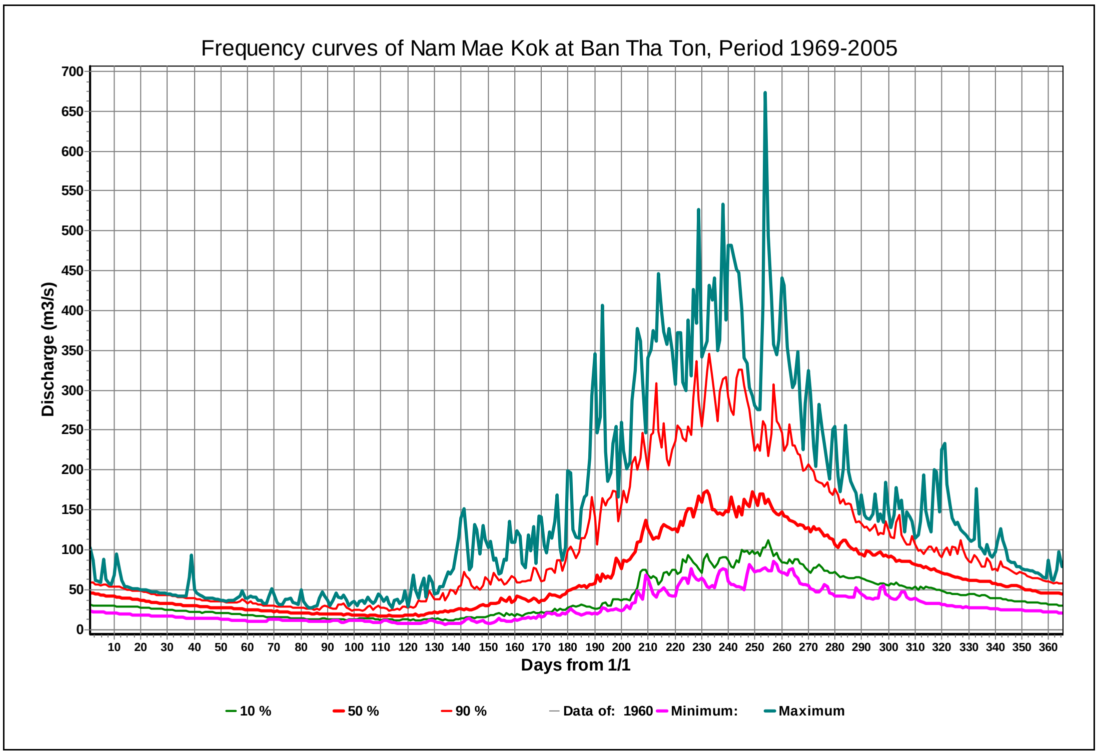

Figure 5.11 Frequency curves of the Nam Mae Kok at Ban Tha Thon

The Nam Mae Ing at Theong again shows very large differences between the lowest annual peak and the largest one, with a difference ratio of 12. The mean annual flood has been exceeded in the past in the period July to mid October. In comparison to the previous two examples the variation from one day to another in the maximum values is considerably less. It indicates that the floods on this river are less flashy then at the other two locations. Note, however, that the area covered by the station is larger and the basin contains the Kwan Phayao Lake reservoir in the upper reaches, which attenuates flood peaks from the source areas.

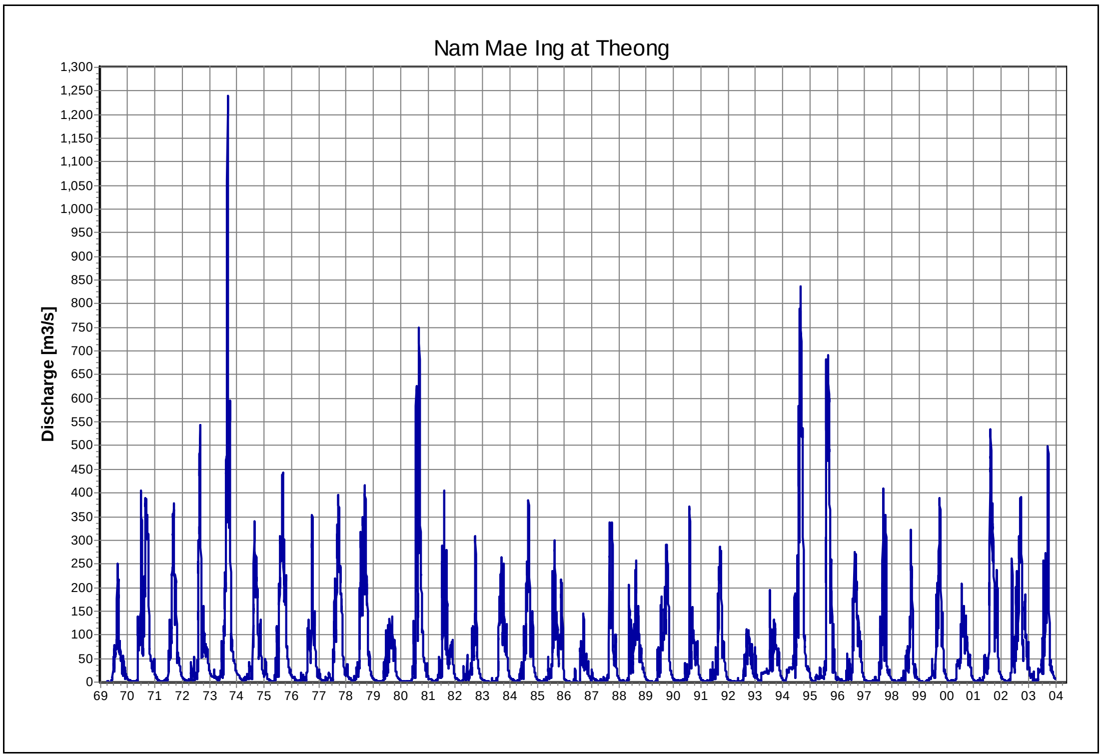

Figure 5.12 Discharge hydrograph of the Nam Mae Ing at Theong.

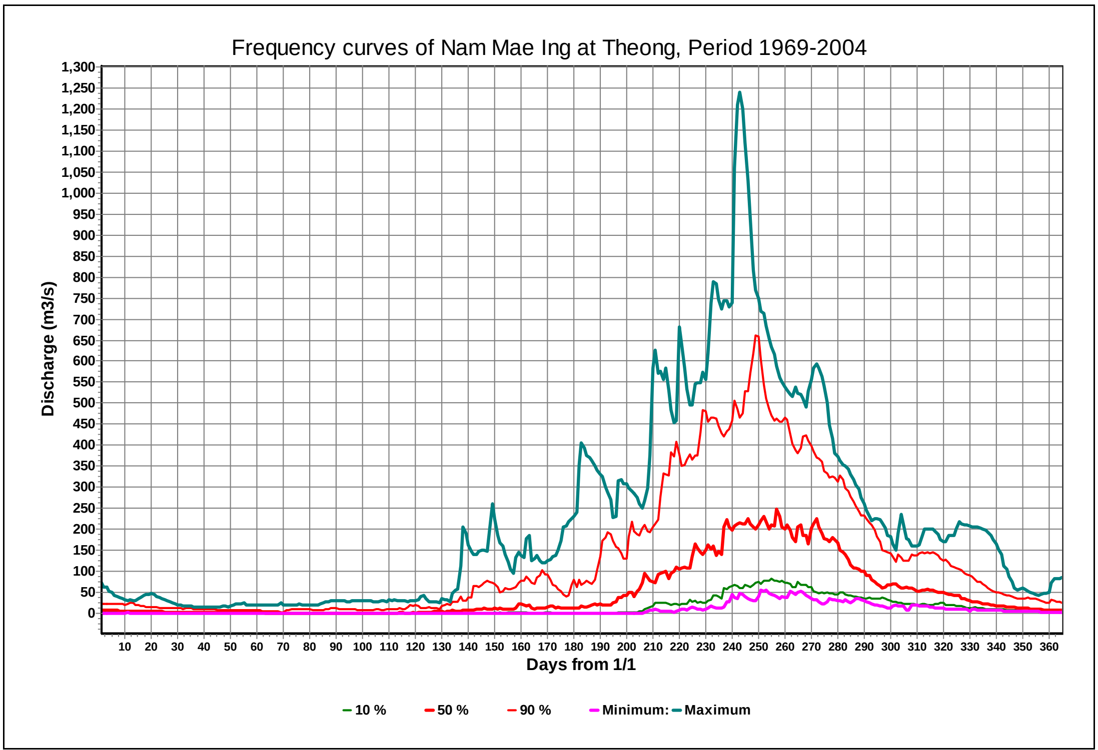

Figure 5.13 Frequency curves of the Nam Mae Ing at Theong.

The average contribution of SA2 to the flow in the Mekong is estimated at 9 BCM/yr. The monthly flows of the Nam Mae Kok at Ban Tha Ton and of the Nam Mae Ing at Theong are presented in Figure 5.14 and Figure 5.15. It is observed that in the Nam Mae Kok the largest volume is discharged in August, whereas in the Nam Mae Ing September is largest. In both cases the first rainfall peak of May as observed in the rainfall record of Chaing Rai, see Figure 5.6, has been eliminated in the runoff record as the first rains are absorbed by the soil to fill up the shortages created in the dry season.

The reliability of the flows in the Nam Mae Kok appears to be much larger then for the Nam Mae Ing; the latter shows a relatively large coefficient of variation in the monthly flows.

The runoff in mm from the Nam Mae Ing is considerably smaller then from the Nam Mae Kok as is shown in Figure 5.16. The runoff per unit area from the Nam Mae Ing is about 50% of the runoff from the Nam Mae Kok.

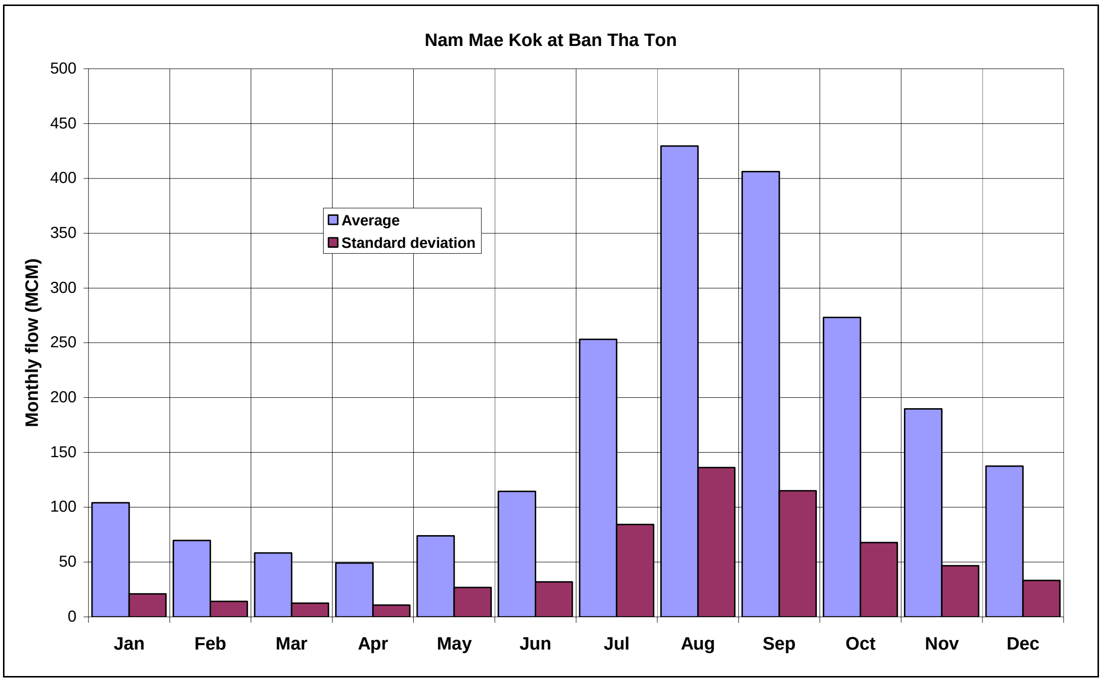

Figure 5.14 Monthly flow charcateristics of the Nam Mae Kok at Ban Tha Ton, Period 1970-2005.

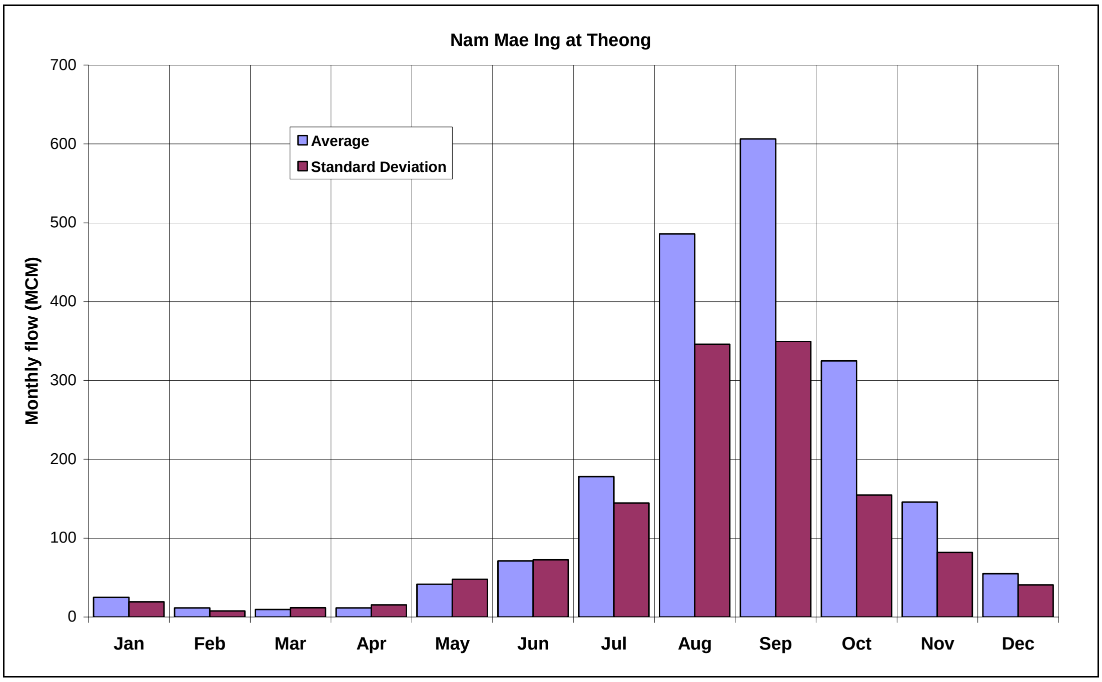

Figure 5.15 Monthly flow characteristics of the Nam Mae Ing at Theong, Period 1970-2003.

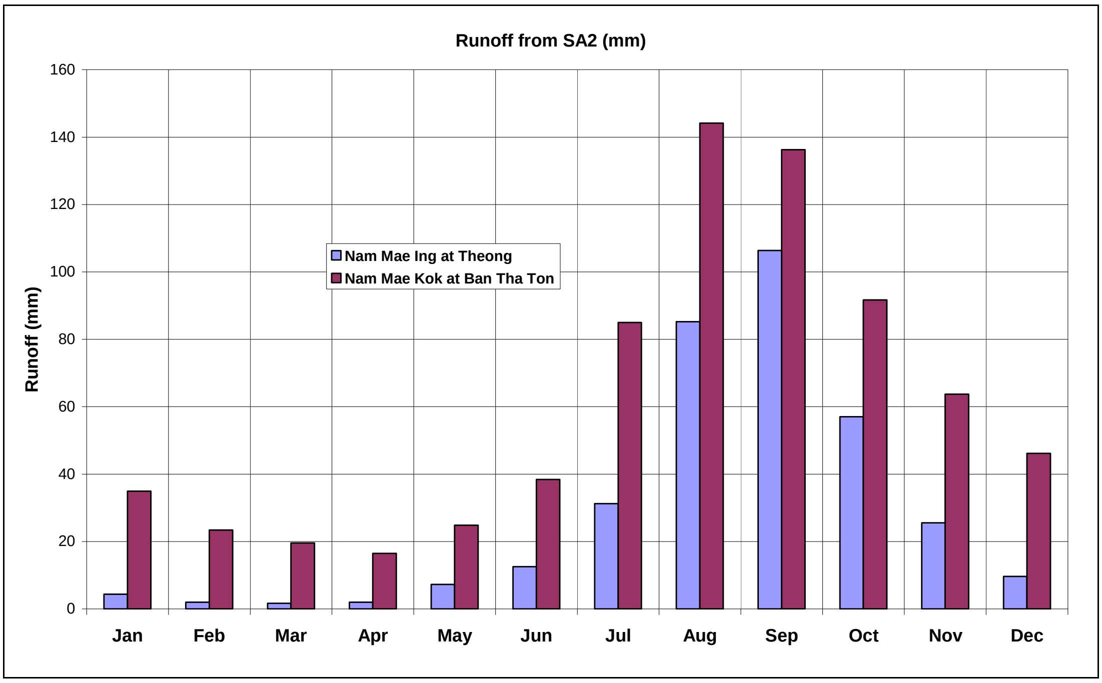

Figure 5.16 Monthly runoff in mm of Nam Mae Ing and Nam Mae Kok in SA2.

5.3 Developments in SA2 affecting the flow regime

Factors which affect or will affect in future the the flow regimes of the basins in SA2 include:

1. land use change including irrigation development
2. hydropower development, and
3. transbasin diversion

Irrigation and hydropower

In 1998 in the basins of the Kok and Ing Rivers about 150,000 ha were irrigated in the wet season and some 15,000 ha in the dry season. Irrigation water requirement for 2000 was estimated at 770 MCM, whereas the needs for domestic and industrial water supply amounted 31 MCM. Some 8 reservoirs are planned to achieve an expansion of 30% of the irrigated area. These projects will at least partly be multipurpose, combining irrigation water supply and hydropower production.

The existing and planned hydropower projects in SA2 affecting the flow regime are presented in Table 5.3. The present storage capacity is seen to be very small compared to the annual SA2 flow of about 9 BCM. However, with the Nam Kok hydropower dam implemented the flow in the Nam Mae Kok can be controlled to a large extent as the storage capacity amounts to over 50% of the annual river flow (estimated at 6.3 BCM/yr).

Table 5.3 Existing and planned hydropower projects in SA2 (source BDP, 2006).

Existing

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

Planned

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

Diversion

To reduce the water shortage in the Chao Praya River Basin the Kok-Ing-Nan Water Diversion Project has been proposed by the TNMC (BDP, 2006). It includes a 100 km long tunnel to the Nan River, a Chao Praya tributary. A feasibility study for this project was carried out in 1999. The diversion will affect the flow in the Kok and Ing Rivers. The status of the proposal at present is uncertain, also because of the adverse environmental impacts.

5.4 Floods

According to BDP (2006) flood problems in SA2 are less severe than in other sub-areas of the LMB. Nevertheless, flooding does occur, particularly in the lower parts of the Ing and Cham rivers. Flash floods and combined floods when both the main stream and tributary are high do occur.

5.4.1 Tributary floods

Ocasionally, extreme high flashy floods have occurred in SA2, particularly on the Nam Mae Kham and Nam Mae Kok as can be observed from the discharge records presented in Section 5.2. Examples of extreme floods on record are presented in Figure 5.17 and Figure 5.18. The areas covered by the stations are respectively 200 and 2,980 km^2. The flashiness of the Nam

Mae Kham flood is evident. However, it is observed that even for the larger area part of the flood hydrograph has still the characteristics of a flashy flood. The flood hydrograph shown in Figure 5.19 for Theong (drainage area 5,700 km^2) on the Nam Mae Ing has a different character, partly because of the larger area, though the rate of rise is still very high and leaves little warning time for the population.

From the discharge records available an inventory has been made of the severeness of the floods on the tributaries since 2000. For this a comparison was made with the flood statistics for the tributaries as developed by Adamson (2007), who applied a TCEV to the available discharge extremes, see also Section 4.3. The results are presented in Table 5.4. From the table it is observed that the Nam Mae Kok and particularly the Nam Mae Fang have experienced severe floods, also induced by the local topography, see Figure 5.3. The confluence of the Lao River with the Ing River is also reported to be prone to flooding. It is also observed from the table that the occurrence of floods is very diverse and may be confined to a small area only.

In 2005 no flooding was reported for SA2, however, the area was severely hit in 2006. In that year the severe tropical storms Prapiroon (August) and Xangsane (September) created floods in the country. The flood report mentions flash floods in the Kok-basin in Chiang Rai and Pa-yaw provinces inundating in total 534 km^2 of land, creating large damages.

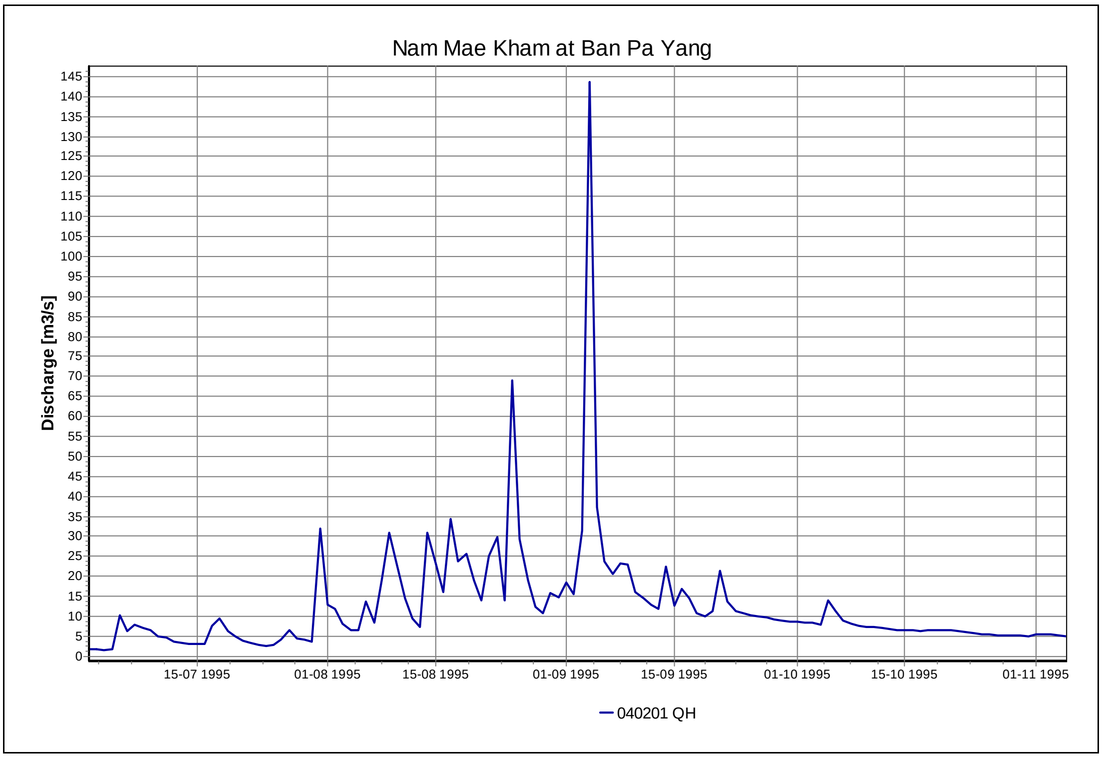

Figure 5.17 Flash flood on Nam Mae Kham at Ban Pa Yang in September 1995.

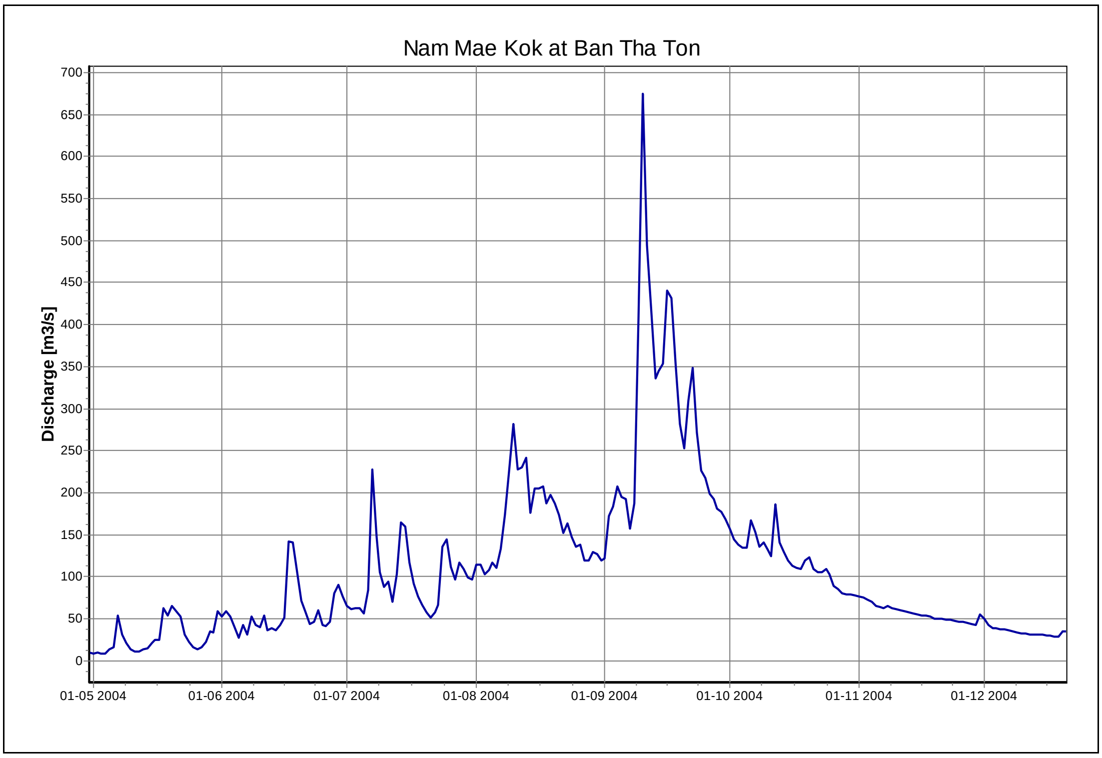

Figure 5.18 Flood on Nam Mae Kok at Ban Tha Ton in September 2004.

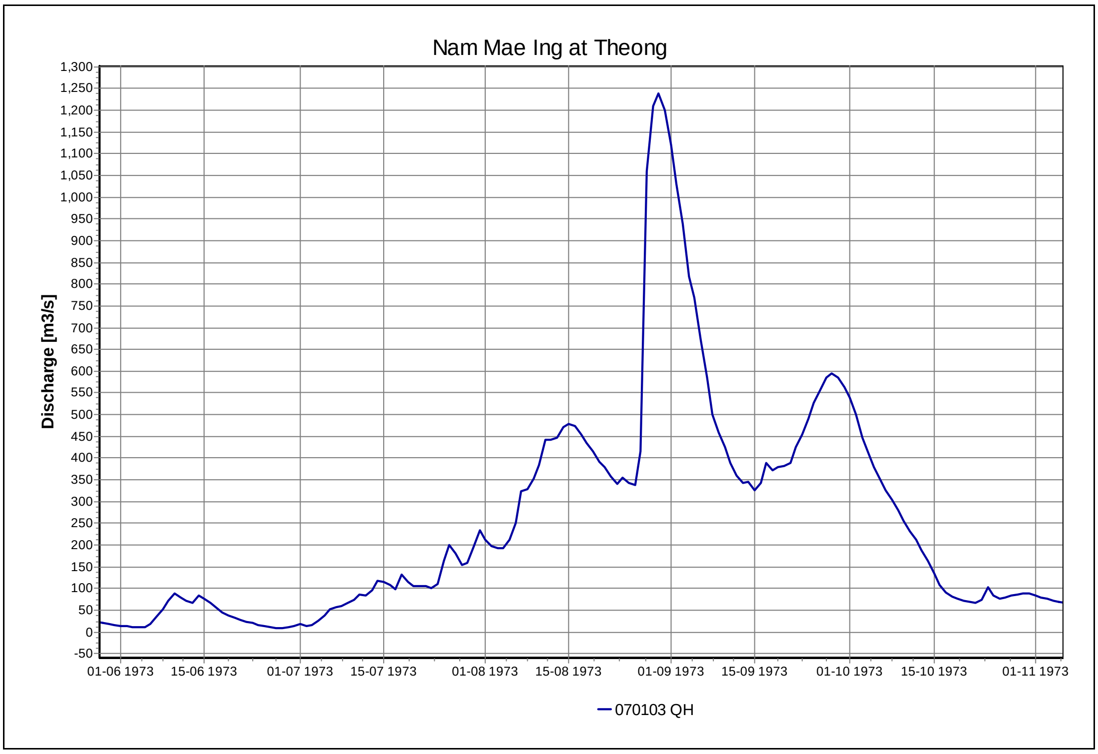

Figure 5.19 Flood on Nam Mae Ing at Theong in August-September 1973.

Table 5.4 Return period of annual extremes on tributaries of SA2 since 2000.

Year	N M Chan B. Huai Y. Mai		N M Kham Ban Pan Yang		N M Kok Ban Tha Thon		N M Fang B T Mai Liam		N M Ing Theong	
	Q_{peak}	T	Q_{pea}	T	Q_{pea}	T	Q_{pea}	T	Q_{pea}	T
2000	34	<2	21	<2	281	<2	227	4	207	<2
2001	37	<2	66	5	293	<2	279	10	535	6
2002	83	<2	68	6	350	2	300	15	391	3
2003	76	<2	46	3	217	<2	483	>100	499	5
2004	-	-	-	-	674	>20	-	-	-	-
2005	-	-	-	-	342	2	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-

From the availability of rainfall data in SA2 it follows a density of 1 station per 1,500 km^2. Though the conditions are much better than in SA1, such density is still too low to carry out detailed rainfall-runoff modelling for hydrological hazard determination. Furthermore, the daily time interval of the available data is too large for a proper description of the flash flood phenomenon. The regional approach as suggested by Adamson (2007), see also Section 4.4.1, is a solution, provided that an improved relation between the mean annual flood, rainfall extremes and basin characteristics can be developed.

BDP (2006) states that land-use and agricultural encroachment on forest areas have contributed to floods in SA2, and that the most effective measures for flood control and mitigation in SA2 would be rehabilitation and conservation of upstream watersheds, to retard the river flow. Enhancing the use of wetlands is also considered as an important flood control measure. Adamson (2007), however, disputes these statements and found neither clear evidence in the data nor in literature that land use changes and deforestation have had a major impact on flooding in this region. The available data sets on rainfall and runoff (network density, length of record, time interval) are insufficient to draw conclusions.

With the large hydropower project in Myanmar implemented, the flooding along the Nam Mae Kok main stream is expected to be controlled to some extent in view of the relatively large storage capacity upstream.

5.4.2 Main stream floods

Reference is made to Section 4.4.2 for an analysis of the main stream floods and the determination of flood hazards along the Mekong River.

5.4.3 Combined floods

According to BDP (2006) at the confluences of the Nam Mae Kok and of the Nam Mae Ing with the Mekong River flooding problems have occurred in the past due to reduced discharge capacity in the tributaries caused by backwater from the Mekong. The extremes on the Mekong and on the tributaries generally coincide, more so for the Nam Mae Kok than for the Nam Mae Ing (see Figure 5.20 and Figure 5.21). The physical conditions for backwater at those locations are clearly visible from the slope map of the sub-area, see Figure 5.3. Particularly the Nam Mae Kok reach from Chiang Rai city to the Mekong floods are regularly encountered. A provisional hydraulic model was developed for the lower reach of the Nam Mae Kok to analyse the extent of flooding and to design flood control/mitigating measures. The quality of the model at present is, however, insuffucient for reliable risk assessment. It is understood that in 2008 in the frame of Partners for Water (Netherlands funding) hydrological and hydraulic modelling of the lower Nam Mae Kok will be taken up.

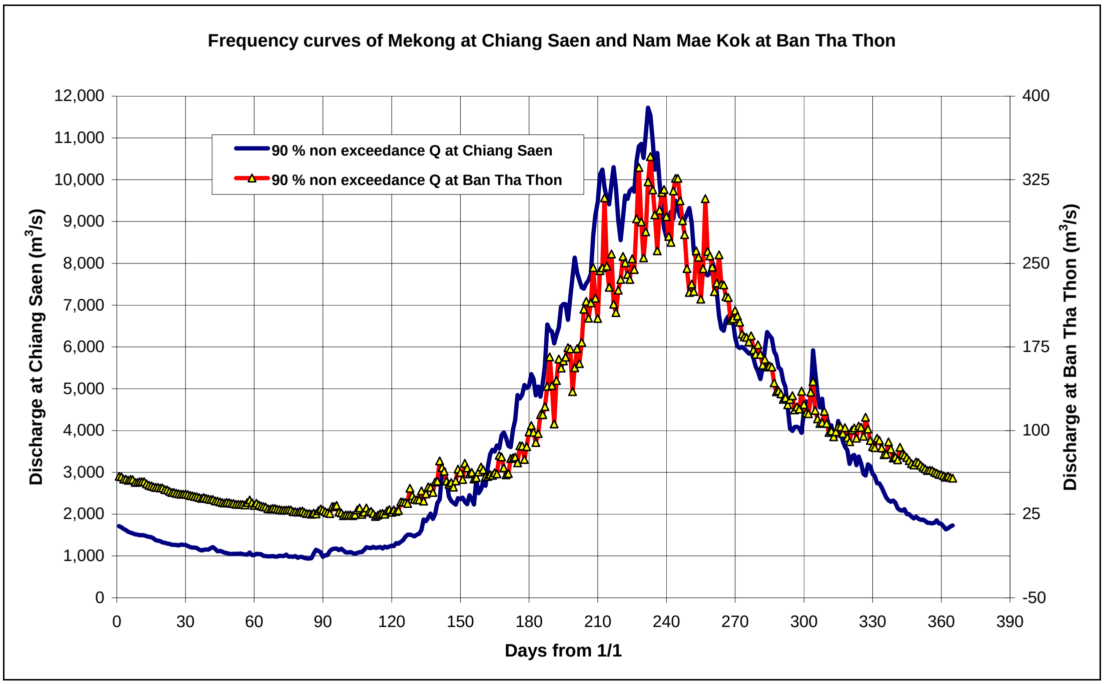

Figure 5.20 Frequency curves (90 %) of Mekong at Chiang Saen and Nam Mae Kok at Ban Tha Thon.

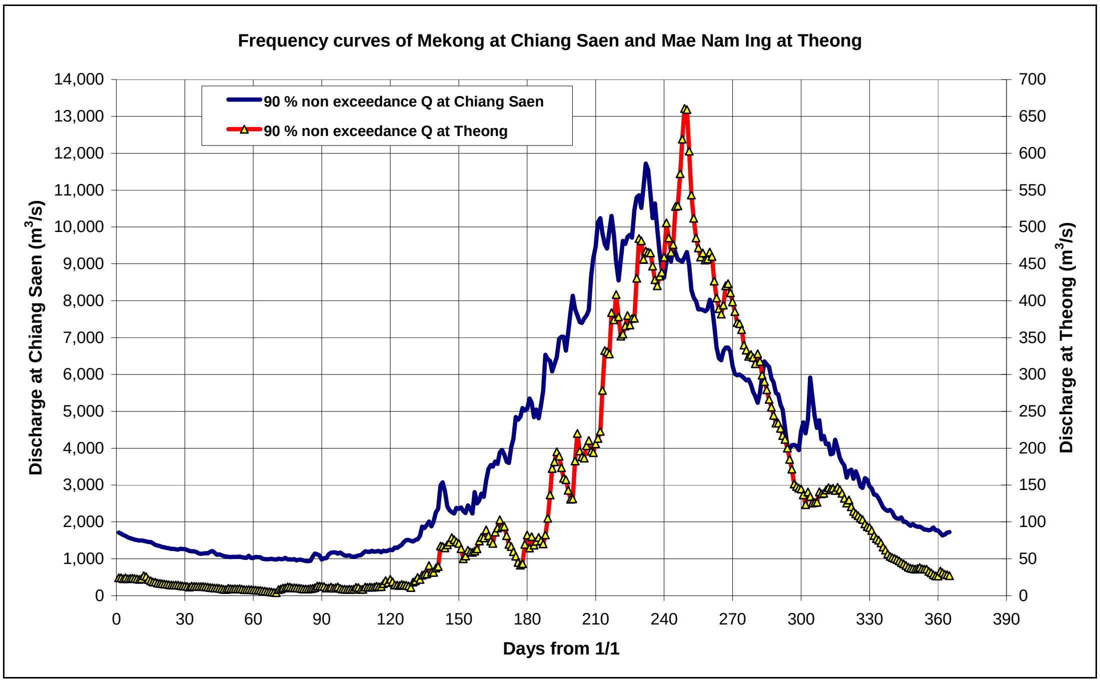

Figure 5.21 Frequency curves (90 %) of Mekong at Chiang saen and Nam Mae Ing at Theong.

5.4.4 Summing up

For the tributary floods the hydrological hazard for the gauged streams can be obtained from available discharge records. For the remaining area the procedure proposed by Adamson (2007) could be applied provided that a suitable relationship can be developed between the average annual flood and rainfall and basin characteristics. The flood hazard can only be determined when the bathymetry of the tributaries is known. Such information is generally not available. Hence, only when such measurements are being made, flood hazard can be mapped.

The hydrological hazard for the Mekong 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 satelitte based flood maps would be available for different times during the passage of the flood, inundation maps for different hazard levels could be made.

Combined floods do occur in SA2 at the lower reaches of the Nam Mae Kok and the Nam Mae Ing rivers. Modelling of the lower Nam Mae Kok is envisaged for 2008 financed by Partners for Water.

6 HYDROLOGICAL AND FLOOD HAZARDS IN SUB-AREA 3

6.1 Basin characteristics

Sub-area 3 (SA3), see Figure 6.1, covers a total area of 50,560 km^2, comprising the right bank tributaries of the Mekong between Paklay (rkm 1,800) and Khong Chiam (rkm 910) just upstream of the mouth of the Mun River. In Thailand the area is called the Mae Khong sub-basin or Songkrham/Nong Khai sub-basin. The area of SA3 between Paklay and Chiang Khan is located in Laos, whereas the remainder is on the territory of the Thailand. It comprises the following main tributaries:

- Nam Heung (drainage area 4,900 km^2, mouth at rkm 1,736), upstream of Chiang Khan (rkm 1,717)
- Nam Man and Nam San, some smaller tributaries, which drain between the Nam Heung and the Nam Loei outlets,
- Nam Loei (drainage area 3,900 km^2, mouth at rkm 1,725)
- Huai Mong (drainage area 2,720 km^2, mouth at rkm 1,571), downstream of Vientiane (rkm 1,580) and upstream of Nong Khai (rkm 1,551)
- Nam Huai Luang (drainage area 4,120 km^2, mouth at rkm 1,503) at Ban Phon Phisai Nam Songkhram (drainage area 13,100 km^2, mouth at rkm 1,263) upstream of Nakhon Phanom (rkm 1,217), with tributaries Huai Khong, Huai Nam Yam, Nam Oon and Lam Khong Long
- Nam Pung/Nam Kam draining between Nakhon Phanom and the mouth of Huai Bang Sai, opposite of the mouth of the Se Bang Fai in Laos
- Huai Bang Sai (drainage area 3,500 km^2, mouth at rkm 1,130) upstream of Mukdahan (rkm 1,123)
- Huai Bang I, draining between Mukdahan and Khong Chiam.

Note that the left bank tributaries of the same Mekong reach are all contained in SA4.

The topographical and slope maps of SA3 are shown in Figure 6.2 and Figure 6.3. The maps show a very distinct difference between the western fringe and the middle and eastern part of SA3. West of Loei the topgraphy is hilly with levels exceeding 1,100 m at locations, but the rest of SA3 is very flat, creating a lot of drainage problems, when also the main stream is in flood.

The land use of SA3 is shown in Figure 6.4. Over 80 % is agricultural land, some 16% is deciduous forest and 2% is wetlands. The forests are mainly found in the western part of SA3 and south of Sakon Nakhon. Some 13% of the agricultural land is irrigated. The soils are predominantly classified as acrisols. Soil salinity, resulting from deforestation, excessive irrigation in the dray season and poor drainage, is a major problem in the area.

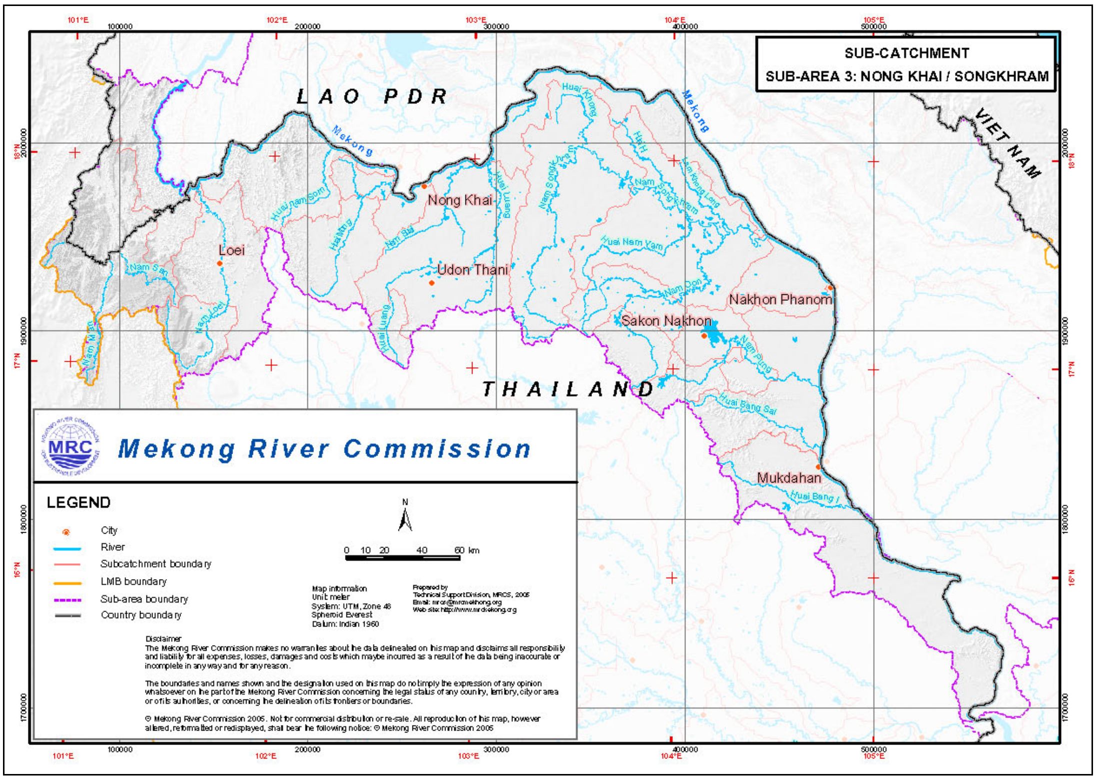

Figure 6.1 Layout of river basins in SA3 (BDP, 2006).

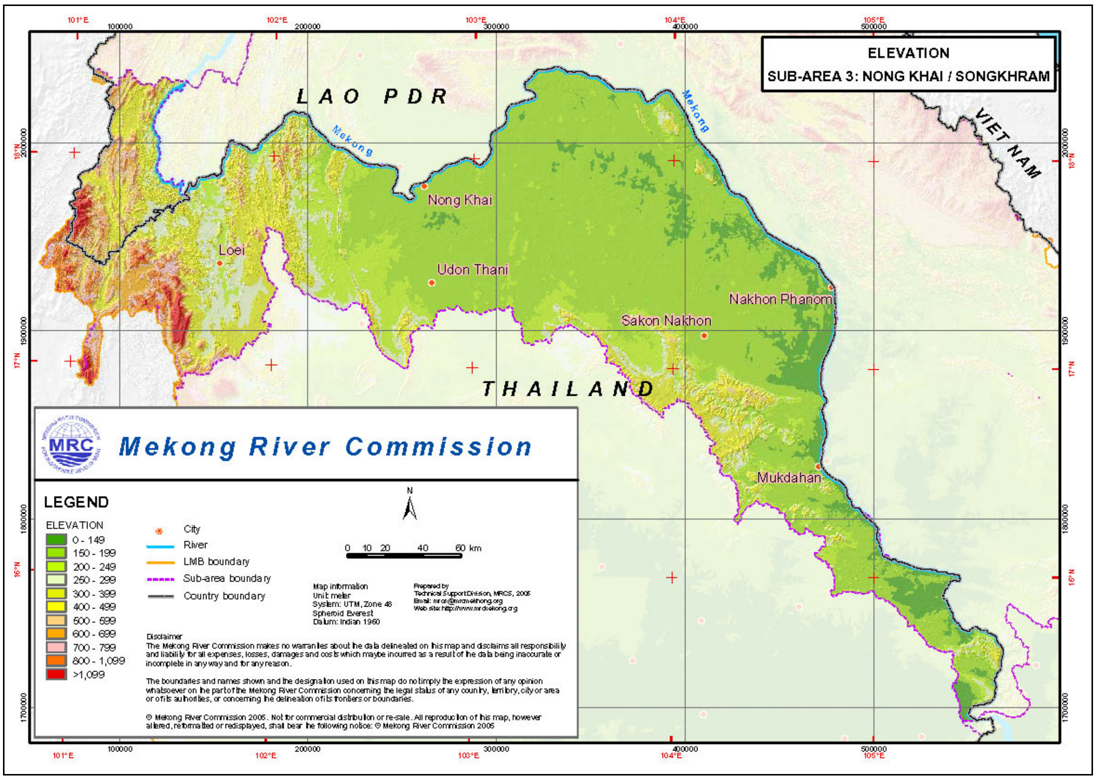

Figure 6.2 Topographical map of SA3 (BDP, 2006).

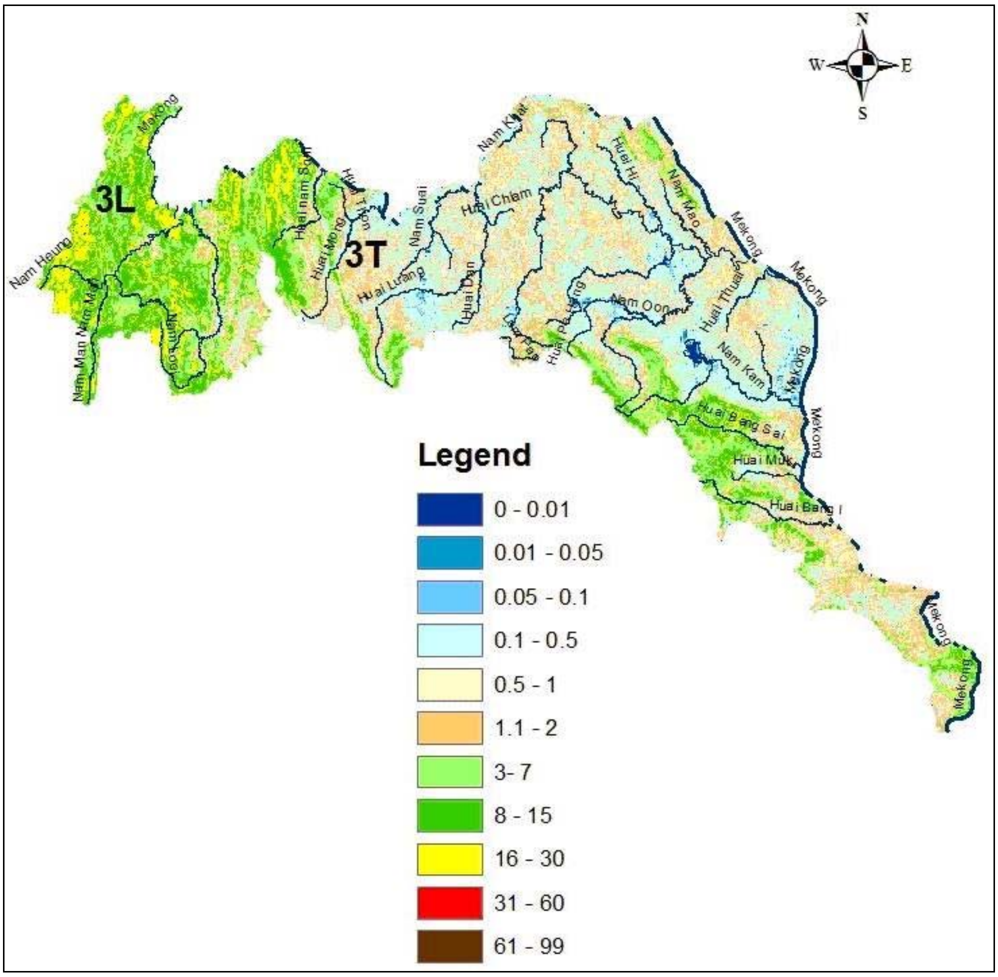

Figure 6.3 Slope map of SA3.

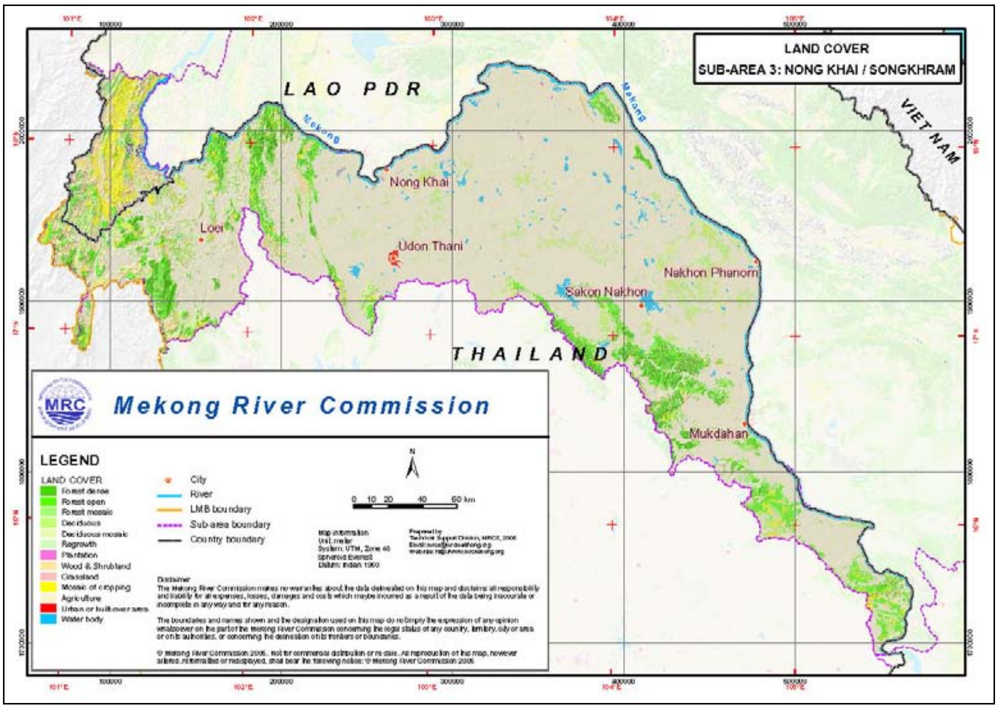

Figure 6.4 Land cover in SA3 (BDP, 2006).

6.2 Hydrological characteristics

6.2.1 Data availability

The location of the rainfall stations and the availability of rainfall data in SA3 is presented in Table 6.1, Table 6.3 and Figure 6.5.

The total number of rainfall stations in SA3 amounts 38. It implies a network density of 1 station per 1,330 km^2. Some 6 stations have records as from the mid fifties onwards, whereas the rest starts in the period between 1960 and 1980. The individual records appear to be fairly complete.

Wih respect to water level data 9 stations are located along the Mekong, whereas for the same river stretch another 6 stations are on the other river bank in Laos. In total of 9 water level stations on the tributaries data is available, generally with records as from the sixties and seventies onward. The series have not yet been updated till 2006; most records extend till 2003 or 2005.

Discharge data is available from 5 stations in Thailand, of which 2 (Nakhon Phanom and Mukdahan) have records as from 1925 onward. On the Laotian side of the Mekong use can be made of another 3 stations, with one of the longest records available of the Mekong at Vientiane. Regarding the tributaries, about the same situation applies as for the water levels: from the sixties onward generally data is available.

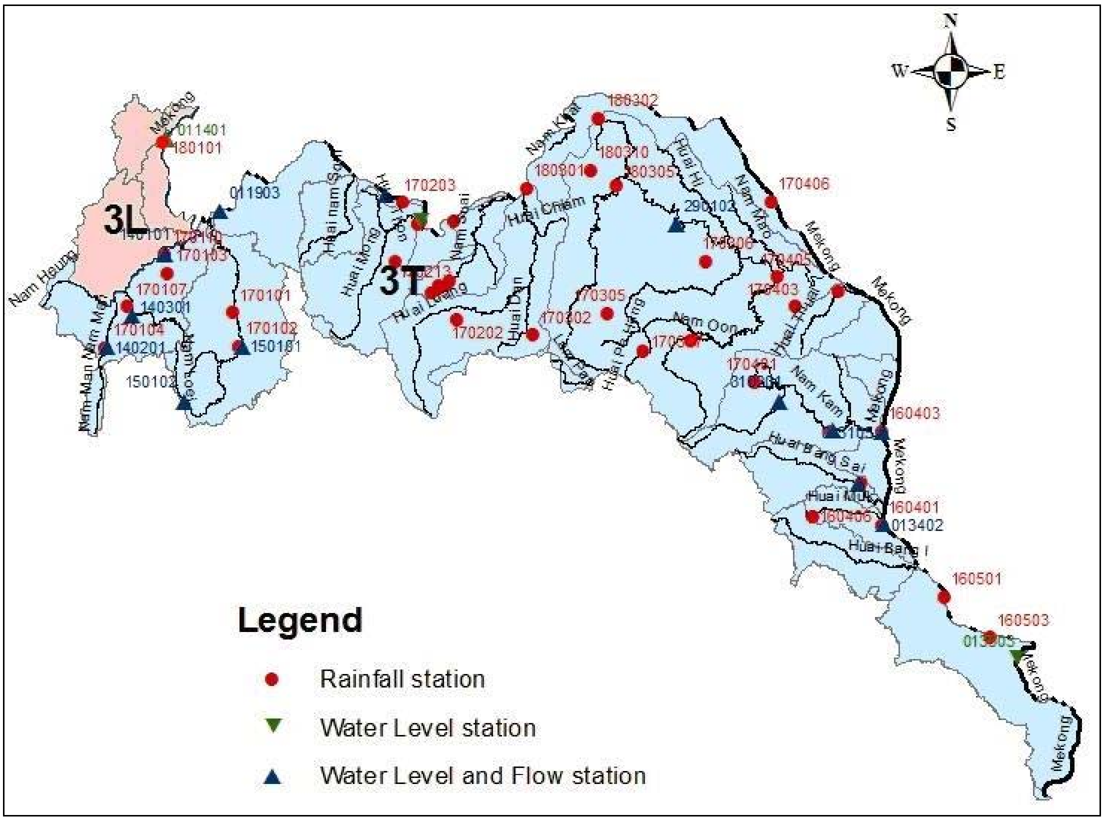

Figure 6.5 Network of rainfall, water level and stream gauging stations in SA3.

Table 6.1 Overview of rainfall stations and their locations in SA3.

Station location

Rainfall

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
160401	MUKDAHAN	Mekong	16.5334	104.7334
160402	NA KAE	Nam Kam	16.9500	104.5000
160403	THAT PHANOM	Mekong	16.9500	104.7334
160406	KHAM CHA-I	Huai Muk	16.5667	104.4167
160408	BAN KHAM PA LAI	Huai Bang Sai	16.7167	104.6334
160501	CHANUMAN	Mekong	16.2167	105.0167
160503	KHEMARAT	Mekong	16.0334	105.2334
170101	LOEI	Nam Loei	17.4500	101.7334
170102	WANG SAPHUNG	Nam Loei	17.3000	101.7667
170103	THA LI	Nam Heung	17.6167	101.4334
170104	DAN SAI	Nam Heung	17.2834	101.1500
170105	CHIANG KHAN	Mekong	17.9000	101.6667
170107	NAM SAN DAM SITE	Nam Heung	17.4667	101.2500
170110	BAN PAK HUAI	Nam Heung	17.7000	101.4167
170201	THA BO	Huai Mong	17.8500	102.5834
170202	UDON THANI	Huai Luang	17.4334	102.7667
170205	BAN PHU	Huai Mong	17.6834	102.4834
170206	NONG KHAI	Nam Suai	17.8667	102.7500
170209	BAN SRI BOON RUAN	Nam Suai	17.5835	102.7167
170210	BAN SOM SA AT	Nam Suai	17.6000	102.7334
170211	BAN NA SI	Nam Suai	17.5500	102.6500
170212	BAN DONG YEN	Nam Suai	17.5834	102.6834
170213	BAN THUAM	Nam Suai	17.5667	102.6834
170302	NONG HAN	Huai Luang	17.3667	103.1167
170304	PHANNA NIKHOM	Nam Songkhram	17.3500	103.8500
170305	SAWANG DAEN DIN	Nam Songkhram	17.4667	103.4667
170306	PHEN	Nam Songkhram	17.7000	103.9167
170307	WARITCHAPHUM	Nam Songkhram	17.3000	103.6334
170401	SAKON NAKHON	Nam Kam	17.1667	104.1500
170402	THA UTHEN	Huai Thuai	17.5667	104.5334
170403	NAKHON PHANOM	Nam Songkhram	17.5000	104.3334
170405	SISONGKHRAM	Nam Songkhram	17.6334	104.2500
170406	BAN PHAENG	H. Bang Bot	17.9667	104.2167
180208	BAN PHA TANG	Mekong	18.0334	102.3834
180301	PHON PHISAI	Mekong	18.0167	103.0834
180302	BUNG KAN	Nam Songkhram	18.3334	103.4167
180305	BAN THA KOK DAEN	Nam Songkhram	18.0334	103.5000
180310	SO PHISAI	Nam Songkhram	18.1000	103.3834

Table 6.2 Overview of water level and stream gauging stations in SA3.

Water Level

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
011903	Chiang Khan	Mekong	17.8967	101.6684
011904	Pa Mong Dam Site	Mekong	17.9850	102.4300
012001	Nong Khai	Mekong	17.8767	102.7200
012008	Tha Bo	Mekong	17.8567	102.5917
012301	Phon Phisai	Mekong	18.0217	103.0784
013101	Nakhon Phanom	Mekong	17.3984	104.8034
013105	That Phanom	Mekong	16.9500	104.7334
013402	Mukdahan	Mekong	16.5400	104.7367
013501	Khemarat	Mekong	16.0667	105.2000
140101	Ban Pak Huai	Nam Heung	17.7034	101.4150
140201	Dan Sai	Nam Man	17.2850	101.1517
140301	Dam Site	Nam San	17.4317	101.2700
150101	Wang Saphung	Nam Loei	17.2984	101.7800
150102	Ban Wang Sai	Nam Loei	17.0517	101.5200
290102	Ban Tha Kok Daeng	Nam Songkhram	17.8617	103.7800
310102	Nam Kae	Nam Kam	16.9550	104.5084
310201	Ban Tham Hai Bridge	Nam Pung	17.0800	104.2567
330103	Ban Na Kham Noi	Huai Bang Sai	16.7184	104.6250

Flow

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)		
			Latitude	Longitude	Catchment Area, km²
011903	Chiang Khan	Mekong	17.8967	101.6684	292000
011904	Pa Mong Dam Site	Mekong	17.9850	102.4300	299000
012001	Nong Khai	Mekong	17.8767	102.7200	302000
013101	Nakhon Phanom	Mekong	17.3984	104.8034	373000
013402	Mukdahan	Mekong	16.5400	104.7367	391000
140101	Ban Pak Huai	Nam Heung	17.7034	101.4150	235
140201	Dan Sai	Nam Man	17.2850	101.1517	401
140301	Dam Site	Nam San	17.4317	101.2700	703
150101	Wang Saphung	Nam Loei	17.2984	101.7800	1240
150102	Ban Wang Sai	Nam Loei	17.0517	101.5200	235
290102	Ban Tha Kok Daeng	Nam Songkhram	17.8617	103.7800	4650
310102	Nam Kae	Nam Kam	16.9550	104.5084	2360
310201	Ban Tham Hai Bridge	Nam Pung	17.0800	104.2567	1070
330103	Ban Na Kham Noi	Huai Bang Sai	16.7184	104.6250	1220

Table 6.3 Availability of rainfall data in SA3.

Daily Data Availability of BDP Sub-Area 3T (before 1960)

Rainfall

Station ID	Station Name	River	1950									
			0	1	2	3	4	5	6	7	8	9
160401	MUKDAHAN	Mekong	+	+	+	+	+	+	+	+	+	+
170101	LOEI	Nam Loei				+	+	+	+	+	+	+
170202	UDON THANI	Huai Luang	+	+	+	+	+	+	+	+	+	+
170206	NONG KHAI	Nam Suai		+	+	+	+	+	+	+	+	+
170401	SAKON NAKHON	Nam Kam				+	+	+	+	+	+	+
170403	NAKHON PHANOM	Nam Songkhram				+	+	+	+	+	+	+

3L

Station ID	Station Name	River	1920										1930										1940									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
180101	Paklay	Mekong										+	+	+	+	+	+	+	+	+	+	+	+									

Daily Data Availability of BDP Sub-Area 3T (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
160401	MUKDAHAN	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
160402	NA KAE	Nam Kam																			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	92	+	+	
160403	THAT PHANOM	Mekong							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
160406	KHAM CHA-I	Huai Muk																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	92	+	+	
160408	BAN KHAM PA LAI	Huai Bang Sai																	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
160501	CHANUMAN	Mekong																	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
160503	KHEMARAT	Mekong							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170101	LOEI	Nam Loei	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170102	WANG SAPHUNG	Nam Loei							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170103	THA LI	Nam Heung																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
170104	DAN SAI	Nam Heung							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170105	CHIANG KHAN	Mekong							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170107	NAM SAN DAM SITE	Nam Heung							+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170110	BAN PAK HUAI	Nam Heung																	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170201	THA BO	Huai Mong							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170202	UDON THANI	Huai Luang	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170205	BAN PHU	Huai Mong																			+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	31	31	+	+	
170206	NONG KHAI	Nam Suai	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170209	BAN SRI BOON RUAN	Nam Suai																			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	
170210	BAN SOM SA AT	Nam Suai																			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	
170211	BAN NA SI	Nam Suai																			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	
170212	BAN DONG YEN	Nam Suai															+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170213	BAN THUAM	Nam Suai																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	
170302	NONG HAN	Huai Luang																					+	+	+		+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	275	+	30	+	+	
170304	PHANNA NIKHOM	Nam Songkhram																					+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	122	+	92	+	+	
170305	SAWANG DAEN DIN	Nam Songkhram		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170306	PHEN	Nam Songkhram																						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	61	31	31	+	+	+	
170307	WARITCHAPHUM	Nam Songkhram																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	92	+	+	
170401	SAKON NAKHON	Nam Kam	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170402	THA UTHEN	Huai Thuai																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170403	NAKHON PHANOM	Nam Songkhram	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
170405	SISONGKHRAM	Nam Songkhram																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+			
170406	BAN PHAENG	H. Bang Bot							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
180208	BAN PHA TANG	Mekong																	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
180301	PHON PHISAI	Mekong							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
180302	BUNG KAN	Nam Songkhram																				+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
180305	BAN THA KOK DAENG	Nam Songkhram							+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
180310	SO PHISAI	Nam Songkhram																										+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	61		151	212	+	+	
3L																																															
180101	Paklay	Mekong						+	+	+	+	+	+	+	+	+	+	+	+				+		+					+	+	+	+	+	+	184													

Table 6.4 Availability of water level and discharge data in SA3.

Water Level

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
011903	Chiang Khan	Mekong						98	111	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
011904	Pa Mong Dam Site	Mekong									91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	122	19	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
012001	Nong Khai	Mekong						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
012008	Tha Bo	Mekong																					172	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
012301	Phon Phisai	Mekong													136	6	89	9	25	8	14	4	+	+	+	+	+	+	+	59	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
013101	Nakhon Phanom	Mekong													91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
013105	That Phanom	Mekong													91	+	+	+	+	+	+	+	+	3	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
013402	Mukdahan	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
013501	Khemarat	Mekong						+	+	+	+	+	+	+	+	49	+	+	+	+	104	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
140101	Ban Pak Huai	Nam Heung								90	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
140201	Dan Sai	Nam Man								+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
140301	Dam Site	Nam San							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
150101	Wang Saphung	Nam Loei							143	+	+	+	10	1	14	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
150102	Ban Wang Sai	Nam Loei																	91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
290102	Ban Tha Kok Daeng	Nam Songkhram						+	90	+	+	+	+	+	+	+	+	+	17	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
310102	Nam Kae	Nam Kam																90	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
310201	Ban Tham Hai Bridge	Nam Pung						+	90	+	+	+	+	+	+	+	34	1	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
330103	Ban Na Kham Noi	Huai bang Sai																									91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			
3L																																																	
011401	Paklay	Mekong	243											272	146	280					317	175	296	233							328	+	+	+	+	275	+	273	+	4	+		31	+	+	+		+	+

Flow

Station ID	Station Name	River	1920										1930										1940										1950									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
013101	Nakhon Phanom	Mekong					91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
013402	Mukdahan	Mekong				31	91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Flow

Station ID	Station Name	River	1960										1970										1980										1990										2000					
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
011903	Chiang Khan	Mekong								90	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
011904	Pa Mong Dam Site	Mekong									91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	122	19	+	+	+	+	+	+	+	+	+	+									
012001	Nong Khai	Mekong										90	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
013101	Nakhon Phanom	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
013402	Mukdahan	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
140101	Ban Pak Huai	Nam Heung								90	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+		
140201	Dan Sai	Nam Man								90	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
140301	Dam Site	Nam San							+	+	+	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	1	+	+		
150101	Wang Saphung	Nam Loei								90	+	+	10	+	14	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+		
150102	Ban Wang Sai	Nam Loei																	91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
290102	Ban Tha Kok Daeng	Nam Songkhram						+	+	+	+	+	+	+	+	+	+	112											+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
310102	Nam Kae	Nam Kam																90	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+						
310201	Ban Tham Hai Bridge	Nam Pung						+	+	+	+	+	+	+	+	+	34	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
330103	Ban Na Kham Noi	Huai bang Sai																									91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		

Notes: + = no missing
blank = missing
90 = number of missing days in a year

6.2.2 Rainfall

The climate in SA3 is determined by the monsoons. During the occurrence of the SW-Monsoon from May to October moist air from the Indian Ocean is brought into the Mekong Basin creating long periods with extensive rain, occasionally further aggravated by incursions of typhoons from the east. In winter time when the NE Monsoon winds bring cold dry air from the China mainland the rainfall amounts are low as was described in the discussion on the typical climatic features of the LMB in Chapter 2.

The annual rainfall in SA3 amounts about 1,500 mm, with a clear west-east trend; in the west of SA3 the rainfall amounts on average 750 mm, whereas in the north-eastern part of the sub-area the rainfall has increased to 3,000 mm, as a result of orographical effects of the mountains on the other side of the river (see Figure 4.6). The variation of the annual rainfall from 1960 onward is shown in Figure 6.6. It clearly reflects the west-east increasing trend. Another remarkable fact is that the annual rainfall from one location to another, apart from the trend varies considerably. This can be observed from the low correlation coefficients between annual rainfall of selected stations in SA3.

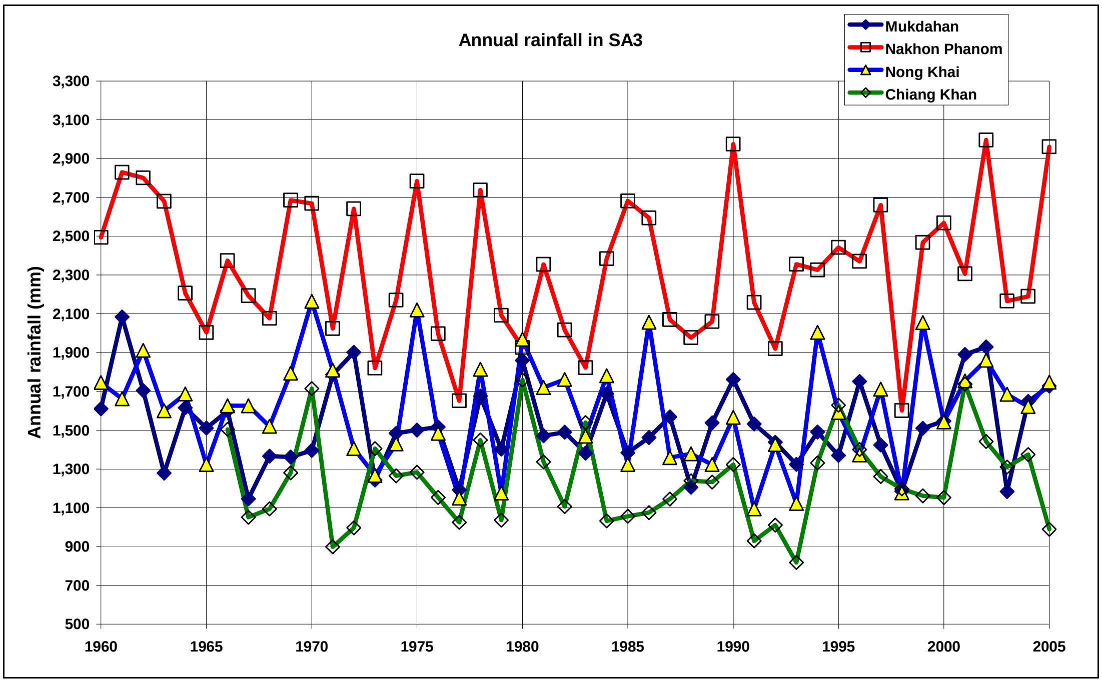

Figure 6.6 Annual rainfall at selected stations in SA3.

Table 6.5 Correlation between annual rainfall at selected stations in SA3.

Station	Chiang Khan	Nong Khai	Nakhon Phanom	Mukdahan
Chiang Khan	1.00	0.40	0.09	0.21
Nong Khai	0.40	1.00	0.51	0.32
Nakhon Phanom	0.09	0.51	1.00	0.45
Mukdahan	0.21	0.32	0.45	1.00

There is a strong seasonality in the rainfall as a result of the monsoons, as may be observed from Figure 6.7 to Figure 6.10. It is observed that the double peak in the monthly rainfall pattern, characteristic for the north-western part of the LMB, and visible from the statistics of Chiang Saen, vanishes towards the east and the south. Apart from Chiang Khan in the west, towards the east and south August is the wettest month in the year on average.

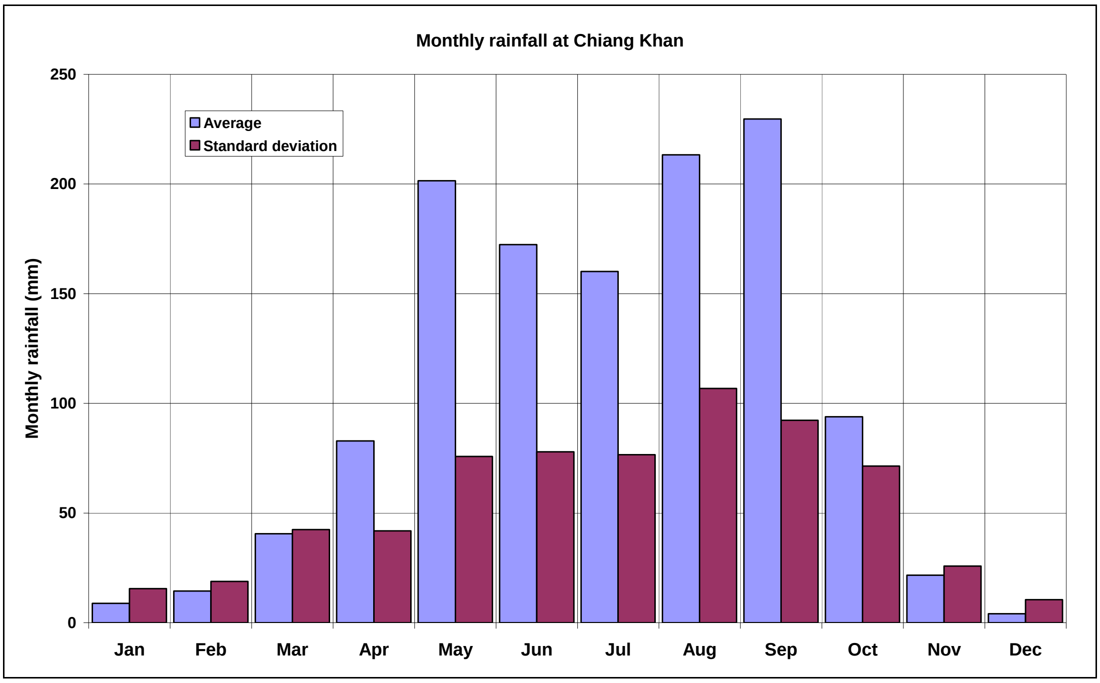

Figure 6.7 Monthly rainfall characteristics of Chiang Khan.

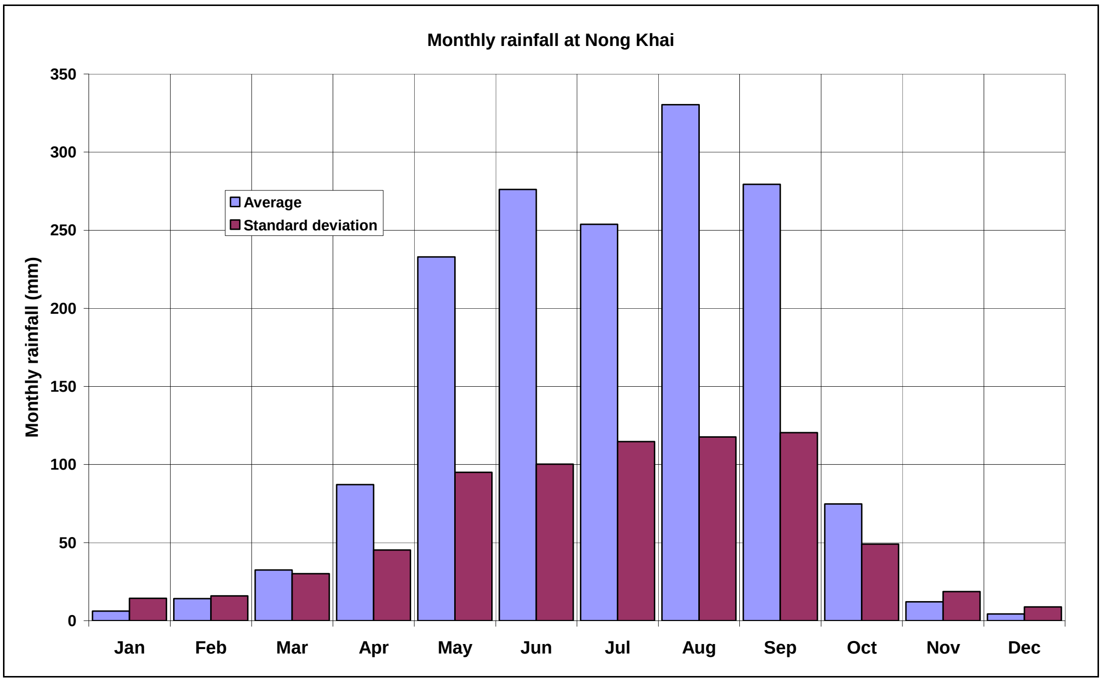

Figure 6.8 Monthly rainfall characteristics of Nong Khai.

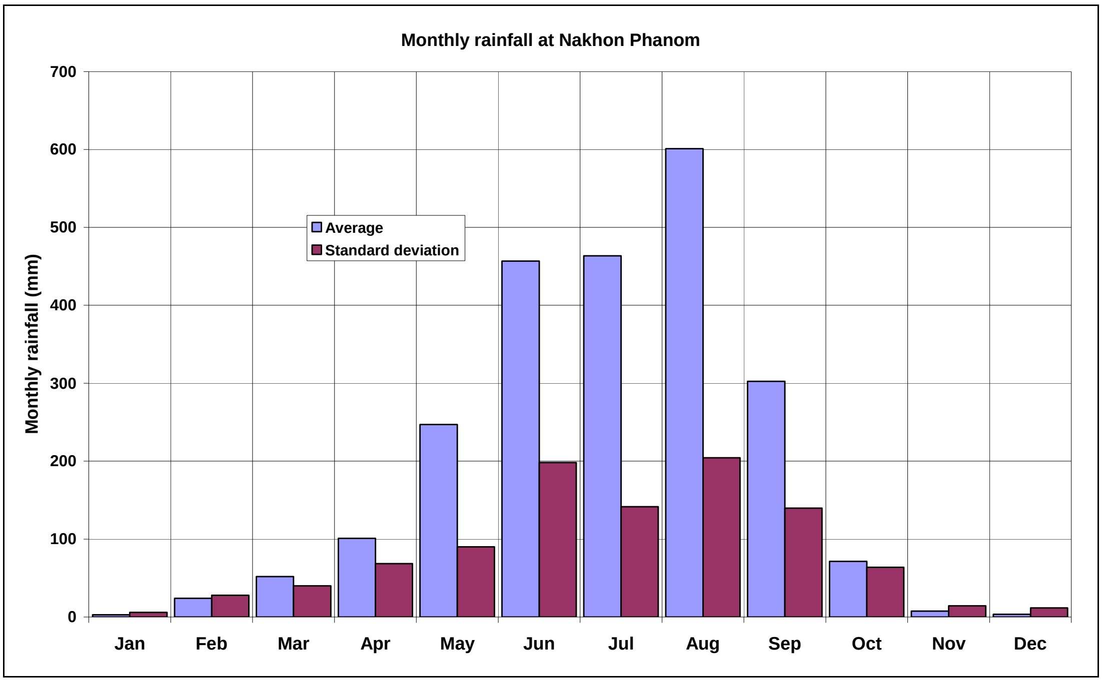

Figure 6.9 Monthly rainfall characteristics of Nakhon Phanom.

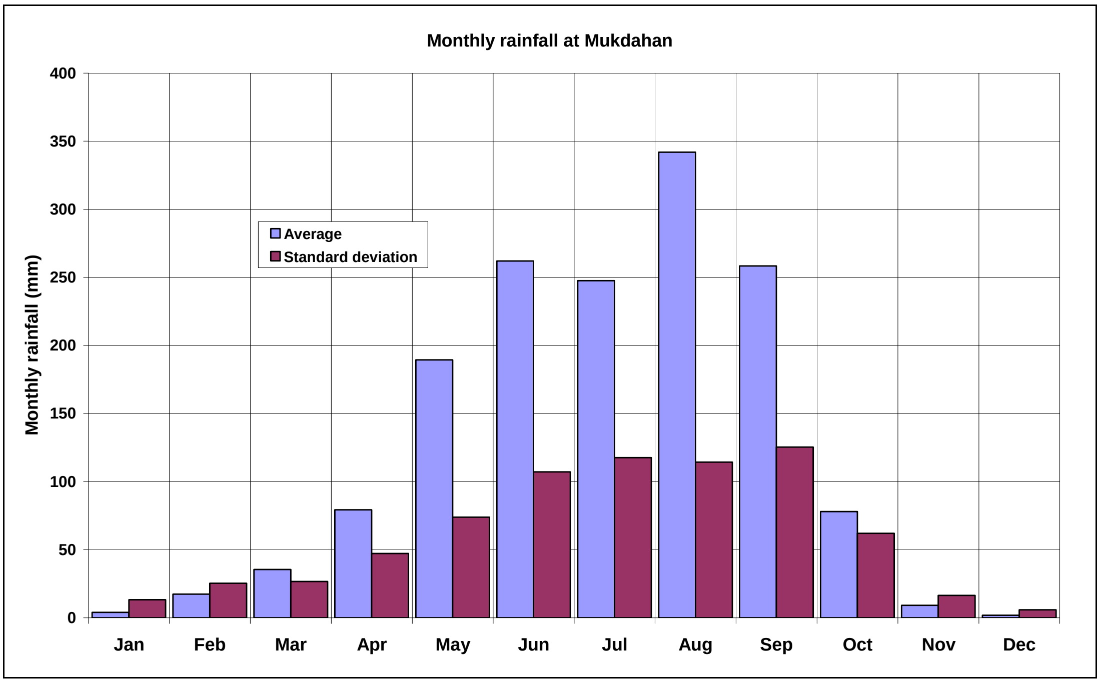

Figure 6.10 Monthly rainfall characteristics of Mukdahan.

6.2.3 Runoff

The total contribution to the Mekong between Chiang Khan (basin area 292,000 km^2) and Mukdahan (basin area 391,000 km^2) comprises 72% of the BDP-sub-areas SA3 and SA4. Based on the records of these two stations (1968-2005) it is estimated that the average annual contribution of SA3 and SA4 is (241-134)/0.72 ≈ 150 BCM. The major part is produced by the basins of SA4. The average annual runoff of SA3 estimated from extrapolation of observed flows of 24% of the total area of SA3 leads to a value of about 32 BCM, which is slightly more than 20 % of the total.

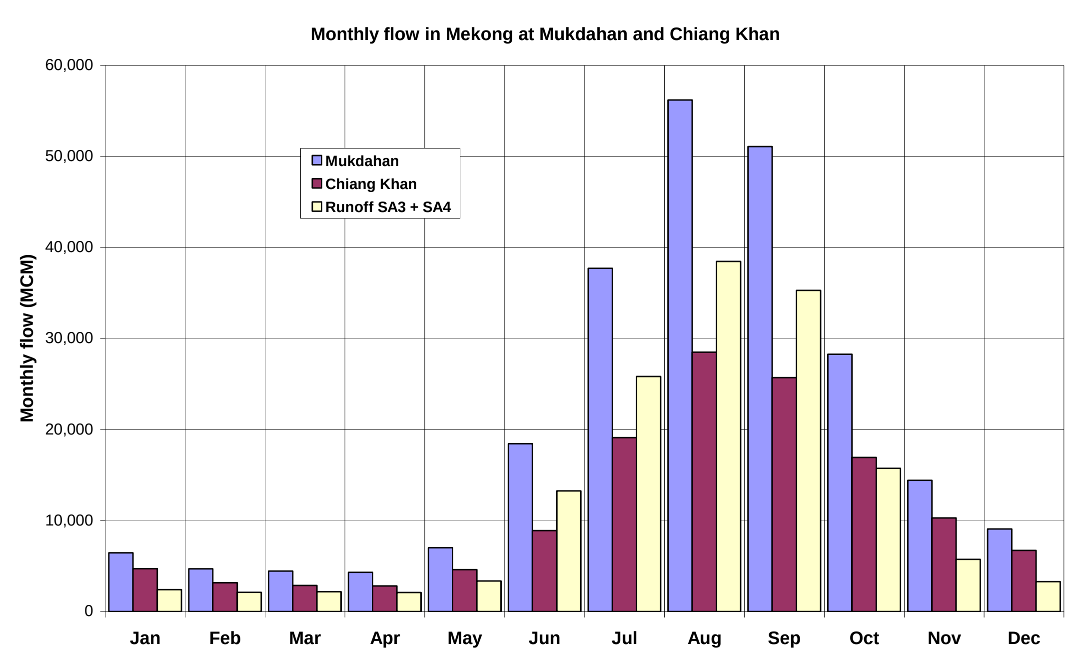

Figure 6.11 Monthly flows in Mekong at Mukdahan and Chiang Khan.

In terms of runoff depth SA3 and SA4 produce annually about 1100 mm, whereas the runoff from the area upstream of Chiang Khan is only 460 mm. The seasonal variation is observed from the average monthly contribution of SA3 and SA4 as presented in Figure 6.11 taken as 1.38 x difference between Mukdahan and Chiang Khan. It is seen that from June to September the lateral inflow from SA3 and SA4 exceeds the flow at Chiang Khan, although the upstream drainage area is about 2 times larger than of SA3 and SA4. The higher rainfall in the north-western part of LMB in September and October and the Yunnan melt component is reflected in the higher flows at Chiang Khan from October to May.

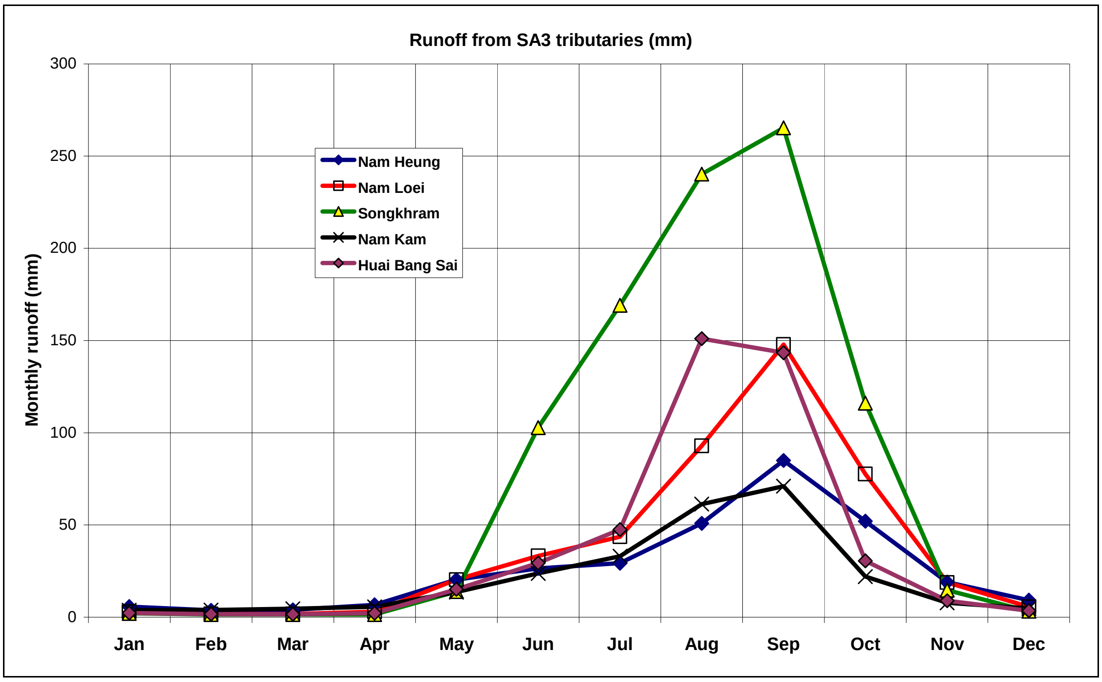

Figure 6.12 Monthly runoff in mm of selected tributaries in SA3.

In terms of runoff depth SA3 produces on average 640-700 mm annually. The seasonal variation can be observed from Figure 6.12. It generally shows highest values for September, with a few exceptions. Note also the large differences between Songkhram River and the rest of the basins: the runoff from the former seems to be more than double than from the remaining areas. This is consistent with the much higher rainfall in the north eastern part of SA3. To some extent the runoff values are affected by irrigation water use, though SA3 represents one of the least irrigated areas in Thailand.

Tributaries

The discharge hydrographs and frequency curves of selected tributaries (Nam Heung, Nam Loei and Nam Songkhram) are presented in Figure 6.13 and Figure 6.18. The different character of the hydrographs of Nam Heung and Nam Loei on the one hand and of Nam Songkhram on the other is clearly visible from the frequency curves. The flows on Nam Heung and Nam Loei do have a rather flashy character, whereas the hydrograph of Nam Songkhram has a large base width and is slowly varying. The differences may also be observed from a comparison of median and maximum values, which is more than 10 for the first two and less than 2 for last one.

Above average floods on Nam Heung occurred from mid-August till the end of September, whereas on Nam Loei such floods can also be expected up to the end of October. On Songkhram the flood period is much longer, starting as early as June and lasting till the end of October.

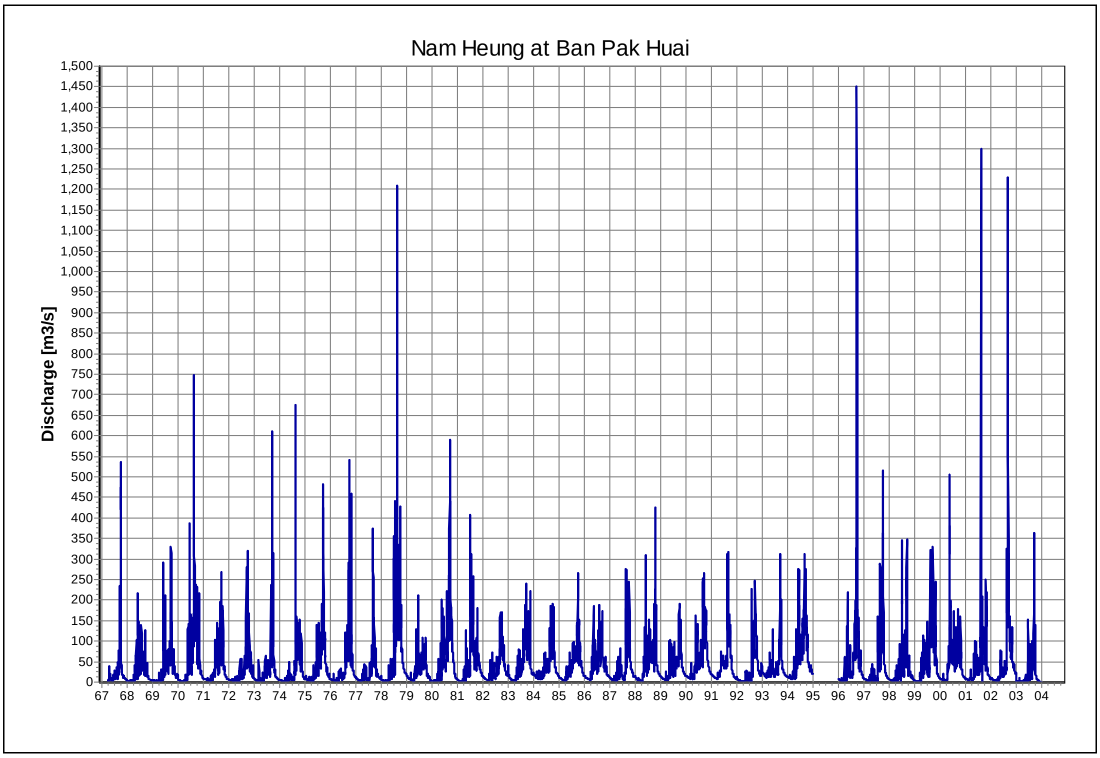

Figure 6.13 Discharge hydrograph of Nam Hueng at Ban Pak Huai.

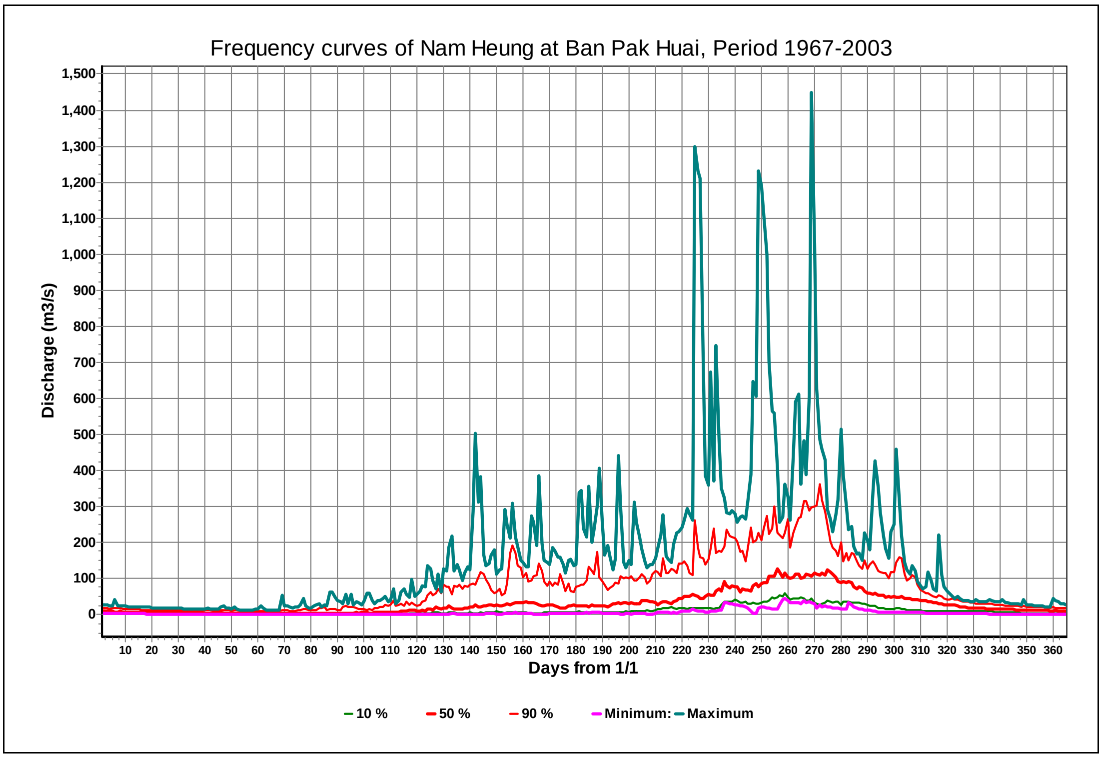

Figure 6.14 Frequency curves of daily diascharge of Nam Heung at Ban Pak Huai.

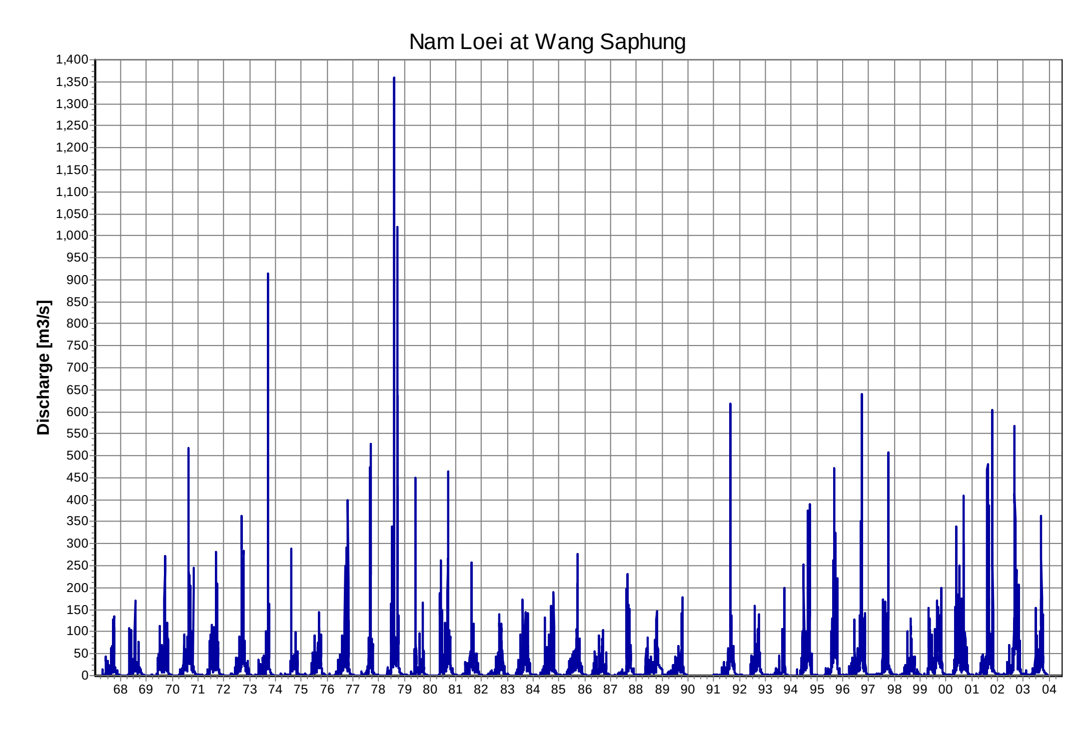

Figure 6.15 Discharge hydrograph of Nam Loei at Wang Saphung.

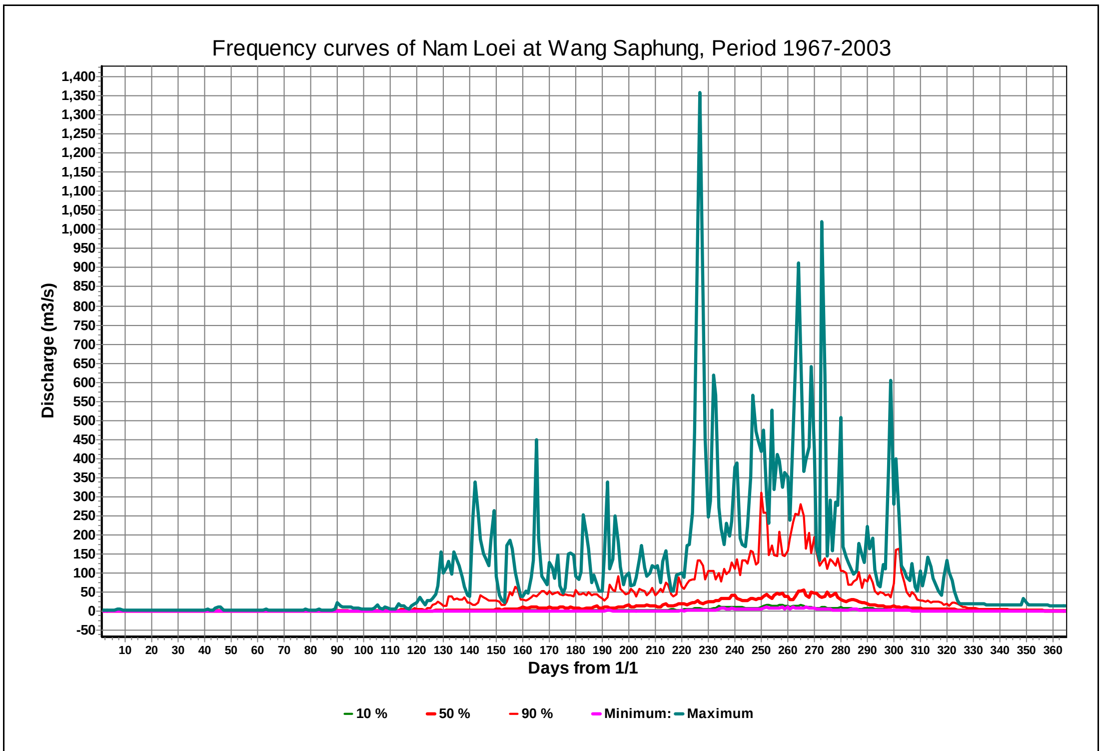

Figure 6.16 Frequency curves of daily discharge of Nam Loei at Wang Saphung.

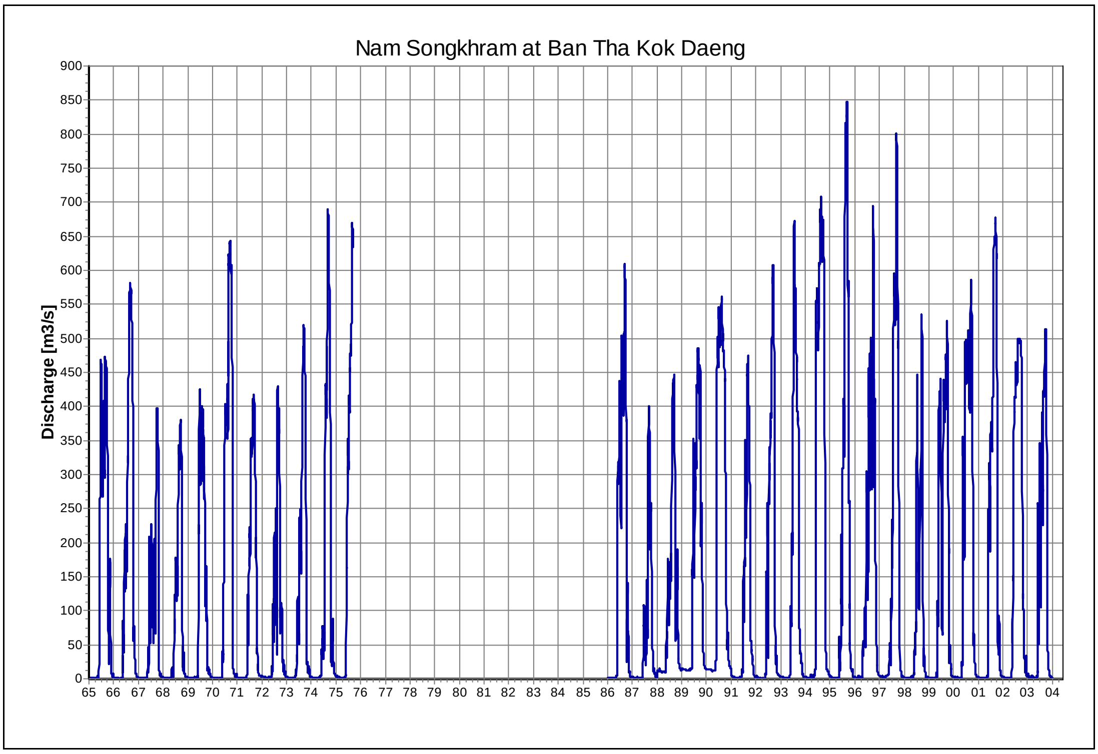

Figure 6.17 Discharge hydrograph of Nam Songkhram at Ban Tha Kok Daeng.

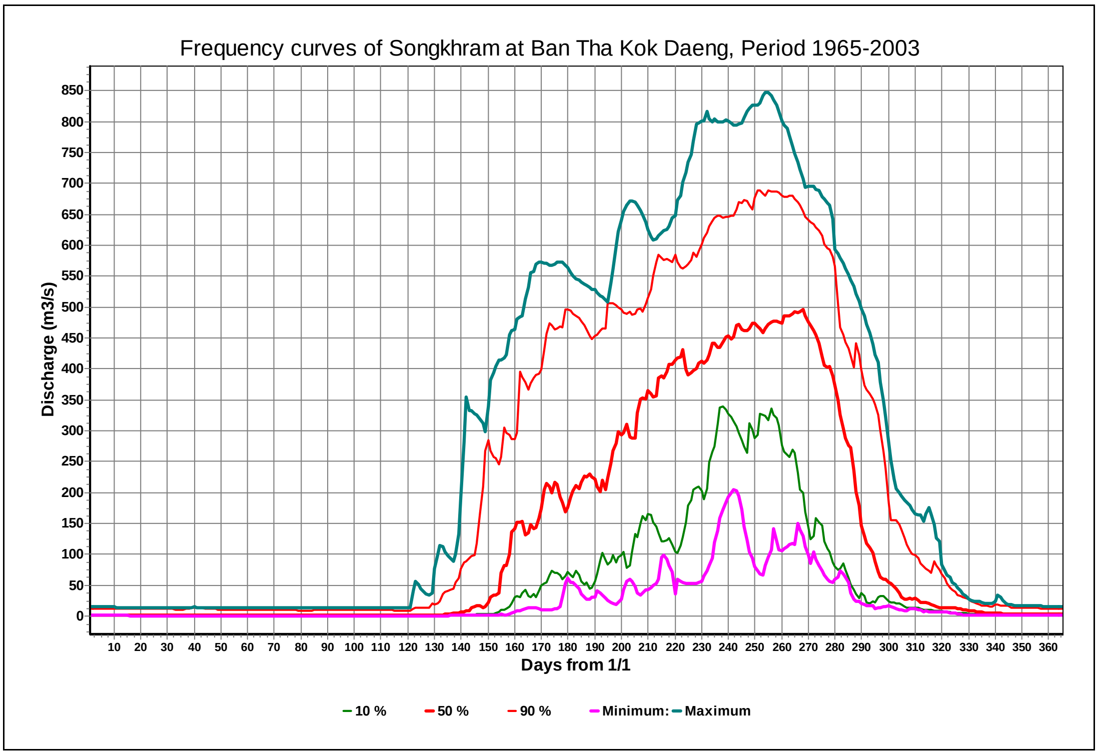

Figure 6.18 Frequency curves of daily discharge of Nam Songkhram at Ban Tha Kok Daeng.

Main stream

The annual flow of the main stream stations Chiang Khan, Vientiane/Nong Khai, Nakhon Phanom and Mukdahan since 1960 is presented in Figure 6.19. It is observed that the major inflow occurs between Vientiane and Nakhon Phanom. It is also observed that from 1994 onward the derived annual flow at Nakhon Phanom is larger than at Mukdahan, which hints at abstraction of water between the two sites if the data would be correct. It is more likely that the applied rating curves at the respective sites require further attention before conclusions are drawn. Comparison of the flow at Mukdahan with Savannakhet shows very little deviation, so first attention in the validation process requires the Nakhon Phanom series.

In Figure 6.20 the lateral inflow to the Mekong between Nong Khai and Mukdahan and the flow at Nong Khai are displayed. It appears that there is very little correlation. It follows, since annual volumes and flood volumes and flood peaks are strongly correlated, that the flood characteristics upstream and downstream of Vientiane/Nong Khai will be very different.

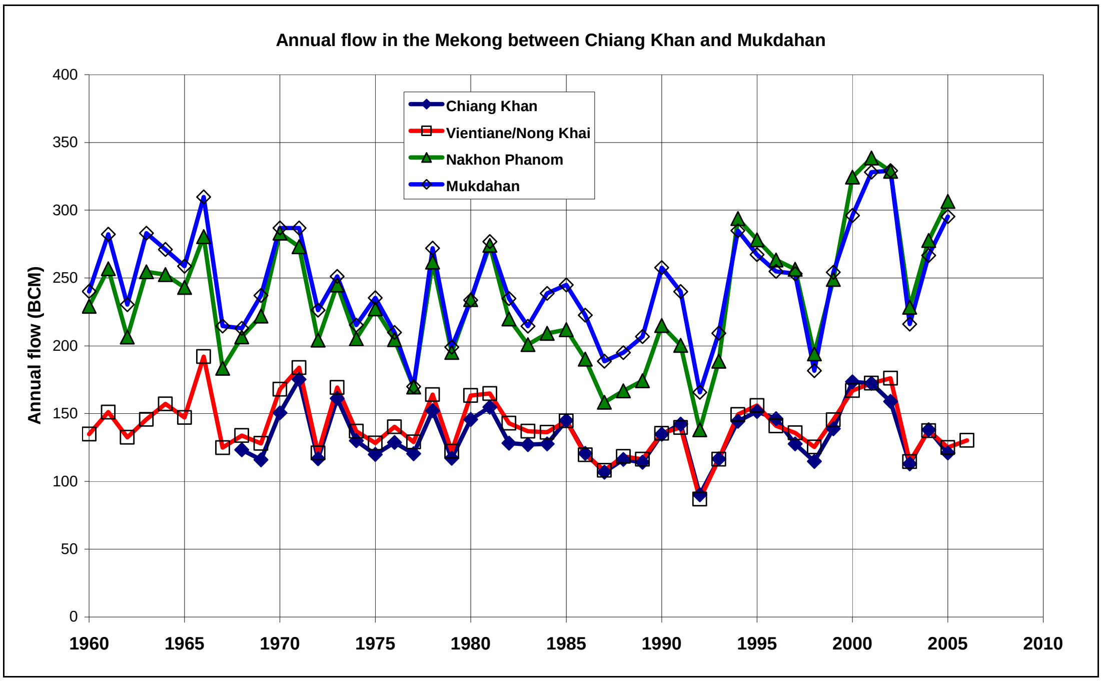

Figure 6.19 Annual flow in Mekong at Chiang Khan, Vientiane/Nong Khai, Nakhon Phanom and Mukdahan.

The frequency curves of daily discharges at the 4 main stream sites Chiang Khan, Vientiane/ Nong Khai, Nakhon Phanom and Mukdahan are presented in Figure 6.21 to Figure 6.24. It is observed that particularly between Nong Khai and Nakhon Phanom large quatities of water have entered the Mekong River. The first time the 2-year flood discharge is exceeded in a year is fairly constant throughout the reach and varies from mid to end of July. The last time it exceeded in a year ends mid September upstream of Vientiane and in the first week of October downstream of Vientiane, about 3 weeks later than in the upper area.

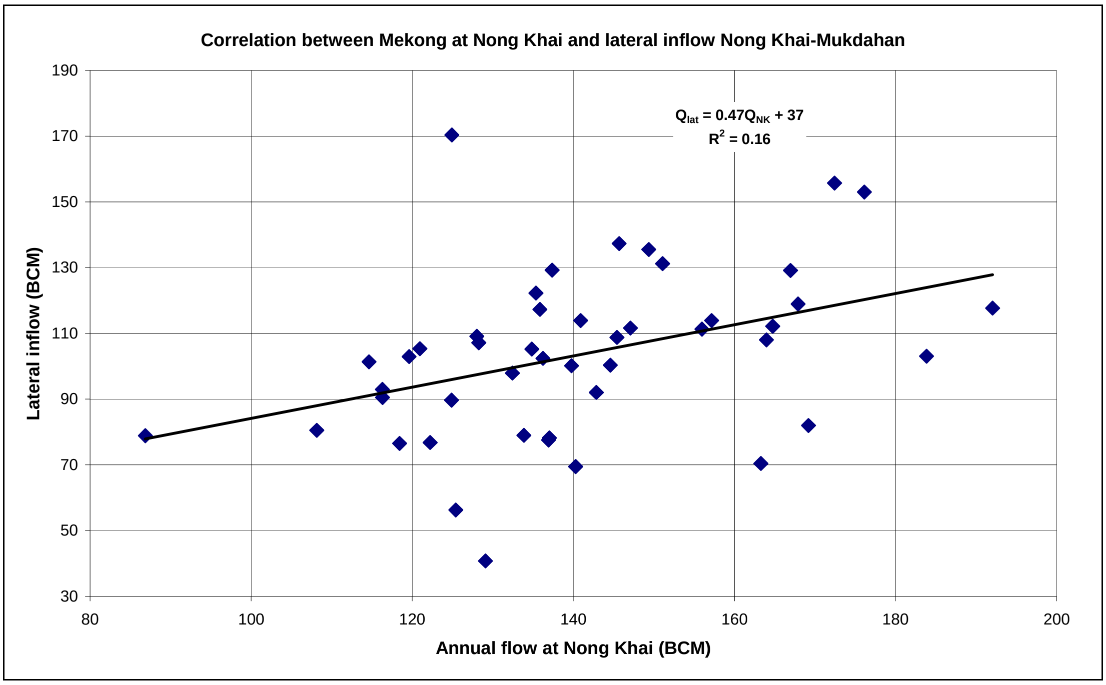

Figure 6.20 Relation between the annual flow at Nong Khai and the lateral inflow between Nong Khai and Mukdahan.

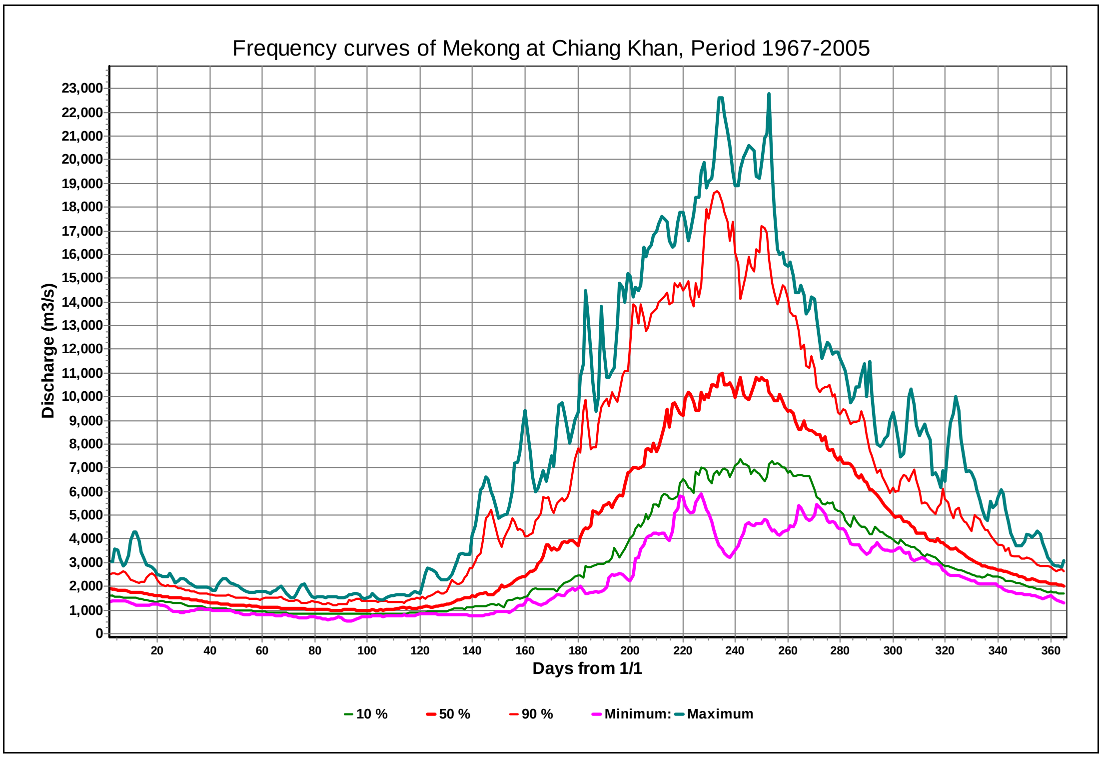

Figure 6.21 Frequency curves of daily discharge of the Mekong at Chiang Khan.

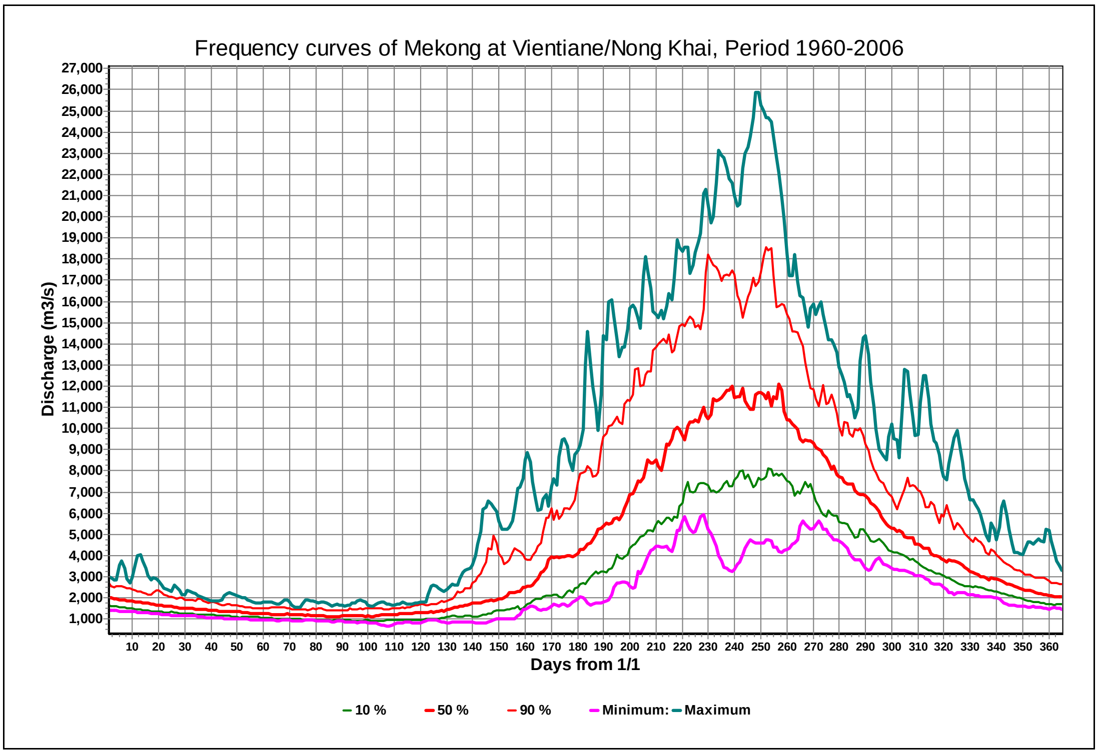

Figure 6.22 Frequency curves of daily discharge of the Mekong at Vientiane/Nong Khai.

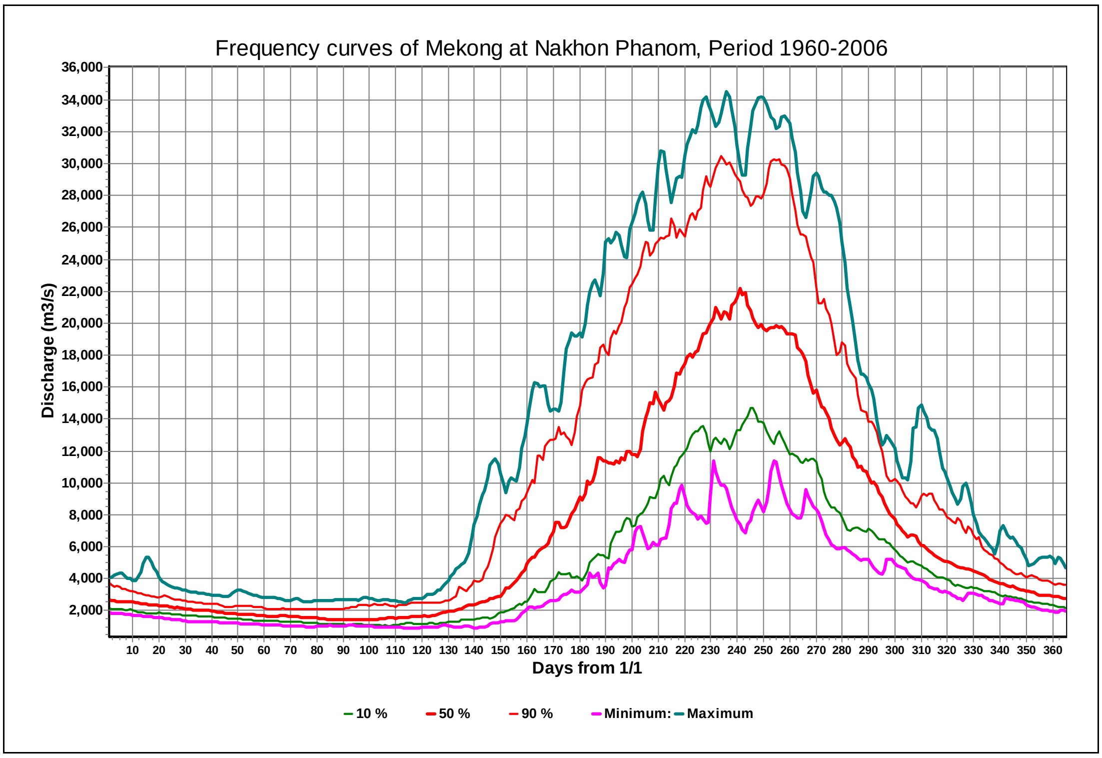

Figure 6.23 Frequency curves of daily discharge of the Mekong at Nakhon Phanom.

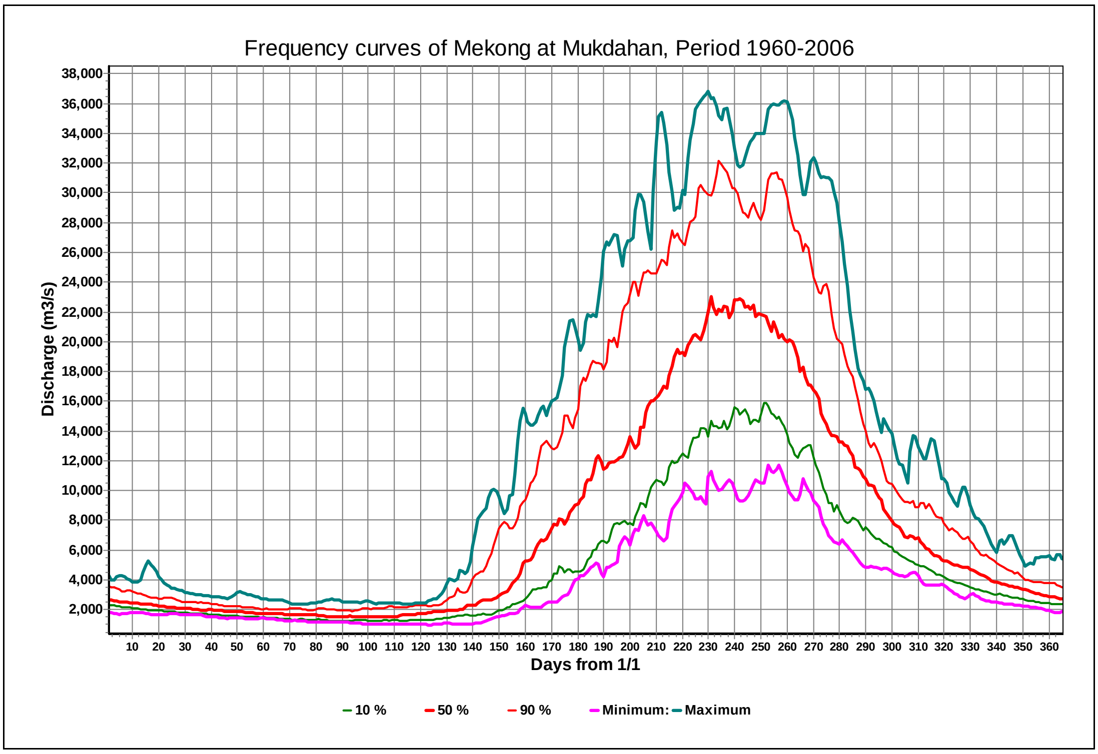

Figure 6.24 Frequency curves of daily discharge of the Mekong at Mukdahan.

6.3 Developments in SA3 affecting the flow regime

Irrigation and hydropower

Water scarcity is a major problem in SA3 and hence the hydraulic infrastructure has been adapted to store water for irrigation puposes. The total irrigation water demand amounts about 1.2 BCM/yr and about 0.2 BCM/yr for domestic and industrial purposes, which is only a small portion of the annual flow of over 30 BCM. The total storage capacity in SA3 is less than 1 BCM. The following reservoirs are included in SA3:

- Nam Oon reservoir with a total storage capacity of 520 MCM and an active capacity 477 MCM in the Nam Oon Irrigation Project in Sakon Nakhon Province, serving an area of 29,728 ha
- Nam Phung with a total storage capacity of 166 MCM created by a 40 m high and 1,720 m long dam about 30 km southwest of Sakon Nakhon province ,
- Huai Luang reservoir with a storage capacity of 113 MCM in the Huai Luang Irrigation Project in Udon Thani, serving an area 13,918 ha
- Some 90 medium sized reservoirs with capacities between 2 and 100 MCM, serving an area of 71,322 ha, and
- 1,138 small scale projects with reservoir sizes < 2 MCM, serving in total an area of 102,168 ha.

About 290 irrigation projects on an area of 270,000 ha have been proposed for SA3 (BDP, 2006).

Hydropower is insignificant in SA3 because of its flat topography. Only on Phung dam irrigation is combined with hydropower; a capacity of 6 MW has been installed at the site. No new hydropower schemes are planned in SA3.

Diversions

To increase the supply of water for agricultural purposes the following diversions have been proposed for SA3:

- The Nam Ngum diversion with a tunnel under the Mekong supplying 100 m^3/s of water to SA3.
- Kong-Chi-Mun diversion from the Mekong in northern SA3 to irrigate 320,000 ha in the Mun and Chi basins, using 6.6 BCM/yr.

The status of these proposals is unknown.

6.4 Floods

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. The tributary, main stream and combined floods are analysed hereafter.

6.4.1 Tributary floods

Typical flood hydrographs of selected tributaries in SA3 are presented in Figure 6.25 to Figure 6.28. It is observed that a typical flood in the upper reaches of the Nam Heung at Ban Pak Huai (area 4,090 km^2) lasts a few days. On the Nam Loei at Wang Saphung (area 1,240 km^2) the character is flashier, also because the drainage area is smaller. Similarly, the flood in the Huai Bang Sai at Ban Na Khan Noi (area 1220 km^2) is flashy The typical flood hydrograph in the Nam Songkhram at Ban Tha Kok Daeng (area 4,650 km^2) is completely different and last nearly two months. The hydrograph here is not a response to rainfall but to impeded drainage caused by backwater from the Mekong and should be considered under the Combined Floods.

The annual extremes of the Nam Heung, Nam Loei and Nam Songkhram have been presented in Figure 6.29 to Figure 6.31. It is observed that the extremes vary strongly from one year to another, with the exception of the Songkhram. Adamson (2007) analysed the floods on the Nam Heung and Nam Loei. A TCEV distribution was fitted to the extremes. The series of annual extremes have been compared with the discharges of given return period as derived in the referenced study. It is observed that the recent floods in the Nam Heung have been quite extreme, whereas in the Nam Loei the levels hardly exceeded the 5 year return period flow. Still the flood annals report severe flooding in 2002 on the Nam Loei covering over 100 km^2, with flooding in Wang Saphung, Loei, Ban Ton and near the Mekong confluence at Chiang Khan. Statistics for the Nam Songhkram have not been established yet, but the annual maximum discharge series indicates that particularly the mid nineties were high. The values since 2000 were not particularly extreme, though wide spread flooding has been reported to be an annual phenomenon.

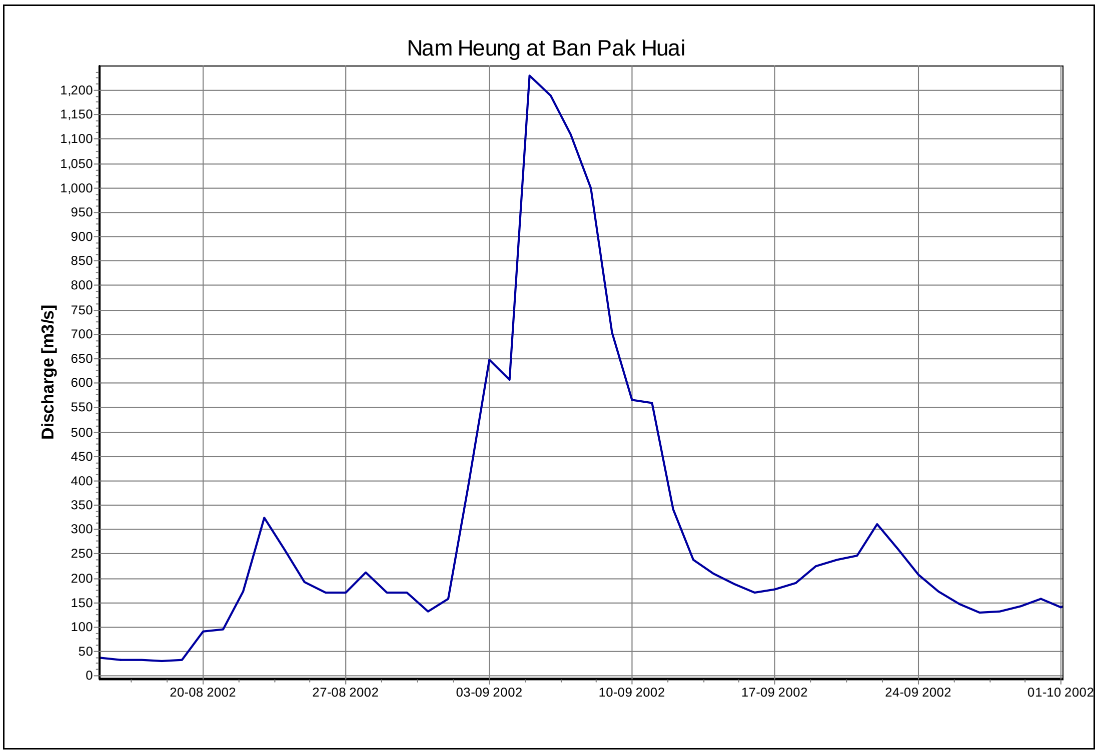

Figure 6.25 Flood hydrograph of Nam Heung at Ban Pak Huai, Year 2002.

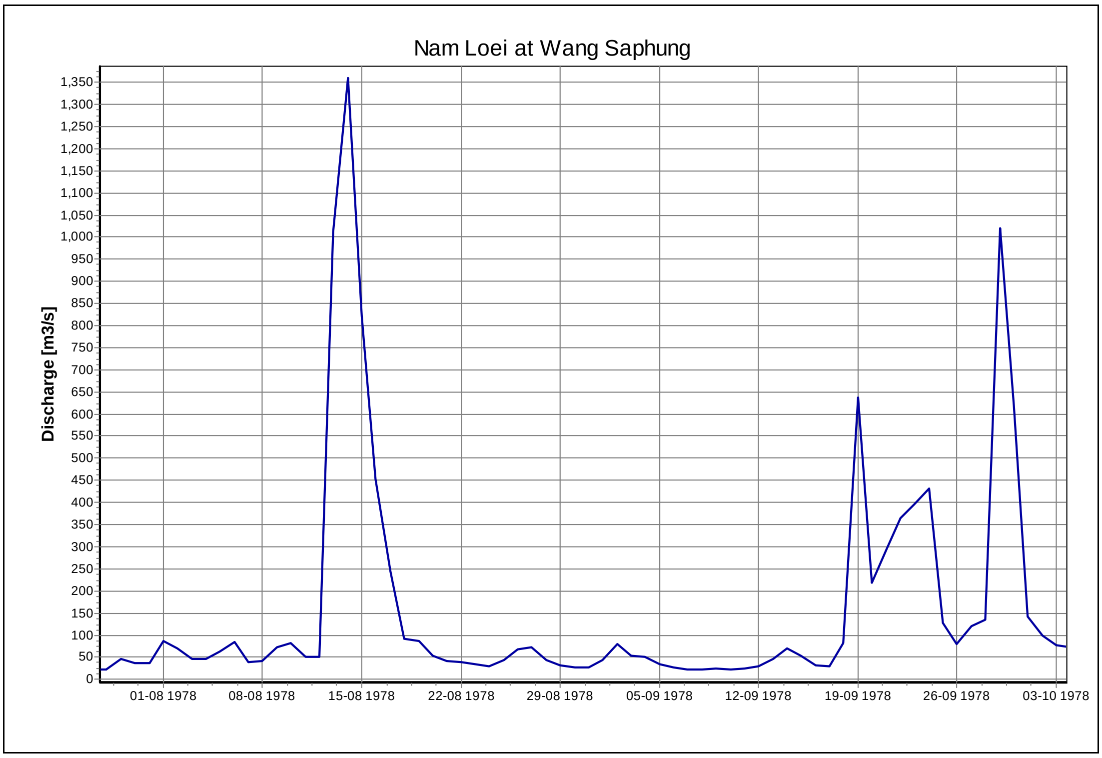

Figure 6.26 Flood hydrograph of Nam Loei at Wang Saphung, year 1978.

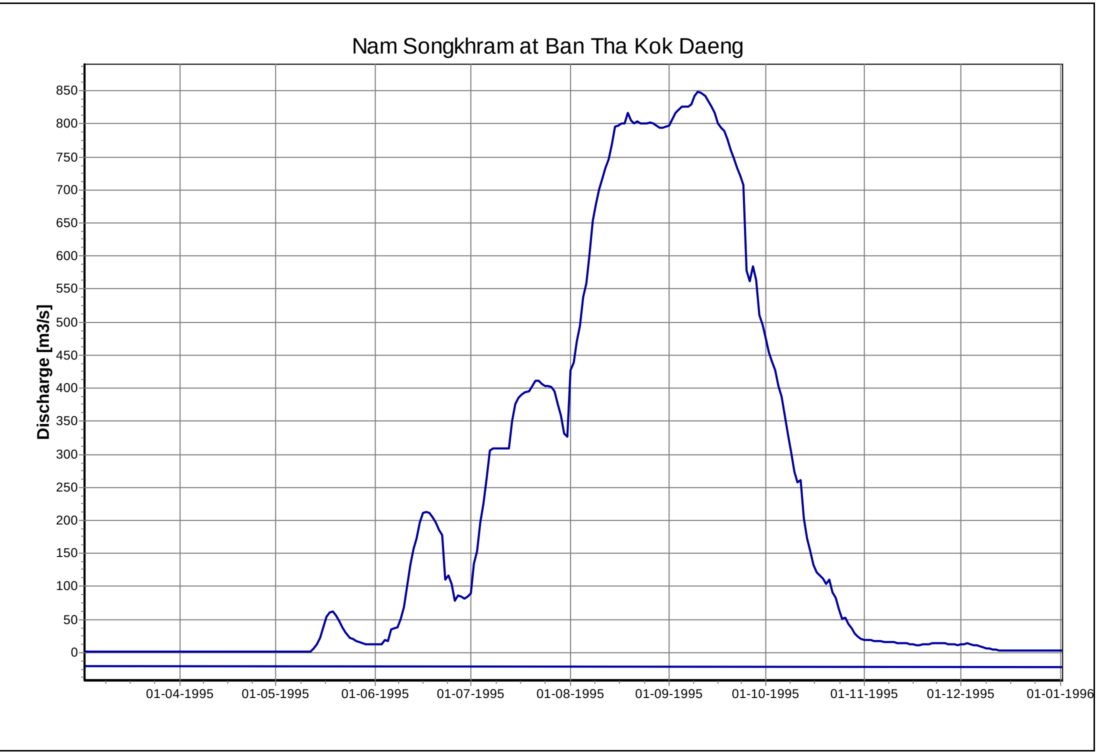

Figure 6.27 Flood hydrograph of Nam Sangkhram at Ban Tha Kok Daeng, Year 1995.

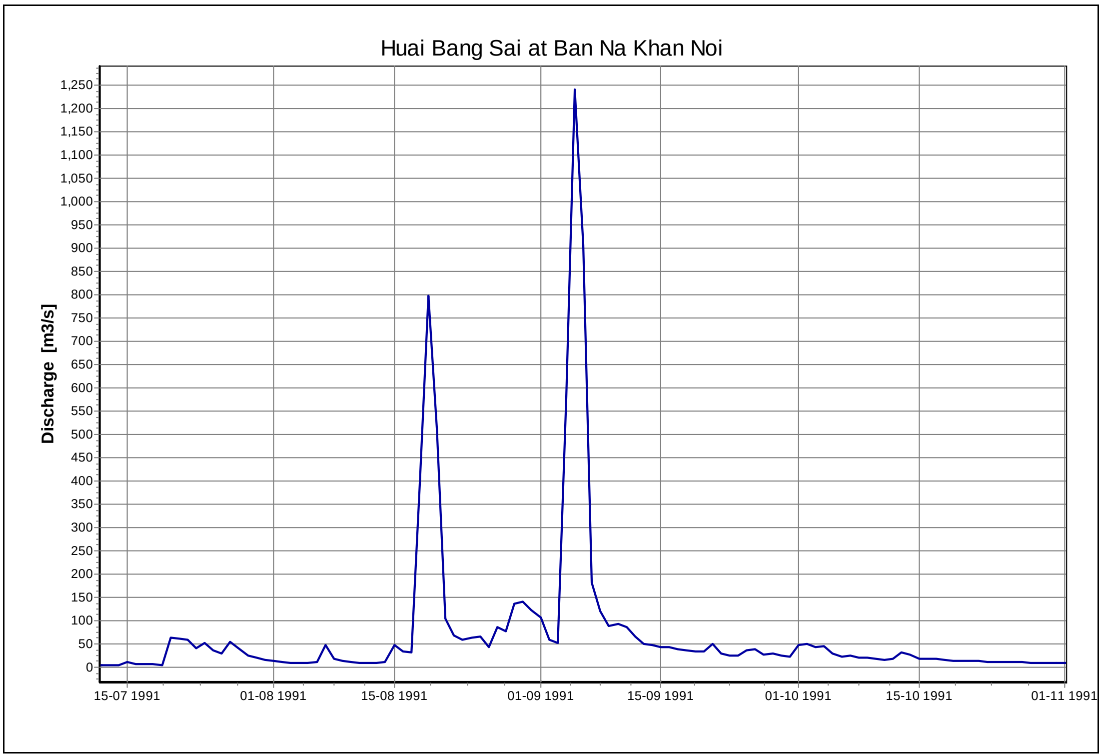

Figure 6.28 Flood hydrograph of Huai Bang Sai at Ban Na Khan Noi, Year 1991.

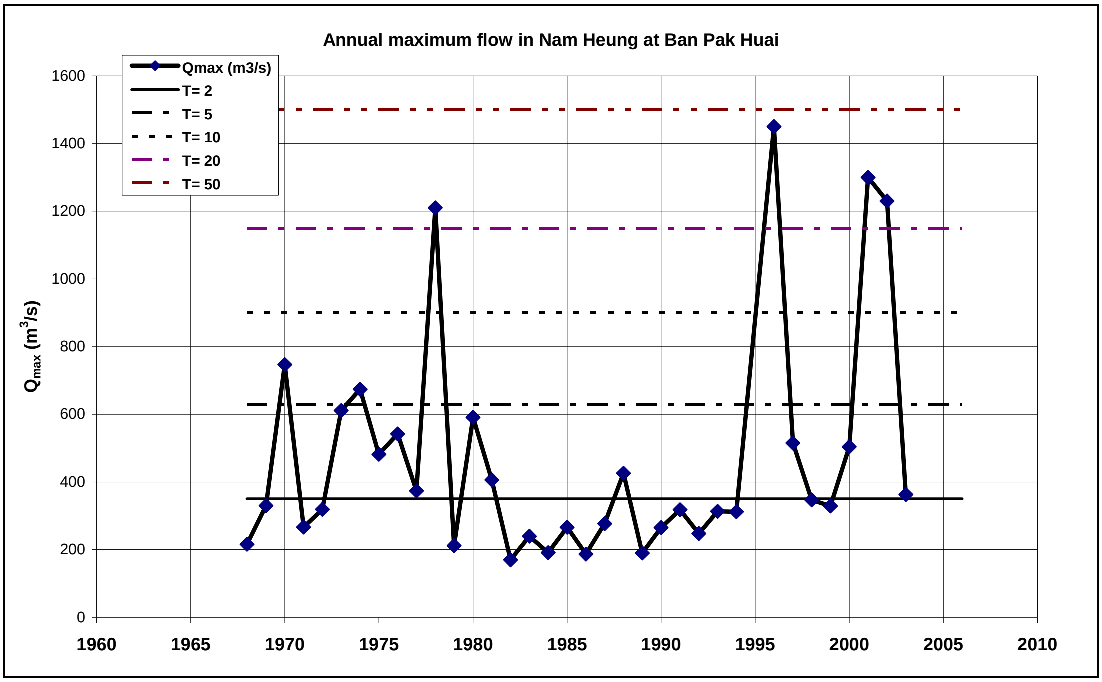

Figure 6.29 Annual maximum discharge of Nam Heung at Ban Pak Huai.

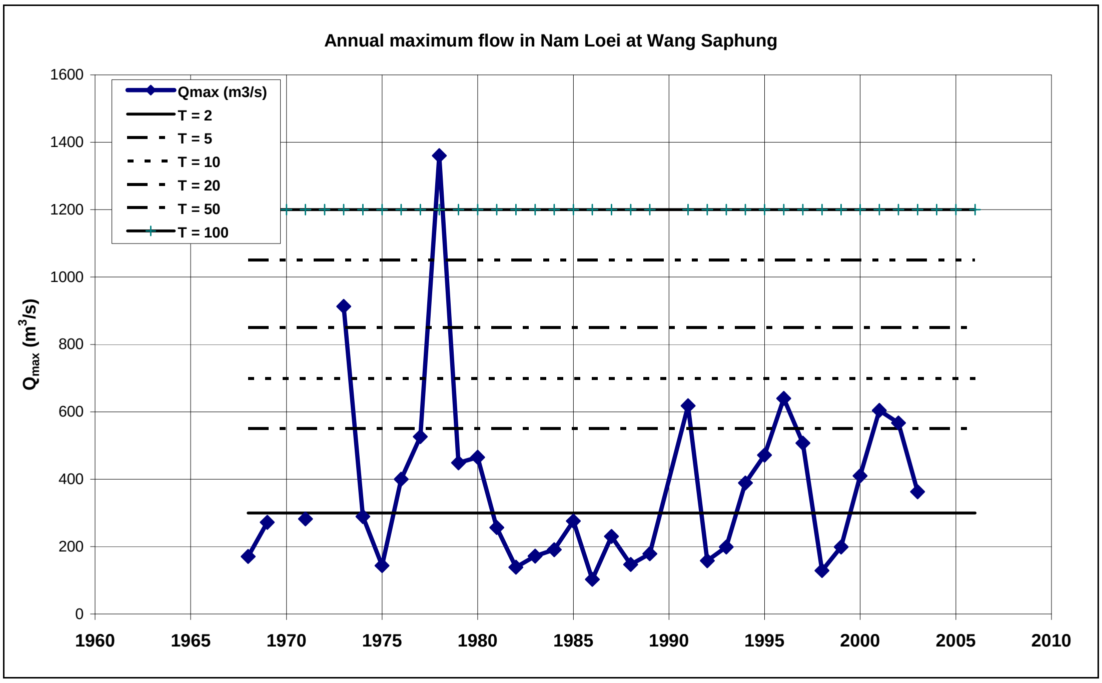

Figure 6.30 Annual maximum discharge of Nam Loei at Wang Saphung.

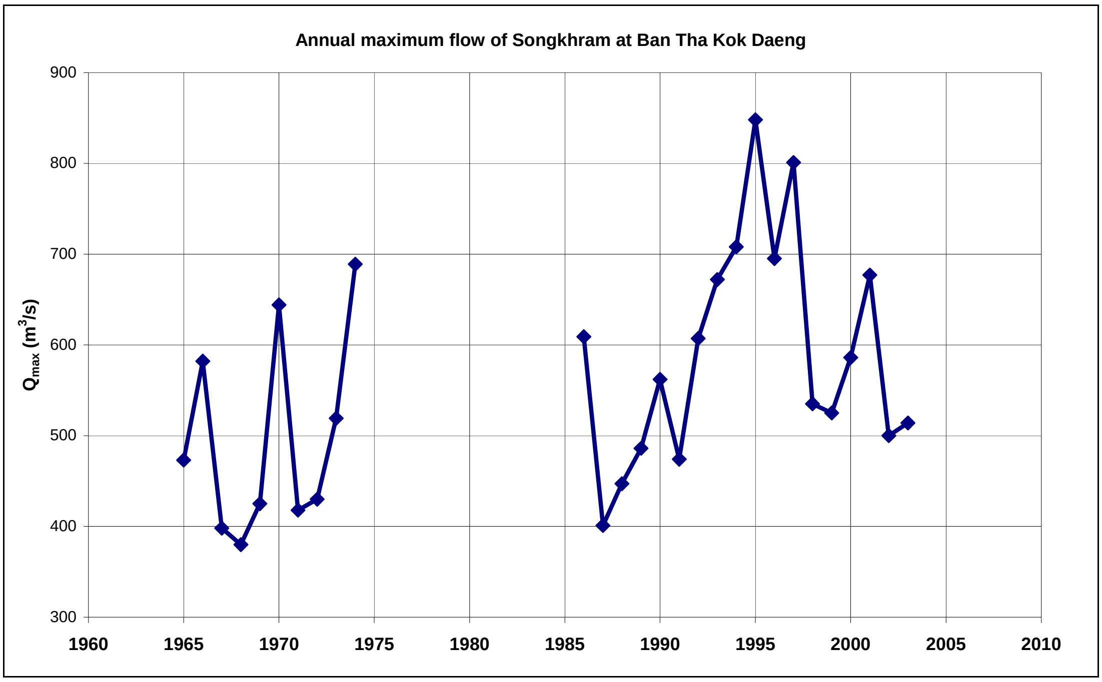

Figure 6.31 Annual maximum discharge of Nam Songkhram at Ban Tha Kok Daeng.

6.4.2 Main stream floods

The annual maximum discharges as documented for the gauging stations Chiang Khan, Vientiane, Nong Khai, Nakhon Phanom and Mukdahan is presented in Figure 6.32, and the rank of the floods as far as available for the period 2000-2006 is given in Table 6.6 . The figure and table show **a very diverse pattern**:

- In Chiang Khan in the year 2000 the highest flood on record (since 1968) was recorded, whereas 2002 has also been extreme (see figure). Note that the record misses the extreme high 1966 flood for that river reach.
- For Vientiane the flood of 2002 was extreme whereas the rest ranks low. The flood of 2002 ranks highest for Nong Khai, also because the record starts only in 1970.
- The recent years at Nakhon Phanom were very extreme: the highest, third and forth highest were recorded in 2005, 2001 and 2000 respectively.
- The recent years were also extreme in Mukdahan, particularly the year 2001, whereas the floods of 2000 and 2005 were also high.

Table 6.6 Rank of 2000-2006 floods in records of annual maximum discharges of gauging stations along Mekong River is SA3.

Year	Vientiane	Nakhon Phanom	Mukdahan
2000	21	4	6
2001	56	3	1
2002	4	7	15
2003	82	16	60
2004	68	20	19
2005	67	1	7
2006	74	-	-
N of Years	94	81	81

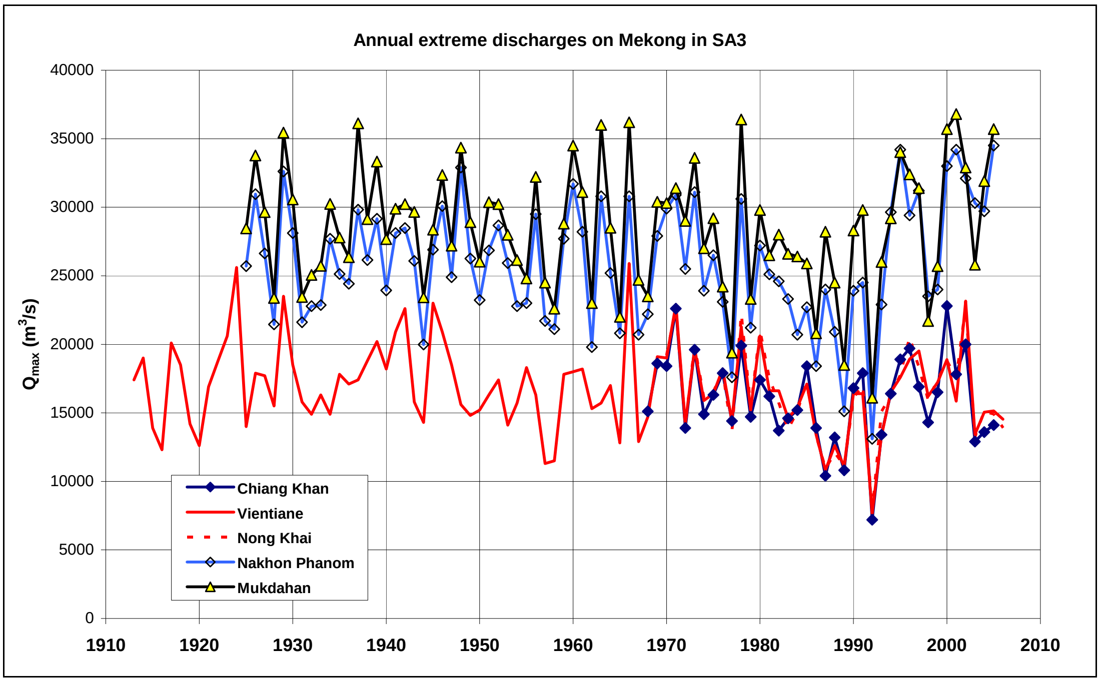

Figure 6.32 Annual maximum discharges on the Mekong in SA3.

The duration that a discharge with given return period at a station was exceeded during recent years is presented in Table 6.7 to Table 6.10, which confirms the rank of the floods. Whether severe flooding occurred during those years can be determined from a comparison with the flood level discharge for a particular station.

- At Chiang Khan the flood level of 23,000 m^3/s was not reached in the period 2000-2006.
- In Vientiane the flood level for the city (19,900 m^3/s) was exceeded in 2002 during 6 days.
- The 2002 flood was more severe in Nong Khai. The flood level of 16,900 m^3/s was exceeded in 2002 during 20 days. In 2000 that level was exceeded during 5 days.
- For Nakhon Phanom the flood level is defined at 38,800 m^3/s. In the recent years according to the flood levels no flooding took place in Nakhon Phanom, even in 2005 when the highest flood on record was experienced. The annual flood reports of 2005 and 2006, however reported large scale flooding in this area caused by backwater from the Mekong, see also combined flooding.
- At Mukdahan the flood level is set at 33,500 m^3/s, which level was exceeded in 2000, 2001 and 2005 for about 1 week. Similar to Nakhon Phanom, backwater from the river has caused large scale flooding in this area (MRC, 2006).

Table 6.7 Exceedances (days) of Mekong discharges with distinct return period at Chiang Khan for period 2000-2006.

T (Years)	**2**	**5**	**10**	**20**	**50**	**100**
Q (m^3/s)	**16,000**	**18,500**	**20,000**	**21,500**	**23,000**	**24,500**
2000	14	5	3	1	0	0
2001	5	0	0	0	0	0
2002	11	2	1	0	0	0
2003	0	0	0	0	0	0
2004	0	0	0	0	0	0
2005	0	0	0	0	0	0
2006	0	0	0	0	0	0

Table 6.8 Exceedances (days) of Mekong discharges with distinct return period at Vientiane/Nong Khai for period 2000-2006.

T (Years)	**2**	**5**	**10**	**20**	**50**	**100**
Q (m^3/s)	**16,500**	**19,000**	**21,000**	**22,500**	**24,000**	**26,000**
2000	6	0	0	0	0	0
2001	0	0	0	0	0	0
2002	22	6	4	1	0	0
2003	0	0	0	0	0	0
2004	0	0	0	0	0	0
2005	0	0	0	0	0	0
2006	0	0	0	0	0	0

Table 6.9 Exceedances (days) of Mekong discharges with distinct return period at Nakhon Phanom for period 2000-2006.

T (Years)	**2**	**5**	**10**	**20**	**50**	**100**
Q (m^3/s)	**26,000**	**30,000**	**32,000**	**33,000**	**34,500**	**36,000**
2000	23	12	5	1	0	0
2001	37	16	8	5	0	0
2002	38	16	1	0	0	0
2003	8	1	0	0	0	0
2004	21	0	0	0	0	0
2005	33	12	8	5	1	0
2006	0	0	0	0	0	0

Table 6.10 Exceedances (days) of Mekong discharges with distinct return period at Mukdahan for period 2000-2006.

T (Years)	**2**	**5**	**10**	**20**	**50**	**100**
Q (m^3/s)	**29,000**	**32,500**	**34,500**	**36,000**	**38,000**	**39,500**
2000	13	7	4	0	0	0
2001	22	10	7	5	0	0
2002	23	5	0	0	0	0
2003	0	0	0	0	0	0
2004	9	0	0	0	0	0
2005	18	8	4	0	0	0
2006	0	0	0	0	0	0

Morphological development of the river bed gave a variation of the flood level of respectively 1.5 m, 2.5 m, 2.5 m and 2.0 m for Chiang Khan, Nong Khai, Nakhon Phanom and Mukdahan. This uncertainty has te be taken into consideration when transforming hydrological hazards into flood hazards. To prevent main stream flooding dikes have been constructed along the Mekong around urban areas.

To tranform the hydrological hazard to a flood hazard inundation maps have to be made. As for SA1 and SA2 the hydrodynamic ISIS-model of the Mekong for this reach is not suitable as it lacks a proper flood plain schematisation. 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.

6.4.3 Combined floods

Floodings in the lower reaches of the tributaries, caused by impeded drainage of flood water due to high water levels on the Mekong are a major problem for basically all tributaries in SA3, particularly in the Nong Khai, Nakhon Phanom and Mukdahan provinces.

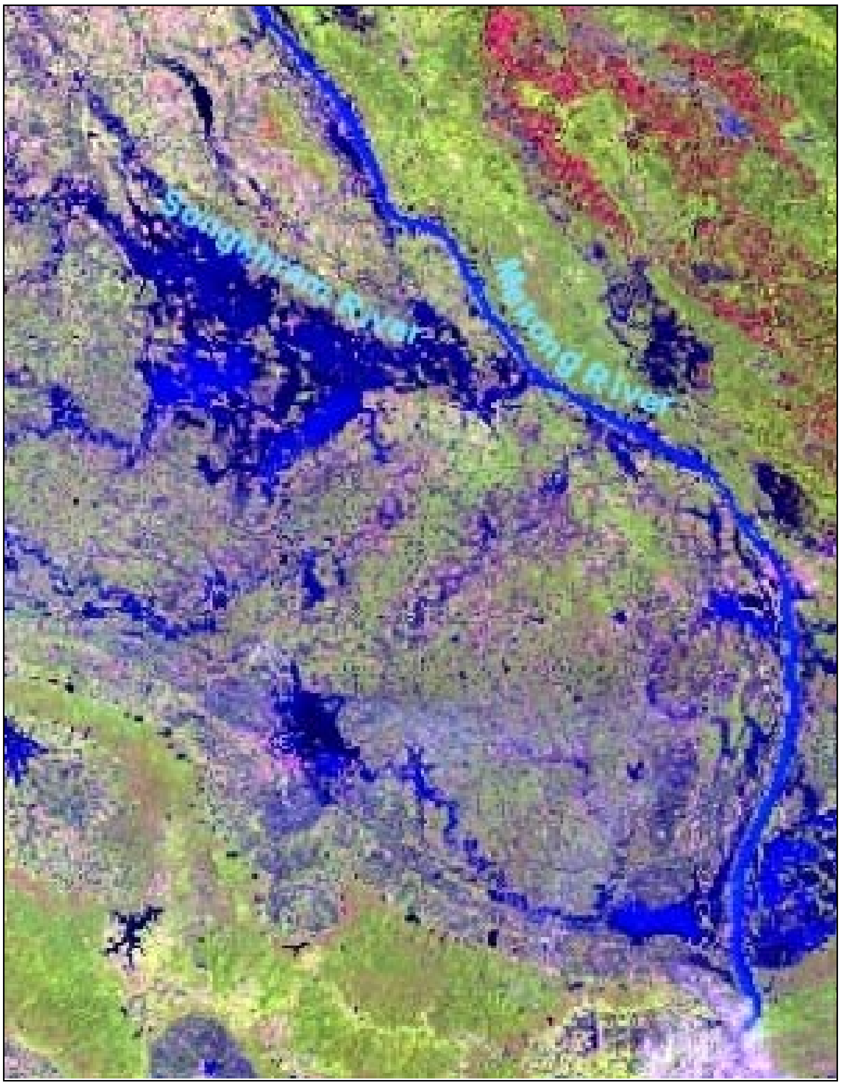

Figure 6.33 Landsat image of flooded area on Nam Songkhram.

Tributaries with frequent flooding are the low lying Nam Songkhram and Nam Kam, but also at other locations. It is observed from Figure 6.34 that higher flows on Mekong and on the Nam Songkhram generally coincide, though the Songkhram peak occurs often one month behind the Mekong peak. No effective protection measures do exist for these rivers and flooding is an annually returning event. A number of these flooded areas are wetlands, which are beneficial for fisheries. Also reverse flow is observed on the tributaries, which is welcomed by the villagers too as it is claimed to bring fertile sediments from the Mekong to their flood plains. In view of the high frequency of flooding people have adapted to it and live on elevated area like levees etc, whereas their cattle is moved to dawns (higher grounds).

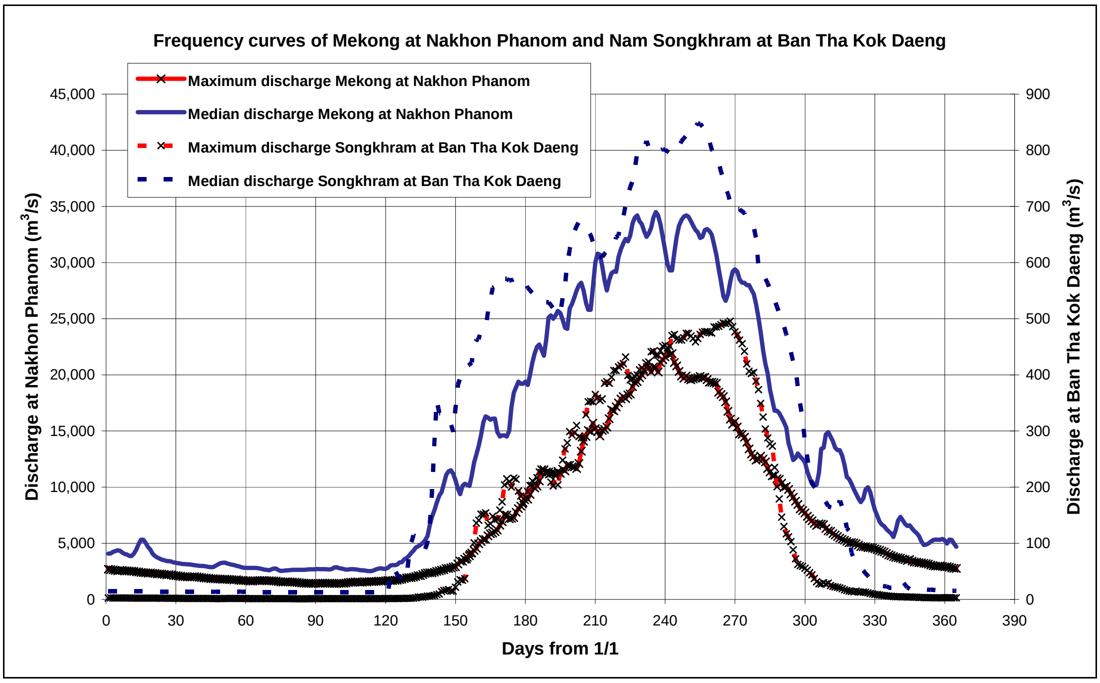

Figure 6.34 Frequency curves of Mekong at Nakhon Phanom and Nam Songkhram at Ban Tha Kok Daeng.

Some tribuaries are protected against Mekong water, like the Huai Muong. Its outflow to the Mekong is controlled by a head regulator with 9 pumping stations. The capacity is apparently insufficient for flood drainage when the levels on the Mekong are high, so flooding is also a frequently returning event in this basin. In 2002 an area of 190 km^2 area was inundated. Diversions have been proposed to drain to downstream locations.

Of a number of tributaries river bathymetric information is available and hydraulic models have been constructed, e.g. for Nam Loei and Huai Mong. In the past Consultants have carried out hydraulic model studies for the Nam Songkhram. Hence, some basic information is available for important tributaries for design and assessment of effectiveness of flood mitigation measures in SA3 by hydrologic/hydraulic modelling. The area covered by the hydrological stations is however limited, hence rainfall-runoff modelling is needed to complete lateral inflow boundaries. The downstream boundary is formed by the Mekong river with sufficient information available.

With respect to the main stream the situation is similar to SA1 and SA2. The available hydraulic model is not suitable for inundation mapping, but with sufficient satellite images the flood hazard can be assessed.

6.4.4 Summing up

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. Most of the floods are of the combined type, i.e they are due to impeded drainage by backwater from the Mekong. Floods here last long and occur annually. Communities have adapted to live with the floods and consider only extreme floods as a problem. The advantages of the floods for fisheries and supplier of sediments is well recognized by them. 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.

Flash floods do occasionally occur in the upper reaches of the westernmost tributaries. The procedures proposed for SA1 and SA2 apply here as well.

Urban areas along the Mekong have been protected from main stream flooding by dikes. 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.

7 HYDROLOGICAL AND FLOODS HAZARD IN SUB-AREA 4

7.1 Basin characteristics

Sub-area 4 SA4 covers the basins of the left bank tributaries draining to the Mekong between Chiang Khan to the confluence of the Mun River (see Figure 7.1). It measures 86,300 km^2. The area is almost entirely on Laotian territory except for a few small areas (790 km^2) of Quang Tri and Quang Binh provinces in Vietnam. The main tributaries are:

- Nam Ngum (drainage area 17,170 km^2, draining at rkm 1,486 between Vientiane and Paksane, with tributaries Nam Lik and Nam Song,
- Nam Mang (drainage area 1,780 km^2)
- Nam Nhiep (drainage area 4,500 km^2, draining at rkm 1,401)
- Nam Sane (drainage area 2,220 km^2, draining at rkm 1,395), just upstream of Paksane
- Nam Ca Dinh and Nam Theun (drainage area 14,900 km^2, draining at rkm 1,352), with Nam One, Nam Noi, Nam Pao, Nam Nhong and Nam Mouan
- Nam Himboun (drainage area 2,700 km^2, draining at rkm 1,247), just upstream of Nakhon Phanom/Thakek
- Se Bang Fai (drainage area 10,240 km^2, draining at rkm 1,166), draining between Nakhon Phanom/Thakek and Mukdahan/Savannakhet, with Nam Ou La and Se Noy
- Se Bang Hieng (drainage area 19,300 km^2, draining at rkm 1,037), draining downstream of Savannakhet, with Se Pon, Se Lanong, Se Thamouak and Se Xangxoy with Se Champone
- Se Bang Nouan (drainage area 3,100 km^2, draining at rkm 1,012), also draining downstream of Savannakhet.

The topographical and slope maps are presented in Figure 7.2 and Figure 7.3. The major part of SA4 is hilly to mountainous including the Annamite mountains at the border with Vietnam. Highest areas are found in the north-western part of SA4 and along the border with Vietnam. From Vientiane onward up to Thakek a narrow fringe of low land on the left bank exists, which widens near Savannakhet in the lower reaches of the Se Bang Fai and Se Bang Hieng.

The land use map of SA4 is presented in Figure 7.4. Some 3% of SA4 is rock, forest covers about 50% and the rest is classified as agricultural land (13%) and woodland/grassland. About 70% of the soils of SA4 are acrisols, acidic strongly leached tropical soils with low fertility. However, in the flood plains of the Mekong high quality soils are found suitable for lowland agriculture.

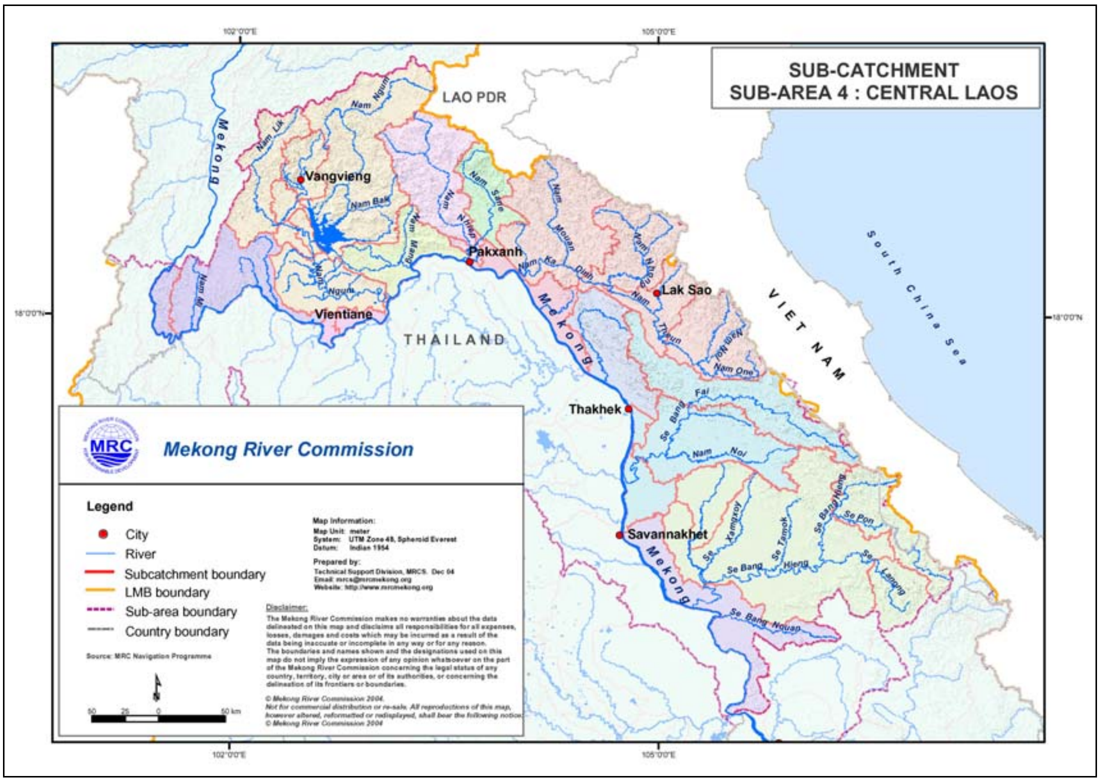

Figure 7.1 Layout of the sub-basins in SA4 (BDP, 2006).

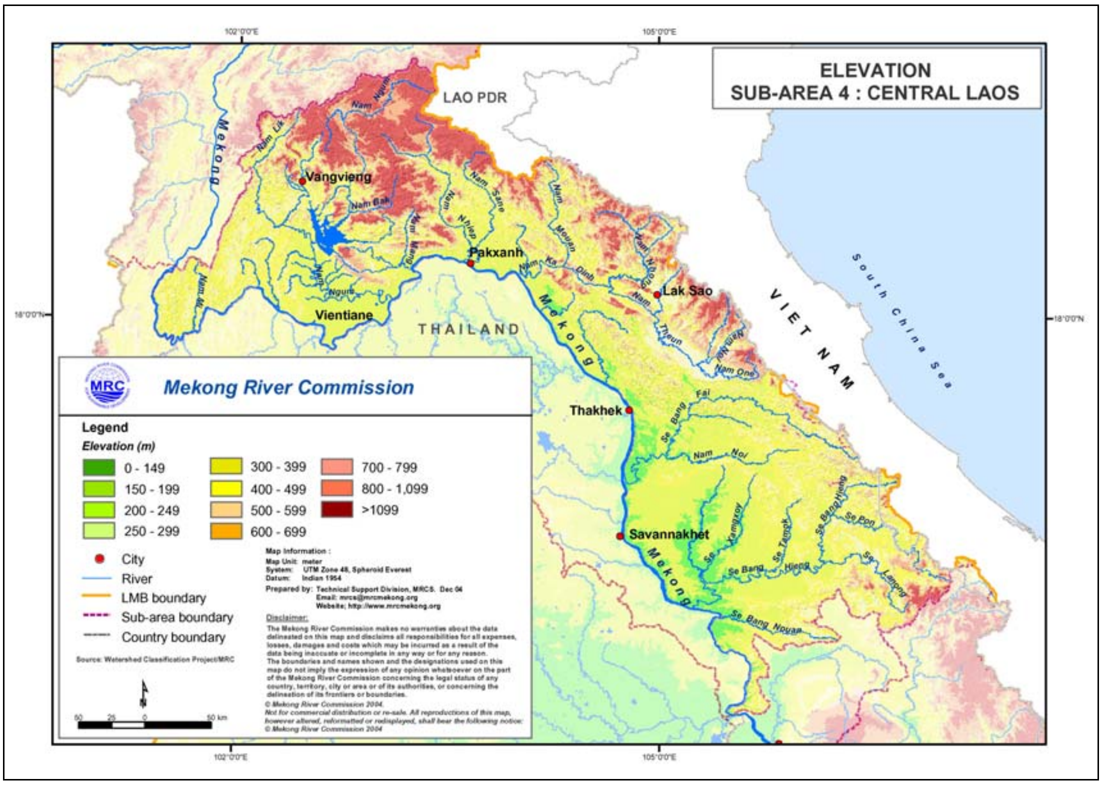

Figure 7.2 Topograpgical map of SA4 (BDP, 2006).

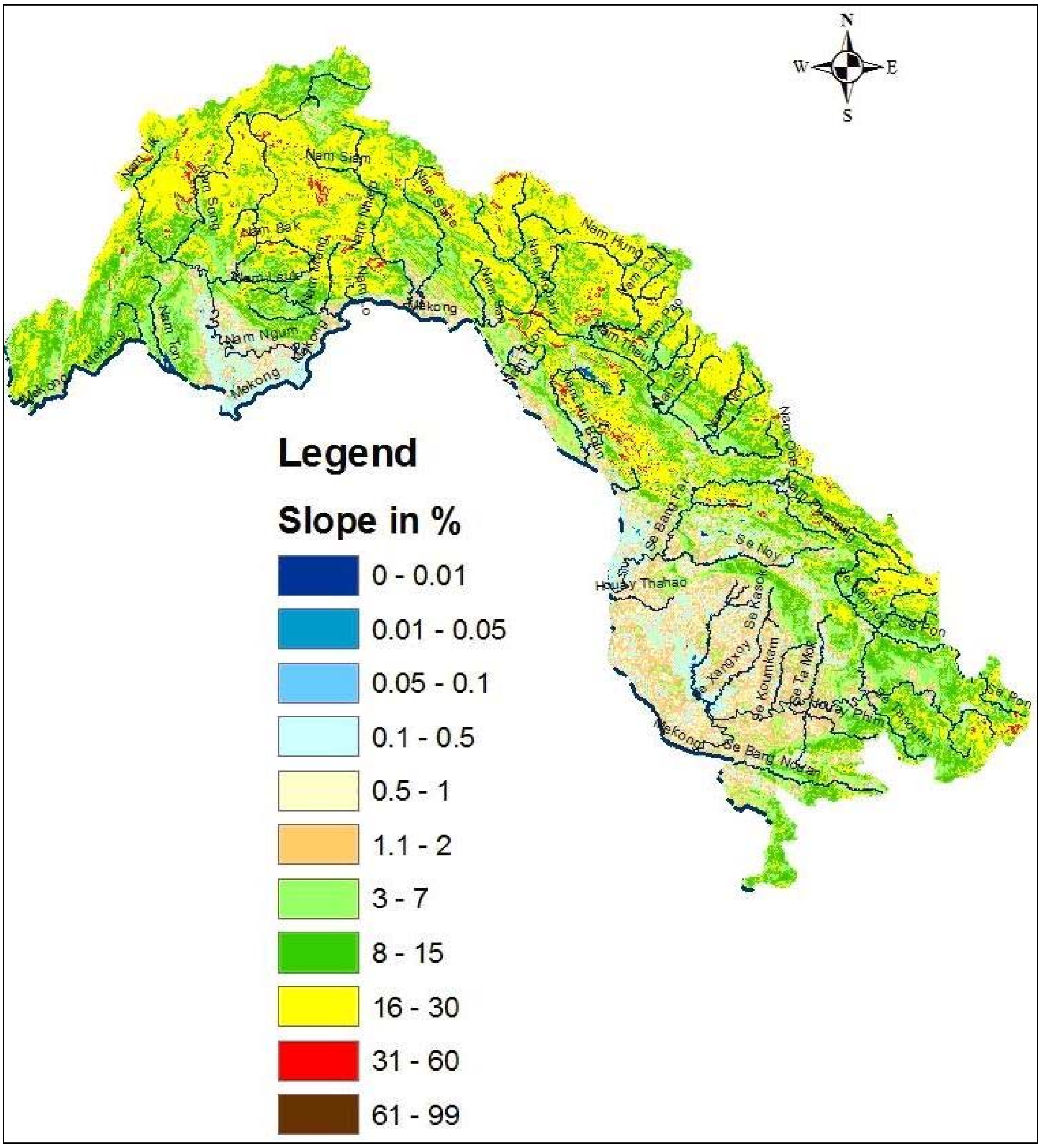

Figure 7.3 Slope map of SA4.

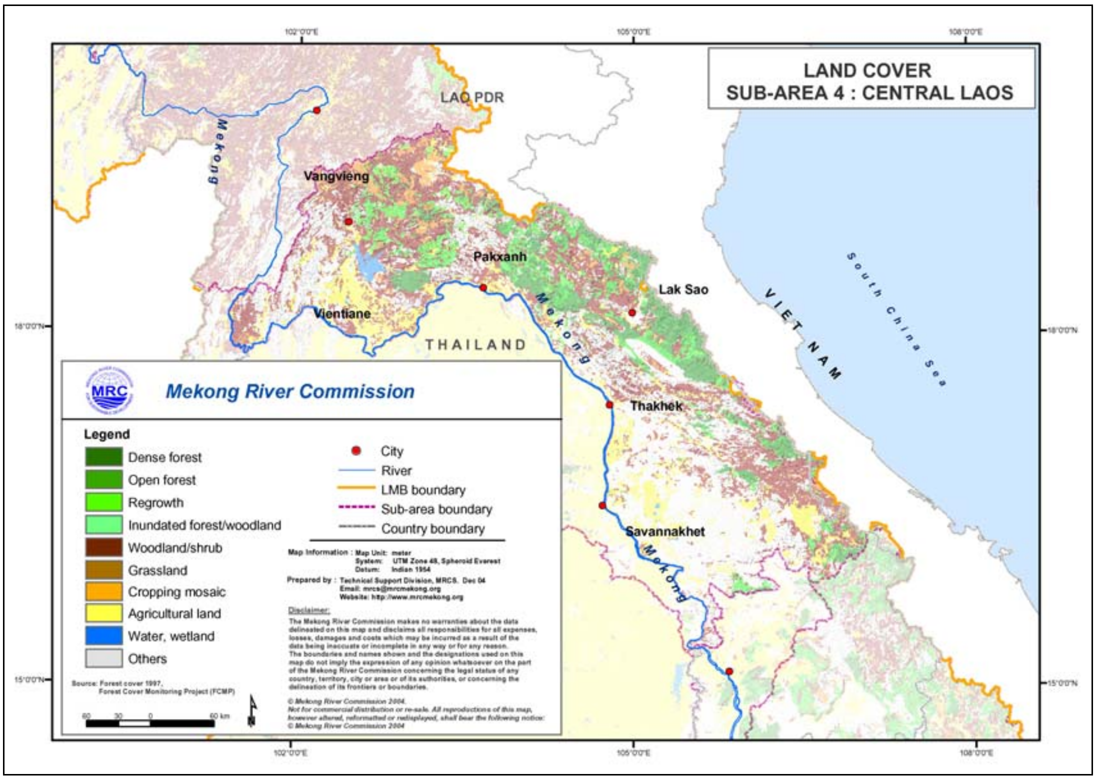

Figure 7.4 Land use map of SA4 (BDP, 2006).

7.2 Hydrological characteristics

7.2.1 Data availability

An overview of the hydro-meteorological network and data availability on rainfall, water level and discharge is presented in Table 7.1 to Table 7.6. The layout of the network is presented in Figure 7.5.

There is data available of 36 rainfall stations in the HYMOS database at MRC. This implies a density of 1 station per 2,400 km^2, far insufficient for rainfall-runoff modelling. More stations appear to be available. To assess the total availability of rainfall stations Consultants visited the Department of Meteorology and Hydrology of Laos. Unfortunately, the Department appeared to be very reluctant to provide any information on the layout of their network. Only a list of names of stations without co-ordinates and elevation could be obtained. From this list it has been deduced that the actual number of stations is larger than those available in the MRC database. The total number of rainfall stations in Laos is 147, of which of 67 stations MRC received data in 2005.

Most stations have records from about 1990, whereas about half of the stations started in the sixties. For a few stations long records are available, already from 1920 onward. The availability barchart shows many missing data.

With respect to water level data, all major tributaries are gauged. The availability of the data though is very scattered. Only for the last 15 years a more or less continuous series af data on water level is available in the database.

More important is the availability of discharge data. The list shows that as for water level the main tributaries have discharge records. From the availability record it appears that most of the stations have 10 – 15 years of data, which is short for statistical inference of the annual extremes.

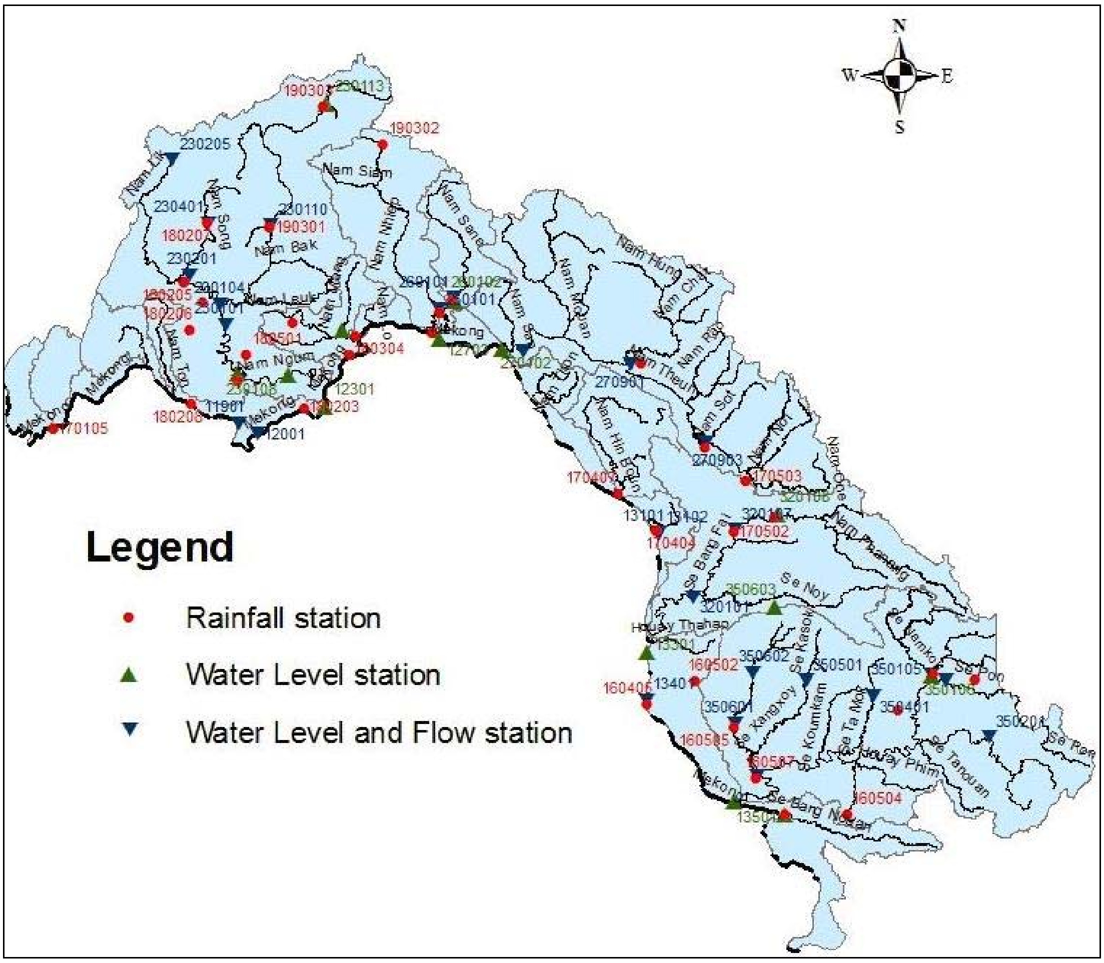

Figure 7.5 Layout of hydro-meteorological network in SA4.

Table 7.1 Overview of rainfall stations in SA4 (Laos and Vietnam).

Station Location

Rainfall

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
160405	Savannakhet	Mekong	16.5500	104.7500
160502	Seno	Huai Som Pak	16.6667	105.0000
160504	Ban Donghen	Se Bang Hieng	16.0000	105.7833
160505	Ban Kengkok	Se Bang Hieng	16.4333	105.2000
160506	Phalan	Se Bang Hieng	16.7000	106.2333
160507	Ban Kengdone	Se Bang Hieng	16.1833	105.3167
160508	Sebangnouane	Se Bang Nouar	16.0000	105.4667
160603	Ban Dong	Se Bang Hieng	16.6667	106.4500
160605	Muong Phine	Se Bang Hieng	16.5170	106.0500
170109	Sanakham	Mekong	17.9000	101.6670
170203	Vientiane	Mekong	17.9500	102.5167
170207	Hatdockeo	Mekong	17.8667	102.6000
170404	Thakhek	Mekong	17.4167	104.8000
170407	Pak Hinboun	Mekong	17.6000	104.6000
170501	Signo	Nam Kadinh	17.8333	105.0500
170502	Muong Mahaxay	Se Bang Fai	14.7500	107.2167
170503	Nakai	Nam Kadinh	17.6667	105.2667
170505	Ban Kouanpho	Se Bang Fai	17.4833	105.4167
180203	Ban Nasone(Maknao)	Mekong	18.0167	102.9667
180205	Ban Hinheup	Nam Ngum	18.6333	102.3333
180206	Kasy	Nam Ngum	18.4000	102.3667
180207	Vangvieng	Nam Ngum	18.9333	102.4500
180213	Veunkham	Nam Ngum	18.1500	102.6167
180221	Tadleuk	Nam Mang	18.4400	102.9000
180303	Paksane	Mekong	18.4000	103.6333
180304	Thabok	Mekong	18.2833	103.2000
180306	Ban Pakthouei(Nakham)	Mekong	18.3833	103.2333
180307	Muong Kao(Borikhane)	Nam Sane	18.5667	103.7333
180308	Muong May	Nam Nhiep	18.5000	103.6667
180405	Khamkeut (Kengkuang)	Nam Kadinh	18.2500	104.7167
180501	Ban Nape	Nam Ngum	18.2833	102.6667
190203	Pakkanhoung	Nam Ngum	18.5333	102.4333
190301	Ban Naluang	Nam Ngum	18.9130	102.7780
190302	Xiengkhouang	Nam Nhiep	19.3333	103.3667
190303	Ban Phiengluang	Nam Ngum	19.5167	103.0500
4V				
160611	Khe Sanh	Se Bang Hieng	16.6300	106.7300

Table 7.2 Overview of water level stations in SA4.

Water Level

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
011901	Vien Tiane	Mekong	17.9283	102.6200
012703	Paksane	Mekong	18.3717	103.6667
013102	Thakhek	Mekong	17.3933	104.8067
013301	Keng Kabao	Mekong	16.8133	104.7500
013401	Savannakhet	Mekong	16.5617	104.7467
013503	Paktaphane	Mekong	15.9333	105.3500
230101	Ban Pak Kanhoung	Nam Ngum	18.4183	102.5500
230102	Tha Ngon	Nam Ngum	18.1350	102.6217
230103	Ban Pak Ngum	Nam Ngum	18.1450	103.1017
230104	Ban Tha Lat	Nam Ngum	18.5167	102.5167
230106	Ba Na Bong	Nam Ngum	18.1800	102.8833
230108	Veunkham	Nam Ngum	18.1833	102.6167
230110	Ban Na Luang	Nam Ngum	18.9133	102.7783
230113	Ban Phien Luang	Nam Ngum	19.5300	103.0650
230201	Ban Hin Heup	Nam Lik	18.6600	102.3550
230205	Muong Kasi	Nam Lik	19.2320	102.2570
230401	Vang Vieng	Nam Song	18.9230	102.4500
240101	Ban Hat Khay	Nam Mang	18.4067	103.1650
250101	Muong Mai	Nam Nhiep	18.5050	103.6583
260101	Muong Borikhane	Nam Sane	18.5617	103.7367
260102	Ban Hatxiengtom	Nam Sane	18.5580	103.7470
270101	Ban Phone Si	Nam Ca Ding	18.3017	104.0983
270102	Ban Pak Ca Ding	Nam Ca Ding	18.3200	103.9970
270901	Kham Keut	Nam Theun	18.2350	104.6620
270903	Ban Signo	Nam Theun	17.8450	105.0520
320101	Se Bang Fai	Se Bang Fai	17.0720	104.9850
320107	Mahaxai	Se Bang Fai	17.4133	105.2020
320108	Kuanpho	Se Bang Fai	17.4970	105.4283
350101	Ban Keng Done	Se Bang Hieng	16.1850	105.3170
350105	Tchepon (Sop Nam)	Se Bang Hieng	16.6867	106.2183
350106	Highway Bridge	Se Bang Hieng	16.6967	106.2200
350201	Muong Nong	Se La Nong	16.3700	106.5133
350301	Ban Muong Chan	SePon	16.6600	106.2920
350401	Highway Bridge	Se Thamouak	16.5770	105.9133
350501	Ban Phalane	Sexangxoy	16.6570	105.5680
350601	Kengkok	Se Champhone	16.4450	105.2030
350602	Dong Hen	Se Champhone	16.6980	105.2920
350603	Muong Atsaphone	Se Noi	17.0334	105.4167
360106	Ban Sebangnouane	Se Bangnouane	16.0000	105.4667

Table 7.3 Overview of stream gauging stations in SA4.

Flow

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)		Catchment Area, km²
			Latitude	Longitude	
011901	Vien Tiane	Mekong	17.9283	102.6200	299000
013102	Thakhek	Mekong	17.3933	104.8067	373000
013401	Savannakhet	Mekong	16.5617	104.7467	391000
230101	Ban Pak Kanhoung	Nam Ngum	18.4183	102.5500	14300
230102	Tha Ngon	Nam Ngum	18.1350	102.6217	
230104	Ban Tha Lat	Nam Ngum	18.5167	102.5167	
230110	Ban Na Luang	Nam Ngum	18.9133	102.7783	5220
230201	Ban Hin Heup	Nam Lik	18.6600	102.3550	5115
230205	Muong Kasi	Nam Lik	19.2320	102.2570	374
230401	Vang Vieng	Nam Song	18.9230	102.4500	
250101	Muong Mai	Nam Nhiep	18.5050	103.6583	4305
260101	Muong Borikhane	Nam Sane	18.5617	103.7367	2230
270101	Ban Phone Si	Nam Ca Ding	18.3017	104.0983	
270901	Kham Keut	Nam Theun	18.2350	104.6620	5650
270903	Ban Signo	Nam Theun	17.8450	105.0520	3370
320101	Se Bang Fai	Se Bang Fai	17.0720	104.9850	8560
320107	Mahaxai	Se Bang Fai	17.4133	105.2020	4520
350101	Ban Keng Done	Se Bang Hieng	16.1850	105.3170	19400
350105	Tchepon (Sop Nam)	Se Bang Hieng	16.6867	106.2183	3990
350201	Muong Nong	Se La Nong	16.3700	106.5133	2011
350301	Ban Muong Chan	SePon	16.6600	106.2920	1979
350401	Highway Bridge	Se Thamouak	16.5770	105.9133	636
350501	Ban Phalane	Sexangxoy	16.6570	105.5680	882
350601	Kengkok	Se Champhone	16.4450	105.2030	2640
350602	Dong Hen	Se Champhone	16.6980	105.2920	1525

Table 7.4 Availability of rainfall data in SA4.

Daily Data Availability of BDP Sub-Area 4L (before 1960)

Rainfall

Station ID	Station Name	River	1910							1920										1930										1940										1950									
			3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
160405	Savannakhet	Mekong								+	+	+		+	+	+	+	+	+	+	+	+	214																+										
160502	Seno	Huai Som Pak															+	+	+		+	+	+	+	+	+	+	+	+	214																+			
160504	Ban Donghen	Se Bang Hieng																																						+	+	+	+	+	+	+	+	+	+
160505	Ban Kengkok	Se Bang Hieng																																															
160506	Phalan	Se Bang Hieng																			+				+	+	+	+	+																				
160507	Ban Kengdone	Se Bang Hieng																																															
160508	Sebangnouane	Se Bang Nouan																																															
160603	Ban Dong	Se Bang Hieng																																															
160605	Muong Phine	Se Bang Hieng																																															
170109	Sanakham	Mekong																	122	+	153	+	+		+	+	+	184	+																				
170203	Vientiane	Mekong																																															
170207	Hatdockeo	Mekong								+	214	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+	+	+
170404	Thakhek	Mekong																																															
170407	Pak Hinboun	Mekong																	122	+	+	+			+	+	+	153	243			+														+			
170501	Signo	Nam Kadinh												+						+	+	+			+	+	+	153			+	+	+																
170502	Muong Mahaxay	Se Bang Fai																																															
170503	Nakai	Nam Kadinh																	92		153	122	61		+		+	153	31		122																		
170505	Ban Kouanpho	Se Bang Fai																																															
180203	Ban Nasone(Maknad	Mekong																																															
180205	Ban Hinheup	Nam Ngum																																															
180206	Kasy	Nam Ngum																																															
180207	Vangvieng	Nam Ngum																																															
180213	Veunkham	Nam Ngum																	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
180221	Tadleuk	Nam Mang																																															
180303	Paksane	Mekong																																															
180304	Thabok	Mekong												+						+	+		+			+	+	184	+		+	+	+																
180306	Ban Pakthouei(Nakh	Mekong																																															
180307	Muong Kao(Borikhar	Nam Sane																																															
180308	Muong May	Nam Nhiep																	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
180405	Khamkeut (Kengkuar	Nam Kadinh																																															
180501	Ban Nape	Nam Ngum																																															
190203	Pakkanhoung	Nam Ngum										+	+	31			+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	306														
190301	Ban Naluang	Nam Ngum																																															
190302	Xiengkhouang	Nam Nhiep																																															
190303	Ban Phiengluang	Nam Ngum																	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	61						+	+	+	334	184	+	+	+	+	+

Daily Data Availability of BDP Sub-Area 4L (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
160405	Savannakhet	Mekong						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+
160502	Seno	Huai Som Pak	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+					+				+		+	+	+	+		+
160504	Ban Donghen	Se Bang Hieng						+	+	+	+	+	+								+	+							+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160505	Ban Kengkok	Se Bang Hieng						+	+	+																						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160506	Phalan	Se Bang Hieng																																+	+	+	+			+				+	+	+	+	+	+
160507	Ban Kengdone	Se Bang Hieng																																	+		+	+		+			+	+	+	+	+		+
160508	Sebangnouane	Se Bang Nouan																																+	+	+	+			+	+	+	+	+	+	+	+	+	+
160603	Ban Dong	Se Bang Hieng																																+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
160605	Muong Phine	Se Bang Hieng																																+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	2
170109	Sanakham	Mekong																																										+	+	+	+	2	+
170203	Vientiane	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
170207	Hatdockeo	Mekong									+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+							
170404	Thakhek	Mekong		+	+	+	31																+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+
170407	Pak Hinboun	Mekong						+	+	+	+	+		153																			+					+	343						+				
170501	Signo	Nam Kadinh																												+		169	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
170502	Muong Mahaxay	Se Bang Fai				61																										+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
170503	Nakai	Nam Kadinh																																				+	+										
170505	Ban Kouanpho	Se Bang Fai																																				+		+	+	92	+	+	+	+	+	+	+
180203	Ban Nasone(Maknao)	Mekong				+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	1	+	+	+
180205	Ban Hinheup	Nam Ngum								+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
180206	Kasy	Nam Ngum																															+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
180207	Vangvieng	Nam Ngum	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	2	+
180213	Veunkham	Nam Ngum																												+	+	+	+	+	+	+	+	+					+			+	+	+	+
180221	Tadleuk	Nam Mang																																				+	+	+	+	+	+						
180303	Paksane	Mekong						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+				+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+
180304	Thabok	Mekong						+	+	+	+	+	+	+	+	+																+	+	+	+	+	+	+							+		+	+	+
180306	Ban Pakthouei(Nakham)	Mekong													+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+
180307	Muong Kao(Borikhane)	Nam Sane	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
180308	Muong May	Nam Nhiep																			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
180405	Khamkeut (Kengkuang)	Nam Kadinh																																	+	+	184	+					+	+	+	+	182	+	+
180501	Ban Nape	Nam Ngum																																		+	+		+	+	+	+	+	+	+	+	+	+	+
190203	Pakkanhoung	Nam Ngum						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+	+	+	+	1	2
190301	Ban Naluang	Nam Ngum																																+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
190302	Xiengkhouang	Nam Nhiep																												+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+
190303	Ban Phiengluang	Nam Ngum																													+		+		+	+				+					+	+	+	+	+
4V																																																	
160611	Khe Sanh	Se Bang Hieng																																										+	+	+	+	+	+

Table 7.5 Availability of water level data in SA4.

Water Level

Station ID	Station Name	River	1910							1920										1930										1940										1950									
			3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
011901	Vien Tiane	Mekong											+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+			+	+	+	+	+	+							

Water Level

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
011901	Vien Tiane	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
012703	Paksane	Mekong																	74	+	16	22	+	211	242	211	26	112	+	+	+	29	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
013102	Thakhek	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	58	77	+	+	+	4	+	+	+	5	35	22	92	35	+	+	33	+	+	+	+	+	+	+	+	+	+	+	60	+	+	+	+	+
013301	Keng Kabao	Mekong													91	30	+	+	+	32	31	31	+	+	+	1	+	+	+	+	61	+	+	+	+	9	1	+	+	+	+	+							
013401	Savannakhet	Mekong											+		91	+	+	+	+	+	+	+	+	+	+	7	12	+	+	2	+	+	3	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
013503	Paktaphane	Mekong																																				256	+	+	+	+	244	+	+	+	275		
230101	Ban Pak Kanhoung	Nam Ngum				+	+	+	+	+	+	31	+	+	+	+	+	245	+	306												+	34	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
230102	Tha Ngon	Nam Ngum	30	37	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	9	+	+	+	+	91	+	+	223		+	+																		
230103	Ban Pak Ngum	Nam Ngum													91	+	+	+	+	+	+	+	+	+	122	+	111	313		+	180			+															
230104	Ban Tha Lat	Nam Ngum							+	+	+																																						
230106	Ba Na Bong	Nam Ngum																							113	69	+	7	334																				
230108	Veunkham	Nam Ngum																																+	+	+	+	+	+							1	+	+	+
230110	Ban Na Luang	Nam Ngum																											212	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
230113	Ban Phien Luang	Nam Ngum																												53	+	158																	
230201	Ban Hin Heup	Nam Lik						49	188	53	+	+	9	+	+	+	+	6			134			257		245	245	255	317	156	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
230205	Muong Kasi	Nam Lik																												134	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	31		
230401	Vang Vieng	Nam Song																				31	275			120	+	206		61	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+
240101	Ban Hat Khay	Nam Mang																										277	188	164	32	+				+													
250101	Muong Mai	Nam Nhiep																			90	31	274		+	101		243		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
260101	Muong Borikhane	Nam Sane																			144	90	109	229						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
260102	Ban Hatxiengtom	Nam Sane																																										+	+	+	+	+	
270101	Ban Phone Si	Nam Ca Ding	232							96	306	2	+	186					78	216	12	109	31				91	+	+						+	+	128						+	+	+	+	+	1	+
270102	Ban Pak Ca Ding	Nam Ca Ding																										+	+	124																			
270901	Kham Keut	Nam Theun																												275					+	+	+	31	61		182	23	8	+	+	145			
270903	Ban Signo	Nam Theun																											147	+	182	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
320101	Se Bang Fai	Se Bang Fai																													225				+		+	+	+	+	+	+	+	+	+	+	+	+	+
320107	Mahaxai	Se Bang Fai																													198	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
320108	Kuanpho	Se Bang Fai																																	+		+	82	187	306	59	275		+	+	+	+	+	
350101	Ban Keng Done	Se Bang Hieng	67	+	+	+	+	+	+	+	+	+	+	+	32	+	62	+	+	+	184	213									197	+	154	+	60	8	1	+	+	+	+	+	+	+	+	+	+	+	+
350105	Tchepon (Sop Nam)	Se Bang Hieng																	323	22	115			161	1	+	15	72		217	+	+	+	+	+	+	+	+	+	61	153	+	+	+	+	+	+	+	+
350106	Highway Bridge	Se Bang Hieng																																	360	+	+		+	+									
350201	Muong Nong	Se La Nong																			231					+	154				190		106	90	+	10	+	+	+	+	+	+	+	+	+	+	+	+	
350301	Ban Muong Chan	SePon																	325	31				151							190	92	75	90	+	8	+	+	+	+	+	+	+	+	+	+	182	+	
350401	Highway Bridge	Se Thamouak																		204	275									218			61	146		10	90	+	+	+	+	+	+	+	+	+	+		
350501	Ban Phalane	Sexangxoy																			204									337			+	120	44	136	59	+	+	+	+	+	+	+	+	+	+		
350601	Kengkok	Se Champhone																	91	+	+	+	92	90	+	+	+	+	+	+	+	+	+	+	+	31	+	+	+	+	+	+	+	+	+	+	+	+	+
350602	Dong Hen	Se Champhone																													216		46			249	+	59	+	+	+	+	+	+	+	+	+	+	+
350603	Muong Atsaphone	Se Noi																																				94	61	+		+							
360106	Ban Sebangnouane	Se Bangnouane																																										+	+	+	+	+	

Table 7.6 Availability of streamflow data in SA4.

Flow

Station ID	Station Name	River	1910							1920										1930										1940										1950									
			3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
011901	Vien Tiane	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
013102	Thakhek	Mekong												91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
013401	Savannakhet	Mekong											31	91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Flow

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
011901	Vien Tiane	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
013102	Thakhek	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	60	+	+	+	+	+
013401	Savannakhet	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
230101	Ban Pak Kanhoung	Nam Ngum				+	+	+	+	+	+	31	+	+	+	+	+	245	+													+	34	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
230102	Tha Ngon	Nam Ngum			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	91	+	+	223		+	+																		
230104	Ban Tha Lat	Nam Ngum							+	+	+	+	+	+	15	+	+	+	91	+	+	+	+	5	90	30		212	153	94	182																		
230110	Ban Na Luang	Nam Ngum																												+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
230201	Ban Hin Heup	Nam Lik								90	+	+	9	+	+	+	+	6			134			257		245	245	255	319	155	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
230205	Muong Kasi	Nam Lik																												243	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	31		
230401	Vang Vieng	Nam Song																												61	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	
250101	Muong Mai	Nam Nhiep																												+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
260101	Muong Borikhane	Nam Sane																												+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
270101	Ban Phone Si	Nam Ca Ding	225																								91	+	+	275																			
270901	Kham Keut	Nam Theun																										192	+	275			+	+	+	+													
270903	Ban Signo	Nam Theun																											147	+	182	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
320101	Se Bang Fai	Se Bang Fai	197	+	39	+	+	+	+	+	+	+	+	+	26	+	+	+	+	+	24	+	+	+	+	+	+	122			225				+		1	+	+	+	+	+	+	+	+	+	+		
320107	Mahaxai	Se Bang Fai																													198	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
350101	Ban Keng Done	Se Bang Hieng	54	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	184	212	275								197	+	154	+	60	8	+	+	+	+	+	+	+	+	+	+	+		
350105	Tchepon (Sop Nam)	Se Bang Hieng																													+	+	+	+	+	+	+	+	+	61	153	+	+	+	+	+	+	+	
350201	Muong Nong	Se La Nong																															107	90	+	10	+	+	+	+	+	+	+	+	+	+	+		
350301	Ban Muong Chan	SePon																															75	92	190	191	+	+	+	+	+	+	+	+	+	+	182		
350401	Highway Bridge	Se Thamouak																														361	92	146		10	90	+	42	+	+	+	+	+	+	+	+		
350501	Ban Phalane	Sexangxoy																															+	120	44	136	59	+	+	+	+	+	+	+	+	+	+		
350601	Kengkok	Se Champhone																			90	+	92	90	+	+	+	+	+	+	+	+	+	+	+	31	92	+	+	+	+	+	+	+	+	+	+		
350602	Dong Hen	Se Champhone																															139			261	+	+	+	+	+	+	+	+	+	+	+		

Notes: + = no missing
blank = missing
90 = number of missing days in a year

7.2.2 Rainfall

The annual rainfall in SA4 according to the LMB average annual rainfall map varies from 1,300 - 1700 mm in the low lands near Savannakhet to 2000 to 3000 mm in the northwestern part and along the border with Vietnam. In absence of large mountainranges east of Savannakhet lower annual values are found here.

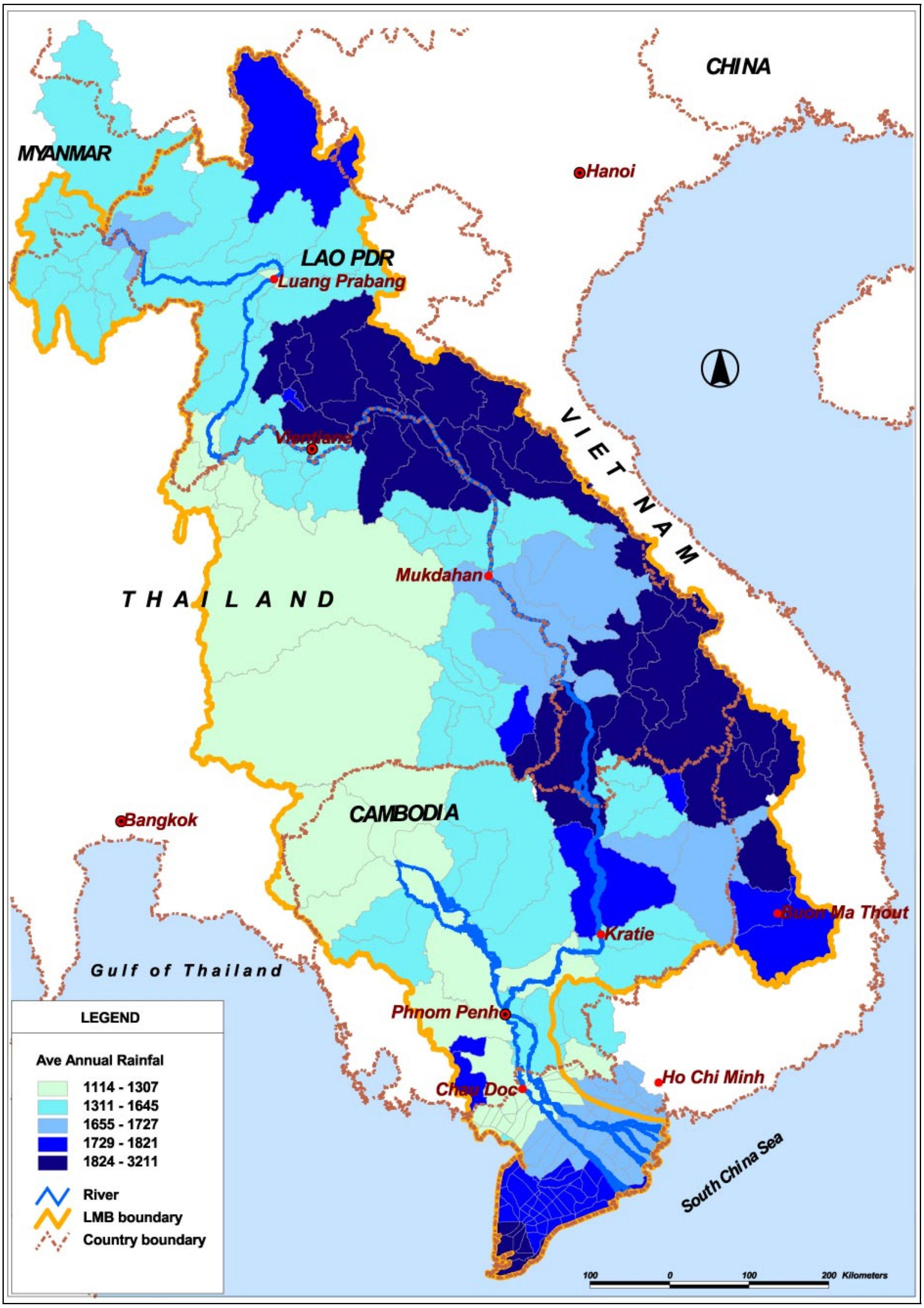

Figure 7.6 Average annual rainfall in LMB (BDP, 2006).

A more detailed picture is obtained from Figure 4.6, which covers the northern and middle part of SA4. It shows high pockets of rainfall around Vang Vien and in the area bordered by Paksane and Lak Sao.

The seasonal variation of the rainfall is shown for selected stations in SA4 from upstream along the Mekong to the confluence of the Mun. A distinct difference is observed between the first two stations and the rest; in the north-western part of SA4 the wet season basically runs from May to September, whereas further to the east and the south the importance of May and to some extent September reduces, and August becomes by far the wettest month.

With respect to the rainfall data it is noted that a thorough validation of the MRC database is required before the series can be applied. Inspection learned that no clear distinction has been made in the past between missing values and days without rainfall. A large number of zero rainfall values should have been entered as missing.

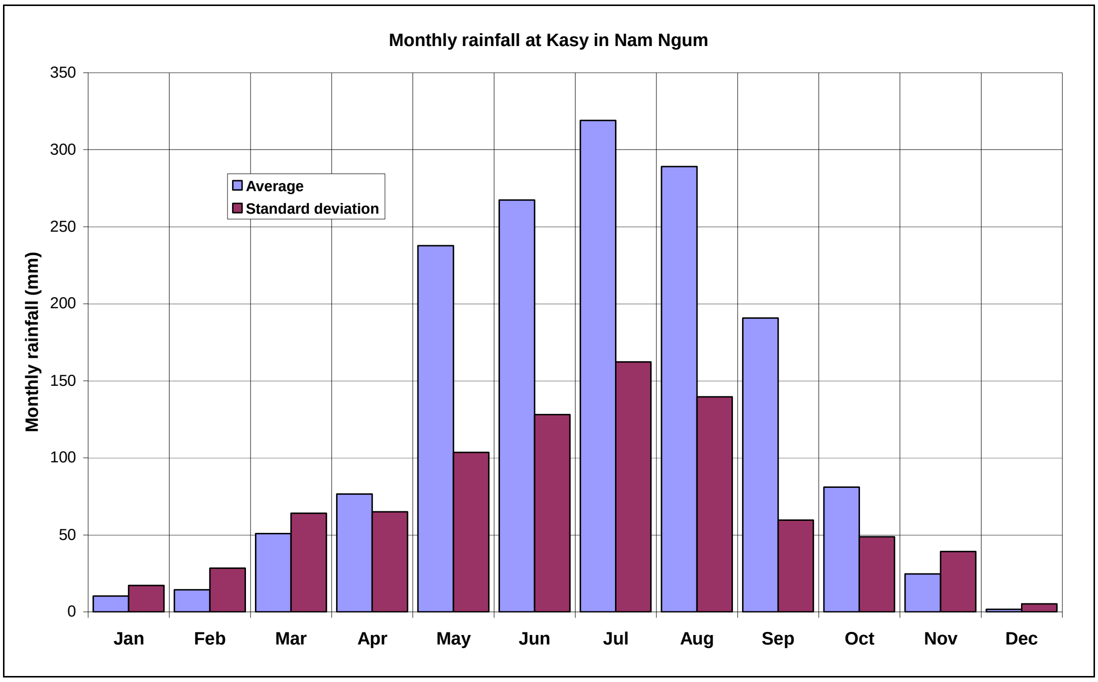

Figure 7.7 Monthly rainfall characteristics at Kasy in Nam Ngum basin.

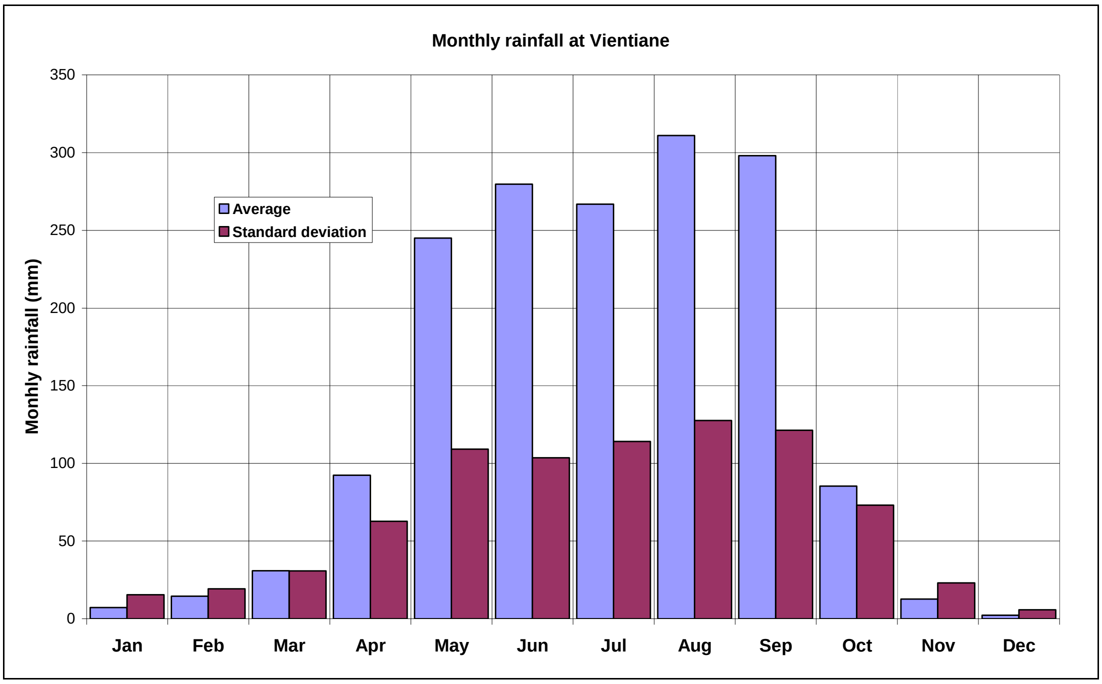

Figure 7.8 Monthly rainfall characteristics at Vientiane along Mekong river.

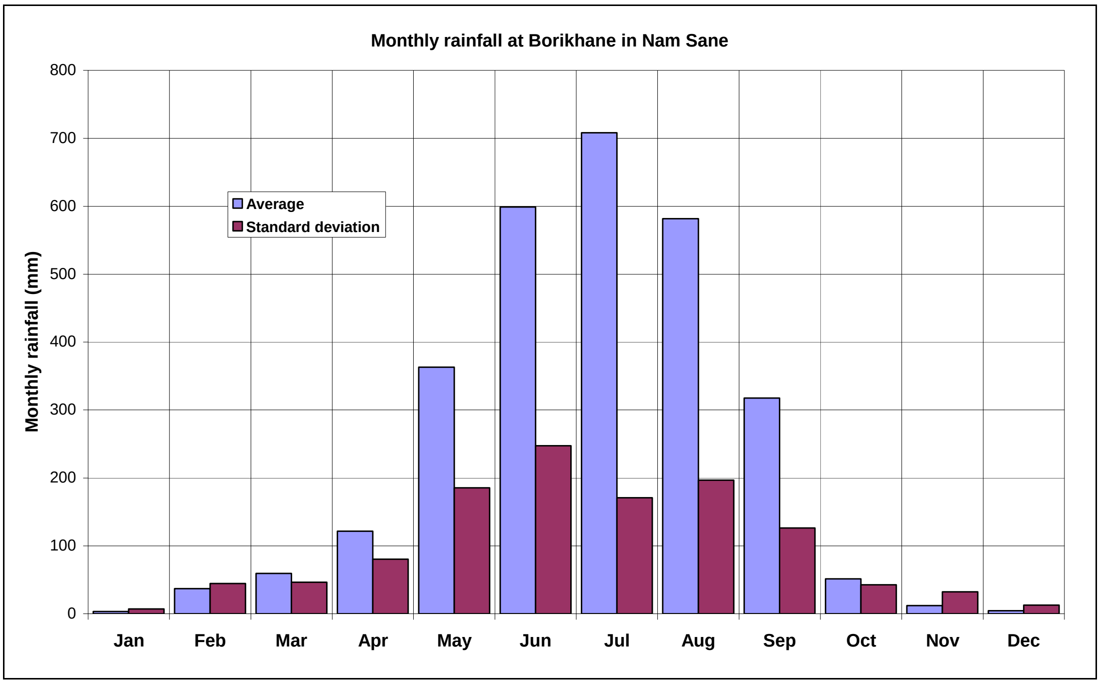

Figure 7.9 Monthly rainfall characteristics of Borikhane in Nam Sane basin.

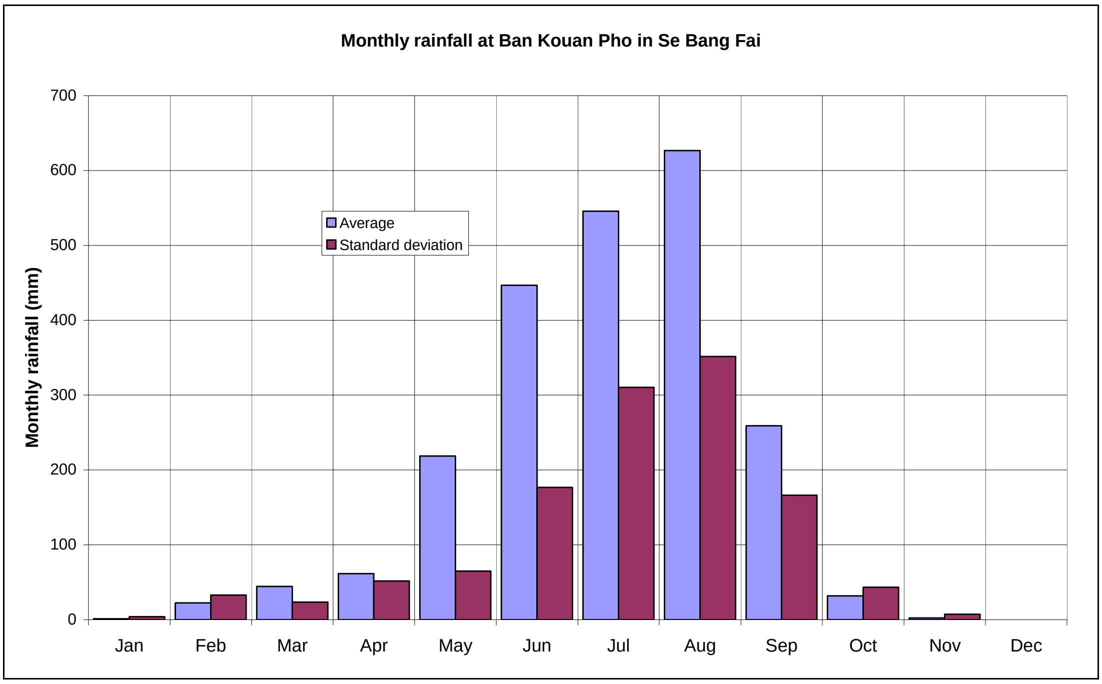

Figure 7.10 Monthly rainfall characteristics of Ban Kuong Po in Se Bang Fai basin.

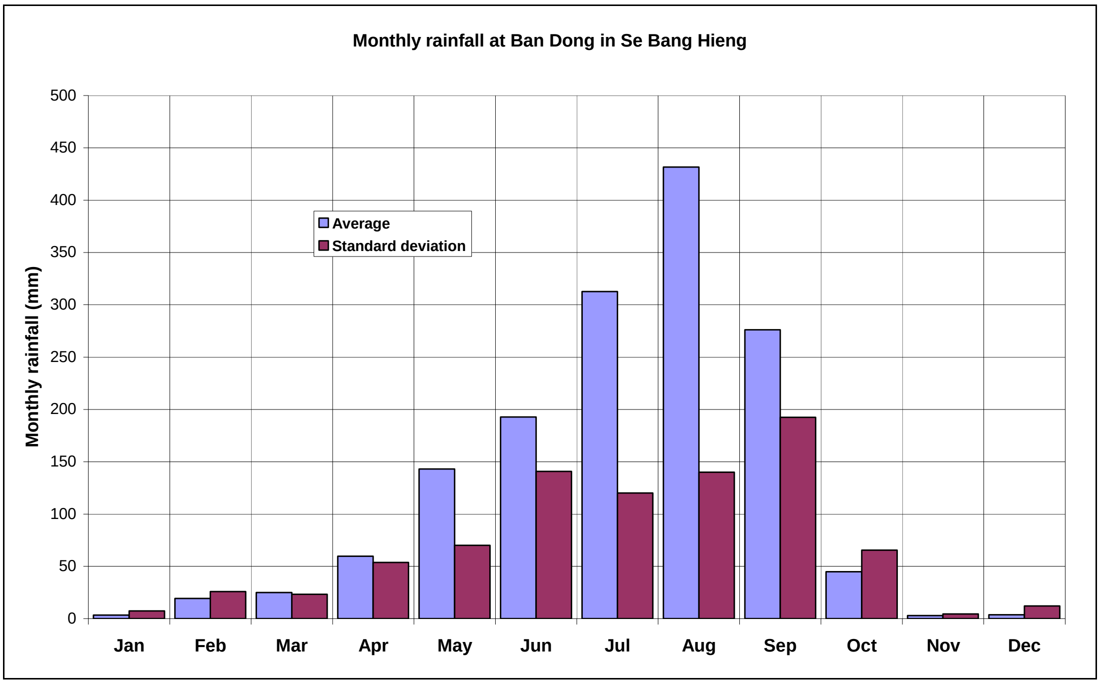

Figure 7.11 Monthly rainfall of Ban Dong in Se Bang Hieng basin.

7.2.3 Runoff

The total contribution to the Mekong between Chiang Khan (basin area 292,000 km^2) and Mukdahan/Savannakhet (basin area 391,000 km^2) comprises some 72% of the BDP-sub-areas SA3 and SA4. Based on the records of these two stations (1968-2005) it is estimated that the average annual contribution of SA3 and SA4 is (241-134)/0.72 or about 150 BCM. The major part (almost 80%) is produced by the basin in SA4. Extrapolation of runoff from 56% of the area gives an average annual contribution of SA4 of 122 BCM, which is consistent with the estimated runoff from SA3 of 32 BCM, adding up to 154 BCM per year for SA3 and SA4 together.

Tributaries

Mean annual flow values for a selected stations in SA4, based on the period 1960-2007 as far as available, have been presented in Table 7.7. The stations are sequenced from upstream to downstream. It is observed that following to the annual rainfall distribution the discharge per unit area rises to a maximum in the basin of Nam Kading/Nam Theun. Further downstream in the plains east of Savannakhet the runoff reduces due to lower rainfall, as orographic effects are less here.

The monthly flows for the same stations are presented in Figure 7.12. The pattern follows the seasonal rainfall distribution with August generally the month with the highest runoff.

Table 7.7 Annual flow values for selection of discharge stations on tributaries in SA4.

Station nr	Station name	Area (km^2)	Flow (m^3/s)	Runoff (mm)
230110	Nam Ngum at Ban Na Luang	5220	132	800
230101	Nam Ngum at Ban Pak Kanhong	14300	615	1360
250101	Nam Nhiep at Muang Mai	4305	185	1360
260101	Nam Sane at Muong Kao	2230	140	1930
270903	Nam Theun at Ban Signo	3370	210	1980
320107	Se Bang Fai at Mahaxai	4520	240	1660
350101	Se Bang Hieng at Ban Keng Done	19400	510	820

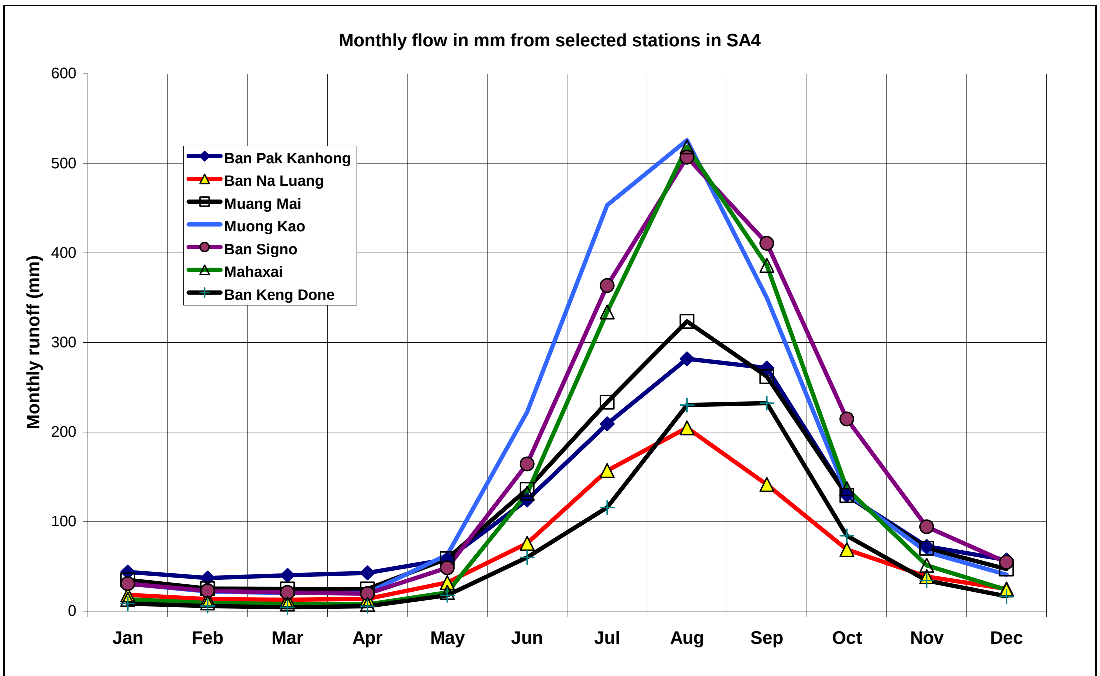

Figure 7.12 Average monthly flow in tributaries of SA4, period 1960-2007.

The characteristics of the daily flows at the selected stations and of the flood waves can be read from Figure 7.13 to Figure 7.30. The following remarks are made:

- The floods on the upper Nam Ngum have a flashy character, and also the peaks from one year to another vary considerably. The period that floods occur ranges from mid July to mid September.
- Also the floods on the Nam Nhiep at Muong Mai have a flashy character. Note that the baseflow in the hydrograph is considerable. The period in which extreme discharges were reported vary from early June till end of September, i.e. about two months longer than for the Nam Ngum.
- The Nam Sane floods at Muong Kao have the same flashy character as the locations discussed above. Floods have occurred in the period early July till the end of September.
- The floods on the Nam Theun at Signo have not a flashy character, they may last for about a month. However, the rate of rise and rate of fall is very similar to that of the flashy floods. The period of occurrence of extremes is typically from July till mid-October.
- Floods on the Se Bang Fai at Mahaxai are not flashy and last one to two months, due to poor conveyance capacity of the river. Floods are a regular phenomenon in the lower Se Bang Fai. Floods do occur in the period July to September.
- A similar type of flood as for Mahaxai is observed for the Se Bang Hieng at Ban Keng Done. The difference, however, is that the basin area at Ban Keng Done is about 4.5 times larger than at Mahaxai. In the upper reaches therefore flash floods will occur. The period in which floods occurred ranged from July to mid October. Even in November a flood may occur on the Se Bang Hieng.

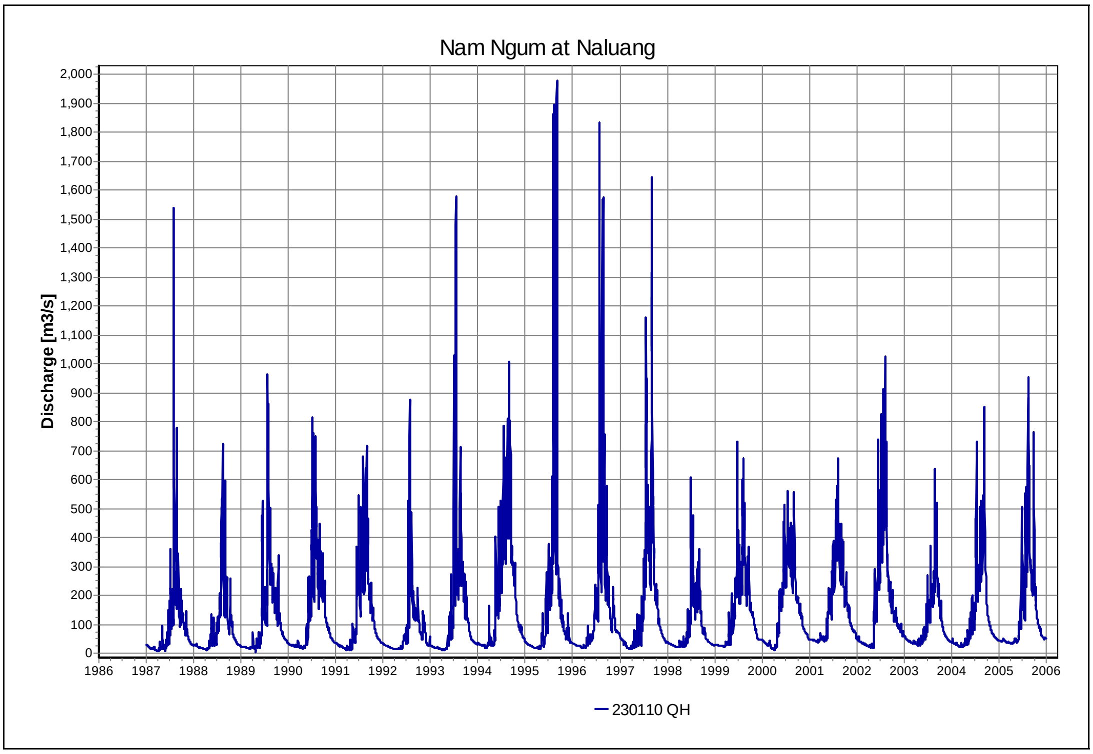

Figure 7.13 Discharge hydrograph of Nam Ngum at Ban Na Luang.

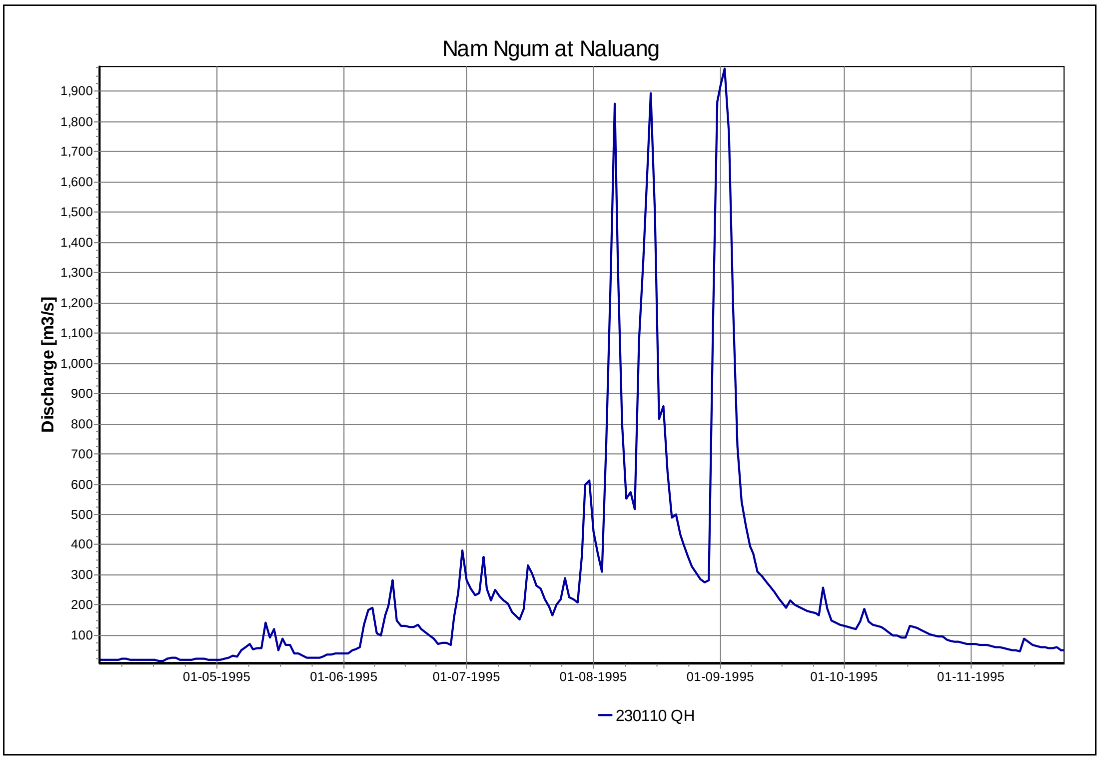

Figure 7.14 Discharge hydrograph of Nam Ngum at Ban Na Luang, year 1995.

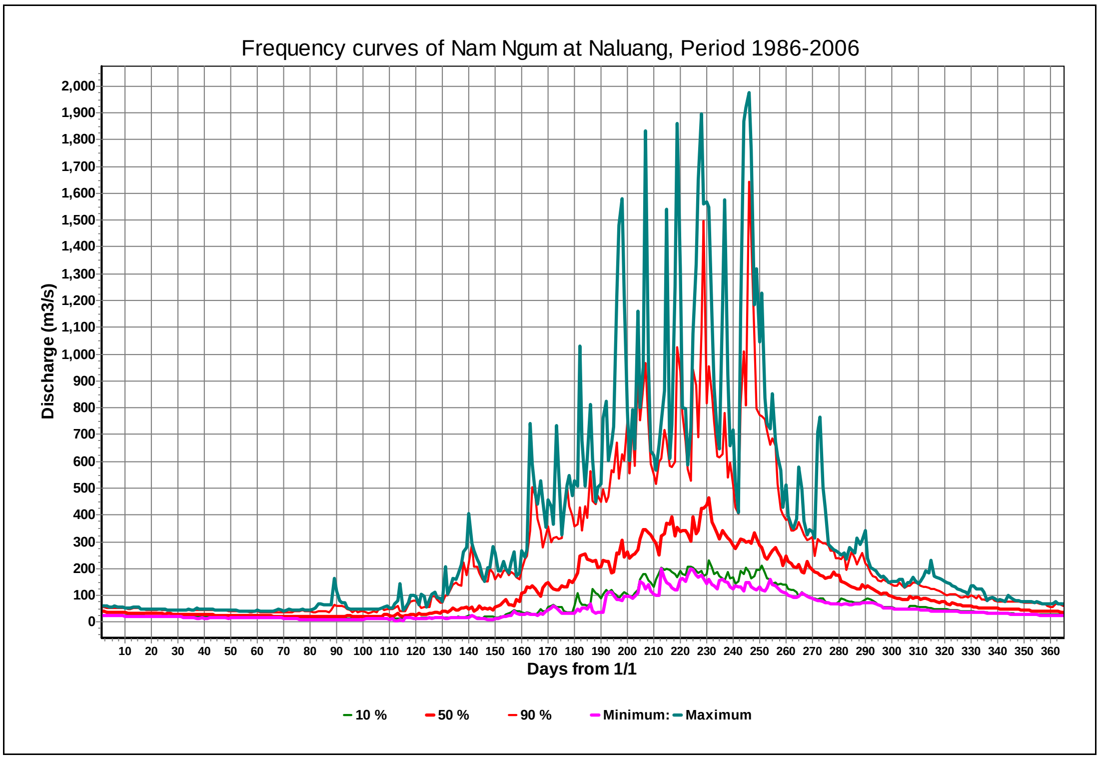

Figure 7.15 Frequency curves of daily discharge of Nam Ngum at Ban Na Luang.

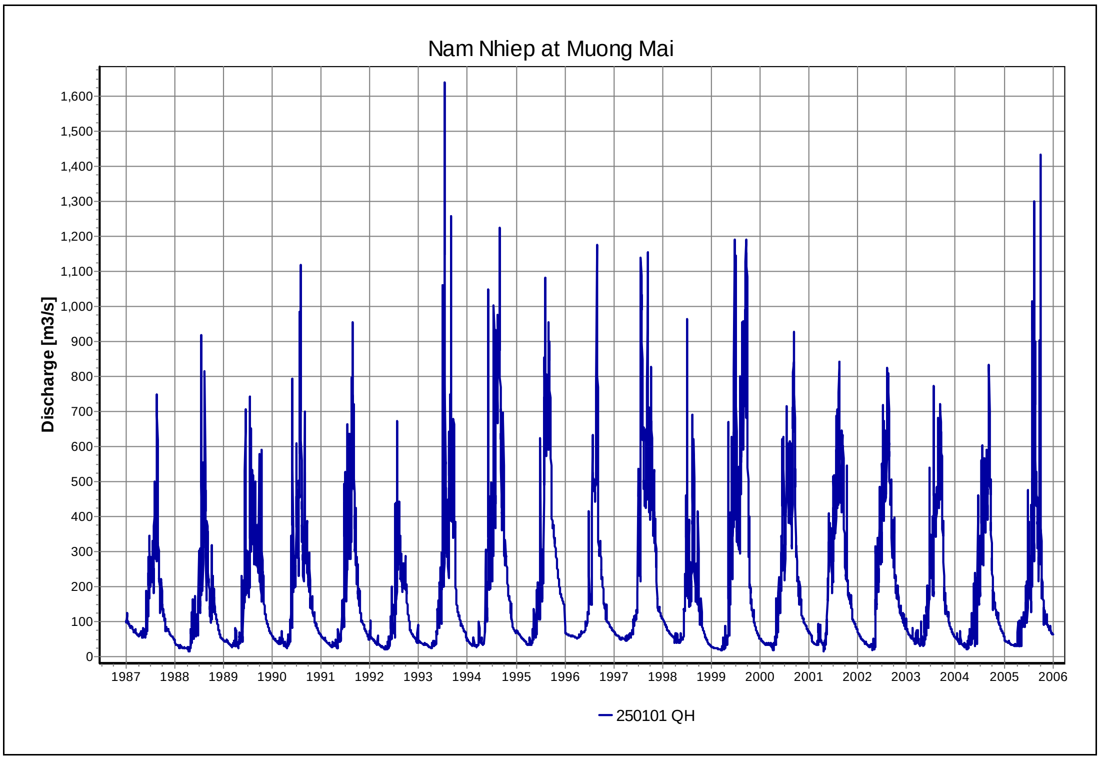

Figure 7.16 Discharge hydrograph of Nam Nhiep at Muong Mai.

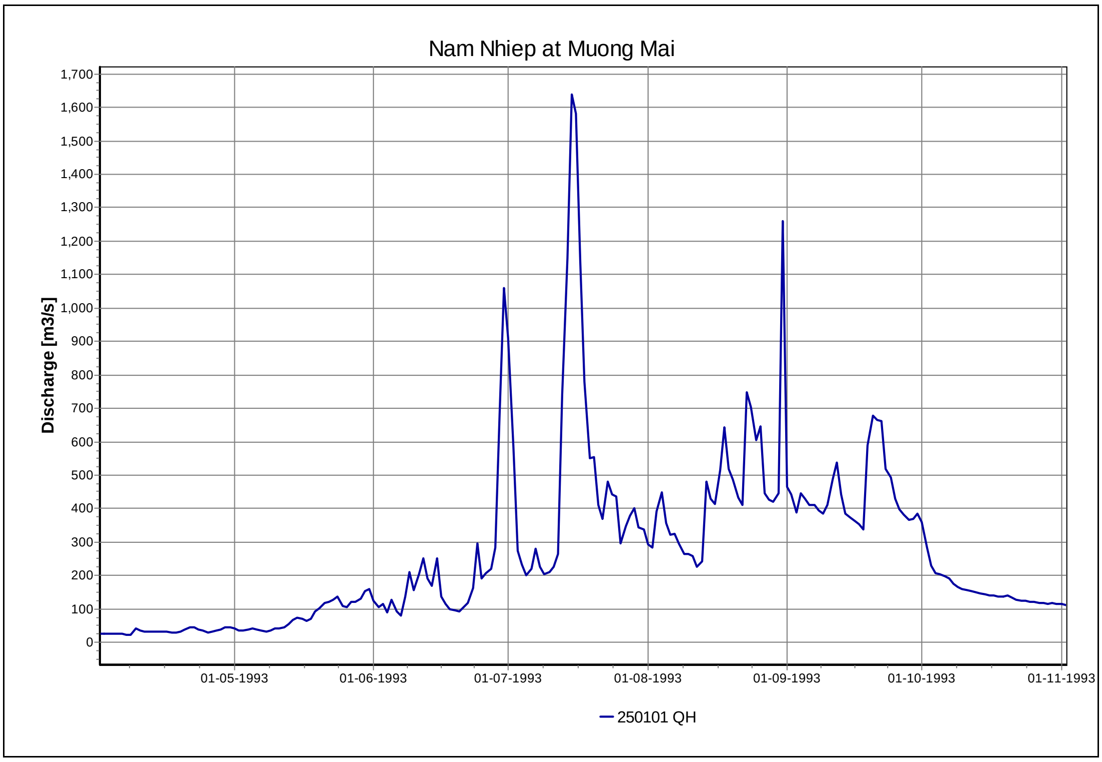

Figure 7.17 Discharge hydrograph of Nam Nhiep at Muong Mai, year 1993.

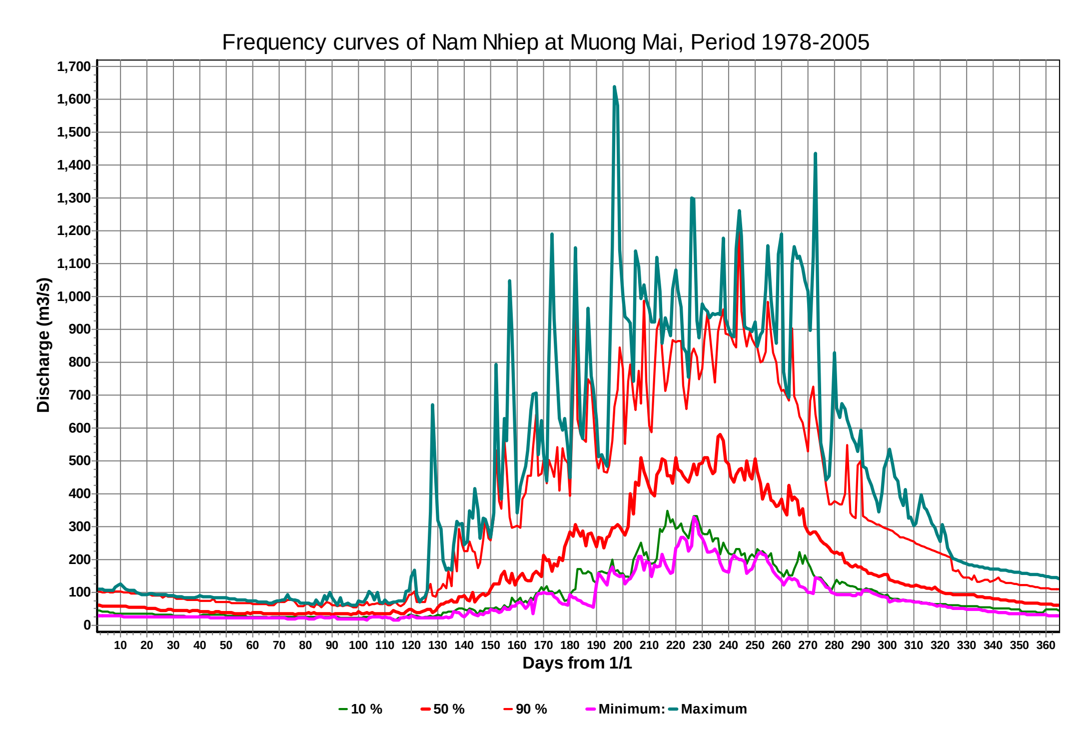

Figure 7.18 Frequency curves of daily discharge of the Nam Nhiep at Muong Mai.

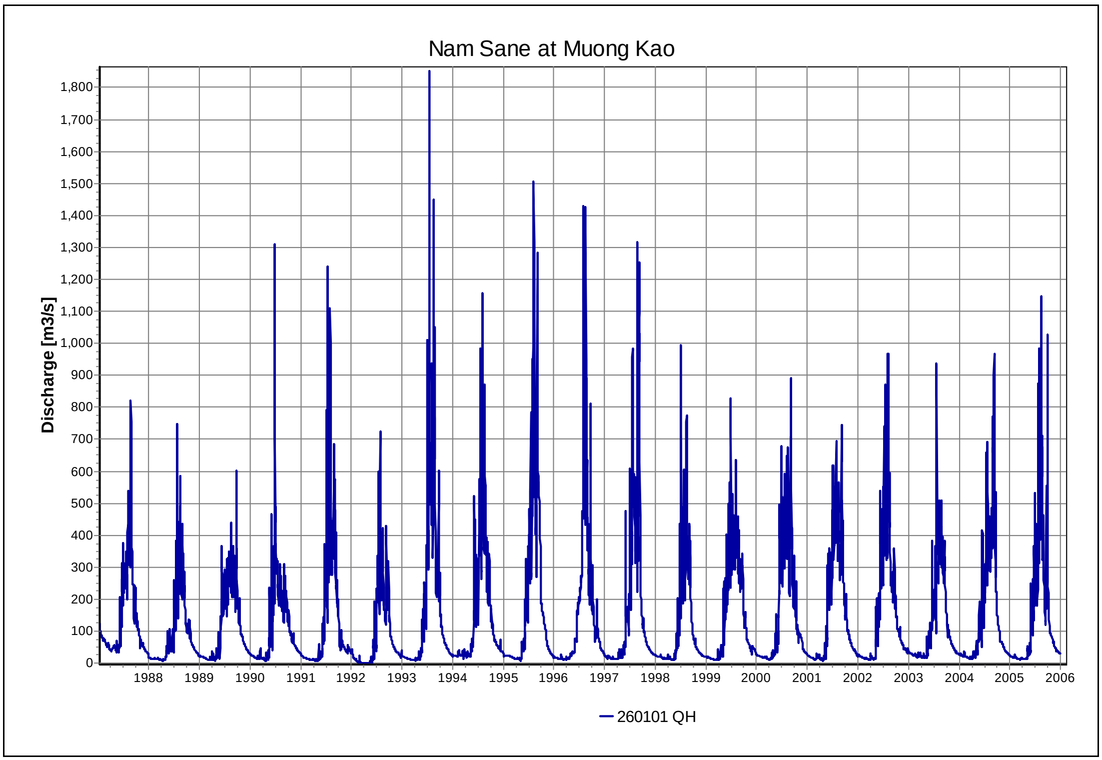

Figure 7.19 Discharge hydrograph of Nam Sane at Muong Kao.

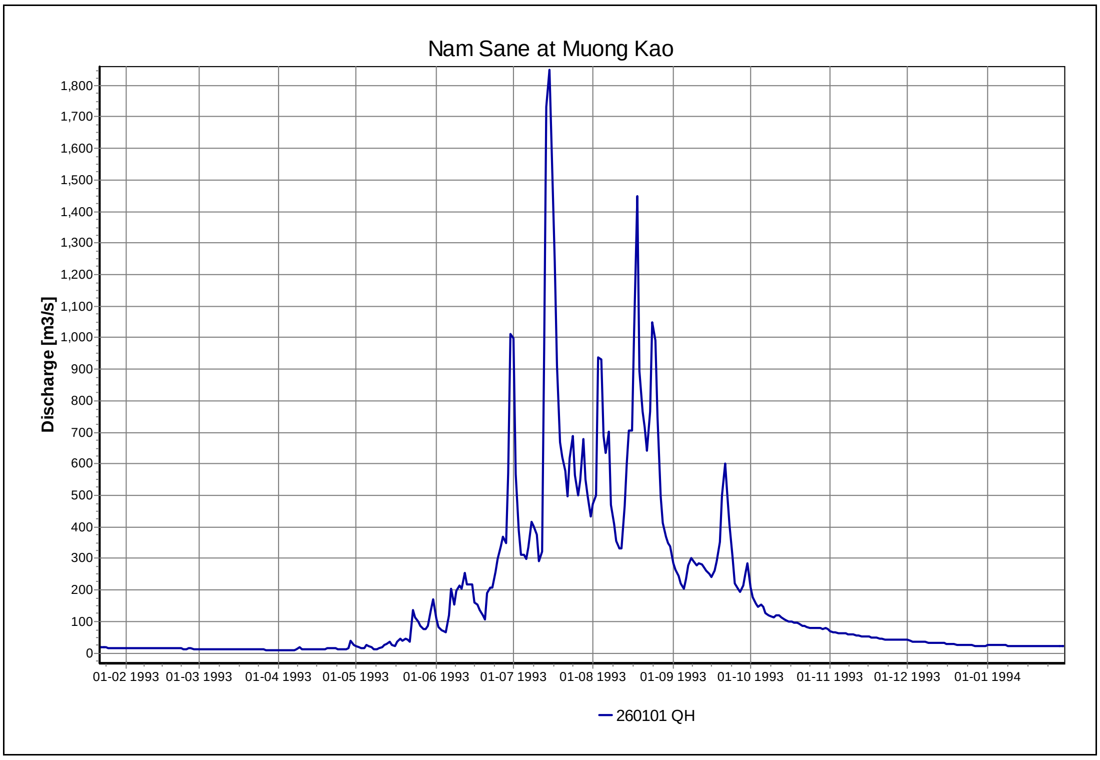

Figure 7.20 Discharge hydrograph of Nam Sane at Muong Kao, year 1993.

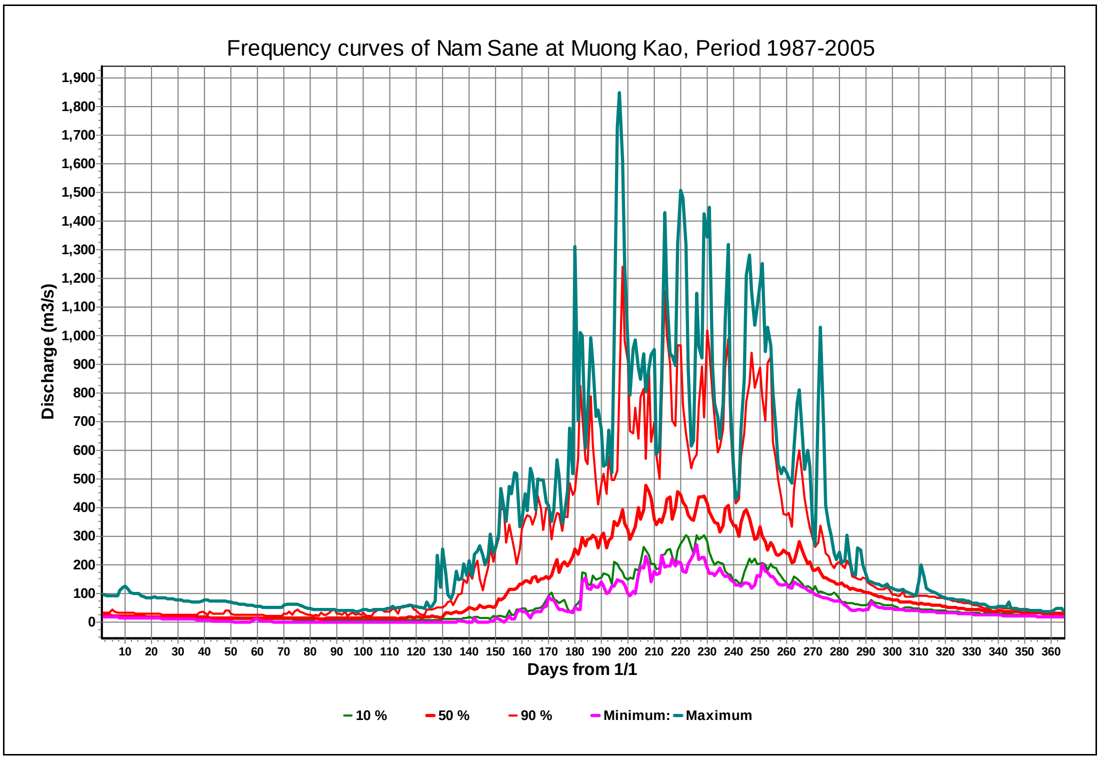

Figure 7.21 Frequency curves of daily discharge of Nam Sane at Muong Kao.

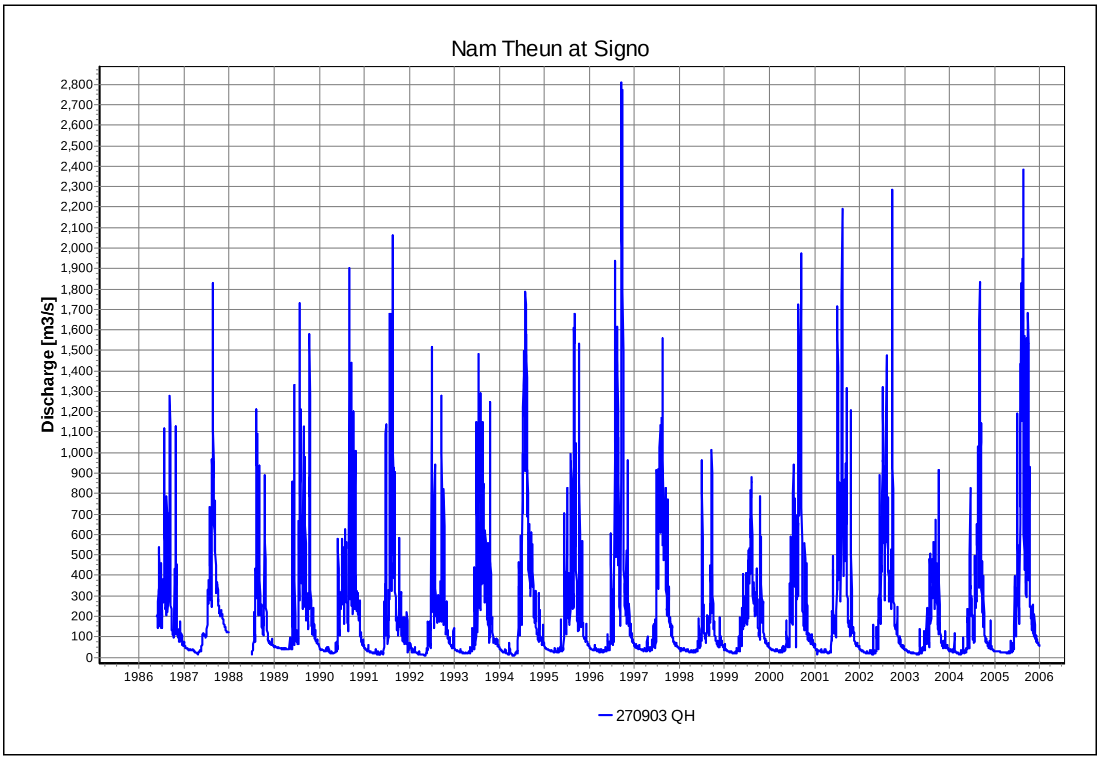

Figure 7.22 Discharge hydrograph of Nam Theun at Signo.

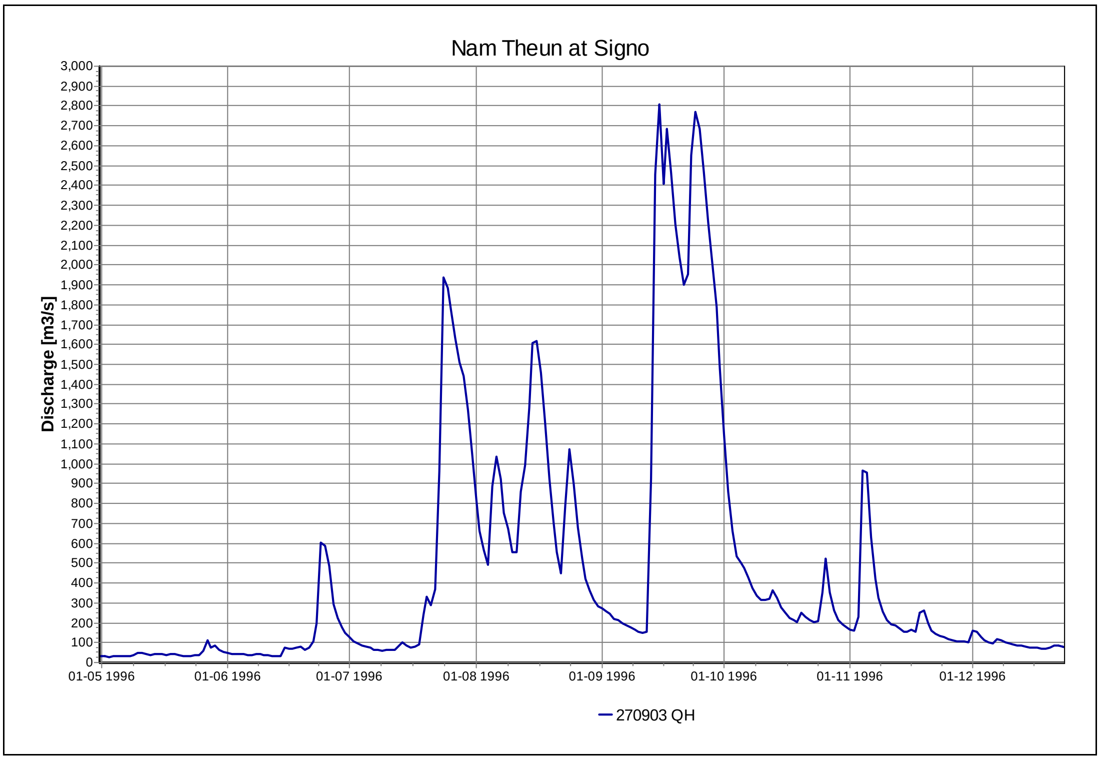

Figure 7.23 Discharge hydrograph of Nam Theun at Signo.

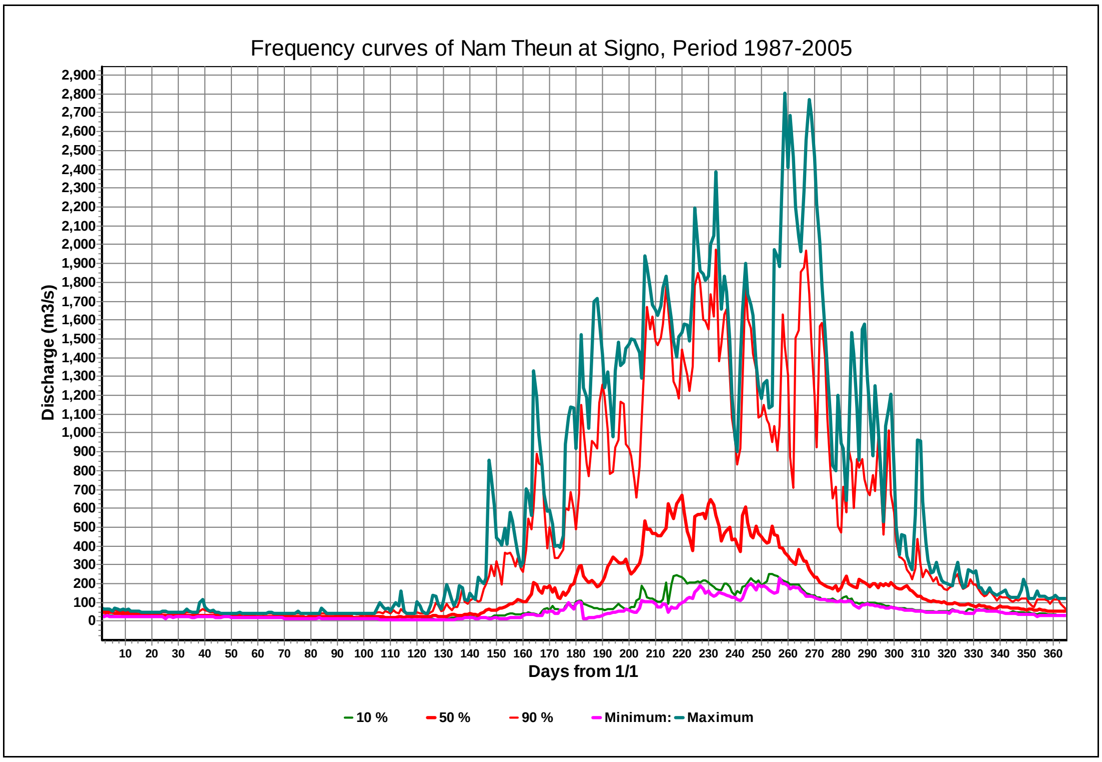

Figure 7.24 Frequency curves of daily discharge of Nam Theun at Signo.

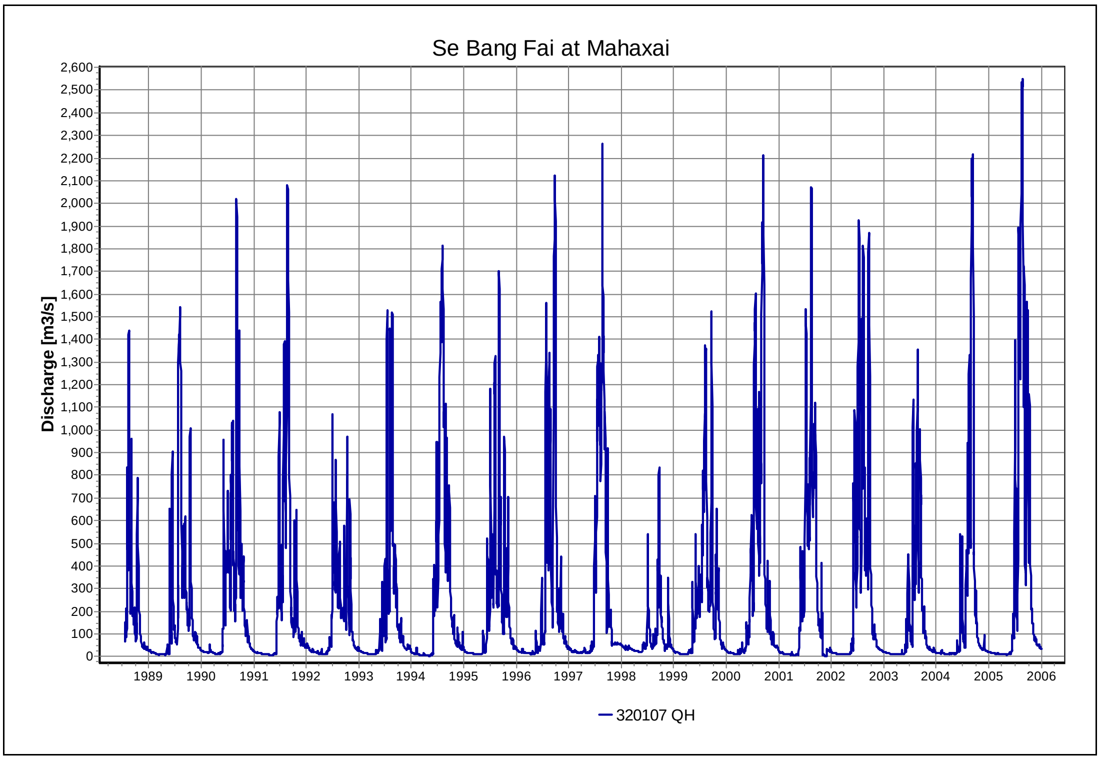

Figure 7.25 Discharge hydrograph of Se Bang Fai at Mahaxai.

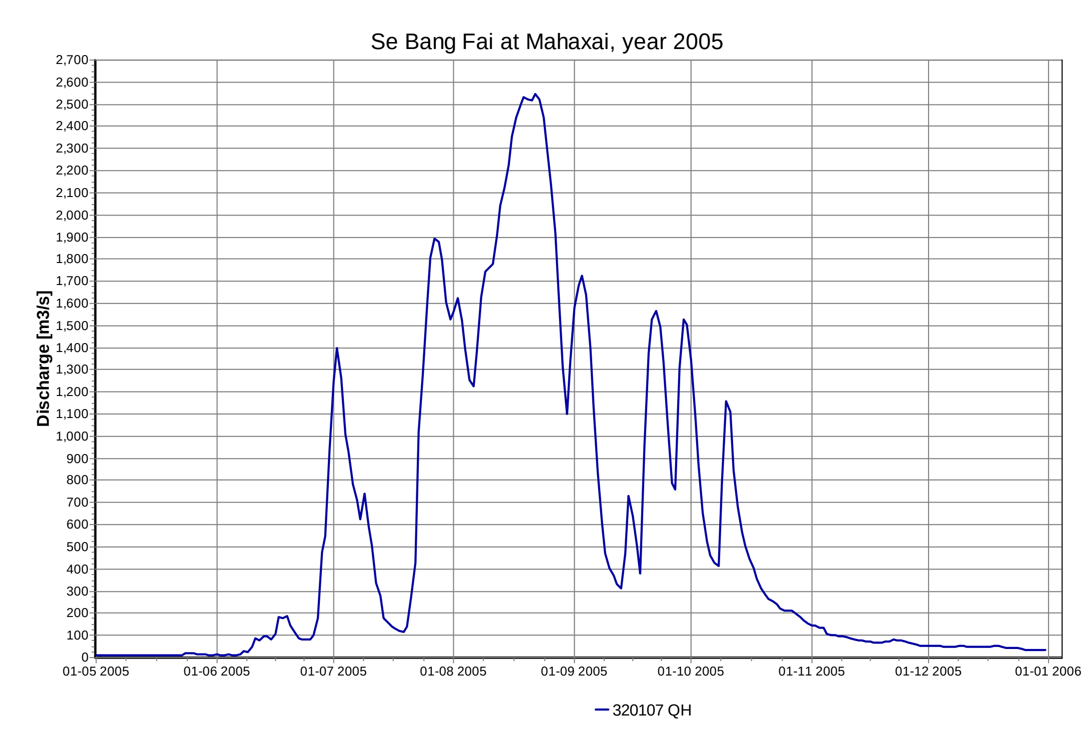

Figure 7.26 Discharge hydrograph of Se Bang Fai at Mahaxai, year 2005.

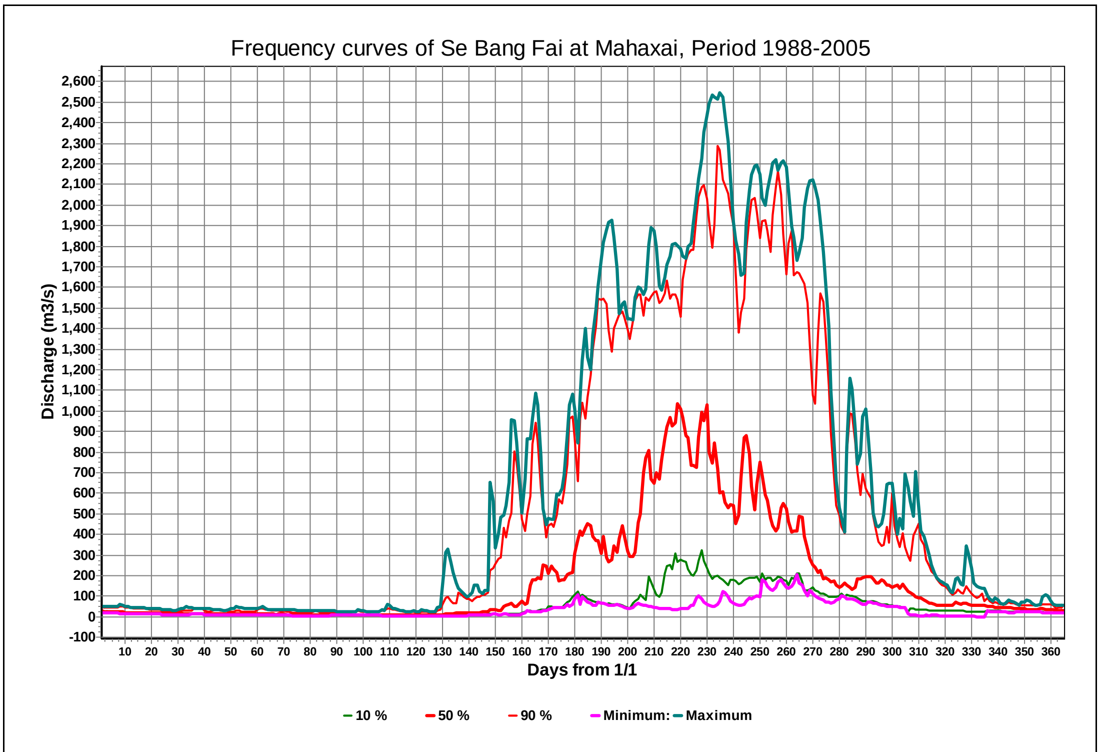

Figure 7.27 Frequency curves of daily discharge of Se Bang Fai at Mahaxai.

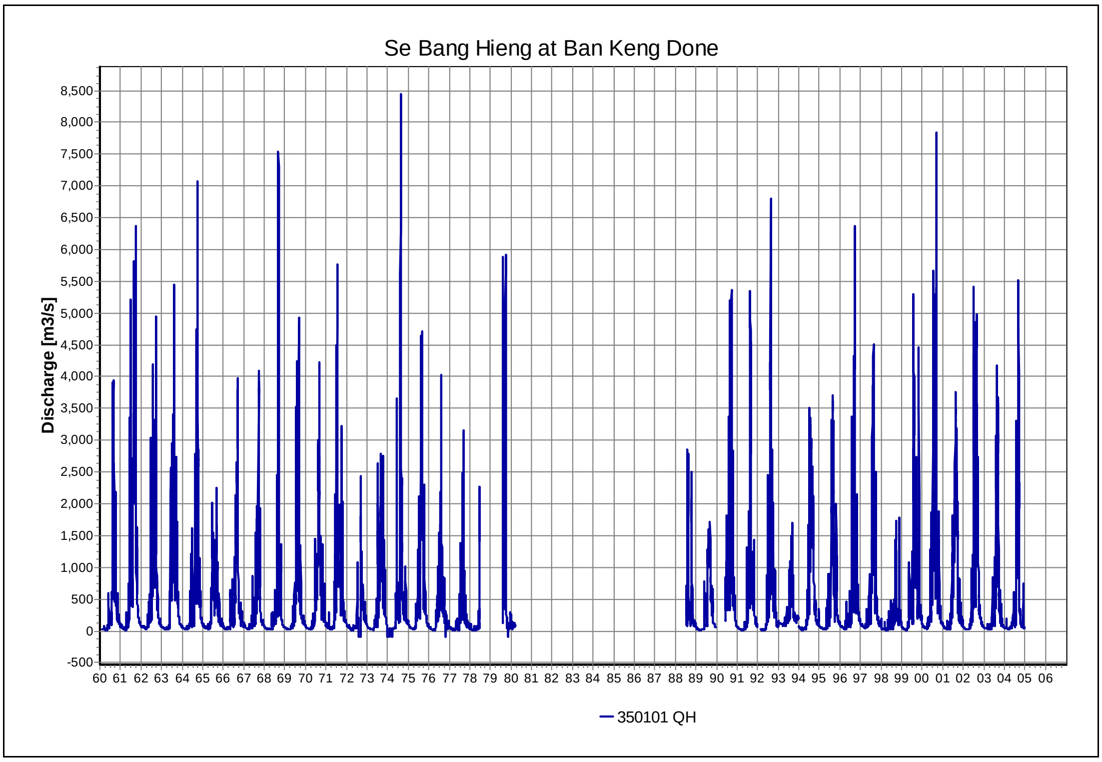

Figure 7.28 Discharge hydrograph of Se Bang Hieng at Ban Keng Done.

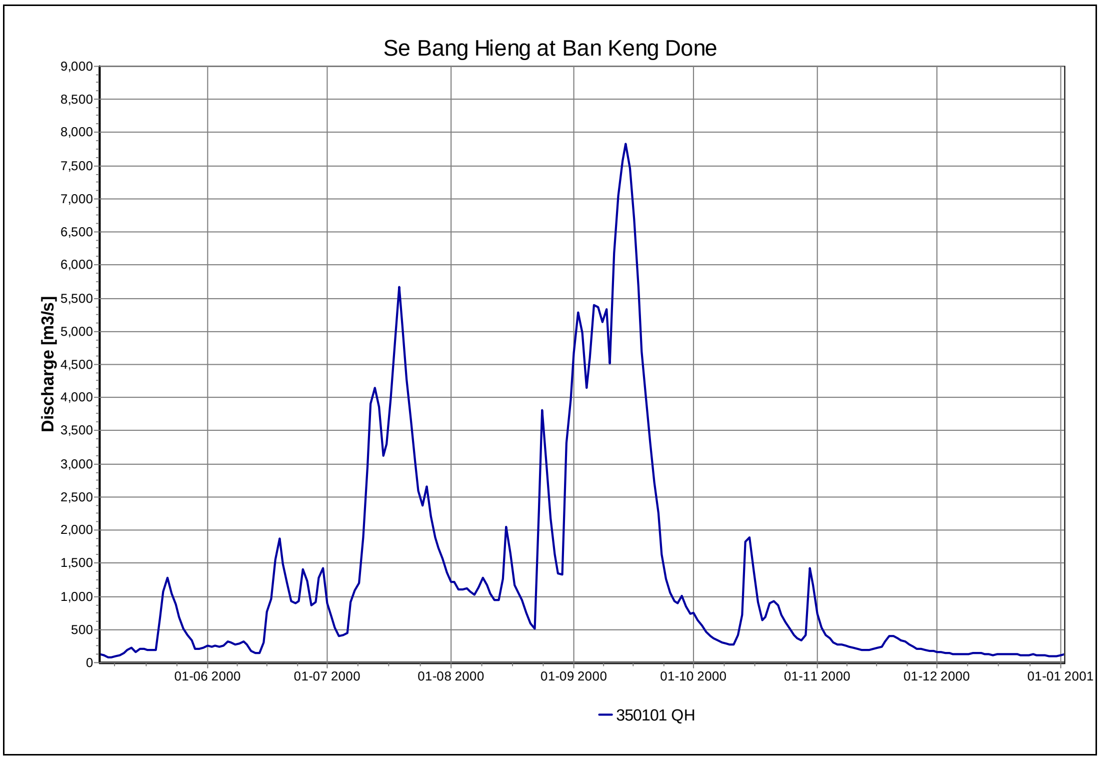

Figure 7.29 Discharge hydrograph of Se Bang Hieng at Ban Keng Done, year 2000.

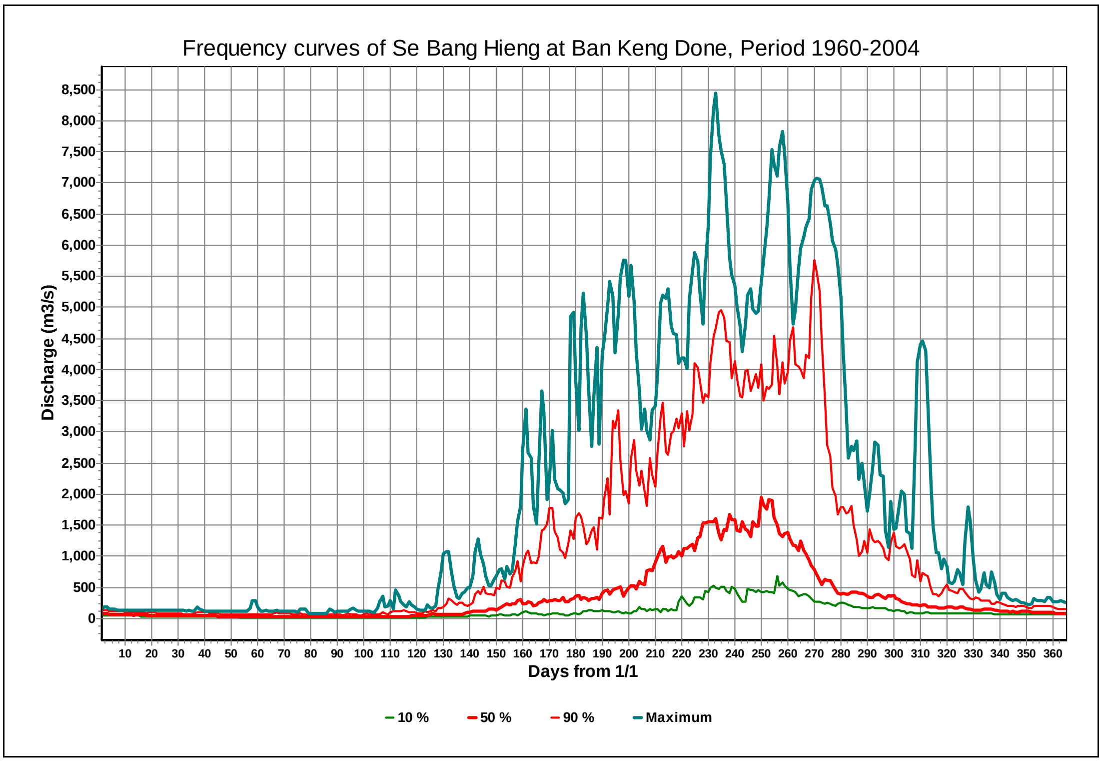

Figure 7.30 Frequency curves of daily discharge of Se Bang Hieng at Ban Keng Done.

Main stream

As the Mekong reach for SA4 is same reach as for SA3 reference is made to Section 6.2 for a description. The discharge records the Laotian stations Thakek and Savannakhet are similar to respectively Nakhon Phanom and Mukdahan on the Thai side.

7.3 Developments in SA4 affecting the flow regime

Irrigation

The irrigation water requirement for SA4 is estimated at 2.1 BCM/yr and some 53 MCM/yr for domestic and industrial purposes. To meet the demand there are 26 small to medium size irrigation reservoirs with a total storage capacity of approximately 50 MCM. In 2003 188,000 ha was irrigated in the wet season and 135,000 ha in the dry season. Expansion till 2013 is estimated at least 30,000 ha, about half of it in Nam Sane, with additional storage requirements. How much irrigation development will affect the regime of the tributaries depends on the former land use, but overall the impact will be small.

Hydropower

The existing hydropower capacity in Laos has developed most in SA4, whereas the planned expansion is largest in this sub-area. An overview of existing capacity, plants under construction and planned developments for which an MOU is available are summarized in Table 7.8. The present storage capacity is about 7.3 BCM,which will in a few years time expand to almost 18 BCM and with the MOU projects implemented to nearly 32 BCM or about 1/4th of the annual flow.

Table 7.8 Hydropower projects, existing, under construction and at MOU status in SA4 (MIME, 2007).

Project	River/Stream	Installed capacity (MW)	Storage capacity (MCM)	Area (km^2)
Existing				
Nam Ngum 1	Nam Ngum	155	7,000	370
N.Theun Hinboum	Nam Theun	210	30	6.3
Nam Leuk	Nam Leuk	60	185	12.8
Nam Mang 3	Nam Mang	40	59	10.2
Total		**465**	**7,274**	**399.3**
Under construction				
Nam Ngum 2	Nam Ngum	615	6,774	122
Nam Theun 2	Nam Theun	1,080	3,680	450
Total		**1,695**	**10,454**	**572**
MOU				
Nam Ngum 5	Nam Ngum	120	314	14.75
Nam Mo	Nam Mo	105	291	10.8
Xayabury	Mekong	1,262	-	30
Nam Ngum 4 (?)	Nam Ngum	250	2,100	118
Nam Hhiep 2	Nam Nhiep	140	364	10.4
Nam Sane 3A	Nam Sane	30	37.6	2.4
Nam Lik 2	Nam Lik	100	1,337	46
Nam Lik 1	Nam Lik	60	175	22
Nam Ngum 3	Nam Ngum	460	1,320	25.6
Nam Bak 1	Nam Bak	115	340	9.2
Nam Bak 2	Nam Bak	68	310	7.5
Nam Feuang	Nam Feuang	-	-	-
Nam Mang 1	Nam Mang	51	738	25.9
Nam Nhiep 1	Nam Nhiep	252	2,250	66.9
Nam Theun 1	Nam Theun	523	2,272	80.7
Theun-Hinboum E.	Nam Theun	220	-	-
Se Pon 3	Se Pon	75	406	29.5
Se Banghouan	Se Banghouan	18	1,707	86.5
Se Lanong 2	Se Bang Hieng	20	95.2	6.1
Total		**3,869**	**14,057**	**592**
Grand total		**6,029**	**31,785**	**1,563**

Adamson (2007) estimated that the total effect of the hydropower development till 2025 on the flood season flows at Mukdahan would be a reduction of 0 to 3 % due to developments in China, which grows to 11% dependent on the development level in Laos. It shows that the development in Laos may have a considerable impact on the flood flows in the Mekong. Generally, however, very little attention is given to flood mitigation in the dam feasibility studies.

7.4 Floods

7.4.1 Tributary floods

The type of floods in the basins in SA4 have been presented in Figure 7.14 for upper Nam Ngum, for the Nam Nhiep in Figure 7.17, Nam Sane in Figure 7.20, Nam Theun in Figure 7.23, Se Bang Fai in Figure 7.26 and Se Bang Hieng in Figure 7.29. It was concluded that basically everywhere in the steeper upper reaches of the basins the floods will be flashy with little lead time. In the lower reaches of the Nam Theun and particularly in the middle and lower parts of the rivers draining east of Savannkhet like the Se Bang Fai and the Se Bang Hieng floods become less flashier and last longer, also induced by the terrain conditions, as may be observed from Figure 7.3.

The annual maximum floods as retrieved from the HYMOS-database are depicted in the following Figure 7.31 to Figure 7.37.

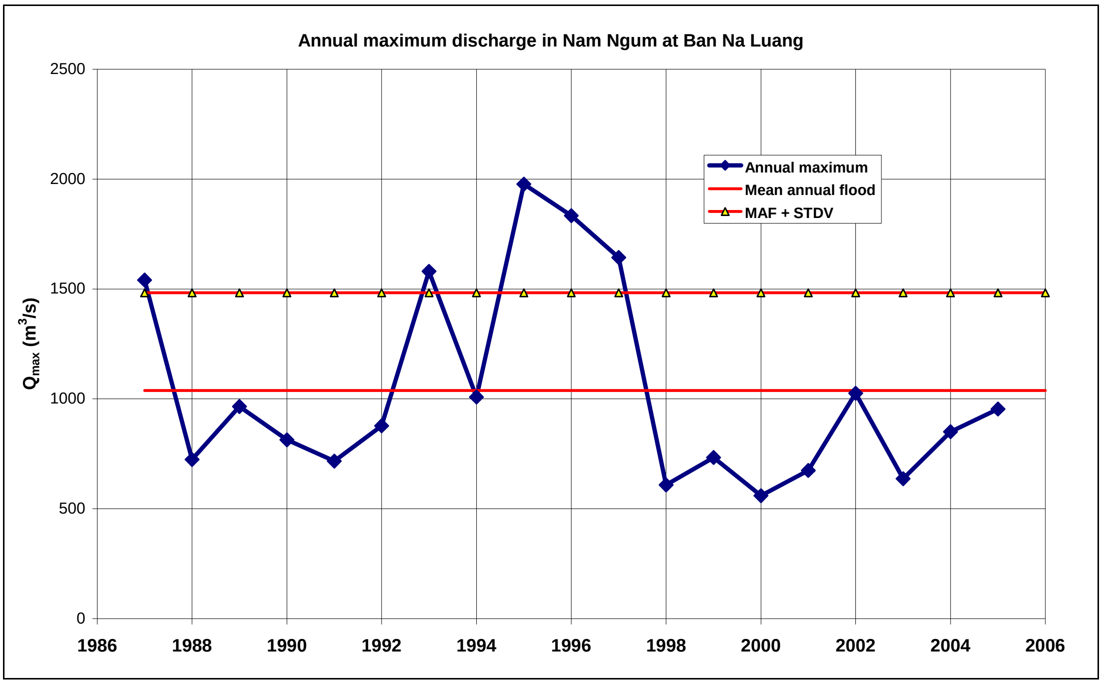

Figure 7.31 Annual maximum discharge in Nam Ngum at Ban Na Luang.

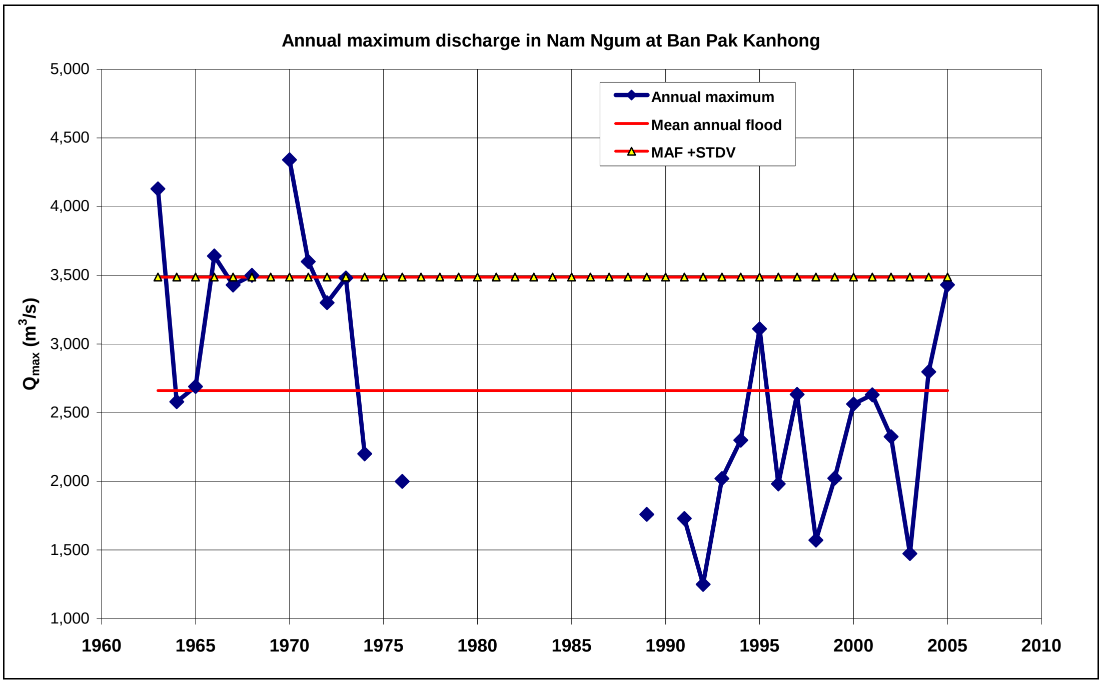

Figure 7.32 Annual maximum discharge in Nam Ngum at Ban Pak Kanhong.

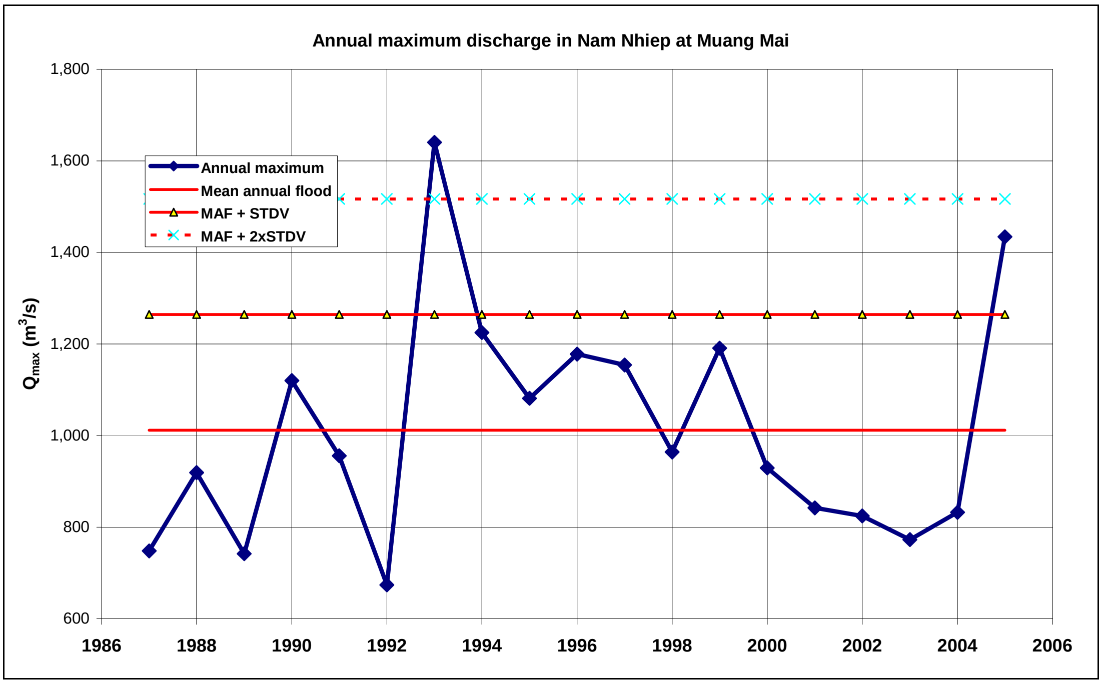

Figure 7.33 Annual maximum discharge in Nam Nhiep at Muang Mai.

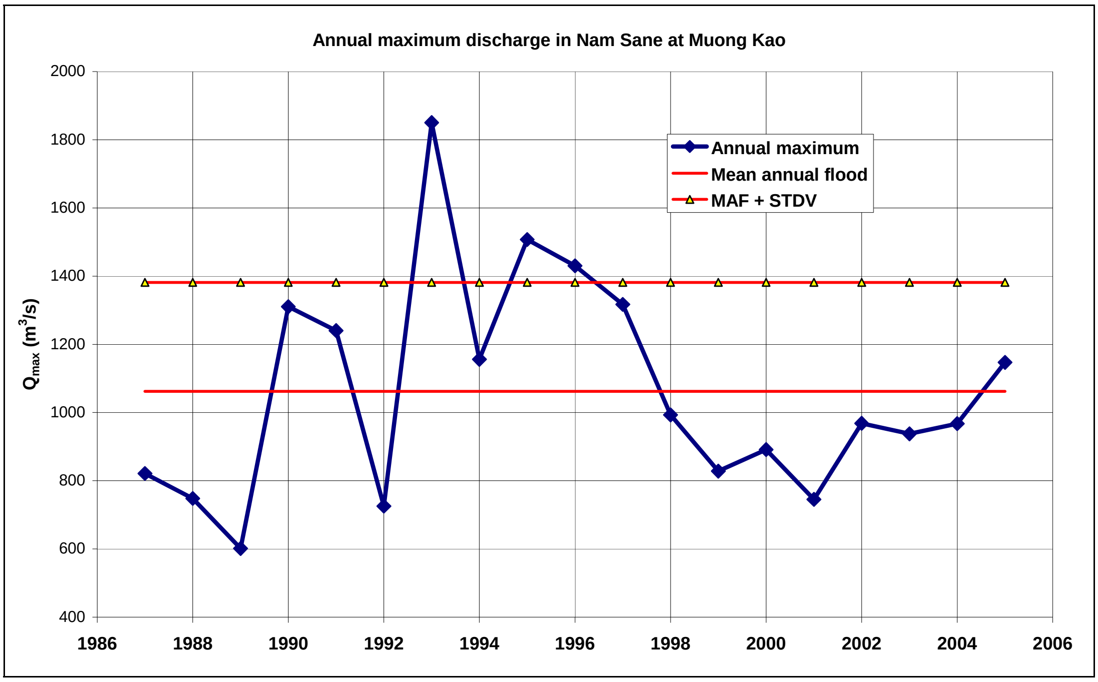

Figure 7.34 Annual maximum discharge in Nam Sane at Muong Kao.

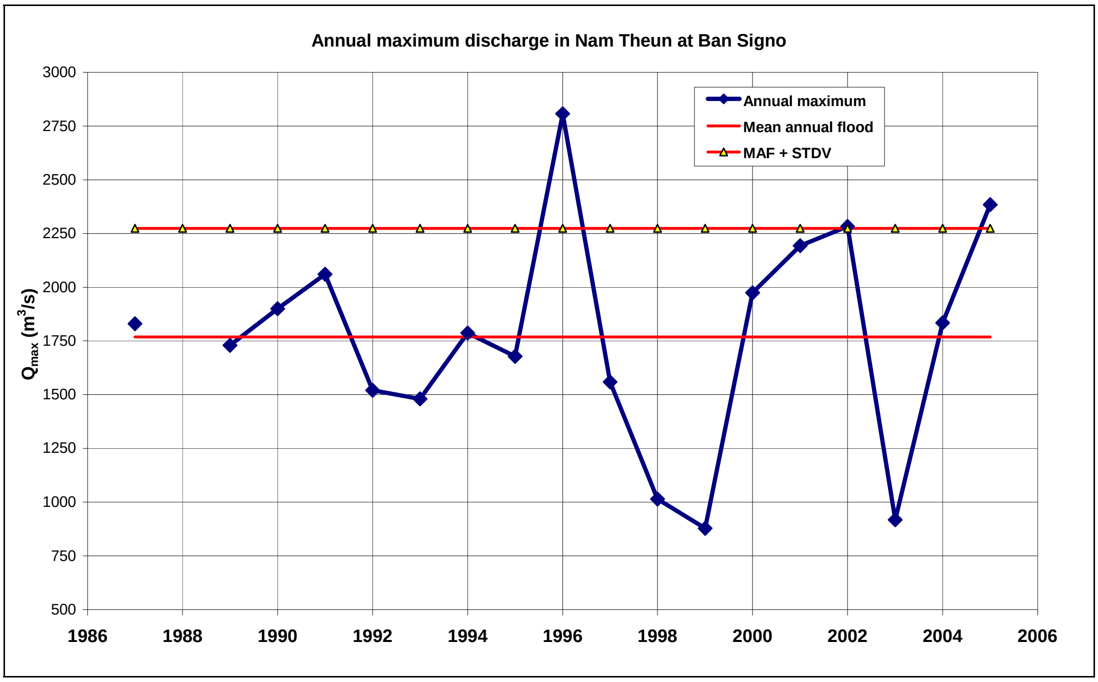

Figure 7.35 Annual maximum discharge in Nam Theun at Ban Signo.

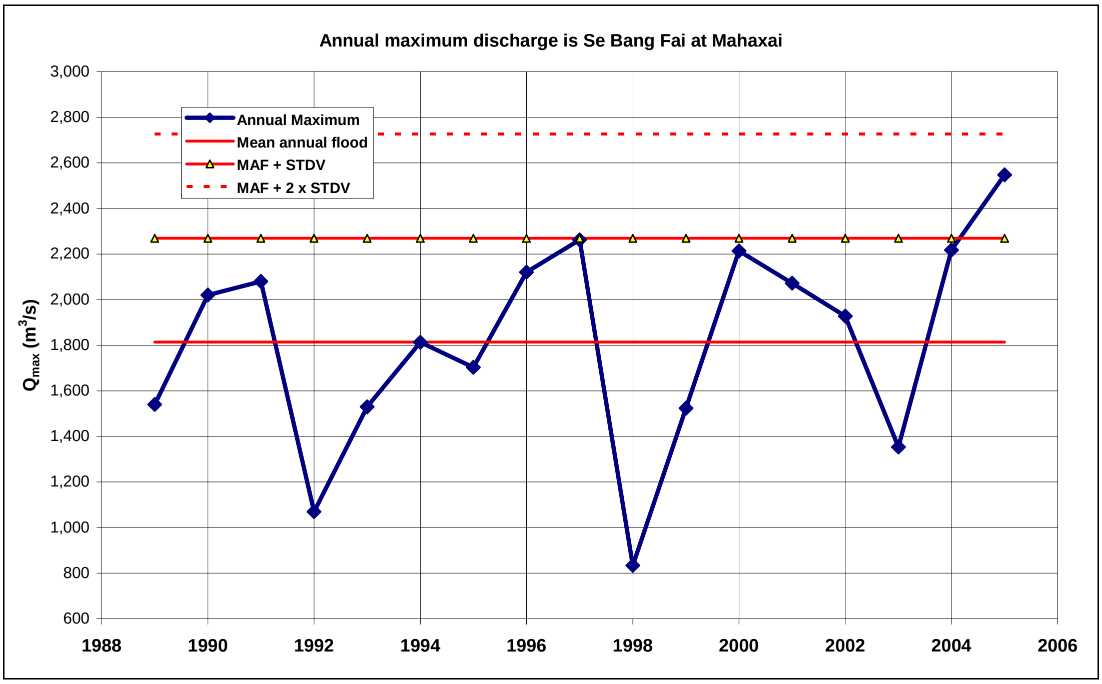

Figure 7.36 Annual maximum discharge in Se Bang Fai at Mahaxai.

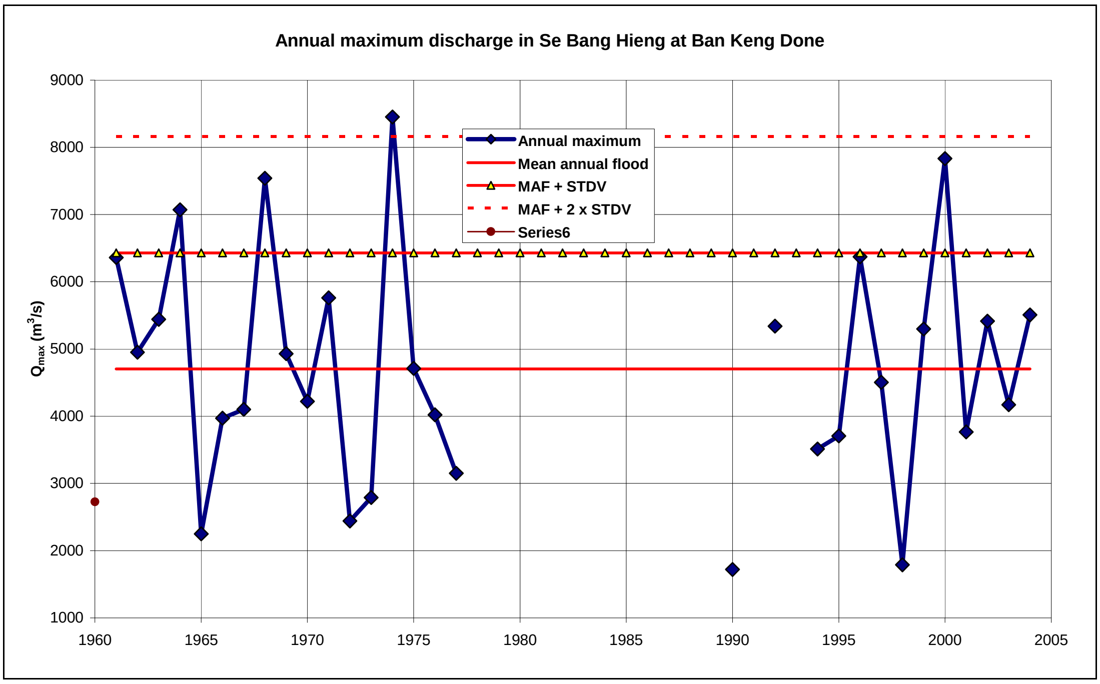

Figure 7.37 Annual maximum discharge in Se Bang Hieng at Ban Keng Done.

With respect to the floods in recent years (2000 – 2006) the following is observed:

- Floods in the Nam Ngum basin have been very moderate, with the exception of the year 2005 in the lower reach, which was the largest recorded since the construction of the Nam Ngum dam. Note that the latter series is therefore nonhomogeneous and can not be used for statistical inference. Large floods on the lower Nam Ngum may pose a threat to Vientiane via the backdoor in view of the local topography.
- The year 2005 has also been high on Nam Nhiep with the one but largest flood peak on record, while the flood in the other recent years have been below avareage.
- On Nam Sane no extreme large flood discharges have been recorded since 2000.
- On Nam Theun since 2000 the flood peaks were all above average with the exception of 2003; the one for 2005 ranked second largest in the series.
- The largest discharge on record for the Se Bang Fai occurred in 2005, causing severe flooding. The record, however, shows that 2001 and 2002 were almost equally large, hence frequent flooding may be expected on this river, also in view of backwater from the Mekong, see below.
- On Se Bang Hieng only the year 2000 has been extreme, with the one but largest flood discharge.

From the series of annual maximum discharges it is also be observed that the occurrence of an extreme flood varies much from basin to basin, like on the main stem.

In the annual flood report of 2005 (MRC, 2006) it is mentioned that the Nam Theun/ Se Bang Fai area covering the districts Hinboun and Nongbok in Khammouan Province were most affected by the floods that year. The sub-area did not suffer any severe flooding problems in 2006 according the annual flood report of 2006 (MRC, 2007).

The hydrological hazard for the locations with record larger then say 15 years can be derived from the available data. Extension with rainfall-runoff modelling is not an option in view of the limited available and partly unreliable rainfall data. A regional analysis, like the one proposed by Adamson, P.T. (2007) but extended with local rainfall and physical basin information as discussed in the previous sections, is an option.

To transform the hydrological hazard into an flood hazard, river conveyance capacities and flood plain details have to be available. Hydrodynamic models of a number of tributaries in SA4 have been developed:

- For the Nam Ngum, downstream of the Nam Ngum dam from the Nam Lik mouth till the Mekong. The model was recently updated and now based on 44 measured river cross-sections and the flood plain developed from a DEM.
- For Se Ban Fai, including the middle and lower part of the river with some tributaries from HEC-RAS modeling for Nam Theun-II. Some 56 measured cross-section for the main stream are available, 76 for Nam Kathay and Nam Nhom, Nam Phit 21 cross-sections, 3 cros-sections of Xe Noy and 6 for Nam Ou La.
- The Se Bang Hieng is modelled from village Tonglaviang to the Mekong including some of the tributaries. Some cross-sections are measured, the rest is estimated. The model has been calibrated.

It implies that flood hazard maps for a limited area of SA4 is possible.

7.4.2 Main stream floods

The main stream floods in recent years have been discussed in Section 6.4 for their impact on the flooding along the Mekong. Though the flood reports of 2005 and 2006 (MRC, 2006, 2007) do not mention specific areas threatened by floods, bank protection projects have been proposed and partly implemented for the major cities in Laos along the Mekong including Vientiane, Paksane, Thakek, Savannakhet and Pakse. But apart from Vientiane no critical flood levels are available in the 2006 annual flood report.

According to the Department of Meteorology and Hydrology of Laos part of the embankment in Vientiane constructed after the 1966 flood was overtopped in 2002 and flooded the premises of the department in the city, see Figure 7.38. In Vientiane the flood level for the city (19,900 m^3/s) was exceeded in 2002 during 6 days (see also Section 6.4.2).

The options for flood hazard determination was discussed in Section 6.4.

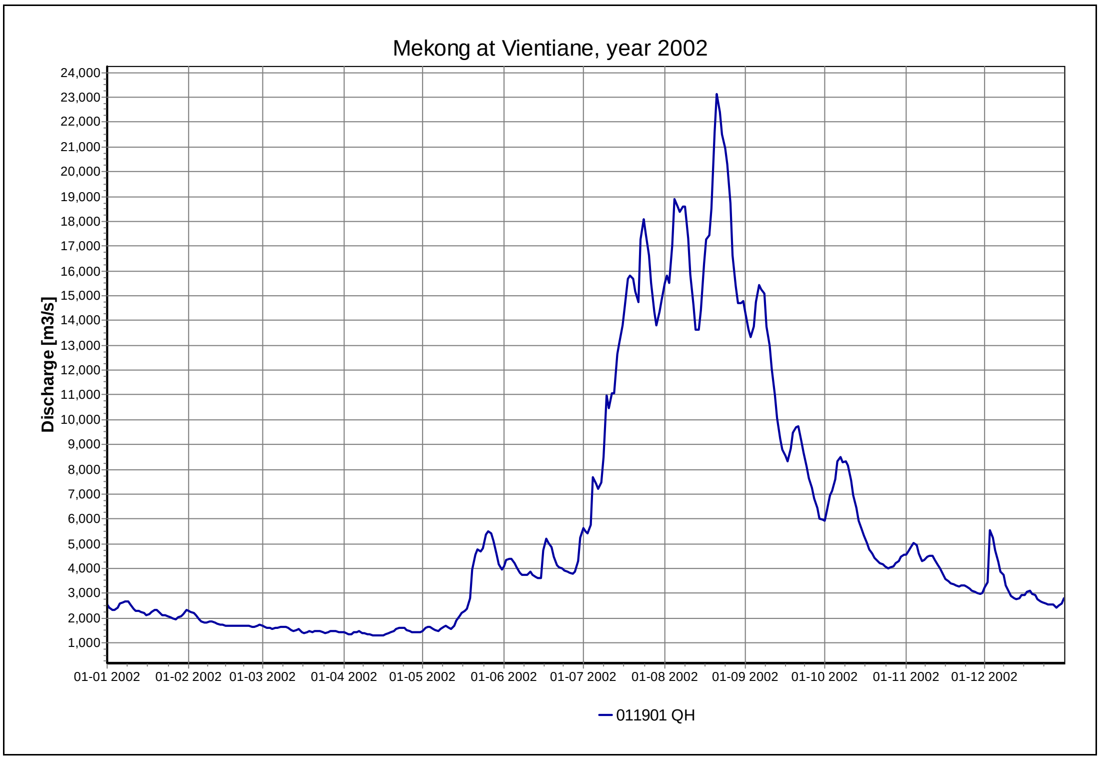

Figure 7.38 Discharge hydrograph of flood of 2002 in Mekong at Vientiane.

7.4.3 Combined floods

The topographical map and particularly the slope map indicate that the lower reaches of all tribuaties draining to the Mekong in SA4 downstream of Vientiane are flat and will be sensitive to combined floods caused by high flows from the tributary itself, backed up by high stages on the Mekong. Particularly the lower reaches of the Nam Ngum, of the Se Bang Fai and of the Se Bang Hieng regularly face combined floods. Figure 7.39 to Figure 7.41 show that the floods on the tributaries are likely to coincide with the occurrence of high stages on the Mekong. Since for all three tributaries hydraulic models are available the extent of flooding for combinations of upstream discharges and downstream stages can be assessed.

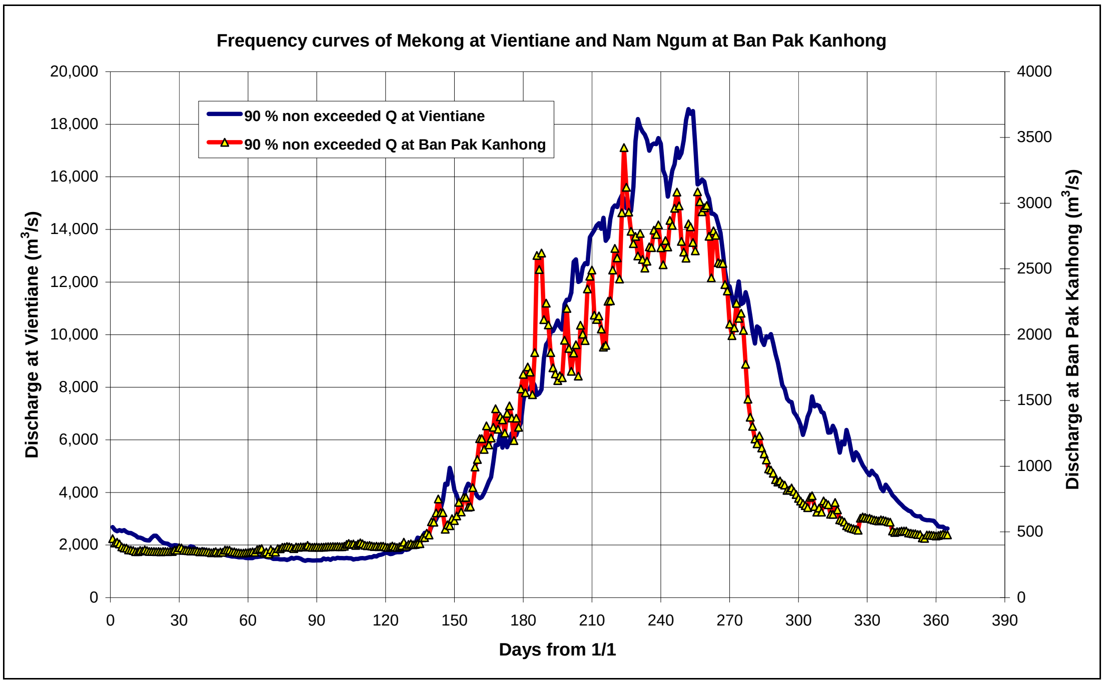

Figure 7.39 Frequency curves (90 %) of Mekong at Vientiane and Nam Ngum at Ban Pak Kanhong.

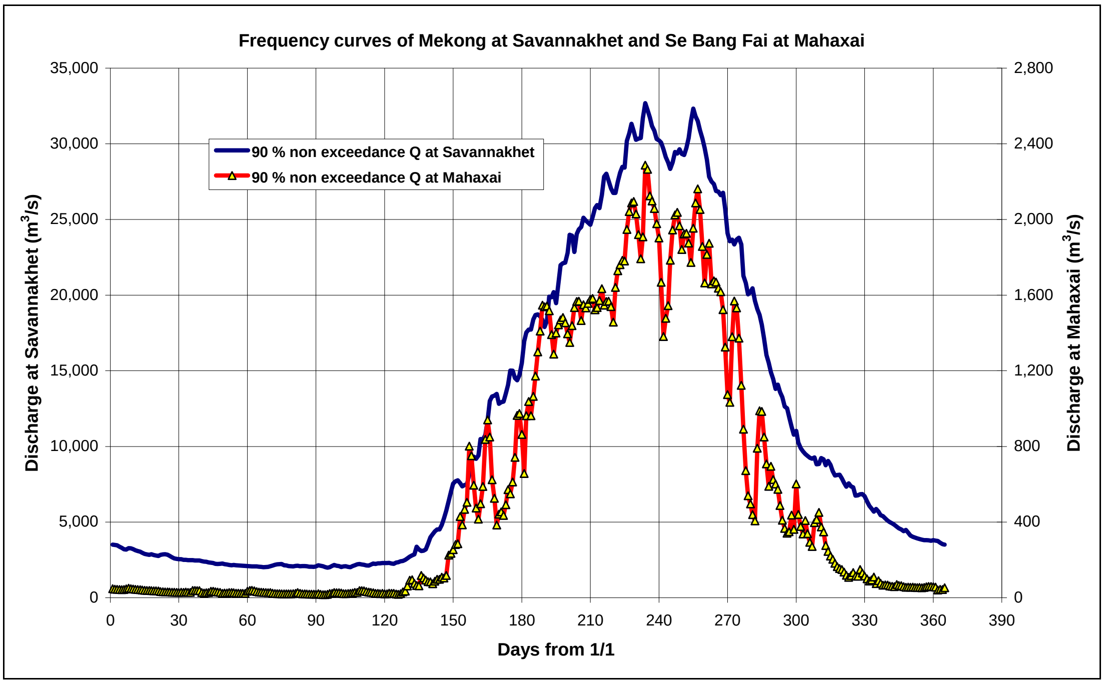

Figure 7.40 Frequency curves (90 %) of Mekong at Savannakhet and Se Bang fai at Mahaxai.

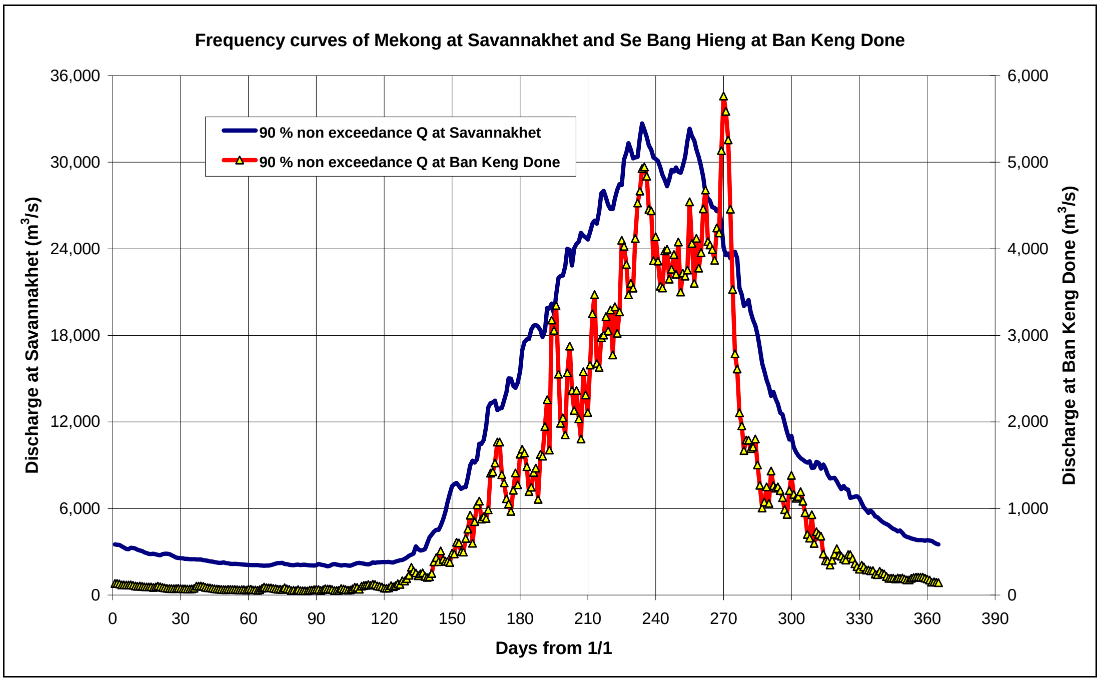

Figure 7.41 Frequency curves (90 %) of Mekong at Savannakhet and Se Bang Hieng at Ban Keng Done.

7.4.4 Summing up

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 record larger then say 15 years can be derived from the available data. Extension with rainfall-runoff modelling 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, Se Bang Fai and Se Bang Hieng models are available to translate the hydrological hazard into flood hazard.

With respect to mainstream floods the presently available hydraulic models are not capable of tranforming hydrological hazrad into flood hazard, However, 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.

8 HYDROLOGICAL AND FLOOD HAZARD IN SUB-AREA 5

8.1 Basin characteristics

Sub-area 5 (SA5) covers the Korat Plateau including the basins of the Mun and Chi rivers in Thailand up the the mouth of the Mun River into the Mekong at rkm 909 just downstream of Khong Chiam, see Figure 8.1. The total area is 119,177 km^2. The Mun rises in the San Kamphaeng Range northeast of Bangkok. It drains the Phanom Malai/Dong Rek Range at the border with Cambodia along the southern border of SA5. The Chi takes its rise in the Petchabun Range which forms the western border of SA5. The northeastern border is formed by the Phu Phan Range stretching from Udon Thani to Ubon Ratchathani.

The Mun river tributaries include:

- Lam Pra Plemg and Lam Chae
- Lam Tha Kong
- Lam Chiang Krai
- Huai Lam Plai Mat
- Lam Sa Theat with Huai Aek
- Lam Phang Chu
- Lam Chi with Lam Lam Tha Tao
- Lam Sieo Noi with Lam Sieo Noi
- Huai Thap Than
- Huai Samran
- Huai Khayung
- Nam Chi, which enters the Mun just upstream of Ubon Ratchathani, and comprises the following tributaries:
  - the headwaters formed by Huai Rai, Lam Krachnan and Lam Phay Chu
  - Huai Pha Thao
  - at Khon Kaen the Nam Pong enters; it hosts the Ubol Dam and receives water from the Nam Mo, Nam Phrom and Lam Choen, and
  - near Kalasin the Lam Pao with the Nam Pao Dam
- Lam Se Bai with Huai Phung
- Lam Se Bok
- Lam Dom Yai
- Huai Kwang, and
- Lam Dong Noi with the Sirinthon Dam.

Apart from the mountain ranges along the western and southern boundaries of SA5, the area is flat with elevations below 250 masl and slopes < 1 %, see Figure 8.2 and Figure 8.3.

The land use is presented in Figure 8.4. Some 85% of the area is agricultural land, with paddy field along the river channels and livestock and other agriculture on higher areas. Forest covers about 12% of the area and the rest is formed by water bodies spread all over the area. Soils comprise mainly acrisols, acidic strongly leached soils with low fertility. Saline soils are widespread and form the largest portion of infertile land in the region.

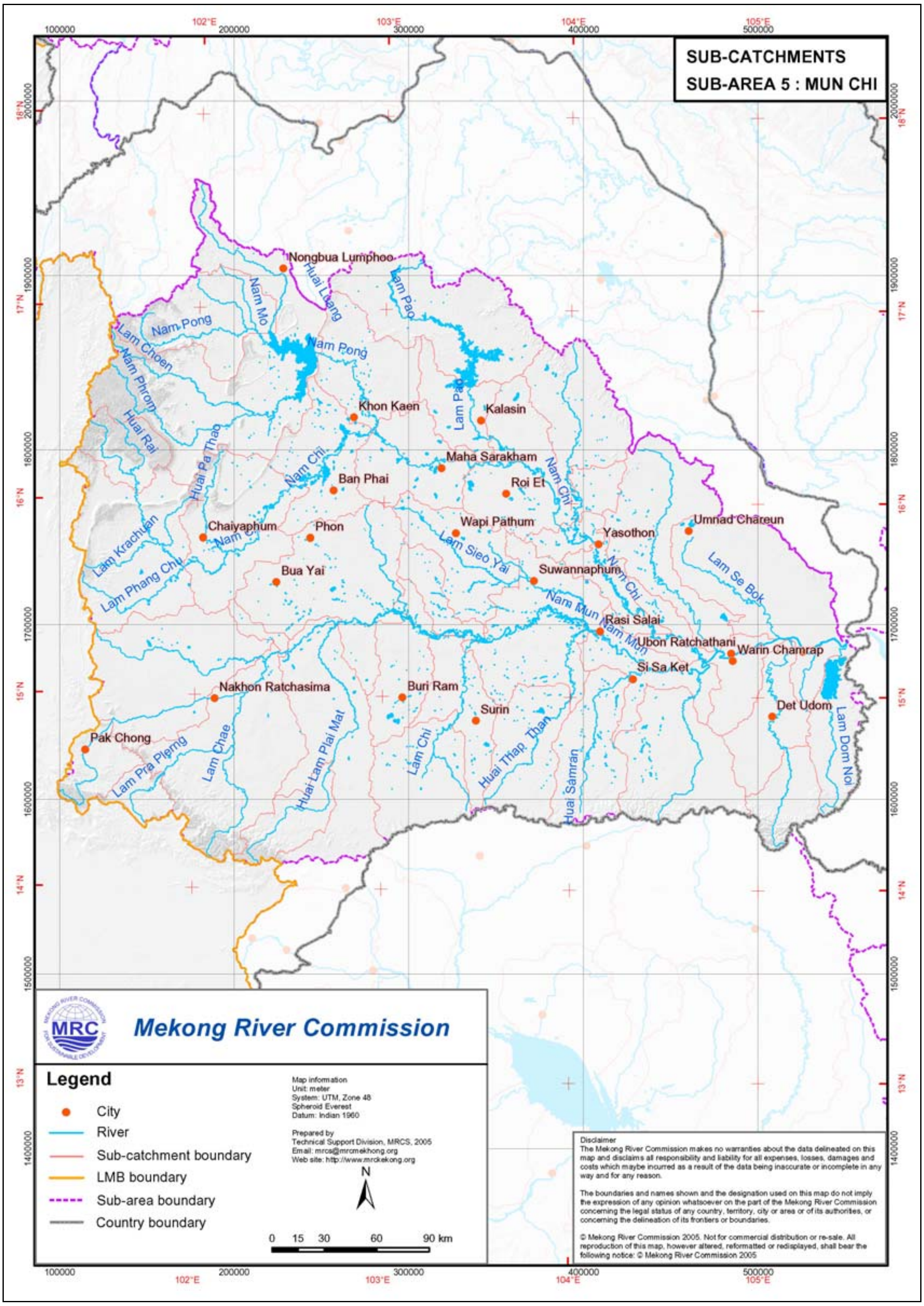

Figure 8.1 Layout of river basins in SA5 (BDP, 2006).

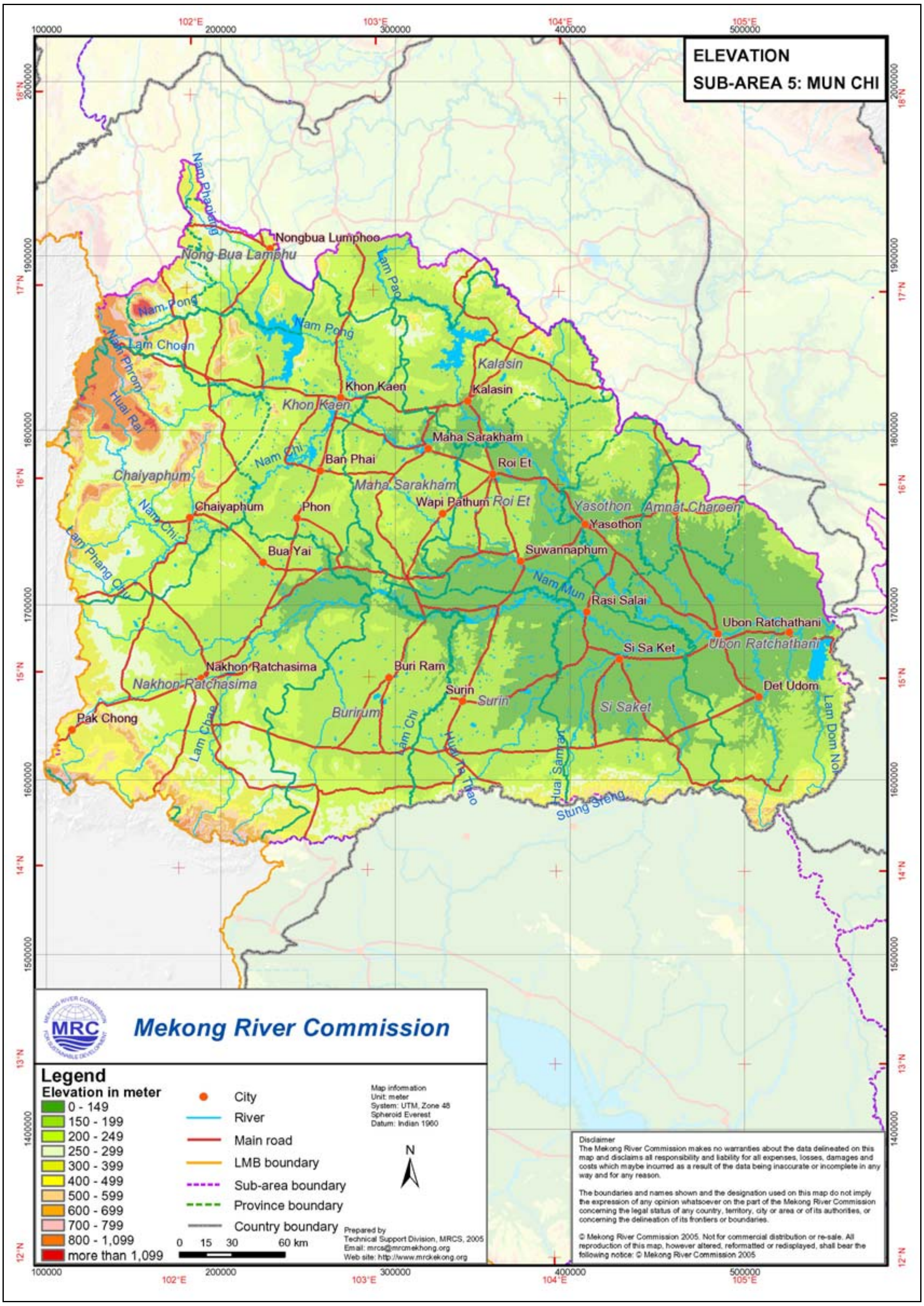

Figure 8.2 Elevation map of SA5 (BDP, 2006).

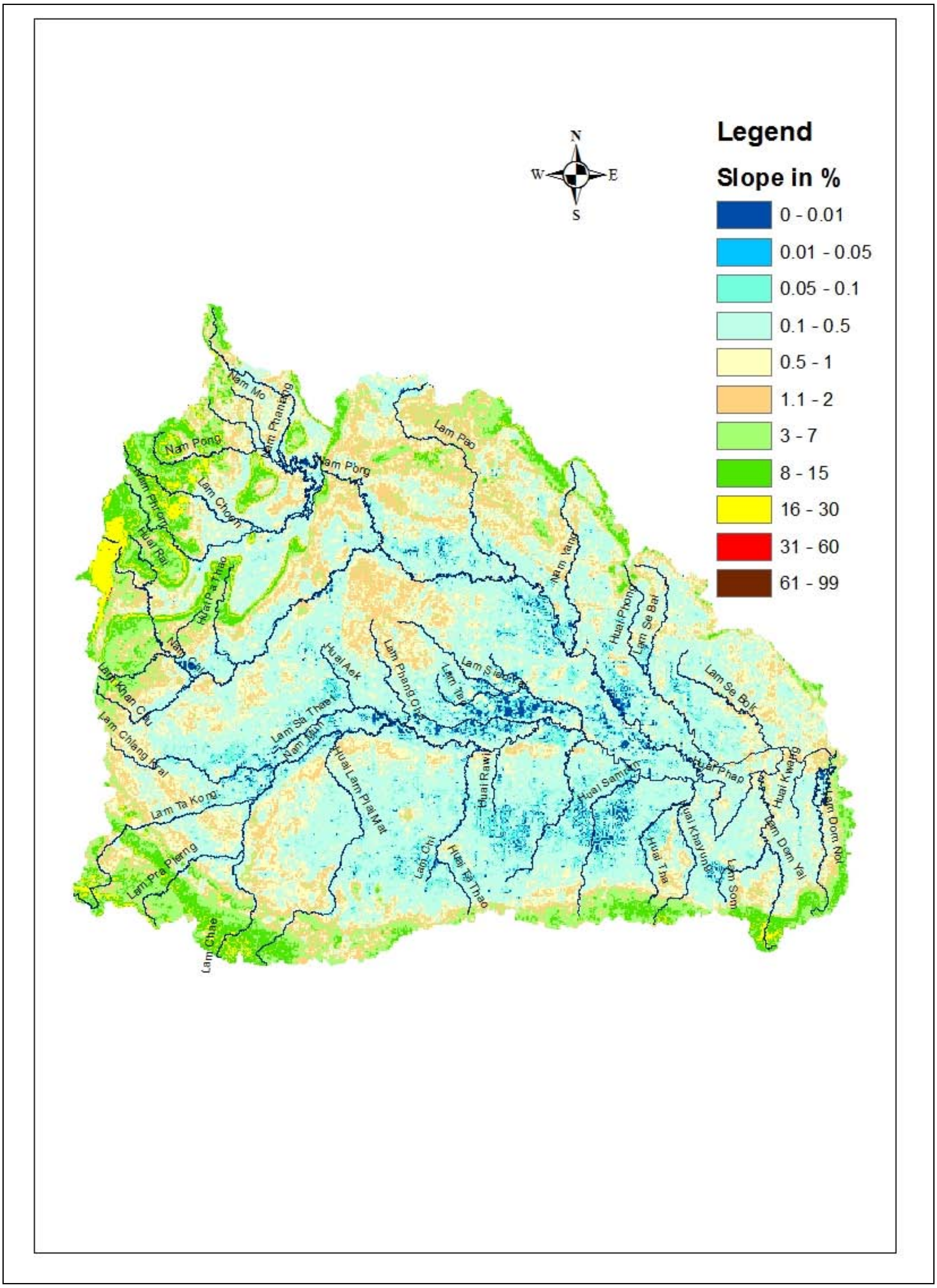

Figure 8.3 Slope map of SA5.

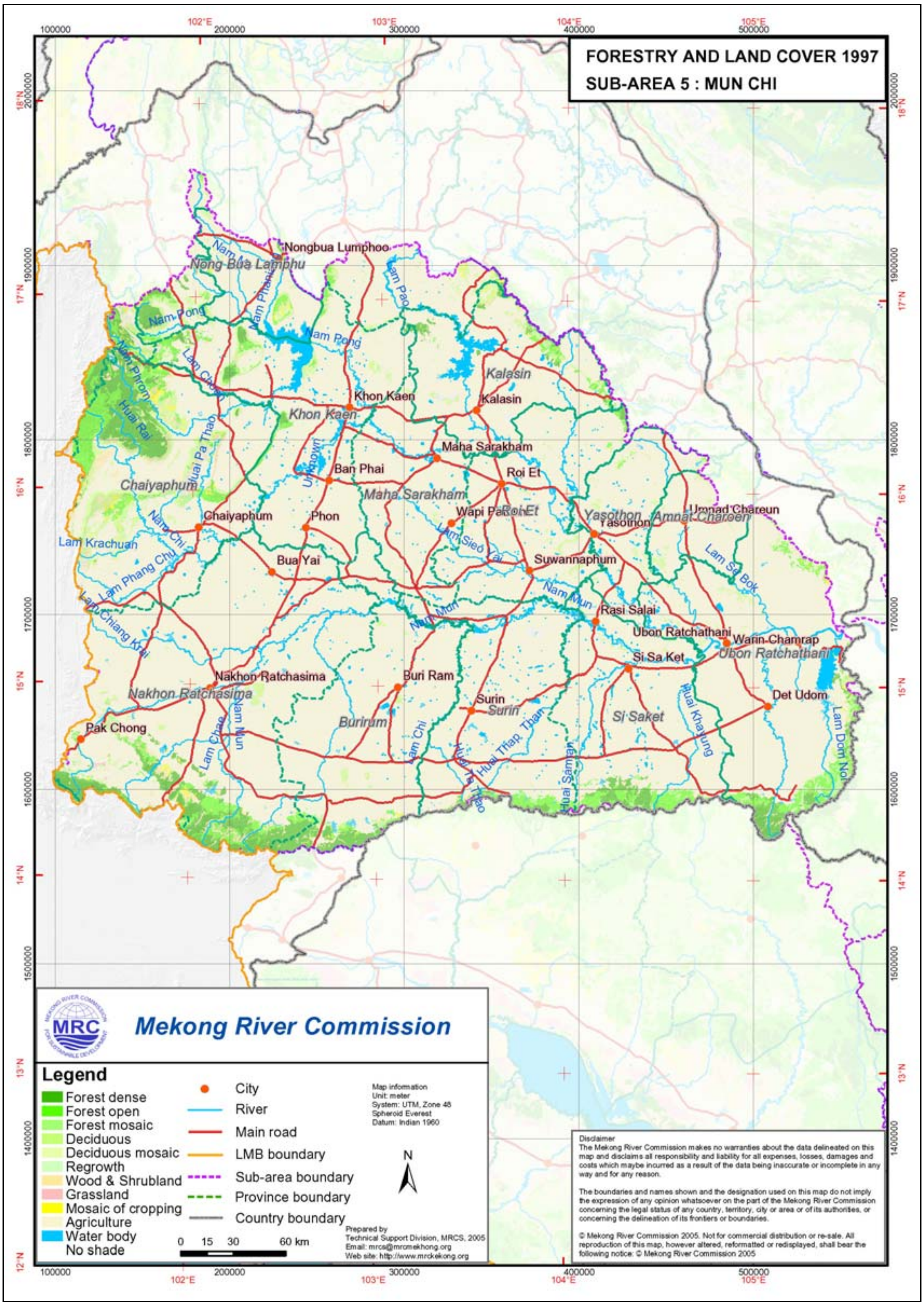

Figure 8.4 Land use map of SA5 (BDP, 2006).

8.2 Hydrological characteristics

8.2.1 Data availability

The hydro-meteorological network in SA5 for which data is available in the MRC HYMOS database is presented in Figure 8.5.

The list, location and availability of rainfall stations is given in Table 8.1 and Table 8.3. The tables list a total number of 87 rainfall stations, which is 1 station per 1,370 km2. Some 9 stations have records from the early fifties onward, whereas the majority of the records start in the nineteen eighties. The stations are operated by the Thai Meteorological Department and the Royal Irrigation Department.

The water level and discharge stations are listed in Table 8.2 and their availability is given in Table 8.4. A total number of 12 water level and discharge is available with records starting in the sixties for two but the rest have data from about 1980 onward.

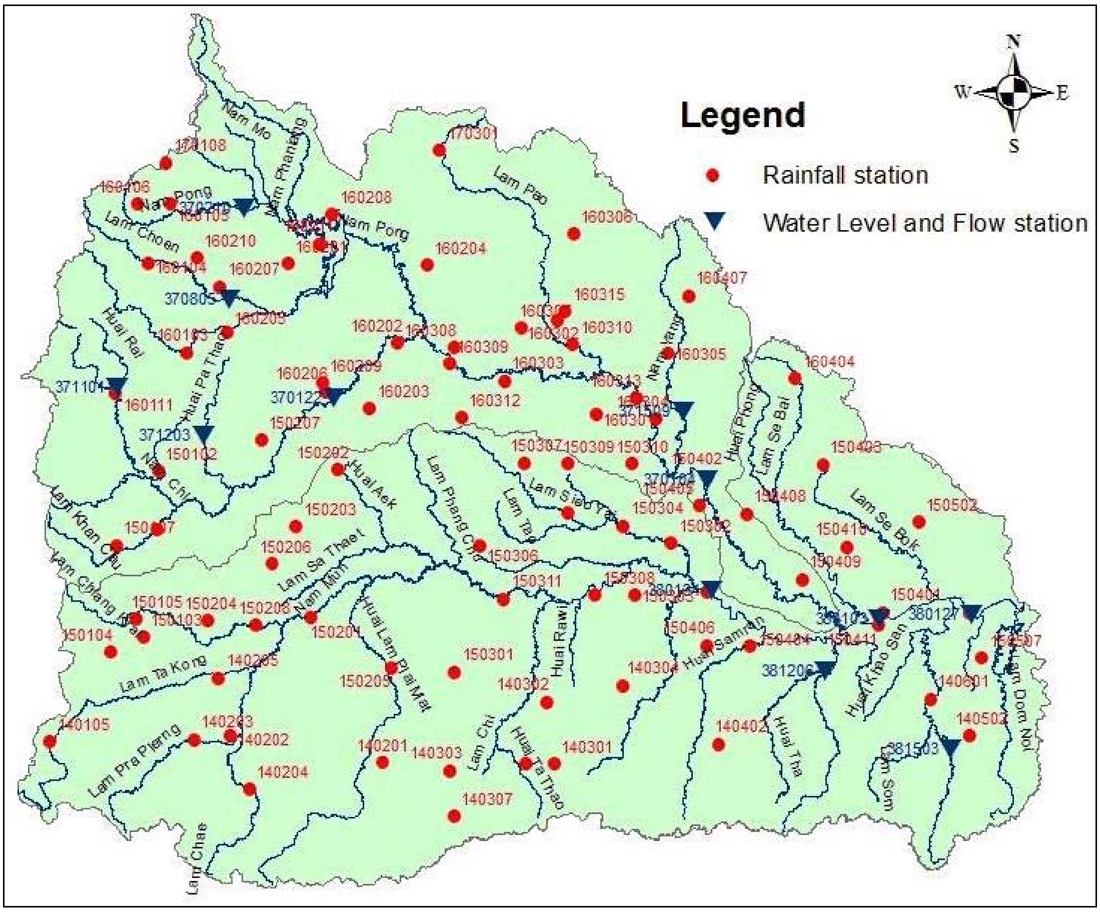

Figure 8.5 Hydro-meteorological network of SA5 as available at MRC.

Table 8.1 Overview of rainfall stations in SA5.

Station Location

Rainfall

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
150107	BAMNET NARONG	Nam Chi	15.5000	101.6834
150207	KHON SAWAN	Nam Chi	15.9334	102.2834
150310	AT SAMAT	Nam Chi	15.8500	103.8334
150402	YASOTHON	Nam Chi	15.8000	104.1500
150405	PHANOM PHRAI	Nam Chi	15.6834	104.1167
150408	KHAM KHUAN KAEO	Nam Chi	15.6500	104.3167
150409	KHUANG NAI	Nam Chi	15.3834	104.5500
160103	KASET SOMBUN	Nam Chi	16.2834	101.9667
160104	BAN SONG KHON	Nam Chi	16.6400	101.7934
160105	BAN SI THAN	Nam Chi	16.8834	101.8834
160106	PHU KRADUNG	Nam Chi	16.8834	101.7500
160111	BAN NON TUM	Nam Chi	16.1167	101.6667
160201	PHU WIANG	Nam Chi	16.6500	102.3834
160202	KHON KAEN	Nam Chi	16.3334	102.8500
160203	BAN PHAI	Nam Chi	16.0667	102.7334
160204	UBOLRATANA DAM	Nam Chi	16.6500	102.9667
160205	PHU KHIEO	Nam Chi	16.3667	102.1334
160206	MANCHA KHIRI	Nam Chi	16.1334	102.5500
160207	CHUM PHAE	Nam Chi	16.5500	102.1000
160208	NON SANG	Nam Chi	16.8500	102.5667
160209	CHONNABOT	Nam Chi	16.1667	102.5334
160210	BAN NA NONG THUM	Nam Chi	16.6667	102.0000
160211	BAN NONG RUA	Nam Chi	16.7334	102.5167
160301	ROI ET	Nam Chi	16.0500	103.6834
160302	KALASIN	Nam Chi	16.4334	103.5167
160303	MAHA SARAKHAM	Nam Chi	16.1834	103.3000
160304	SELAPHUM	Nam Chi	16.0334	103.9334
160305	PHON THONG	Nam Chi	16.3000	103.9834
160306	SAHATSAKHAN	Nam Chi	16.7834	103.5834
160307	YANG TALAT	Nam Chi	16.4000	103.3667
160308	KANTHARAWICHAI	Nam Chi	16.3167	103.0834
160309	KOSUM PHISAI	Nam Chi	16.2500	103.0667
160310	KAMALASAI	Nam Chi	16.3334	103.5834
160312	BORABU	Nam Chi	16.0334	103.1167
160313	THAWATCHABURI	Nam Chi	16.1167	103.8500
160315	KALASIN FARM	Nam Chi	16.4667	103.5500
160407	KUCHINARAI	Nam Chi	16.5334	104.0667
170108	BAN RAI PHUAI	Nam Chi	17.0500	101.8667
170301	KUMPHAWAPI	Nam Chi	17.1167	103.0167
140105	PAK CHONG	Nam Mun	14.7000	101.4167
140202	CHOK CHAI	Nam Mun	14.7334	102.1667
140203	PAK THONG CHAI	Nam Mun	14.7167	102.0167
140204	KHON BURI	Nam Mun	14.5167	102.2500
140205	KORAT	Nam Mun	14.9667	102.1167
140302	SURIN	Nam Mun	14.8834	103.4834
140303	PRAKHON CHAI	Nam Mun	14.6000	103.0834
140304	SIKHORAPHUM	Nam Mun	14.9500	103.8000
140306	PRASAT	Nam Mun	14.6334	103.4000
140307	BAN KRUAT	Nam Mun	14.4167	103.1000
140402	KHUKHAN	Nam Mun	14.7167	104.2000
140502	BUNTHARIK	Nam Mun	14.7500	105.2500
140601	DET UDOM	Nam Mun	14.9000	105.0834
150103	SUNG NOEN	Nam Mun	15.1334	101.8000
150104	SIKHIU	Nam Mun	15.0667	101.6667
150105	DAN KHUN THOT	Nam Mun	15.2000	101.7667
150201	PHIMAI	Nam Mun	15.2167	102.5000
150202	PHON	Nam Mun	15.8167	102.6000

Rainfall

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
150203	BUA YAI	Nam Mun	15.5834	102.4334
150204	NON THAI	Nam Mun	15.2000	102.0667
150205	LAMJ PLAI MAT	Nam Mun	15.0167	102.8334
150206	KHONG	Nam Mun	15.4334	102.3334
150208	NON SUNG	Nam Mun	15.1834	102.2667
150301	BURI RUM	Nam Mun	15.0000	103.1000
150302	PHUTTHAISONG	Nam Mun	15.5334	104.0000
150303	RATTANABURI	Nam Mun	15.3167	103.8500
150304	SUWANNAPHUM	Nam Mun	15.6000	103.8000
150305	KASET WISAI	Nam Mun	15.6500	103.5667
150306	PHAYAKKAPHUMPHISAI	Nam Mun	15.5167	103.2000
150307	WAPI PATHUM	Nam Mun	15.8500	103.3834
150308	THA TUM	Nam Mun	15.3167	103.6834
150309	CHATURAPHAKPHIMAN	Nam Mun	15.8500	103.5667
150311	SATUK	Nam Mun	15.3000	103.3000
150401	UBON	Nam Mun	15.2500	104.8834
150403	AMNAT CHAROEN	Nam Mun	15.8500	104.6334
150404	SISAKET	Nam Mun	15.1167	104.3334
150406	UTHUMPHON PHISAI	Nam Mun	15.1167	104.1500
150407	RASI SALAI	Nam Mun	15.3334	104.1500
150410	MUANG SAMSIP	Nam Mun	15.5167	104.7334
150411	WARIN CHAMRAP	Nam Mun	15.2000	104.8667
150501	PHIBUN MANGSAHAN	Nam Mun	15.2500	105.2500
150502	TRAKAN PHUTPHON	Nam Mun	15.6167	105.0334
150503	KHONG CHIAM	Mekong	15.3167	105.5000
150507	BAN NONG MEK	Nam Mun	15.0667	105.3000
160404	LOENG NOK THA	Nam Mun	16.2000	104.5167

Table 8.2 Overview of water level and discharge stations in SA5.

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
370104	Yasothom	Nam chi	15.7817	104.1417
370122	Ban Chot	Nam Chi	16.1000	102.5767
370210	Ban Kae (Si Chomphu)	Nam Pong	16.8667	102.1850
370805	Ban Tha Dua	Lam Choen	16.4934	102.1284
371101	Ban Nong Kiang	Huai Rai	16.1334	101.6667
371203	Ban Tad Ton	Huai Pa Thao	15.9417	102.0300
371509	Ban Na Thom	Nam Yang	16.0584	104.0384
380103	Ubon	Nam Mun	15.2217	104.8617
380127	Kaeng Saphu Tai	Nam Mun	15.2400	105.2484
380134	Rasi Salai	Nam Mun	15.3350	104.1617
381206	Ban Huai Khayuong	Huai Khayuong	15.0050	104.6384
381503	Ban Fang Phe	Lam Dom Yai	14.6900	105.1600

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)		Catchment Area, km²
			Latitude	Longitude	
370104	Yasothom	Nam chi	15.7817	104.1417	43100
370122	Ban Chot	Nam Chi	16.1000	102.5767	10200
370210	Ban Kae (Si Chomphu)	Nam Pong	16.8667	102.1850	1260
370805	Ban Tha Dua	Lam Choen	16.4934	102.1284	1500
371101	Ban Nong Kiang	Huai Rai	16.1334	101.6667	1370
371203	Ban Tad Ton	Huai Pa Thao	15.9417	102.0300	326
371509	Ban Na Thorn	Nam Yang	16.0584	104.0384	3240
380103	Ubon	Nam Mun	15.2217	104.8617	104000
380127	Kaeng Saphu Tai	Nam Mun	15.2400	105.2484	116000
380134	Rasi Salai	Nam Mun	15.3350	104.1617	44600
381206	Ban Huai Khayuong	Huai Khayuong	15.0050	104.6384	2900
381503	Ban Fang Phe	Lam Dom Yai	14.6900	105.1600	1410

Table 8.3 Rainfall data availability in SA5.

Daily Data Availability of BDP Sub-Area 5T (before 1960)

Rainfall

Station ID	Station Name	River	1950									
			0	1	2	3	4	5	6	7	8	9
160202	KHON KAEN	Nam Chi	+	+	+	+	+	+	+	+	+	+
160301	ROI ET	Nam Chi		+	+	+	+	+	+	+	+	+
160302	KALASIN	Nam Chi		+	+	+	+	+	+	+	+	+
160303	MAHA SARAKHAM	Nam Chi			+	+	+	+	+	+	+	+
140205	KORAT	Nam Mun	+	+	+	+	+	+	+	+	+	+
140302	SURIN	Nam Mun	+	+	+	+	+	+	+	+	+	+
150301	BURI RUM	Nam Mun			+	+	+	+	+	+	+	+
150401	UBON	Nam Mun	+	+	+	+	+	+	+	+	+	+
150404	SISAKET	Nam Mun			+	+	+	+	+	+	+	+

Daily Data Availability of BDP Sub-Area 5T (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000					
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
150107	BAMNET NARONG	Nam Chi																							+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150207	KHON SAWAN	Nam Chi																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150310	AT SAMAT	Nam Chi																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		245	245	+	
150402	YASOTHON	Nam Chi							+	+	+	+	+	+	+	+	+	+												+	+	+	+	+	+	+	+	+	+	+	+	+	+	61		92	+	+
150405	PHANOM PHRAI	Nam Chi																						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	122	122	120	+	+
150408	KHAM KHUAN KAEO	Nam Chi																		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150409	KHUANG NAI	Nam Chi												+	+	+	+						+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160103	KASET SOMBUN	Nam Chi																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160104	BAN SONG KHON	Nam Chi																																									+	+	+	+	+	+
160105	BAN SI THAN	Nam Chi																+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160106	PHU KRADUNG	Nam Chi												+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	92	+	+
160111	BAN NON TUM	Nam Chi																										+	+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+	+
160201	PHU WIANG	Nam Chi																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	31	+	+	+
160202	KHON KAEN	Nam Chi	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160203	BAN PHAI	Nam Chi																					+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	61	61	31	+	+
160204	UBOLRATANA DAM	Nam Chi							+	+													+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160205	PHU KHIEO	Nam Chi																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160206	MANCHA KHIRI	Nam Chi																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	324	+	+	+	+	+	+
160207	CHUM PHAE	Nam Chi	244	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160208	NON SANG	Nam Chi																							+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	31	+	+	+	184	+	+
160209	CHONNABOT	Nam Chi																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	31		92		
160210	BAN NA NONG THUM	Nam Chi																							+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+
160211	BAN NONG RUA	Nam Chi																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+	+
160301	ROI ET	Nam Chi	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+		+	+	+	+	+	+
160302	KALASIN	Nam Chi	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160303	MAHA SARAKHAM	Nam Chi	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160304	SELAPHUM	Nam Chi																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	31	+	+	+

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000					
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
160305	PHON THONG	Nam Chi																							+	+		+	+	+	+	+	+	+	+	+	+	+		+	+		121	92	92	92		
160306	SAHATSAKHAN	Nam Chi																						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	92		+
160307	YANG TALAT	Nam Chi																						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160308	KANTHARAWICHAI	Nam Chi																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	31	+	+
160309	KOSUM PHISAI	Nam Chi												+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160310	KAMALASAI	Nam Chi																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	+
160312	BORABU	Nam Chi																						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160313	THAWATCHABURI	Nam Chi												+	+	+	+						+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	183	30	122		182	+	+
160315	KALASIN FARM	Nam Chi																+														+		+														
160407	KUCHINARAI	Nam Chi			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
170108	BAN RAI PHUAI	Nam Chi																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+
170301	KUMPHAWAPI	Nam Chi																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
140105	PAK CHONG	Nam Mun																							+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
140202	CHOK CHAI	Nam Mun																	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
140203	PAK THONG CHAI	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	31	31	+	+	+	+
140204	KHON BURI	Nam Mun																							+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
140205	KORAT	Nam Mun	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
140302	SURIN	Nam Mun	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
140303	PRAKHON CHAI	Nam Mun																					+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
140304	SIKHORAPHUM	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
140306	PRASAT	Nam Mun																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		122	+	+	122		
140307	BAN KRUAT	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
140402	KHUKHAN	Nam Mun																							+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	61	+	92	92	151	+	+
140502	BUNTHARIK	Nam Mun																					+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	122	+	+
140601	DET UDOM	Nam Mun					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	30	+	+
150103	SUNG NOEN	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150104	SIKHIU	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150105	DAN KHUN THOT	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	31	+	+
150201	PHIMAI	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	122	305	+	+	+		
150202	PHON	Nam Mun	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150203	BUA YAI	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150204	NON THAI	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150205	LAMJ PLAI MAT	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	61	+	+	+	+	+
150206	KHONG	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+		+	+	+
150208	NON SUNG	Nam Mun																							+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	122	+	+	+	+	+	+
150301	BURI RUM	Nam Mun	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+				+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		90	214	61	+	+	+	+
150302	PHUTTHAISONG	Nam Mun																								+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150303	RATTANABURI	Nam Mun																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	61	31	28	+	+
150304	SUWANNAPHUM	Nam Mun																					+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	92	92	+	+	+
150305	KASET WISAI	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	92				
150306	PHAYAKKAPHUMPHISAI	Nam Mun		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	30	+	+
150307	WAPI PATHUM	Nam Mun																					+	+	+		+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	61	30	+	+	+	+
150308	THA TUM	Nam Mun												+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150309	CHATURAPHAKPHIMAN	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	245	+	61	+	31	+	+
150311	SATUK	Nam Mun																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	92	31	+	92	+	+
150401	UBON	Nam Mun	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150403	AMNAT CHAROEN	Nam Mun							+	+	+	+	+	+	+	+		+							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	92	+	+	+
150404	SISAKET	Nam Mun	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+
150406	UTHUMPHON PHISAI	Nam Mun																					+	+	+	+	+	+	+	+		+	+		+	+	+					184						
150407	RASI SALAI	Nam Mun									+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150410	MUANG SAMSIP	Nam Mun																						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	92		
150411	WARIN CHAMRAP	Nam Mun																							+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+
150501	PHIBUN MANGSAHAN	Nam Mun																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150502	TRAKAN PHUTPHON	Nam Mun																						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150507	BAN NONG MEK	Nam Mun					+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+
160404	LOENG NOK THA	Nam Mun																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Table 8.4 Availability of water level and discharge data in SA5.

Water level

Station ID	Station Name	River	1960										1970									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
370104	Yasothom	Nam chi			+	+	+	+	90	+	+	+	+	+	+	+	+	+	+	+	+	+
370122	Ban Chot	Nam Chi																90	+	+	+	+
370210	Ban Kae (Si Chomphu)	Nam Pong																			188	31
370805	Ban Tha Dua	Lam Choen																			130	+
371101	Ban Nong Kiang	Huai Rai																90	+	+	53	+
371203	Ban Tad Ton	Huai Pa Thao																	91	+	+	+
371509	Ban Na Thom	Nam Yang																				90
380103	Ubon	Nam Mun			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
380127	Kaeng Saphu Tai	Nam Mun																				90
380134	Rasi Salai	Nam Mun																				90
381206	Ban Huai Khayuong	Huai Khayuong																				90
381503	Ban Fang Phe	Lam Dom Yai										90	+	+	+	55	+	+	+	+	38	+

Station ID	Station Name	River	1980										1990										2000			
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3
370104	Yasothom	Nam chi	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
370122	Ban Chot	Nam Chi	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
370210	Ban Kae (Si Chomphu)	Nam Pong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	182	152	151	+	+
370805	Ban Tha Dua	Lam Choen	+	+	+	+	+	+	+	+	+	+	+	+	+	83	125	12	+	+	+	+	+	+	+	+
371101	Ban Nong Kiang	Huai Rai	+	1	+	+	+	+	+	+	+	+	+	2	+	+	+	+	+	+	+	+	+	+	+	+
371203	Ban Tad Ton	Huai Pa Thao	+	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
371509	Ban Na Thom	Nam Yang	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
380103	Ubon	Nam Mun	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
380127	Kaeng Saphu Tai	Nam Mun	+	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
380134	Rasi Salai	Nam Mun	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
381206	Ban Huai Khayuong	Huai Khayuong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
381503	Ban Fang Phe	Lam Dom Yai	+	+	+	+	+	+	+	+	+	+	+	+	+	1	+	+	+	+	+	92				

Flow

Station ID	Station Name	River	1960										1970									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
370104	Yasothom	Nam chi	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
370122	Ban Chot	Nam Chi																90	+	+	+	+
370210	Ban Kae (Si Chomphu)	Nam Pong																			188	31
370805	Ban Tha Dua	Lam Choen																			130	+
371101	Ban Nong Kiang	Huai Rai																90	+	+	53	+
371203	Ban Tad Ton	Huai Pa Thao																	91	+	+	+
371509	Ban Na Thom	Nam Yang																				90
380103	Ubon	Nam Mun	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
380127	Kaeng Saphu Tai	Nam Mun																				90
380134	Rasi Salai	Nam Mun																				90
381206	Ban Huai Khayuong	Huai Khayuong																				90
381503	Ban Fang Phe	Lam Dom Yai										90	+	+	+	55	+	+	+	+	38	+

Station ID	Station Name	River	1980										1990										2000			
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3
370104	Yasothom	Nam chi	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	1	+
370122	Ban Chot	Nam Chi	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
370210	Ban Kae (Si Chomphu)	Nam Pong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	182	+	151		
370805	Ban Tha Dua	Lam Choen	+	+	+	+	+	+	+	+	+	+	+	+	+	59	+	12		+	+	+	+	+		
371101	Ban Nong Kiang	Huai Rai	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
371203	Ban Tad Ton	Huai Pa Thao	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
371509	Ban Na Thom	Nam Yang	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
380103	Ubon	Nam Mun	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
380127	Kaeng Saphu Tai	Nam Mun	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
380134	Rasi Salai	Nam Mun	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+
381206	Ban Huai Khayuong	Huai Khayuong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
381503	Ban Fang Phe	Lam Dom Yai	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	92				

Notes:
+ = no missing
blank = missing
90 = number of missing days in a year

8.2.2 Rainfall

The rainfall in SA5 is the lowest in the LMB. The average annual rainfall varies from 800 mm in the western part of the basin i.e. the upper reaches of the Mun to about 2500 mm in the southeasternmost area near to Pakse. Annual rainfall series of locations in the upper reaches of the Chi (Khon Kaen) and of the Mun (Korat) and at Ubon near the confluence of Mun and Chi rivers Khon Kaen are presented in Figure 8.6. The coefficient of variation of the annual rainfall is small and ranges from 0.17 for Ubon to 0.20 for Korat.

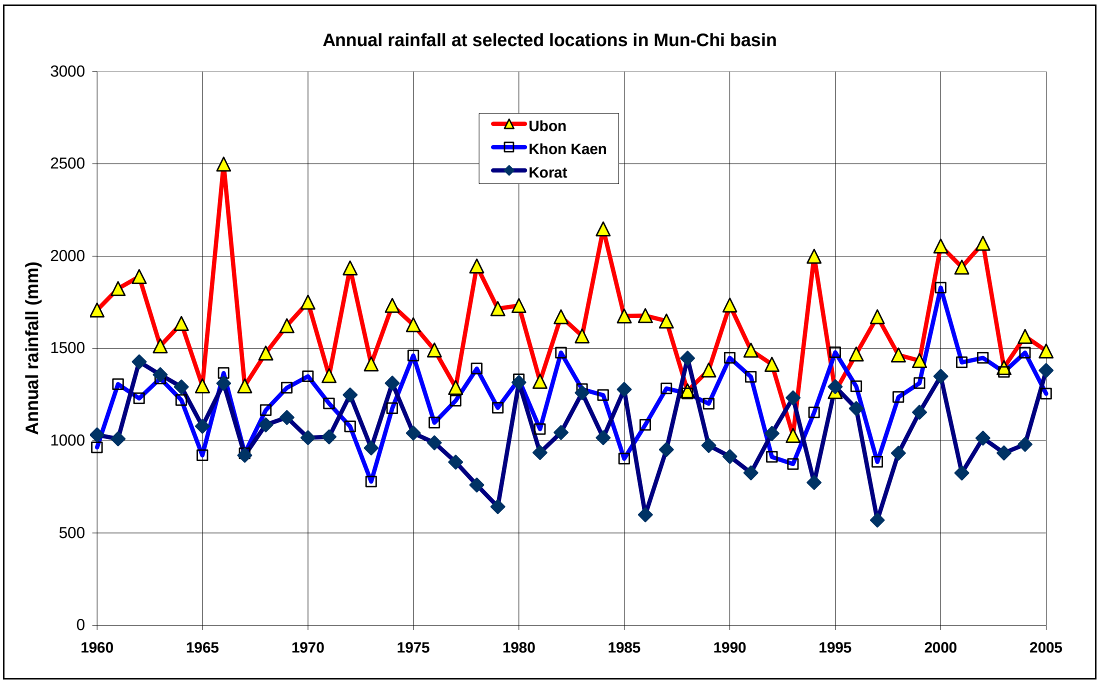

Figure 8.6 Annual rainfall at Ubon, Khon Kaen and Korat.

The climate in SA5 is determined by the air massess brought to the basin by the SW and NE monsoons. Whereas the SW monsoon brings rain from May up to September-October, the NE monsoon is dry as is reflected in the monthly rainfall characteristics of the selected locations, see Figure 8.7 to Figure 8.9. The rainfall is in the Upper Mun-Chi is double peaked with highest rainfall in September. In Ubon the rainfall is significantly higher throughout the monsoon period with the highest values in the second half of the wet season.

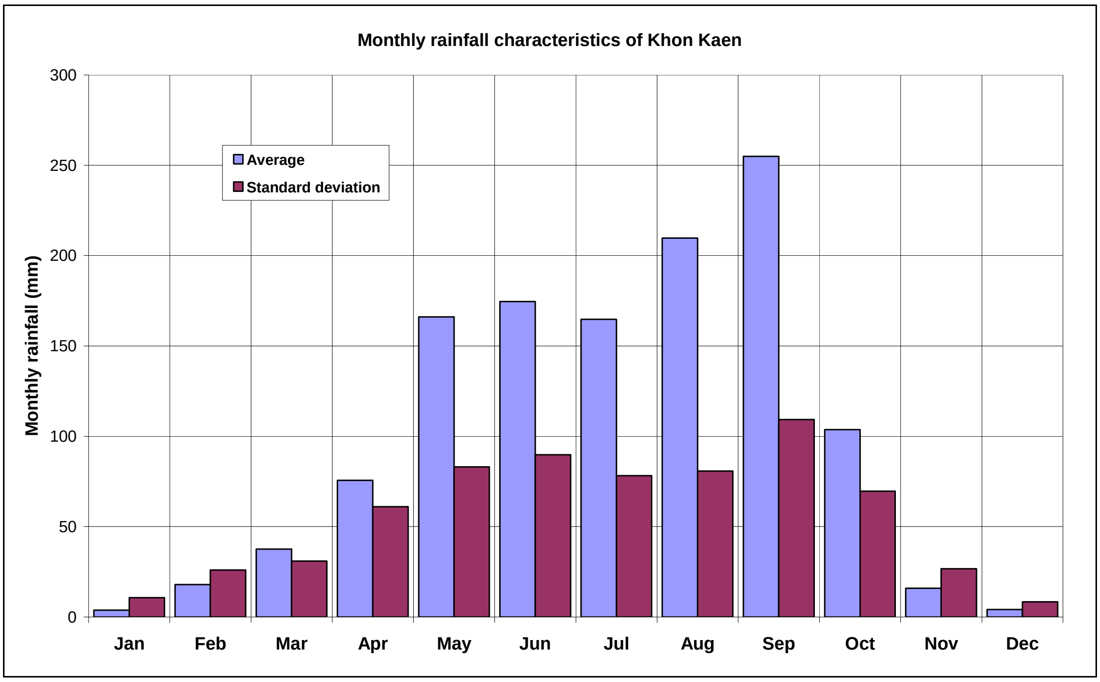

Figure 8.7 Monthly rainfall characteristics of Khon Kaen.

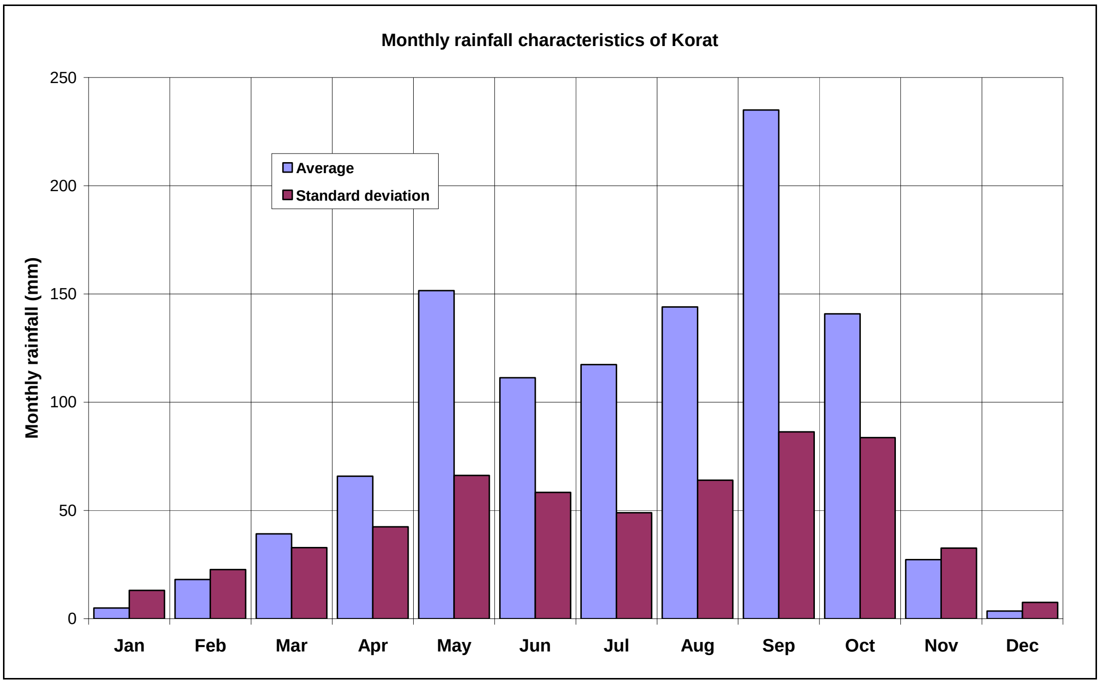

Figure 8.8 Monthly rainfall characteristics of Korat.

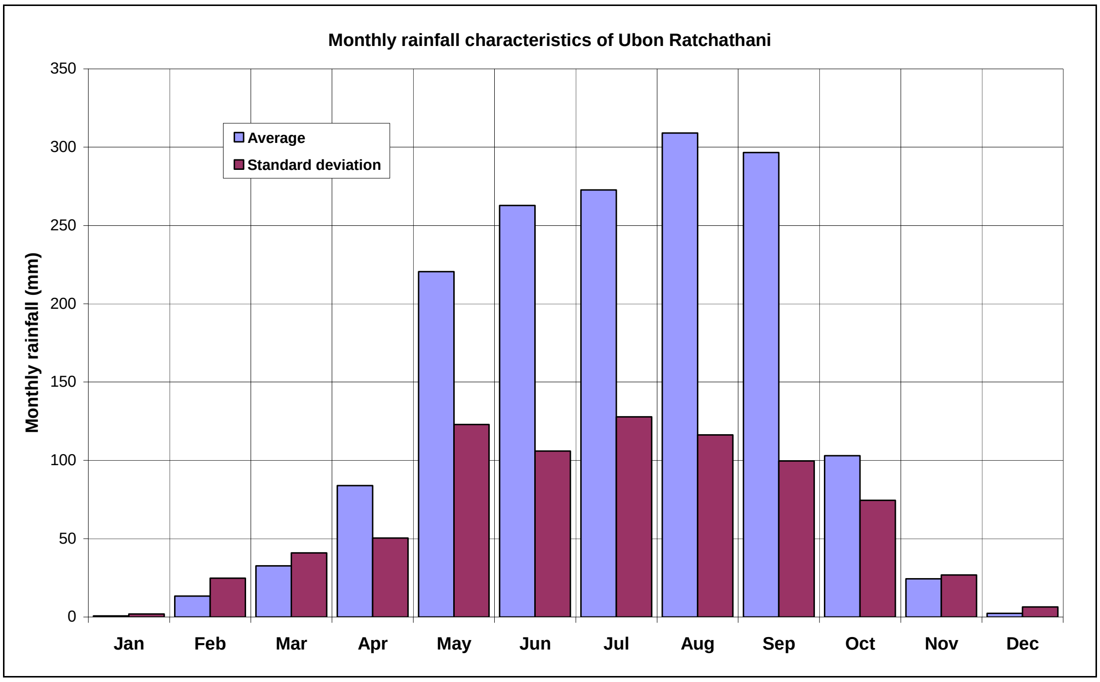

Figure 8.9 Monthly rainfall characteristics of Ubon Ratchathani.

8.2.3 Runoff

The average annual flow of the Mun-Chi basin at mouth is estimated at 26 BCM. Note that in BDP (2006) gives a value of 36 BCM, which might be the natural flow in view of an annual irrigation requirement of 5 to 11 BCM.

The annual flow of the Chi at Yasothom and the Mun at Kaeng Saphu Tai are presented in Figure 8.10. The difference between the two gives the runoff from the Mun proper without Chi. It is observed that the variation from year to year is large; variation coefficients vary from 0.4 to 0.5. This is partly due to variation in the abstraction in the basin for irrigation purposes but mainly because runoff is only a small fraction of the difference between rainfall and evaporation. The rainfall varies from 1100 mm in the west to about 2000 mm in the south-east; the potential evapotranspiration in the Mun-Chi basin is about 1,800 mm and the annual runoff from the Chi is only 170 mm and of the Mun proper 250 mm. So small changes in either rainfall or evaporation has large consequences for the runoff. It is also noted that the flow statistics of the Mun-Chi have to be used with care as the series are not homogeneous due to variable water use for irrigation in SA5.

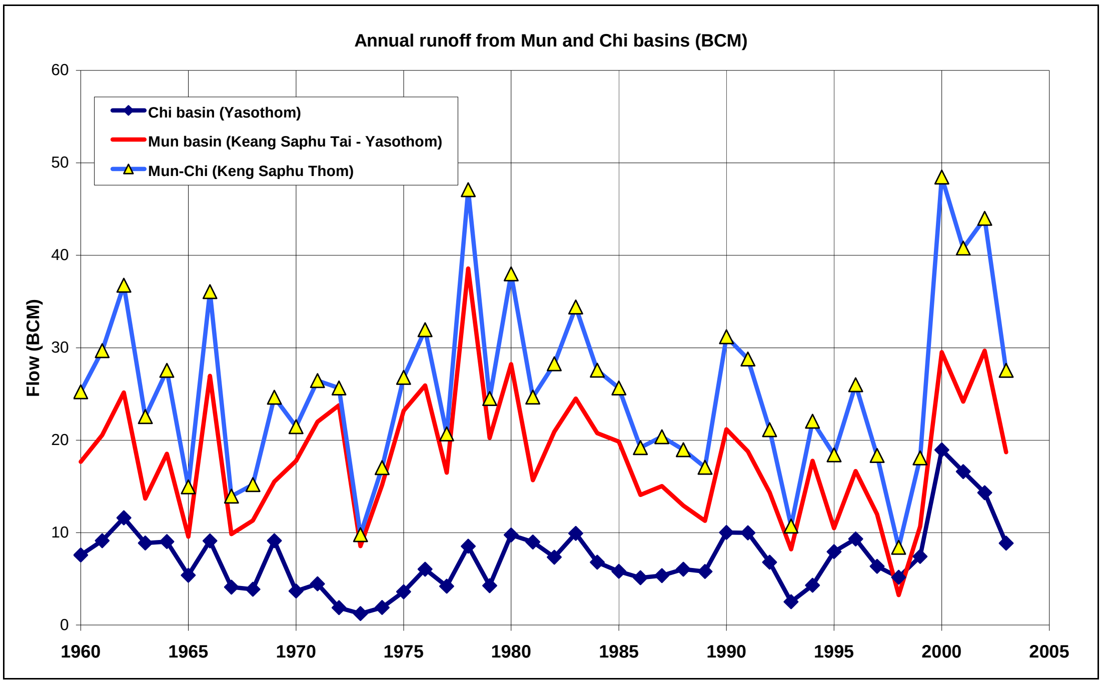

Figure 8.10 Annual flow in Mun-Chi river basin at Yasothom and Kaeng Saphu Tai.

The seasonal variation in the flow from Mun and Chi rivers in MCM and in mm is presented in Figure 8.11 and Figure 8.12. The contribution from Mun is seen to be much larger than of the Chi: the Chi at Yasothom contributes annually about 7 BCM, whereas the Mun proper approximately 18 BCM. From Figure 8.12 it may also be observed that the runoff per unit area in the Mun proper is considerably larger than of the Chi. It is noted here again that the data used are not natural flows but actual flows affected by water used for irrigation.

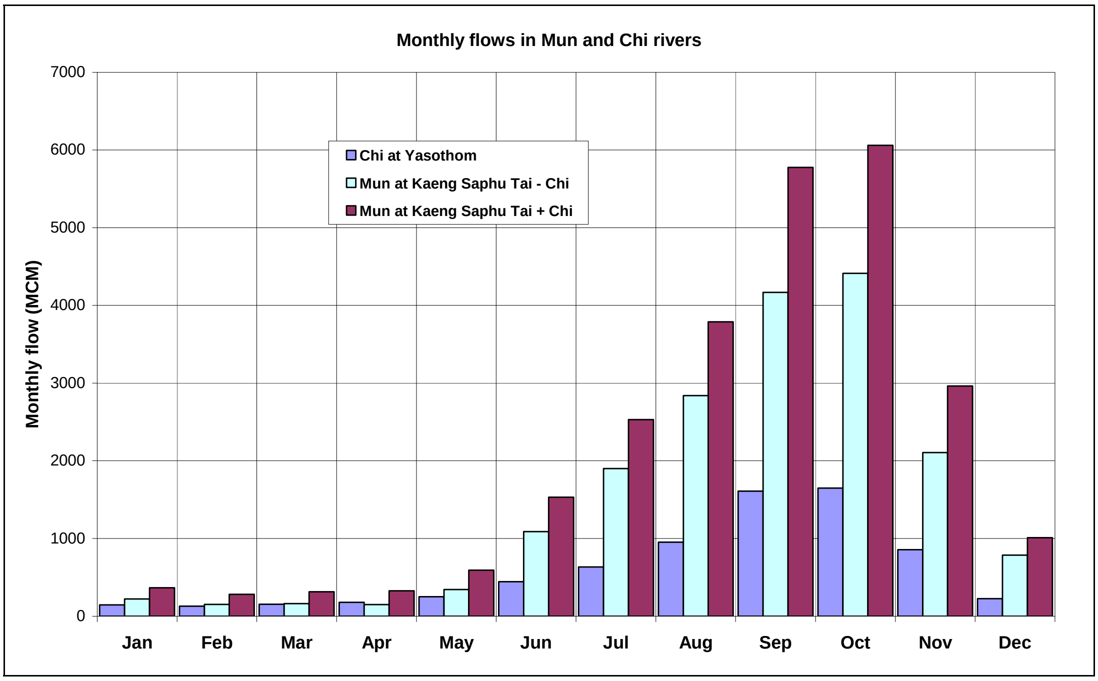

Figure 8.11 Monthly flow in MCM from Mun and Chi basins.

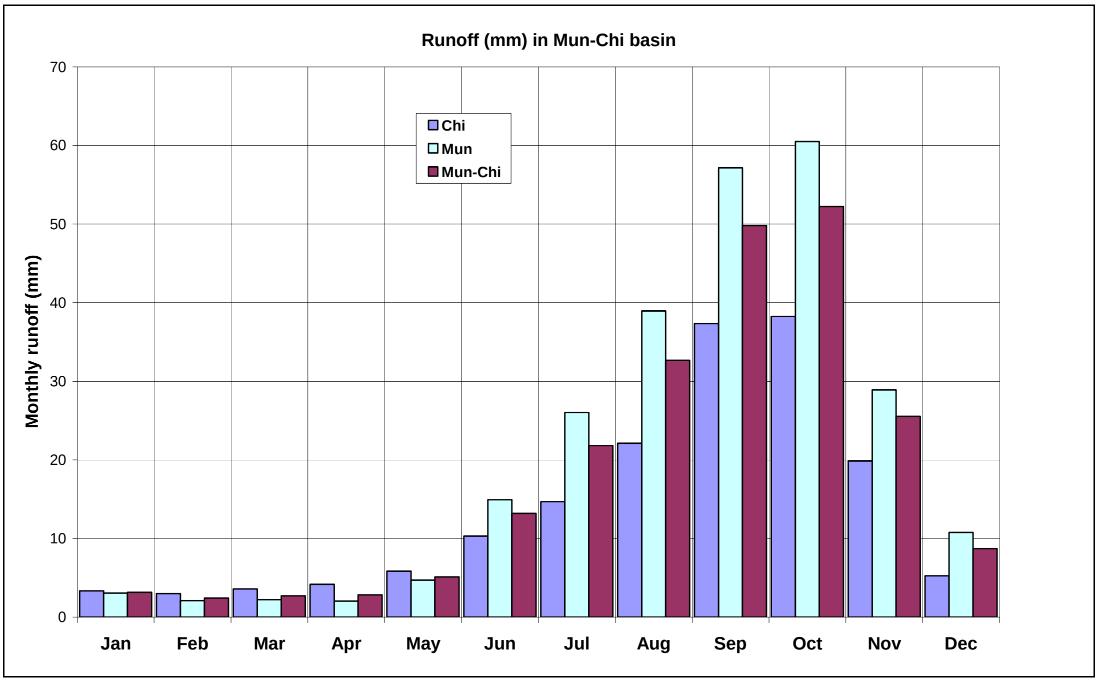

Figure 8.12 Monthly runoff in mm from Mun and Chi basins.

To investigate the character of the runoff and the shapes of the flood from the basins the discharge hydrograph and frequency curves of selected stations in the Chi and the Mun rivers are presented in Figure 8.13 to Figure 8.24. The following can be observed:

- The floods on the smaller tributaries like the Nam Yang and Lam Dom Yai have a flashy character.
- The floods on the larger Chi and Mun mainstream rise slowly and last much longer.
- The mean annual flood discharge in Nam Yang (300 m^3/s at Ban Na Thon) has been exceeded in the period mid June to mid September
- The mean annual flood discharge in Nam Chi main stream (950 m^3/s at Yasothon) has been exceeded in the period from mid June till end of November, i.e. much longer than on the smaller tributaries
- The mean annual flood in the Lam Dom Yai (200 m^3/s at Ban Fang Phe) has been exceeded in the period mid August till mid November
- The mean annual flood in the Nam Mun (2,800 m^3/s at Ubon) has been exceeded in the period early June till mid November, approximately similar to the Chi mainstream.

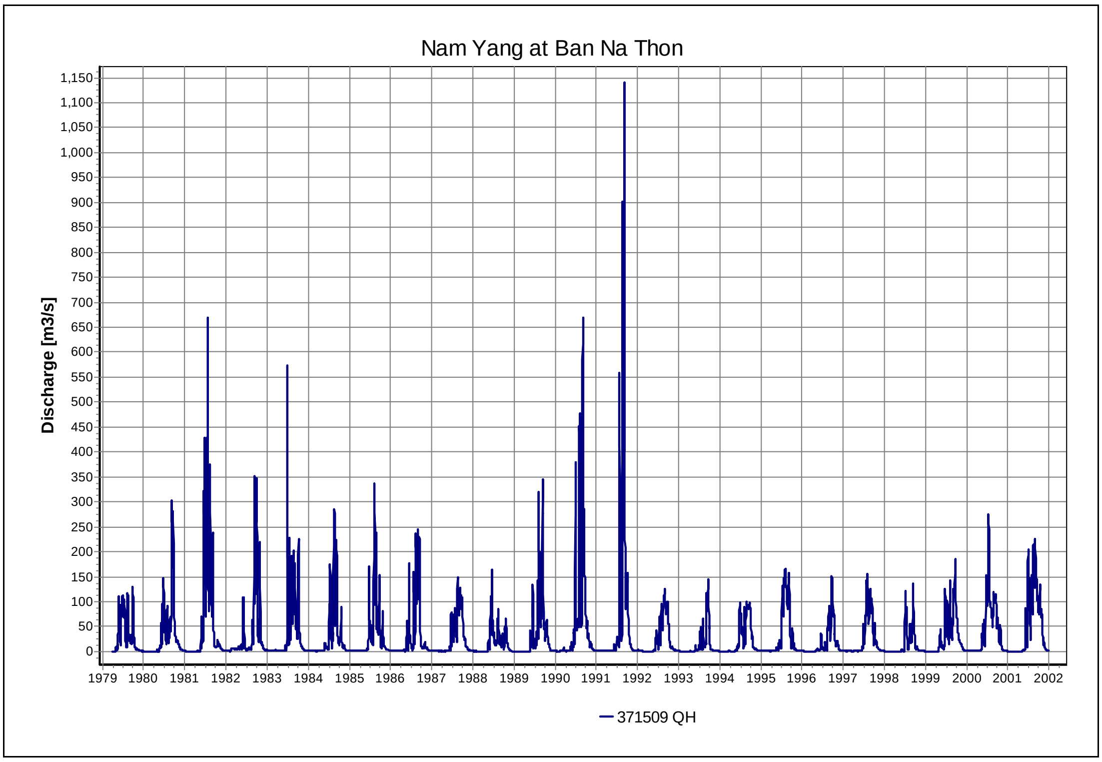

Figure 8.13 Discharge hydrograph of Nam Yang at Ban Na Thon.

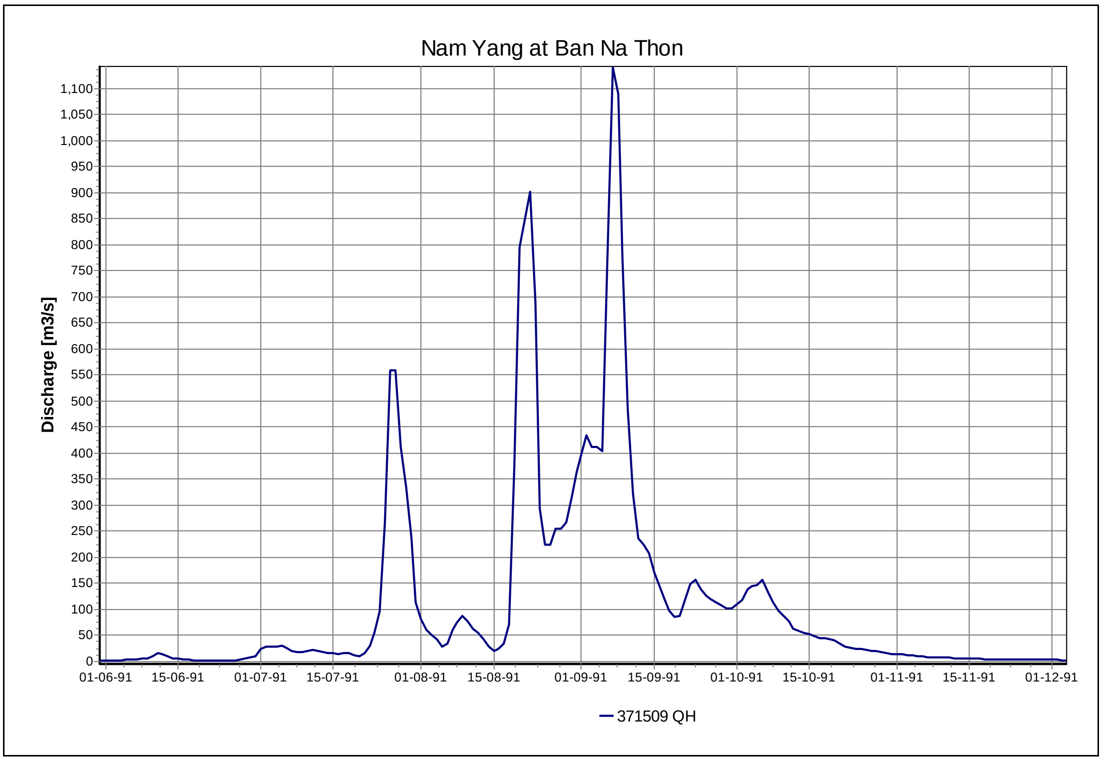

Figure 8.14 Discharge hydrograph of the Nam Yang at Ban Na Thon, year 1991.

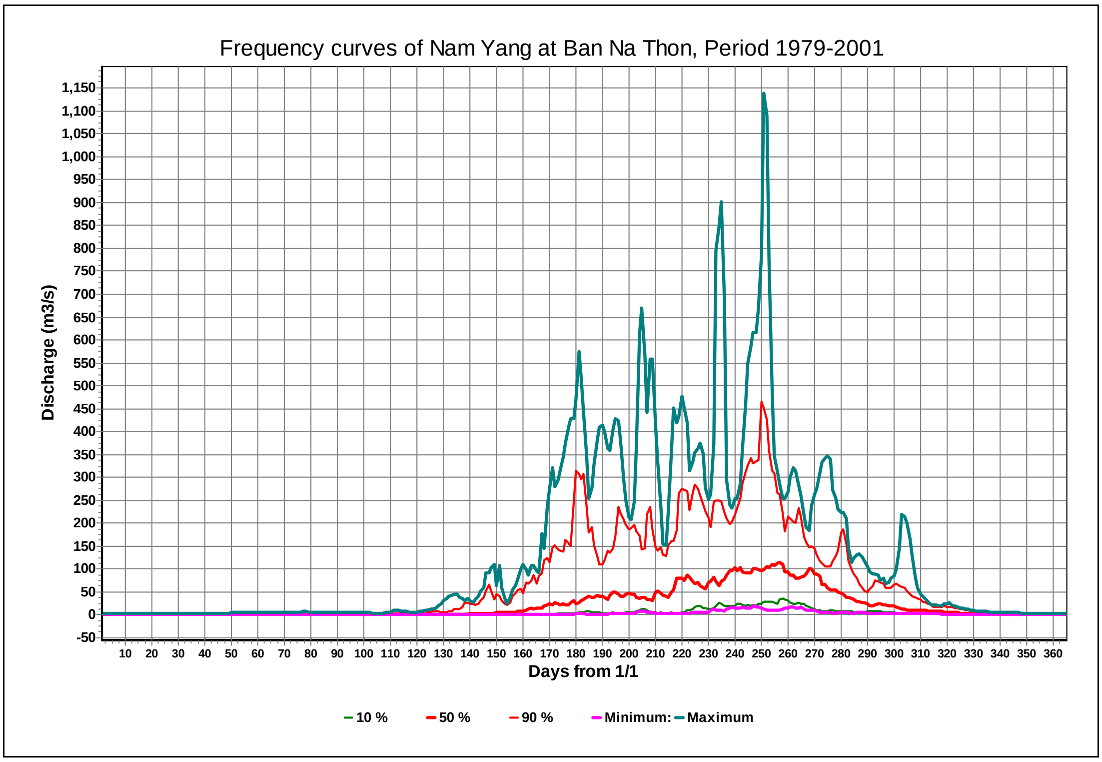

Figure 8.15 Frequency curves of daily discharge of Nam Yang at Ban Na Thon.

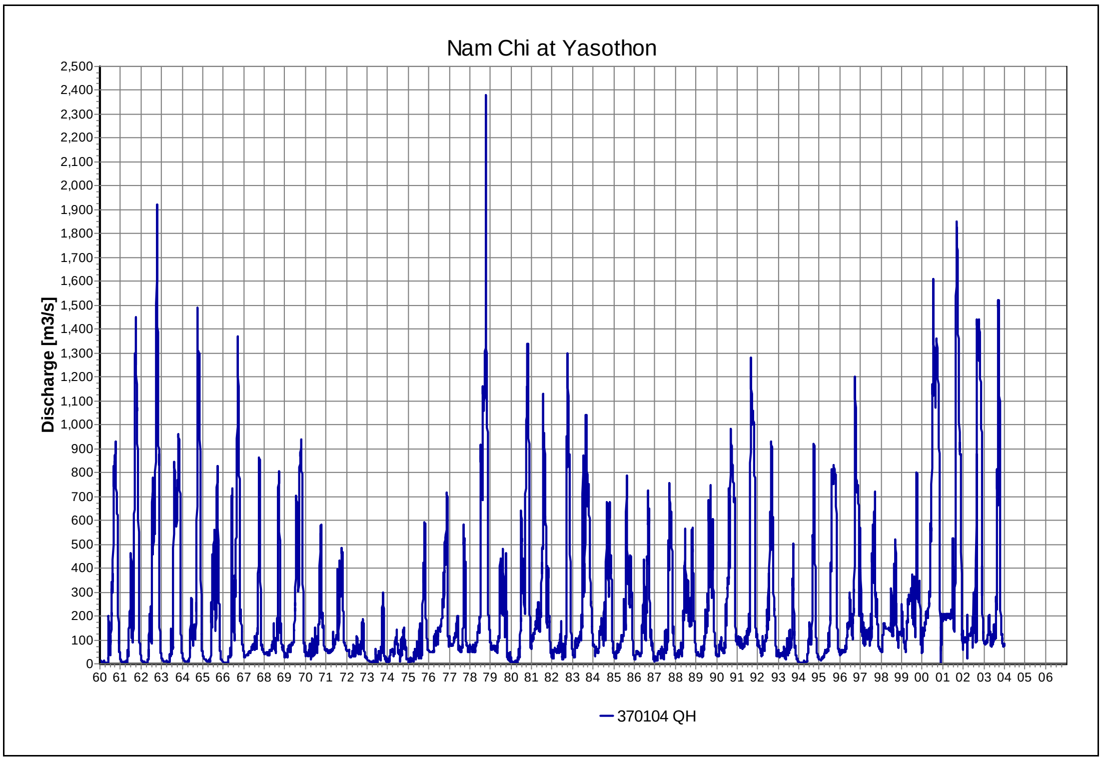

Figure 8.16 Discharge hydrograph of Nam Chi at Yasothon.

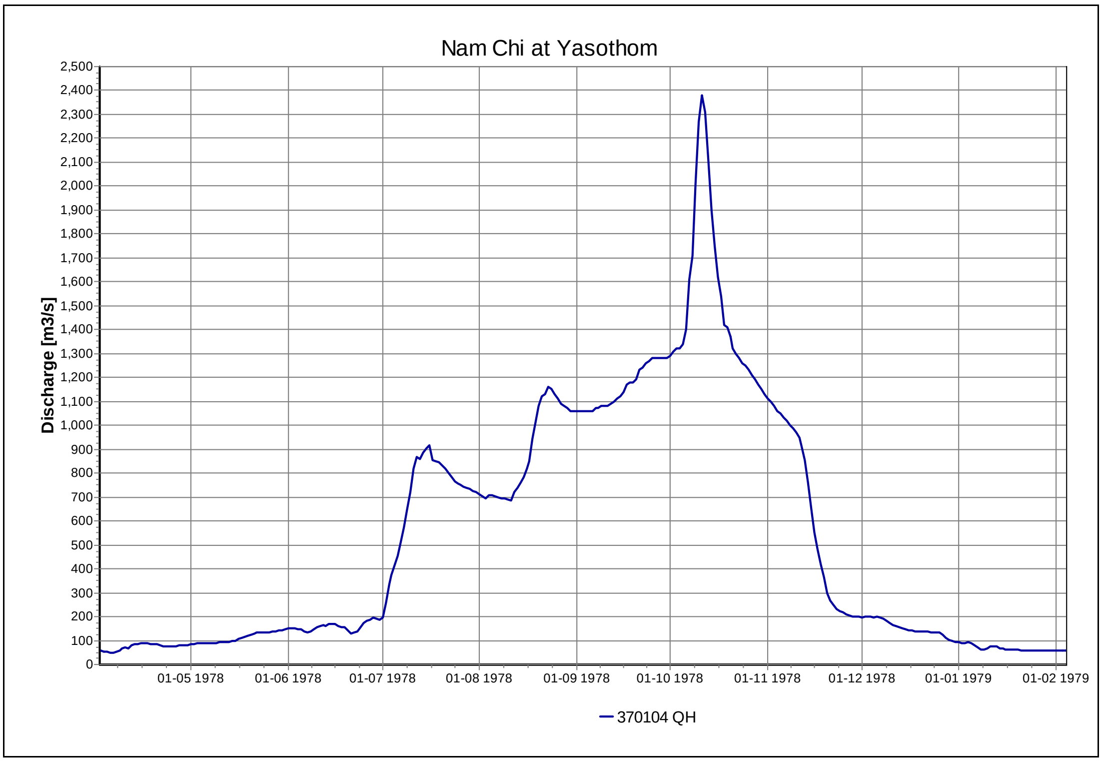

Figure 8.17 Dischargre hydrograph of Nam Chi at Yasothon, year 1978.

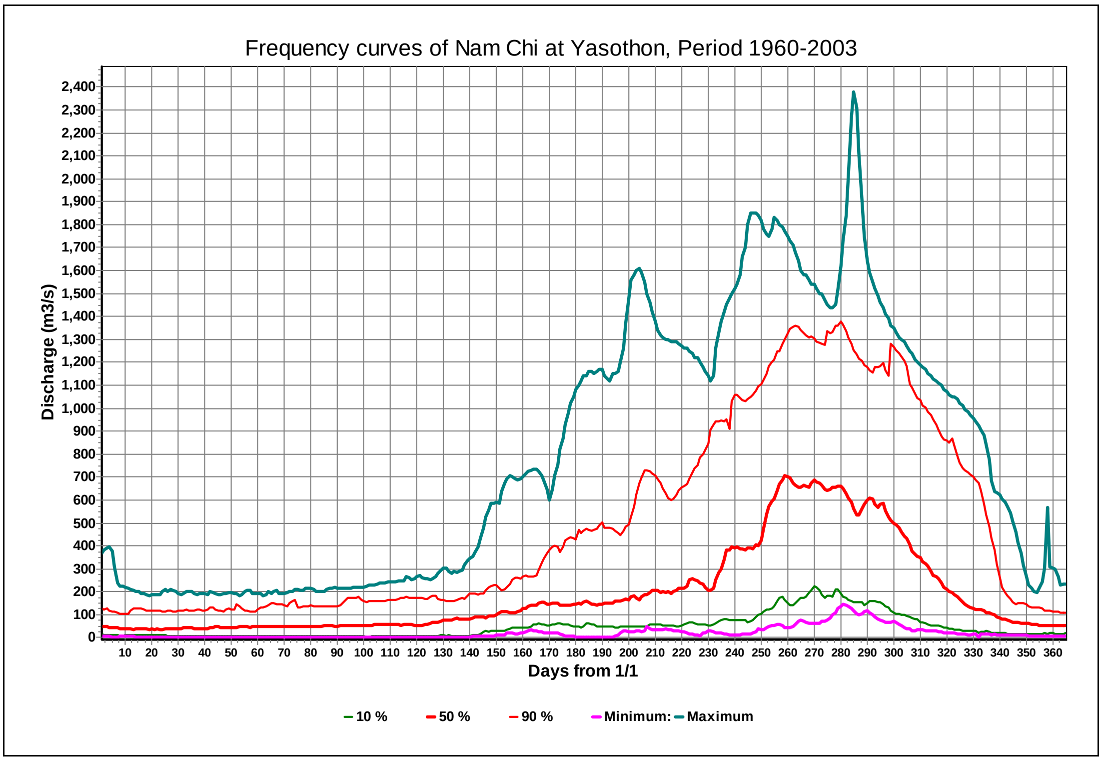

Figure 8.18 Frequency curves of daily discharge of Nam Chi at Yasothon.

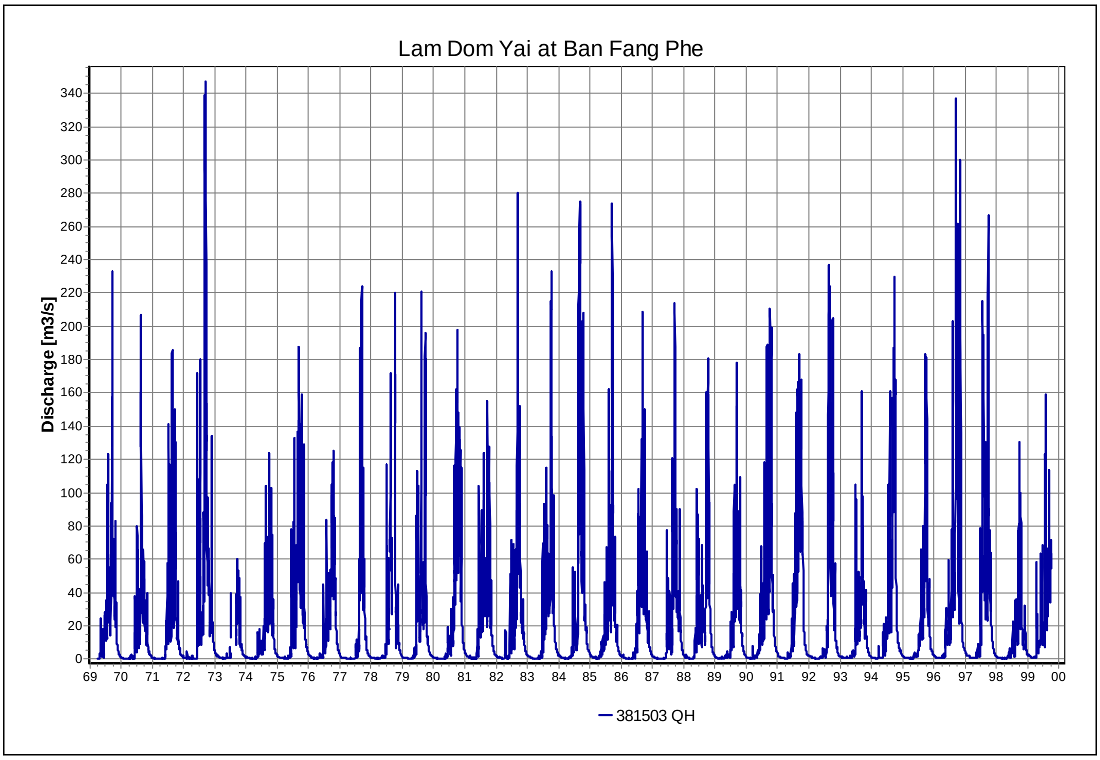

Figure 8.19 Dicharge hydrograph of Lam Dom Yai at Ban Fang Phe.

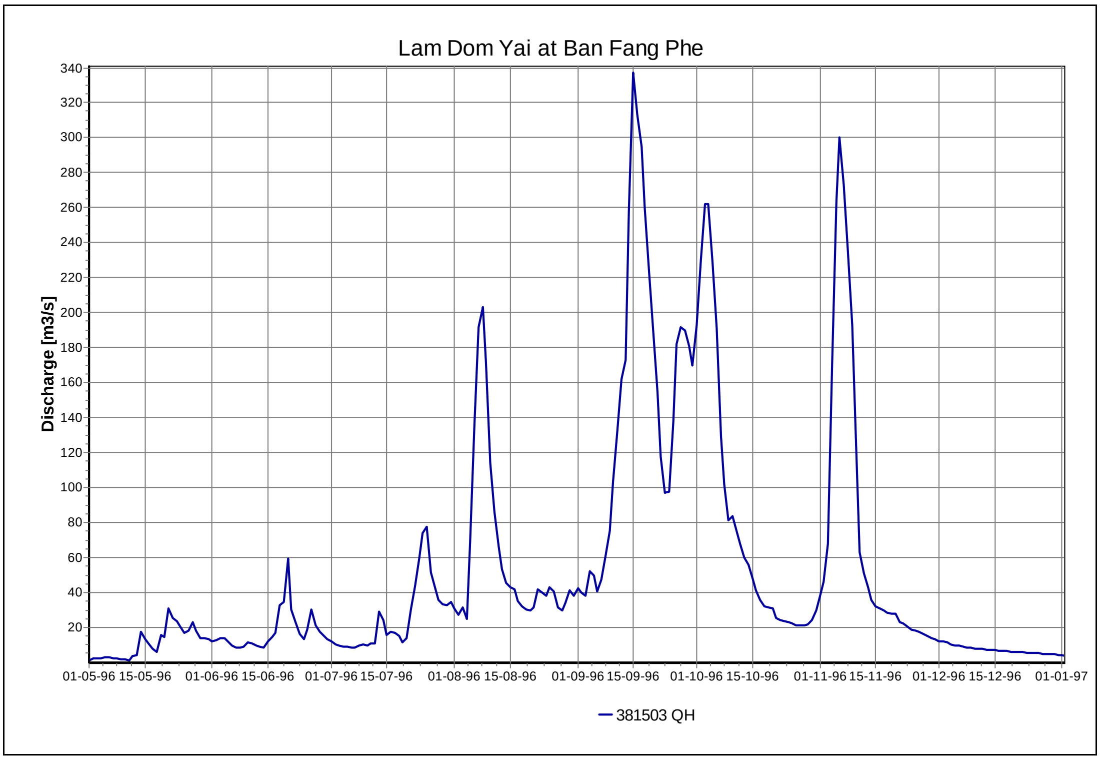

Figure 8.20 Discharge hydrograph of Lam Dom Yai at Ban Fang Phe, year 1996.

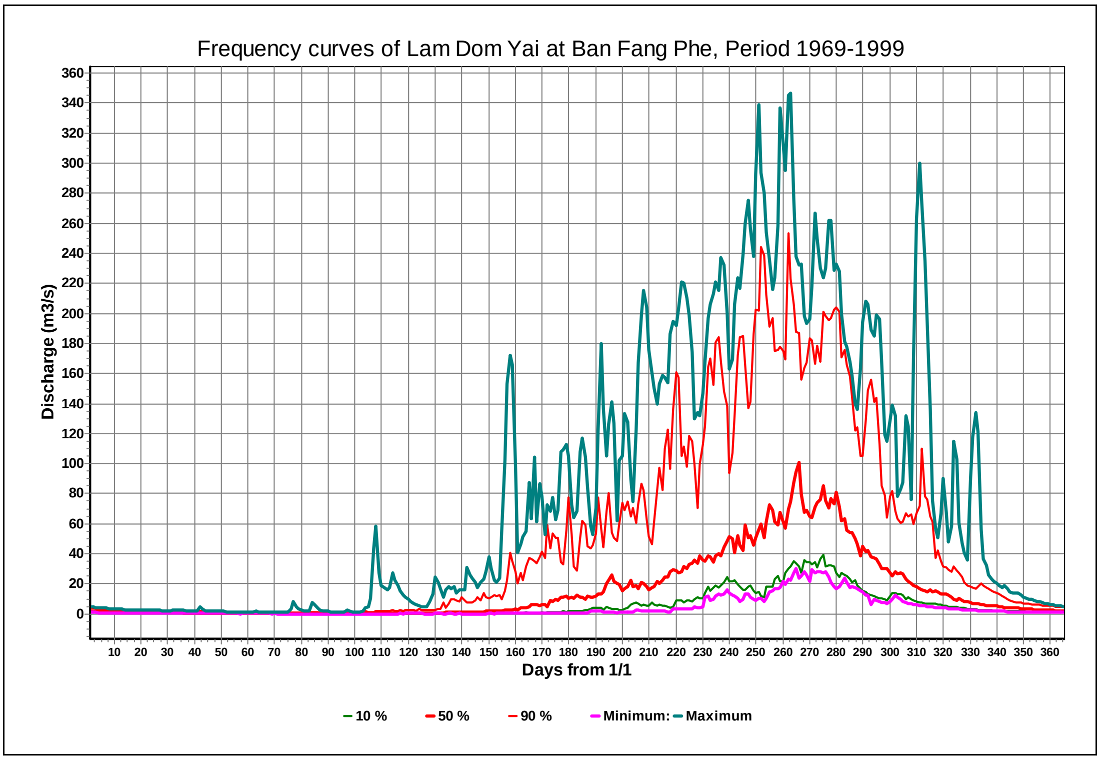

Figure 8.21 Frequency curves of daily discharge of Lam Dom Yai at Ban Fang Phe.

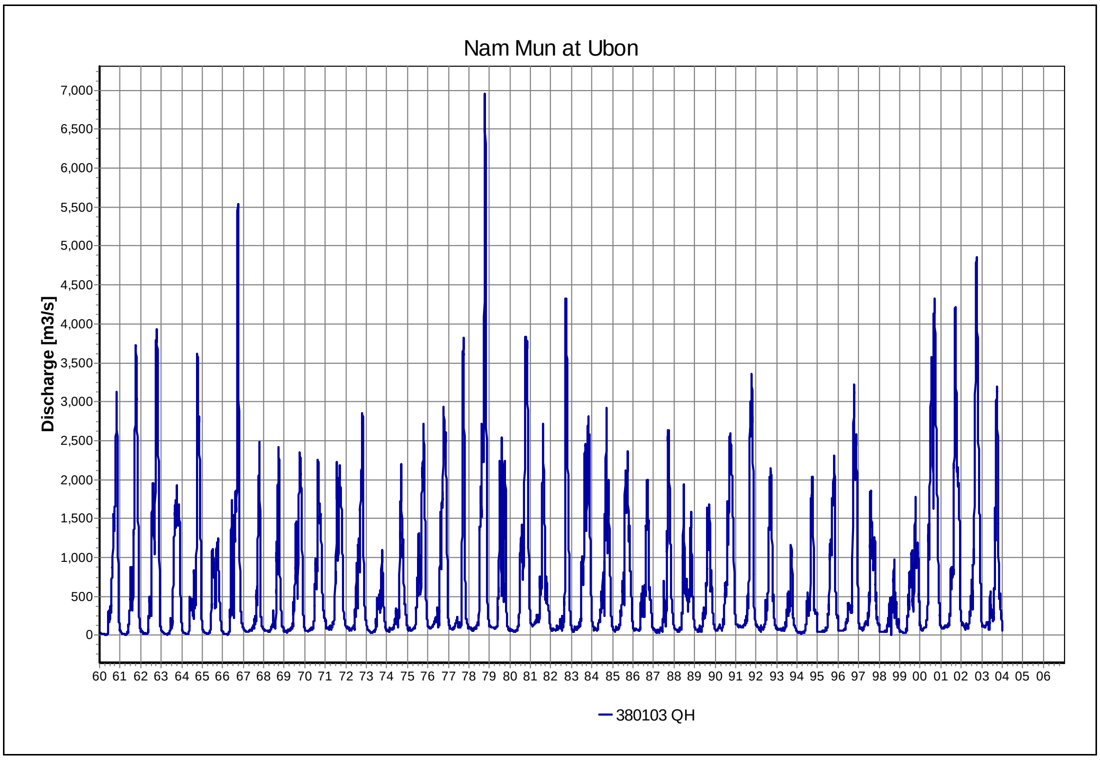

Figure 8.22 Discharge hydrograph of Nam Mun at Ubon.

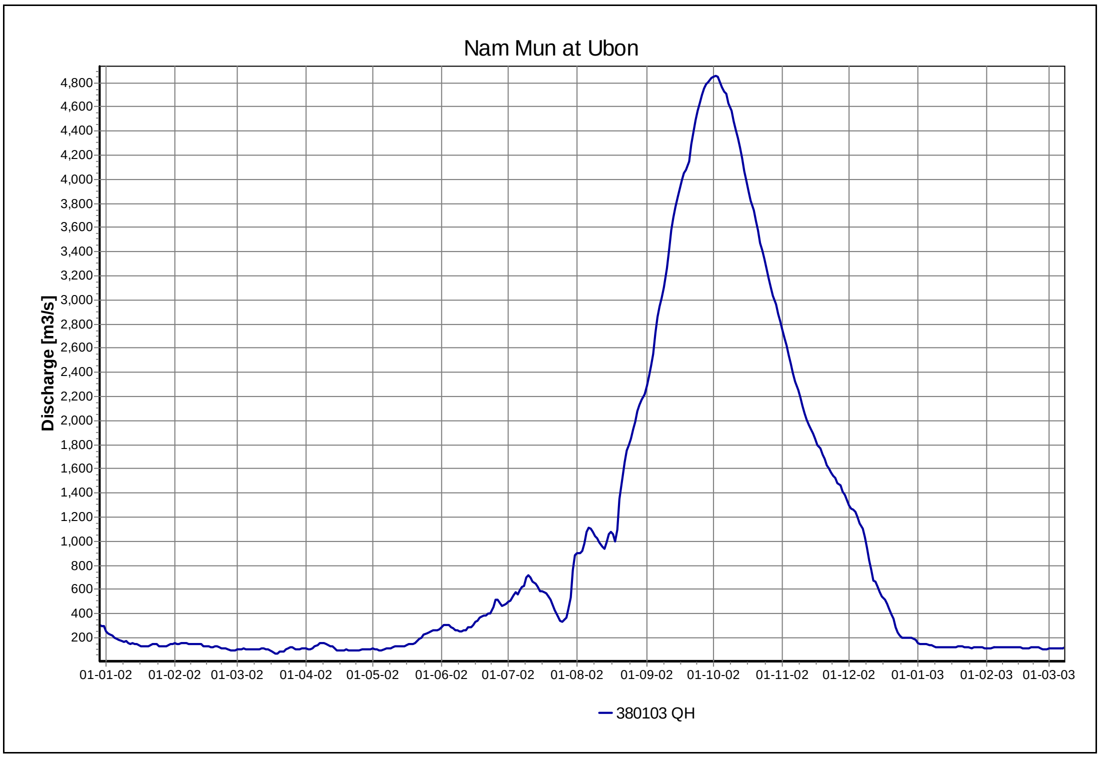

Figure 8.23 Discharge hydrograph of Nam Mun at Ubon, year 2002.

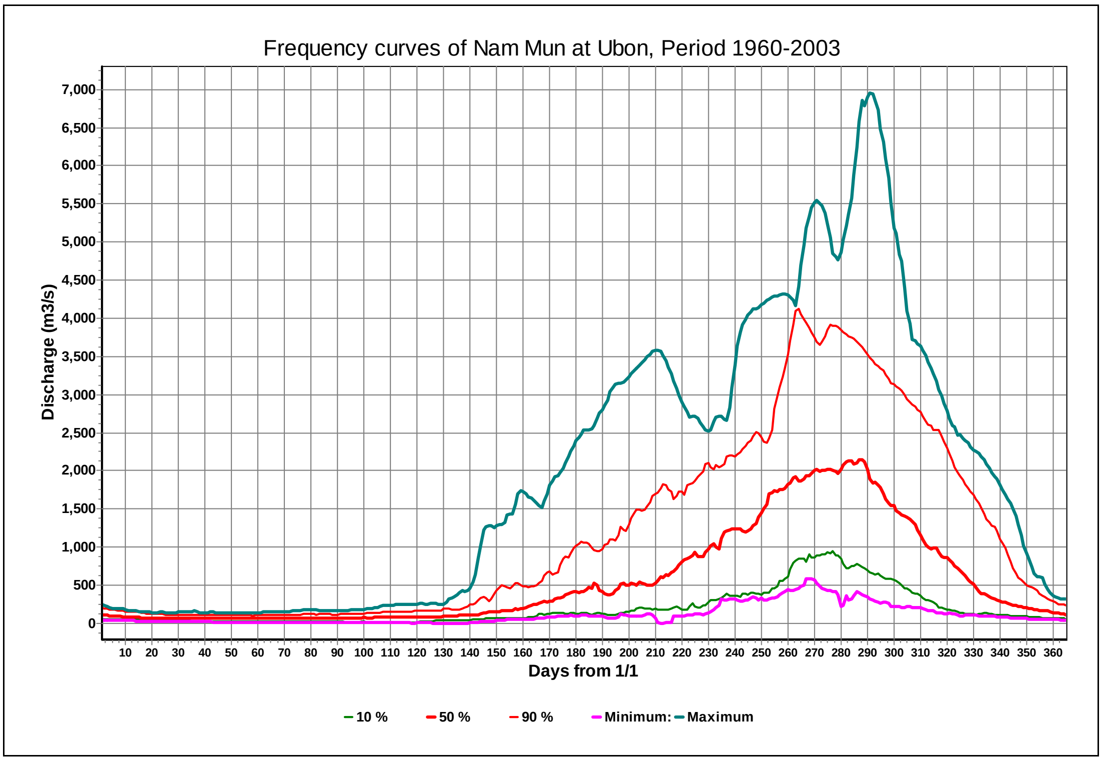

Figure 8.24 Frequency curves of daily discharge of Nam Mun at Ubon.

8.3 Developments in SA5 affecting the flow regime

Developments that affect the flow regime og SA5 include:

- Irrigation,
- Hydropower, and
- Trans-basin diversion.

Irrigation and hydropower

The irrigation water requirement for SA5 amounts 5,6 BCM, and the domestic and industrial water need is about 0.65 BCM/yr (BDP, 2006). There are 15 large scale irrigation projects (> 100 MCM storage) in SA5 with a total storage capacity of 8.6 BCM. The major storages are presented in Table 8.5. In addition there are 154 medium-scale and over 4,000 small scale projects with a total storage capacity of 2.4 BCM, so the total storage capacity in SA5 is 11 BCM or 44% of the annual flow.

Table 8.5 Overview of major reservoirs in SA5 (source: EGAT, 2007 and BDP, 2006).

Project	Basin	Basin area (km^2)	Capacity (MW)	Reservoir Storage (MCM)	Reservoir Area (km^2)
Ubol Ratana (MPP)	Nam Pong/Nam	12,104	25.2	2,264	401.2
Chulabhorn PP	Chi	545	40	188	12
Huai Kum PP	Nam Phrom/Nam	262	1.3	22.8	2.4
Lam Pao	Chi	?	1.7	1,430-	-
Lam Ta Khong PS	Nam Phrom/Nam	1,430	1000	2,640	44.3
Lam Phra Phloeng	Chi	?	0.85	320	?
Sirindhorn	Lam Pao/Nam Chi	2,097	36	220	288
Pak Mun	Lam Ta	117,000	136	1,966	60
Lam Nang Rong	Khong/N.Mun			225	
Upper Lam Mun	Nam Mun			121-214	
Lam Sae	Lam Dom			134	
Lam Plai Mat	Noi/N.Mun			268	
	Nam Mun			110	

From the above table it is observed that part of the projects are multipurpose. The main use of the reservoirs is, however, for irrigation with flood control only second priority. The mitigating capacity of the dams will be limited as the areas controlled by reservoirs with storage capacity is small

More than 600 irrigation projects may still be implemented in north-east Thailand (SA3+SA5) irrigating 224,000 ha (BDP, 200). EGAT is planning to develop the Lam Phan Chad Dam in the Nam Chi basin for hydrpower, installed capacity 5 MW.

Trans-basin diversion

To increase the supply of water for agricultural purposes the Kong-Chi-Mun diversion from the Mekong has been proposed to irrigate 320,000 ha in the Mun and Chi basins, using 6.6 BCM/yr. The status of this proposal is unknown.

8.4 Floods

8.4.1 Tributary floods

Flooding is a common phenomenon in the Mun-Chi basin. Floods are flashy in the upper areas and slow and long lasting on the main streams of the Mun and Chi rivers. High risk areas are the Nam Thon, Nam Thung and Lam Pao, and the main streams. Along Chi and Mun agricultural land and towns like Kalasin and Ubon are affected every year. According to BDP (2006) more than 1,600 km2 in the middle and lower parts of SA5 are considered a high risk zone, including:

- Part of the Muang district of Chaiyaphum Province
- Rasi Salai and Kantra Rom districts in Si Sa Ket
- Phanom Phrai district on Roi Et
- Muang, Kheung Nai Warin Chamrab and Don Mod Daeng districts in Ubon Ratchathani
- Muang, Maha Chanachai, Kho Wang and Kham Kheun Kaew districts in Yasothorn, and
- Ratanaburi and Tha Turn districts in Surin.

The annual maximum flood records of selected stations in the Mun-Chi basin are presented in Figure 8.25 to Figure 8.28. It is observed that in 1978 on the Chi and Mun rivers the highest flood have been experienced, with losses of USD 50 million. BDP (2006) also claims that the 1980 flood caused severe flooding on the Chi River. According to the record of Yasothon on Nam Chi 1980 was a year with an above average flood but not exceptional. On Nam Yang the flood of 1991 has been an extreme one, not found at other locations. In recent years the floods have been considerably above the average level on the main streams as can be observed d from the figures below. The annual flood report of 2005 does not mention specific problems, but in 2006 serious floods occurred (MRC, 2007):

- Chi river basin: major floods in Chaiyaphum, Khon Kaen, Mahasarakam, Roi Et and Yasoton provinces inundating about 2,000 km^2.
- Mun river basin; major flooding in Nakhon Rachasima, Buriram, Surin Sisakets and Ubon Ratchathani provinces, with a flood extent of nearly 3,400 km^2.

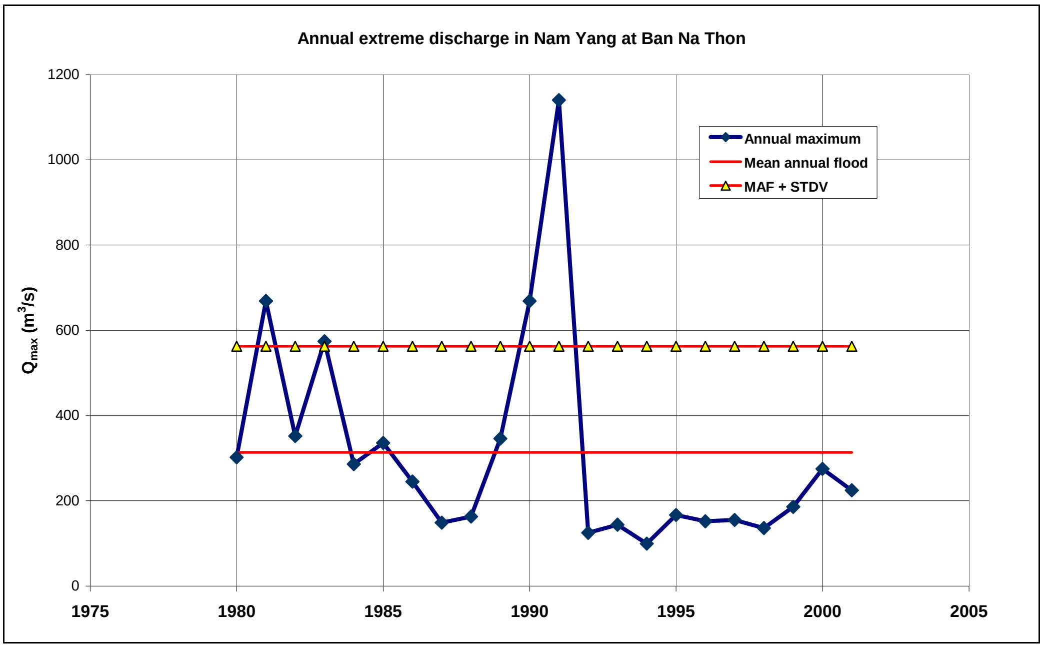

Figure 8.25 Annual maximum discharge of Nam Yang at Ban Na Thon.

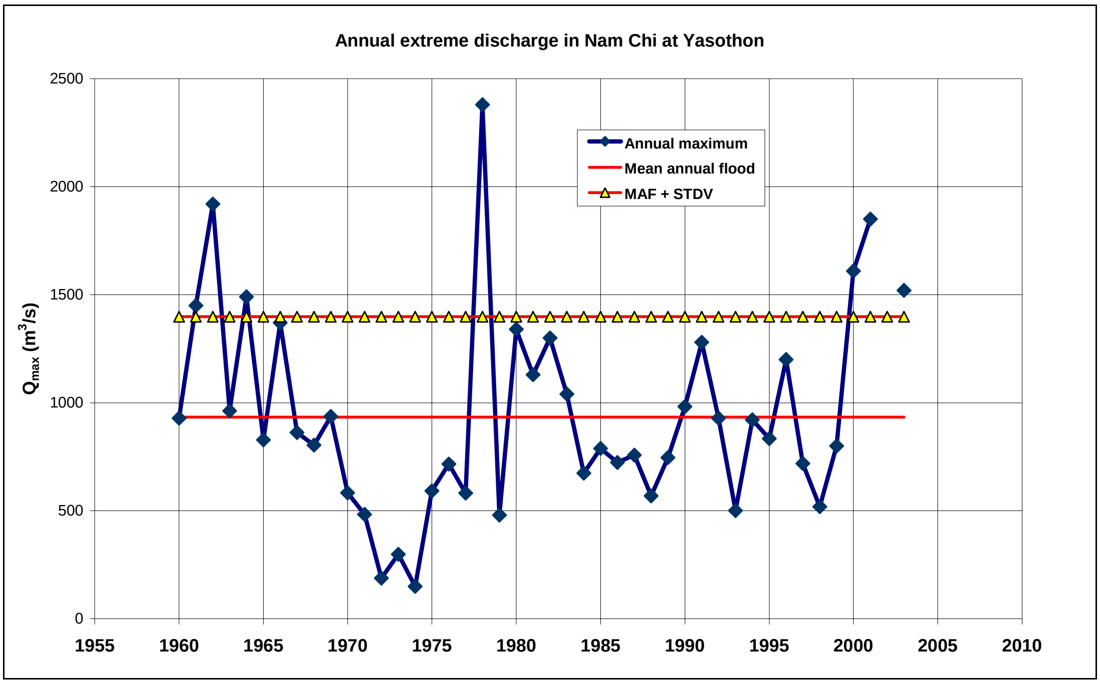

Figure 8.26 Annual maximum discharge in Nam Chi at Yasothon.

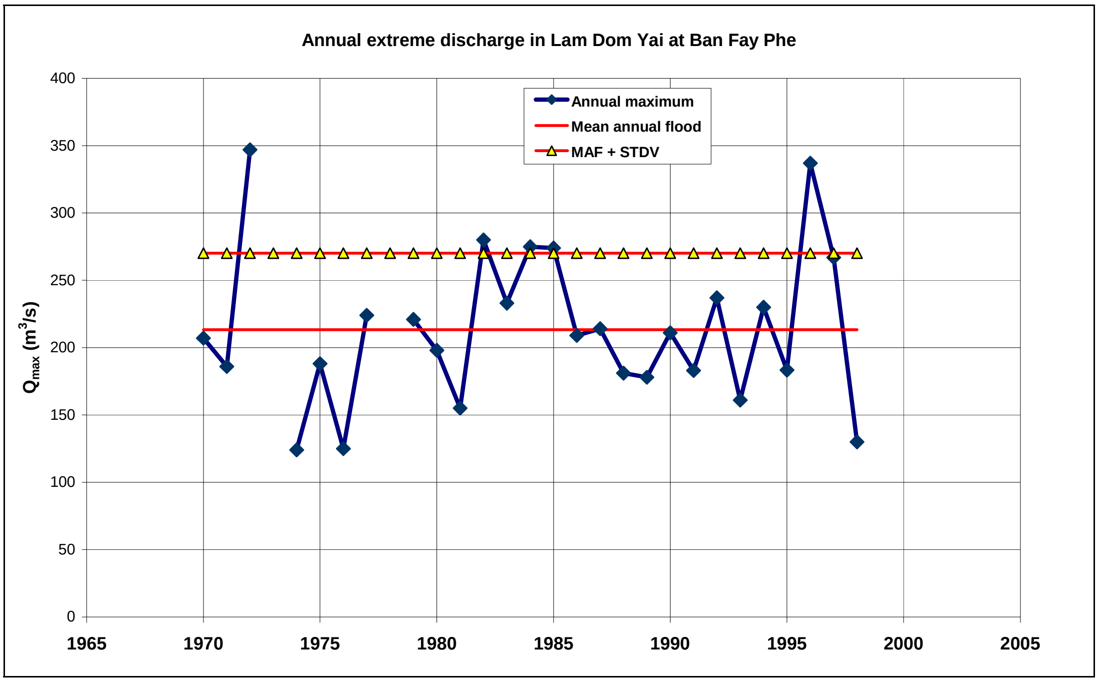

Figure 8.27 Annual maximum discharge in Lam Dom Yai at Ban Fay Phe.

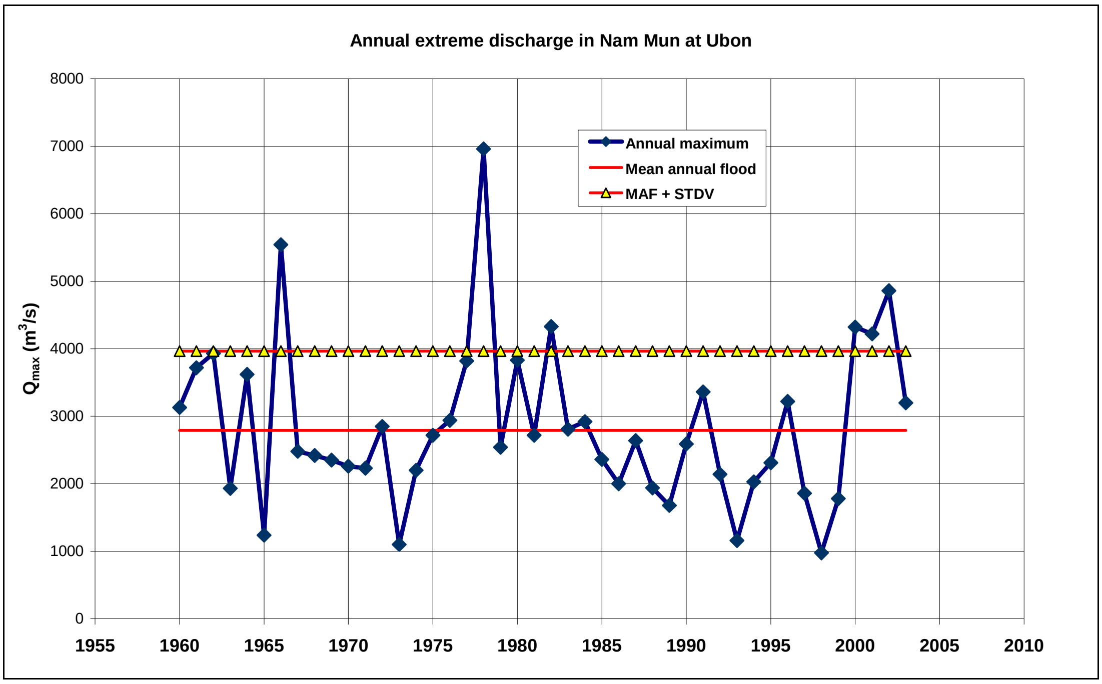

Figure 8.28 Annual maximum discharge in Nam Mun at Ubon Ratchathani.

The low river gradients and meandering nature of the Mun River make the river banks vulnerable to frequent floods. Flood depths in the upper reach of the Mun are on average 0.5 and 2 m for return periods of 2 and 25 years, which rise to 2 to 5 meters in the lower reach for the same return periods.

In the Chi basin, some flood mitigation is implemented through operation of the Ubon Ratana and Lam Pao Dams. Further flood protection measures include 300 km of dikes preventing the areas for 10 year return period flood levels In the Mun basin, several dams like the Lam Takhong Dam, Lam Phra Ploeng Dam, Upper Mun Dam, Lam Nang Rong Dam, Sirindhorn Dam and Pak Mun Dam have already been built, but their reservoirs are primarily for irrigation, not for flood control.

For some 12 locations sufficient data is available to derive the hydrological hazard. For translation to flood hazard use can be made of satellite images, which are occasionally available for SA5 since the last 10 years (LANDSAT, RADARSAT, SPOT), without field proofing. Also, the Mike 11 modelling suite, including the hydrodynamic model and the Nam rainfall-runoff model has been applied to the Nam-Chi basin, a.o. for flood modelling. The quality of the models is not known.

Hence, there are options available for flood hazard assessment in SA5.

8.4.2 Main stream floods

SA5 does not include reaches of the Mekong River.

8.4.3 Combined floods

The Pak Mun dam some 5 km upstream of the Mun River mouth prevents a direct interaction between the waters of the Mun and the stages in the Mekong. The Pak Mun dam is 17 m high and 324 m wide dam with a crest elevation of 110 masl. It has a radial gated spillway with a crest level at 94 masl. The water level in the Mekong river at Khong Chiam near to the mouth of the Nam Mun varies between 90 m and at maximum 107 masl. It implies that at high water levels in the Mekong the discharge from Pak Mun dam may be affected. From the discharge frequency curves of Pakse (just downstream of the Mun mouth) and of Ubon Ratchathani it appears however that the flood in the Mun generally comes late relative to the flood on the Mekong. Hence negative interaction on the discharge capacity of the Pak Mun when the Mun is in flood is generally limited.

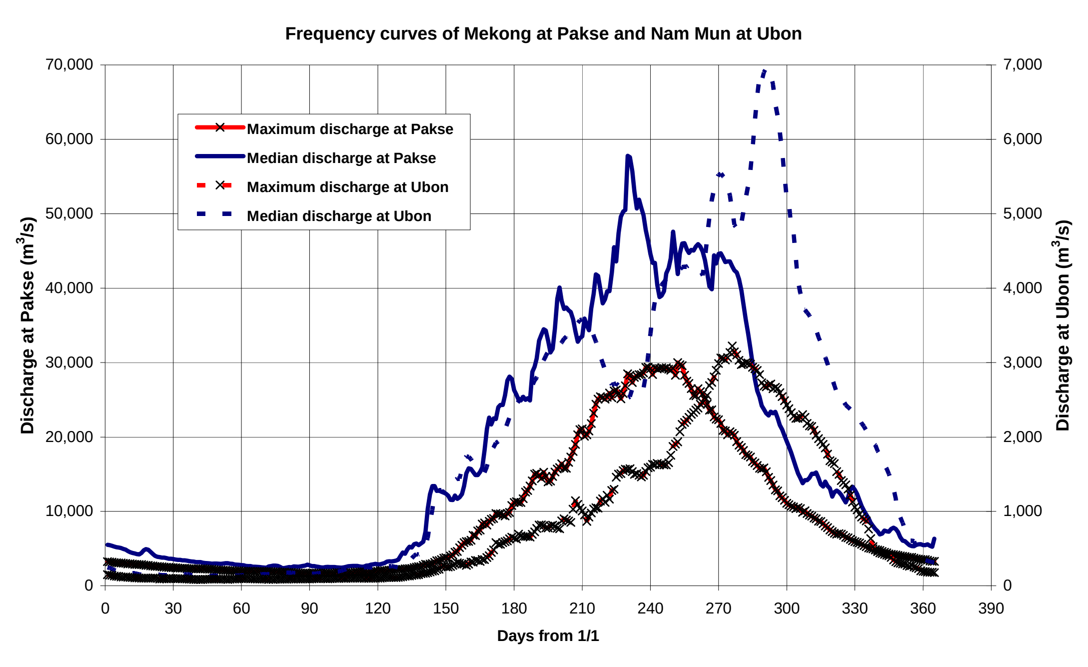

Figure 8.29 Frequency curves of daily discharge of the Mekong at Pakse and of Nam Mun at Ubon Ratchathani, period 1960-2006.

8.4.4 Summing up

Floods in the Mun-Chi system are flashy in the upper reaches and less rapid but much longer lasting in the midlle 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 main stream satellite imagery combined with hydraulic modelling (Mike 11) is an option, provided the model is properly calibrated.

9 HYDROLOGICAL AND FLOOD HAZARD IN SUB-AREA 6

9.1 Basin characteristiscs

Sub-area 6 (SA6) covers the area draining to the Mekong from Khong Chiam, downstream of the mouth of the Nam Mun, to Stung Treng, upstream of the mouth of the Se San (Se Khong, Se San and Sre Pok), see Figure 9.1. It includes the Khon Falls and the key hydrological station Pakse (rkm 869). The total area comprises 19,076 km^2.The major tributaries in this reach of the Mekong are:

- Se Done (drainage area 7,700 km2, draining at rkm 869) with tribuaties Se Set and Huai Chempi in Laos
- Huai Bang Lieng, left bank tributary in Laos
- Huai Tomo, left bank tributary in Laos and Cambodia
- Huai Khamouan, right bank tributary in Laos
- Tonle Repon, right bank tributary forming the border between Laos and Cambodia
- Some small tributaries in Cambodia including Prek Mun and Siem Bok.

The topographical features and slopes are presented in Figure 9.2 and Figure 9.3. SA6 for its major part is flat land along the Mekong. It includes the fertile Se Done plains, considered as the best agricultural land in the region. To the north-east of Pakse SA6 covers part of the Bolaven Plateau with its coffee plantations.

Land cover comprises for almost 60% dense and open forest (see Figure 9.4) and agricultural land in the remaining area. Some 3% is wetland. About 60% of the area acrisols are found, 20% cambisols and about 10% gleysols.

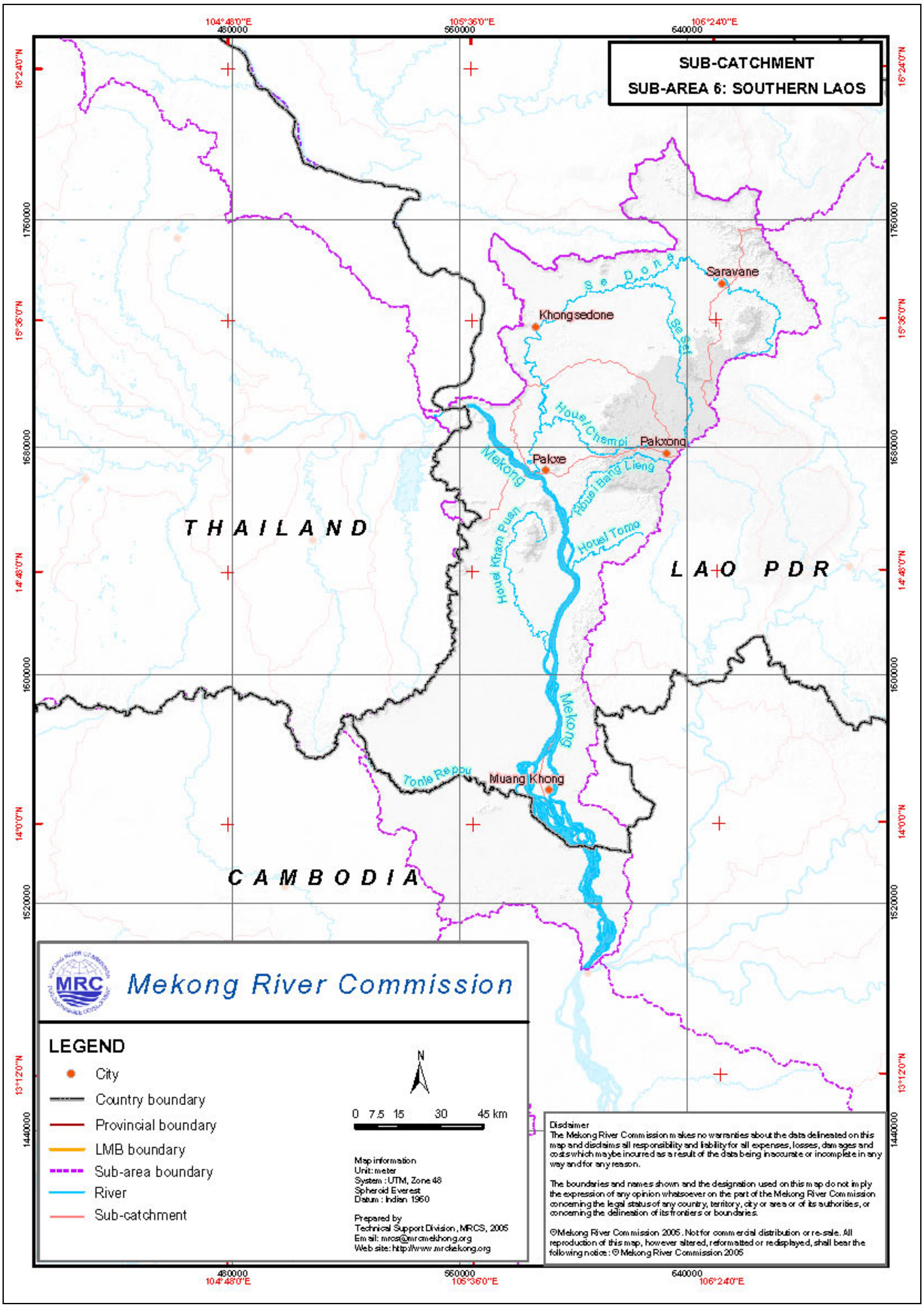

Figure 9.1 Layout of river basins in SA6 (BDP, 2006).

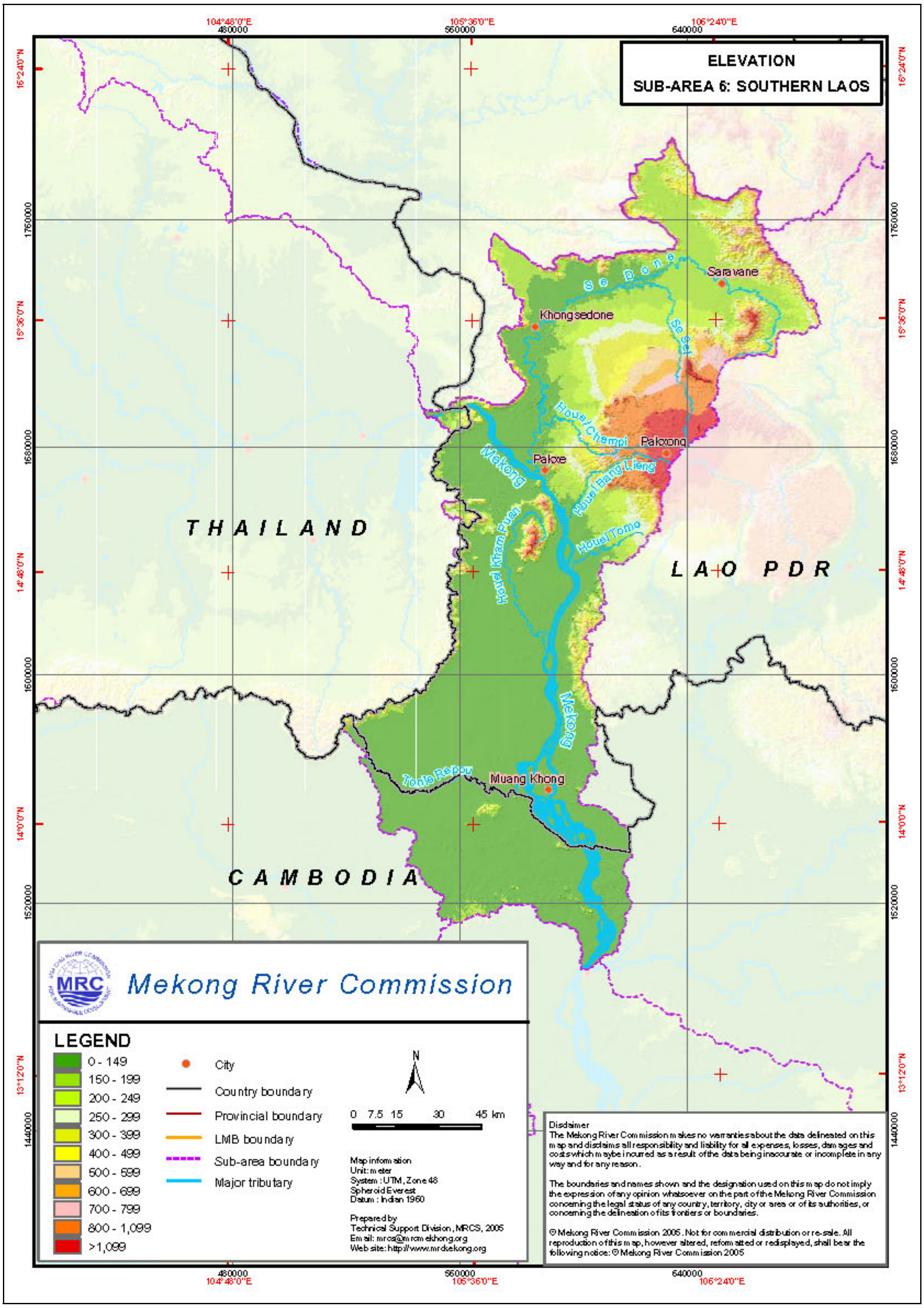

Figure 9.2 Elevation map of SA6 (BDP, 2006).

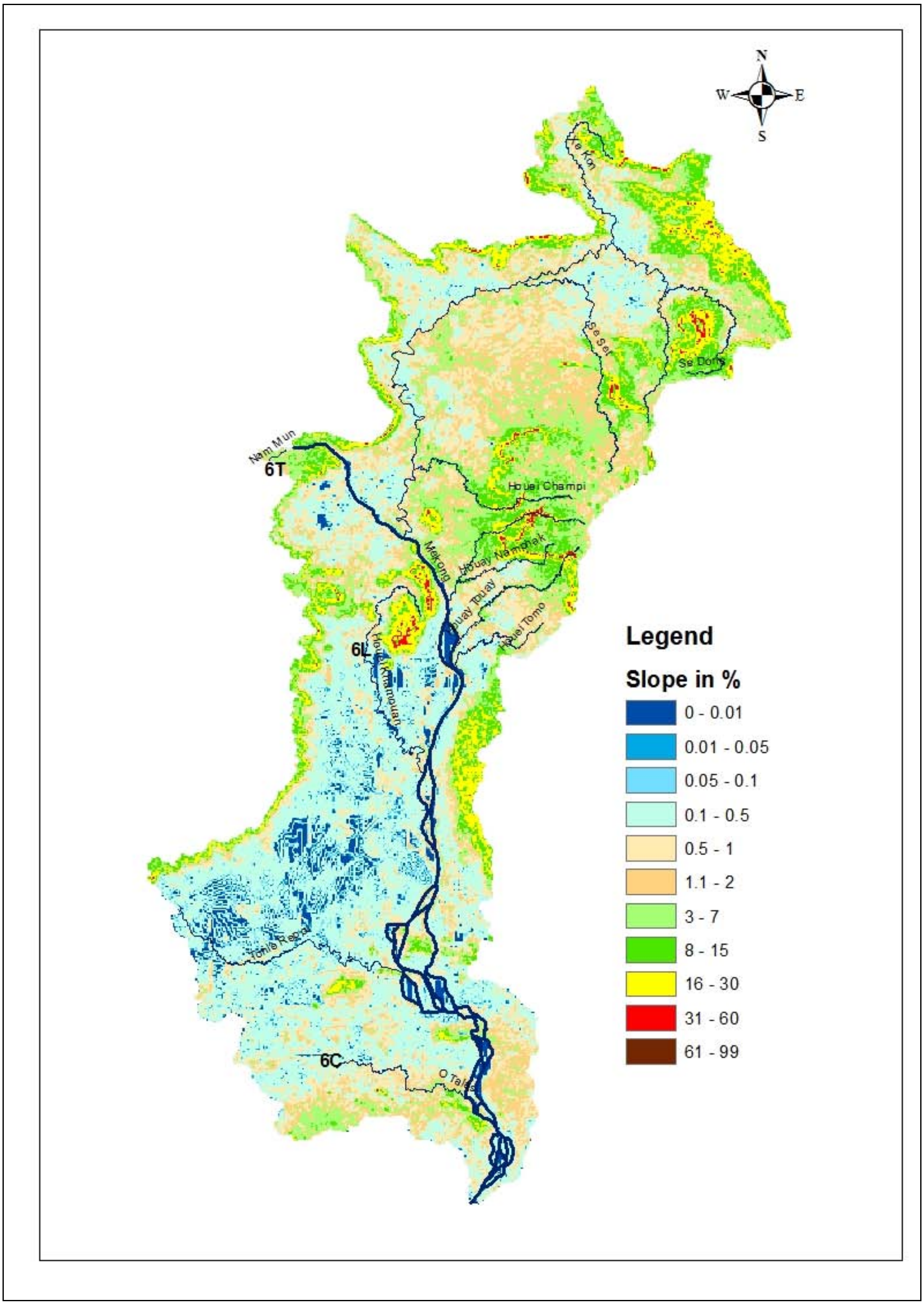

Figure 9.3 Slope map of SA6.

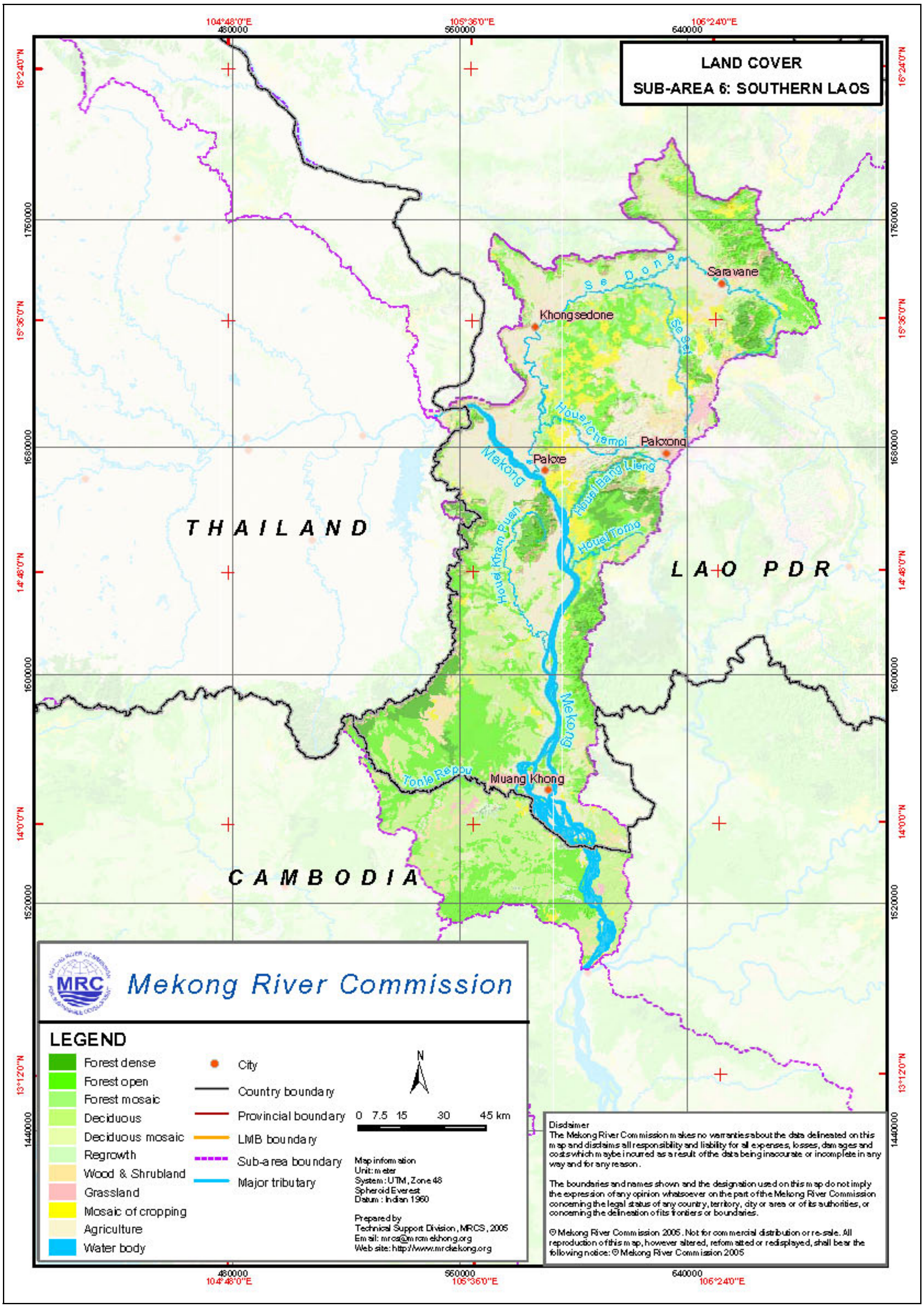

Figure 9.4 Land use map of SA6 (BDP, 2006).

9.2 Hydrological characteristics

9.2.1 Data availability

The list of rainfall, water level and discharge stations is presented in Table 9.1, Table 9.2 and Table 9.3. The locations of the stations are presented in Figure 9.6.

Daily rainfall data is available for some 16 stations, of which 6 are located in the basin of the Se Done and the rest is along the Mekong river. Some very old records are available a.o. for Pakse, but the majority of the station records start in the eighties and nineties of the last century. No records exist of stations in the Cambodian part of SA6.

With respect to water levels of 16 stations records are available, of which 7 are from stations on the Se Done and tributaries. Records for most of the stations on the Mekong start in the sixties. Except for Ban Nanai, which starts in the sixties, the stations on the Se Done have records from the mid-eighties onward.

A very long and complete discharge record is available for Pakse as from 1925 onward. Because the control section of Pakse is very stable due to the rocky section of the Mekong the discharge rating has not changed in the course of time, as can be observed from Figure 9.5. The figure shows that apart from a few apparently erroneous measurements in the seventies, the rating has not changed, different from the stations upstream of Pakse, which showed variation from year to year due to morphological developments in the river.

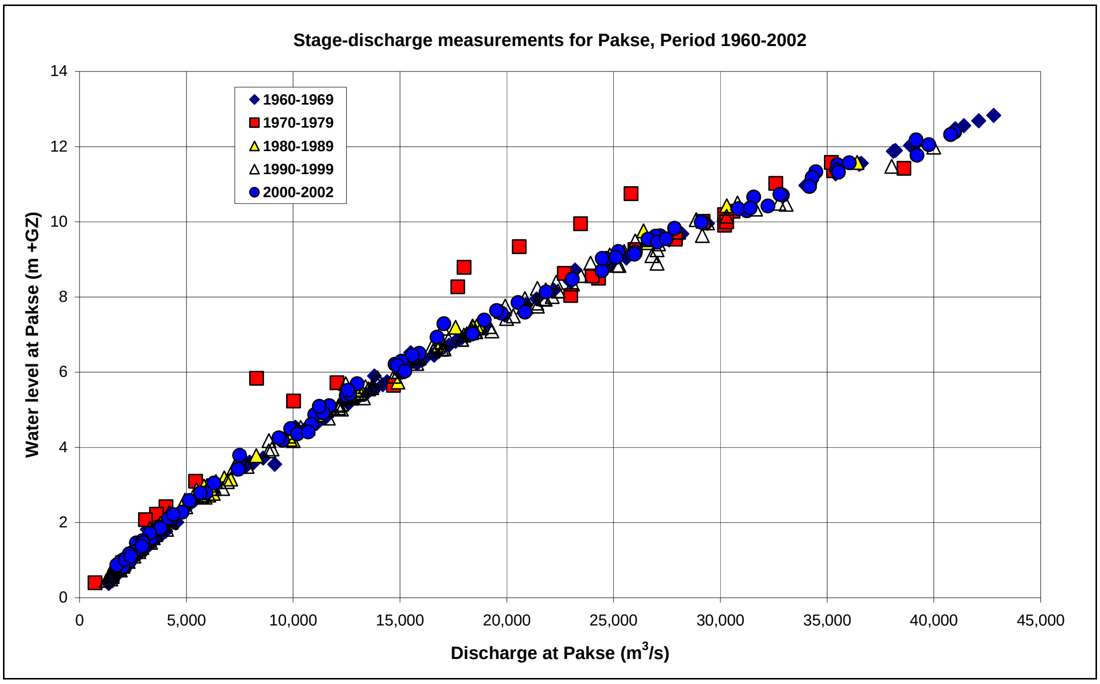

Figure 9.5 Overview of stage-discharge measurements for the Mekong at Pakse, 1960-2002.

Discharge records for 3 stations on Se Done are available from the eighties onward, of which only the series for Souvanna Khili in the upper Se Done is sufficiently long for making statistical inference of flow extremes; the rest has too many gaps.

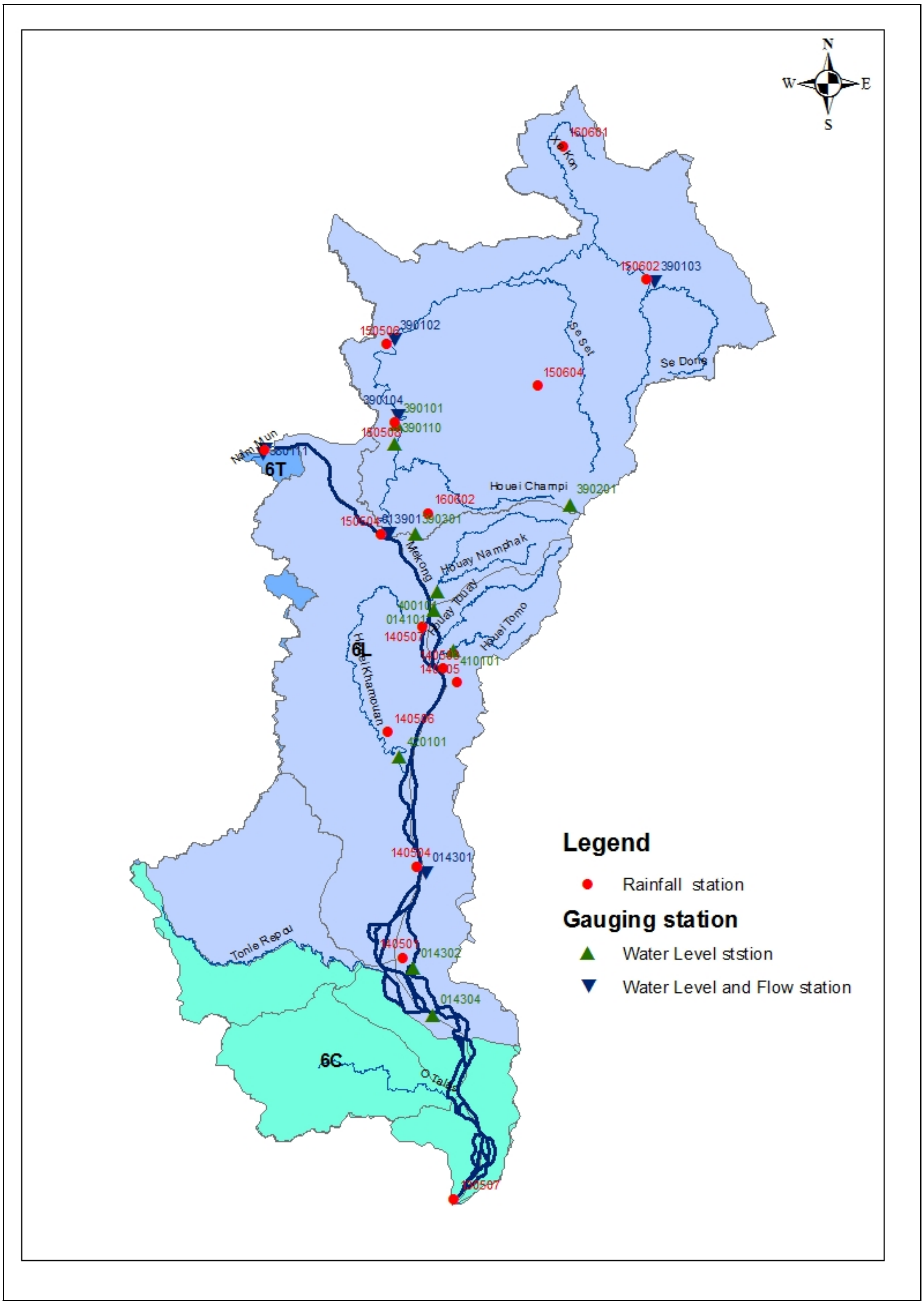

Figure 9.6 Hydrometeorological network of SA6.

Table 9.1 Overview of rainfall stations in SA6.

Station Location

Rainfall

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
013901	Pakse	Mekong	15.1167	105.8000
140501	Muong Khong	Mekong	14.1167	105.8333
140503	Phiafay	Mekong	14.8000	105.9340
140504	Mounlapamok	Mekong	14.3333	105.8667
140505	Pathoumphone	Huai Tomo	14.7667	105.9667
140506	Soukhouma	Huai Khamoua	14.6500	105.8000
140507	Muang Champasack	Mekong	14.9000	105.8833
150504	Pakse	Mekong	15.1167	105.7833
150506	Khongsedone	Se Done	15.5667	105.8000
150508	Selabam	Se Done	15.3833	105.8167
150602	Saravan	Se Done	15.7167	106.4333
150604	Laongam	Se Done	15.4667	106.1667
160601	Muong Tchepon	Se Done	16.0333	106.2333
160602	Muong Nong	Se Done	15.1667	105.9000
6C				
130507	Tala Borivat	Mekong	13.5460	105.9550
6T				
150503	KHONG CHIAM	Mekong	15.3167	105.5000

Table 9.2 Overview of water level stations in SA6.

Water Level

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
013901	Pakse	Mekong	15.1167	105.8000
014101	Ban Mouang	Mekong	14.9383	105.9117
014301	Ban Chan Noi	Mekong	14.3167	105.8867
014302	Ban Hat SaiKhoune	Mekong	14.0917	105.8583
014304	Veunkham	Mekong	13.9800	105.9050
390101	Ban Nanai	Se Done	15.3780	105.8230
390102	Khong Sedone	Se Done	15.5750	105.8150
390103	Saravanne	Se Done	15.7100	106.4500
390104	Souvanna Khili	Se Done	15.3967	105.8250
390110	Ban Done Xe	Se Done	15.3317	105.8170
390201	Km 35	Houei Champi	15.1850	106.2433
390301	Km 8	Houei Gnang	15.1167	105.8667
400101	Ban Bang Lieng	Houei Banglien	14.9800	105.9217
410101	Km40	Houei Tomo	14.8417	105.9583
420101	B.Mai Vang Makxeo	Houei Bangkha	14.5900	105.8267
6T				
013801	Khong Chiam	Mekong	15.3184	105.5000

Table 9.3 Overview of discharge stations in SA6.

Flow 6L

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)		Catchment Area,
			Latitude	Longitude	km2
013901	Pakse	Mekong	15.1167	105.8000	545,000
014301	Ban Chan Noi	Mekong	14.3167	105.8867	549,000
390102	Khong Sedone	Se Done	15.5750	105.8150	6,170
390103	Saravanne	Se Done	15.7100	106.4500	1,172
390104	Souvanna Khili	Se Done	15.3967	105.8250	5,760
6T					
013801	Khong Chiam	Mekong	15.3184	105.5000	419,000

Table 9.4 Availability of daily rainfall data in SA6.

Daily Data Availability of BDP Sub-Area 6L (1960-2006)

Rainfall

Station ID	Station Name	River	1920							1930										1940										1950									
			3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
140501	Muong Khong	Mekong										246			59		92	243																					
140503	Phiafay	Mekong								+					+	+	+	+	+																				
150504	Pakse	Mekong							+	+	+	+	30	+	59	+	90	31	90											243	184	+	+	31	+	+	+	63	90
150602	Saravan	Se Done						+	243	+	91	244	121		90	122	151	274	274			59																	
150604	Laongam	Se Done								+	+	+	+		+	+	+	184	243																				
160601	Muong Tchepon	Se Done	+	+	122		+			+	122	+			+	92	61	153																					

Daily Data Availability of BDP Sub-Area 6L (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
013901	Pakse	Mekong																				
140501	Muong Khong	Mekong					121	+	+	123	+	+	+	+	+	+	+					+
140503	Phiafay	Mekong					+	+	+	+	+	+	+	+								
140504	Mounlapamok	Mekong						+	92	+	+	+	275									+
140505	Pathoumphone	Huai Tomo																				
140506	Soukhouma	Huai Khamouan																				+
140507	Muang Champasack	Mekong																				+
150504	Pakse	Mekong	152	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150506	Khongsedone	Se Done				212	+	+	+	+	+	+	+		+							+
150508	Selabam	Se Done													+	+	+	+	+		+	
150602	Saravan	Se Done					60						245									
150604	Laongam	Se Done																				
160601	Muong Tchepon	Se Done																				
160602	Muong Nong	Se Done																				
6C																						
130507	Tala Borivat	Mekong																				
6T																						
150503	KHONG CHIAM	Mekong																	+	+	+	+

Station ID	Station Name	River	1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
013901	Pakse	Mekong																					219	+	+	+	+	+	+
140501	Muong Khong	Mekong	+	+	123	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	
140503	Phiafay	Mekong												+															
140504	Mounlapamok	Mekong	+	+	31	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+
140505	Pathoumphone	Huai Tomo														+	+	+	+	+	+	+	+	+	+	+	+	+	
140506	Soukhouma	Huai Khamouan	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+
140507	Muang Champasack	Mekong	+		122	+	+	+	+	+	92	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150504	Pakse	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150506	Khongsedone	Se Done				+					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150508	Selabam	Se Done	+	61	+	+	61	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+						+
150602	Saravan	Se Done								+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150604	Laongam	Se Done										+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160601	Muong Tchepon	Se Done											+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
160602	Muong Nong	Se Done														+	+	+	+	+	+	+	+	+			+	+	+
6C																													
130507	Tala Borivat	Mekong																						+	+		+	+	+
6T																													
150503	KHONG CHIAM	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	

Table 9.5 Availability of daily water level data in SA6.

Water Level

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
013901	Pakse	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
014101	Ban Mouang	Mekong															129	216		230	215	119	175	276	201																							+	+
014301	Ban Chan Noi	Mekong	41	+	+	+	+	+	+	+	+	+	+	+	62	59	275			267	284	114	93	339	195			291					+			92	91	+	+	+	+	+	+	+	+	+	+	+	+
014302	Ban Hat SaiKhoune	Mekong																		271	275	122	122																									+	1
014304	Veunkham	Mekong																																				61		32	+	+	+	+	122	+	+	+	+
390101	Ban Nanai	Se Done	47	+	+	143	+	+	+	+	41	+	+	+	+	+	+	94		231	15	+	+	31	+	122	183	123	212	+	+	+			182		+	+	+	+	+	+	+	+	+	126			
390102	Khong Sedone	Se Done								91	20	3	13	23	214		65	131		309	76	24	40	319		214						+	+	+	+	+	+	+	+					+	+	+	+	+	+
390103	Saravanne	Se Done																											212	89	+	+	+	+	+		+	52	284	184			+	+	+	+	+	+	+
390104	Souvanna Khili	Se Done																											216	+	+	+	+	+	182	+	+	+	+	+	+	+	+	+	+	+	+	+	+
390110	Ban Done Xe	Se Done																											222	+	+	30	122		195	+	+	30	+	+	+	+	+	+	+	+			
390201	Km 35	Houei Champi																				304	275	235	153						81					122	+	+	30	+	+	+	+	+	+	+	+	+	+
390301	Km 8	Houei Gnang																																				+	67	+	+	+	+	+	+	+	+	+	+
400101	Ban Bang Lieng	Houei Banglieng															132	140		296	335	137	31	334							+	40					+	+	140	4	+	+	+	+	+	+	+	+	+
410101	Km40	Houei Tomo															113	122		304	63	+	275												184		+	+	+	+	+	+	+	+	+	+	+	+	+
420101	B.Mai Vang Makxeo	Houei Bangkhamouan																																							+	81	+	+	+	+	+	+	+
6T																																																	
013801	Khong Chiam	Mekong							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
380111	Pak Mun	Nam Mun																						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			

Table 9.6 Availability of daily flow data in SA6.

Flow

Station ID	Station Name	River	1920							1930										1940										1950									
			3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
013901	Pakse	Mekong	31	91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Flow

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
013901	Pakse	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
014301	Ban Chan Noi	Mekong	59	+	+	+	+																																										
390102	Khong Sedone	Se Done																														+	+		+		+	+	+					+	+	+	+	+	
390103	Saravanne	Se Done																											212	89	2	+	+	+	+		+	52	284	185			48	+	+	+	+	+	
390104	Souvanna Khili	Se Done																											216	+	+	+	+	+	182	+	+	+	+	+	+	+	+	+	+	+	+	+	
6T																																																	
013801	Khong Chiam	Mekong							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
380111	Pak Mun	Nam Mun																																			+	53	+				+						

Notes: + = no missing
blank = missing
90 = number of missing days in a year

9.2.2 Rainfall

The annual rainfall in SA5 is among the highest in the LMB. According to Figure 7.6 the average annual rainfall is in the range of 1,800 to 3,200 mm per year. High rainfall amounts are specially experienced on the Boloven Plateau. From the record of Pakse (average annual rainfall = 2,100 mm) a temporal variation from 1,500 to 3,000 mm is observed, see Figure 9.7. The rainfall is highly seasonal as determined by the SW and NE Monsoons. About 90% of the annual rainfall is experienced in the months May to September, with August generally the wettest month, see Figure 9.8.

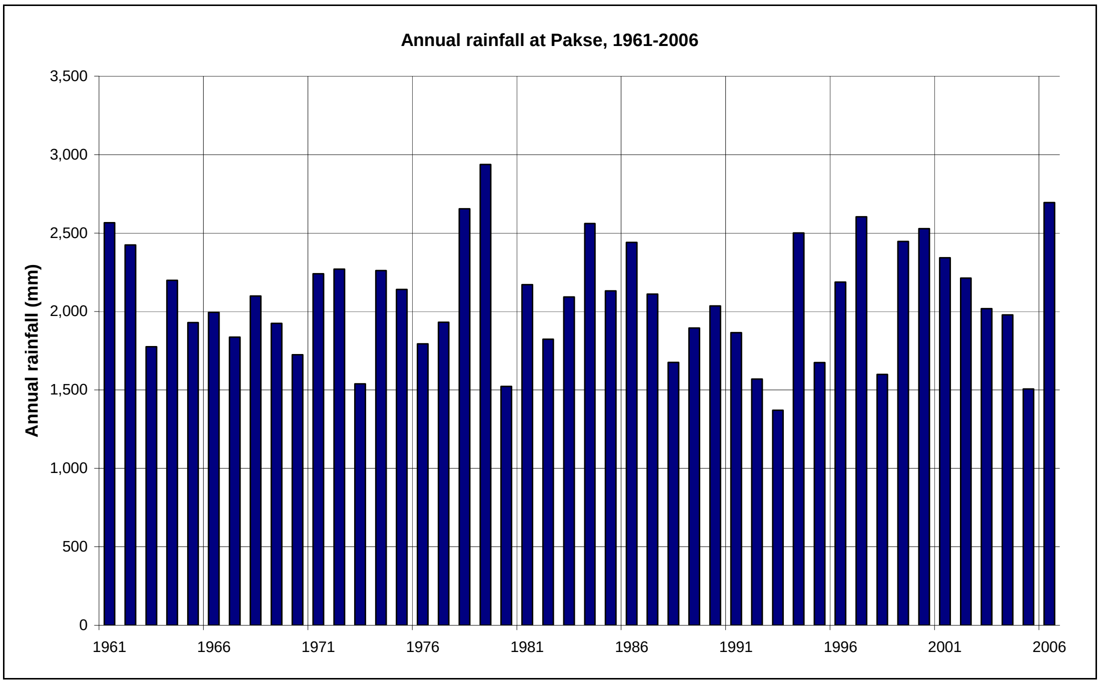

Figure 9.7 Annual rainfall of Pakse, 1961-2006.

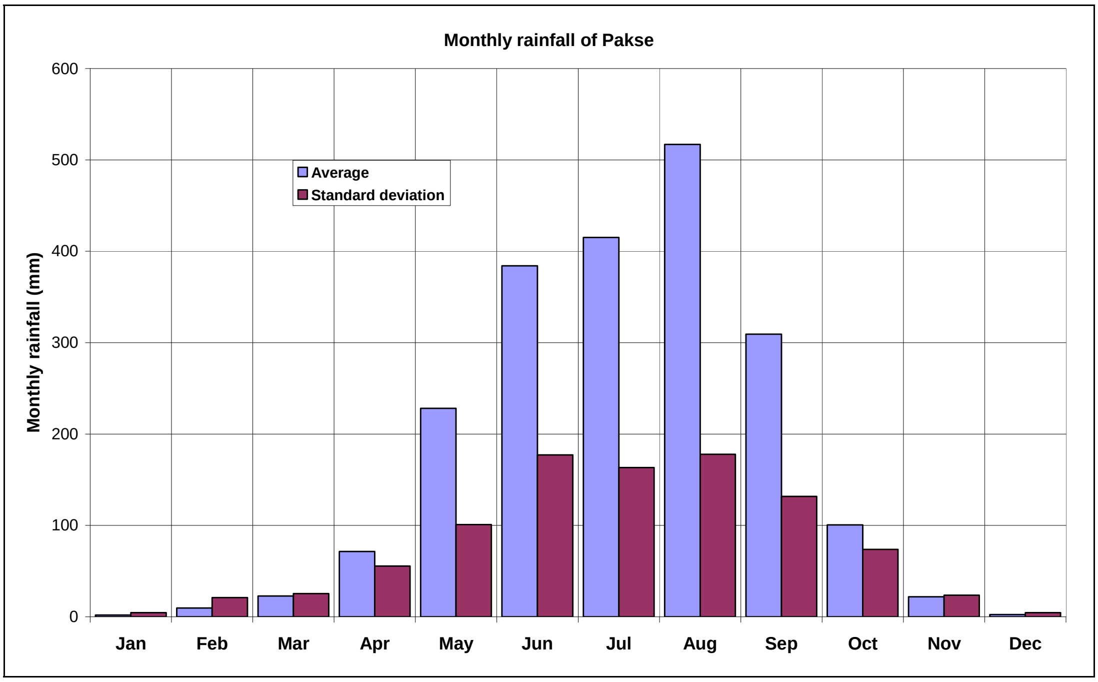

Figure 9.8 Monthly rainfall characteristics of Pakse.

9.2.3 Runoff

The average annual runoff from SA6 according to BDP (2006) for the period 1985-2000 is 21.8 BCM. An estimated runoff of 18 BCM or 960 mm per year can be derived for SA6 from an extrapolation of the flow at Souvanna Khili on Se Done. In view of the variation of the rainfall through the year there is a strong seasonality in the runoff, with highest flows in July to September, peaking in August, see Figure 9.9. The seasonality is more pronounced as of the Mekong flows at Pakse as can be seen from a comparison with Figure 9.10. When expressed in runoff depth it is observed from Figure 9.11 that the runoff from SA6 in June to September exceeds the runoff from the entire basin upstream of Pakse by far, whereas from October to April the higher values are in the Pakse record. In general the monthly flows in August are highest in both records.

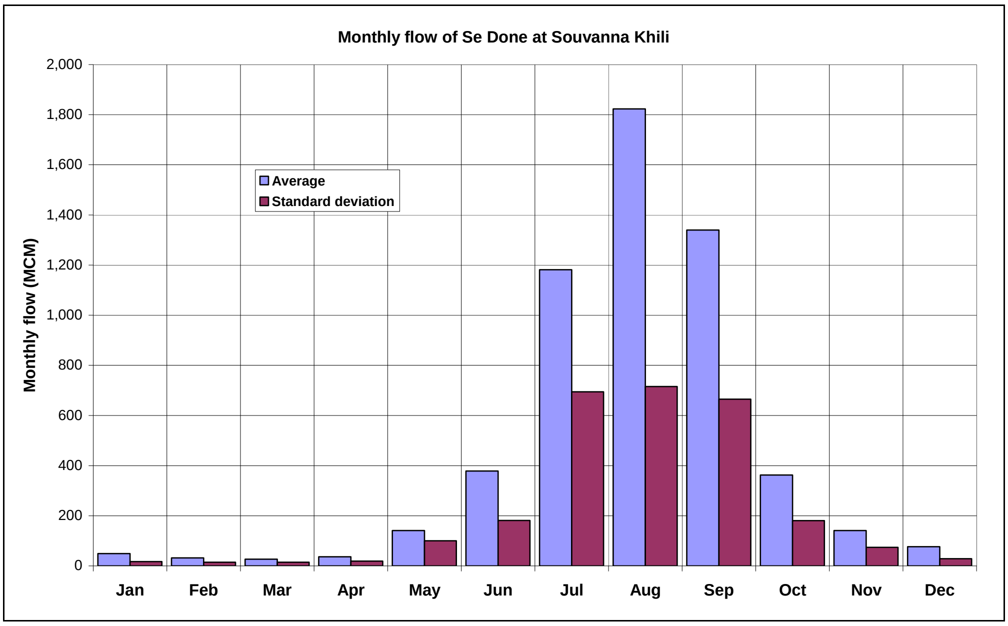

Figure 9.9 Monthly runoff characteristics of Se Done at Souvanna Khili.

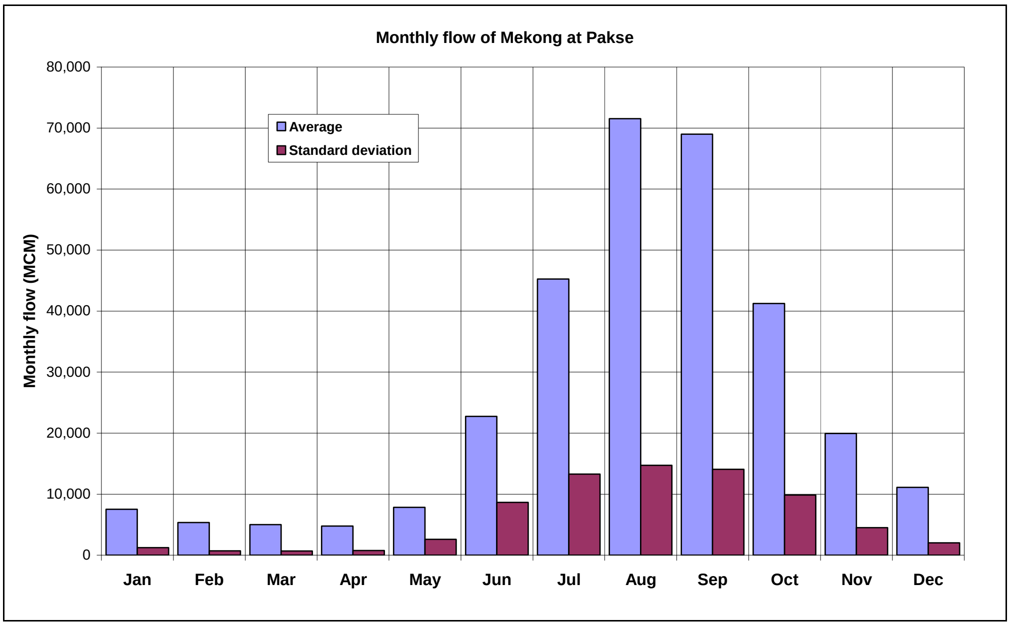

Figure 9.10 Monthly runoff of Mekong at Pakse.

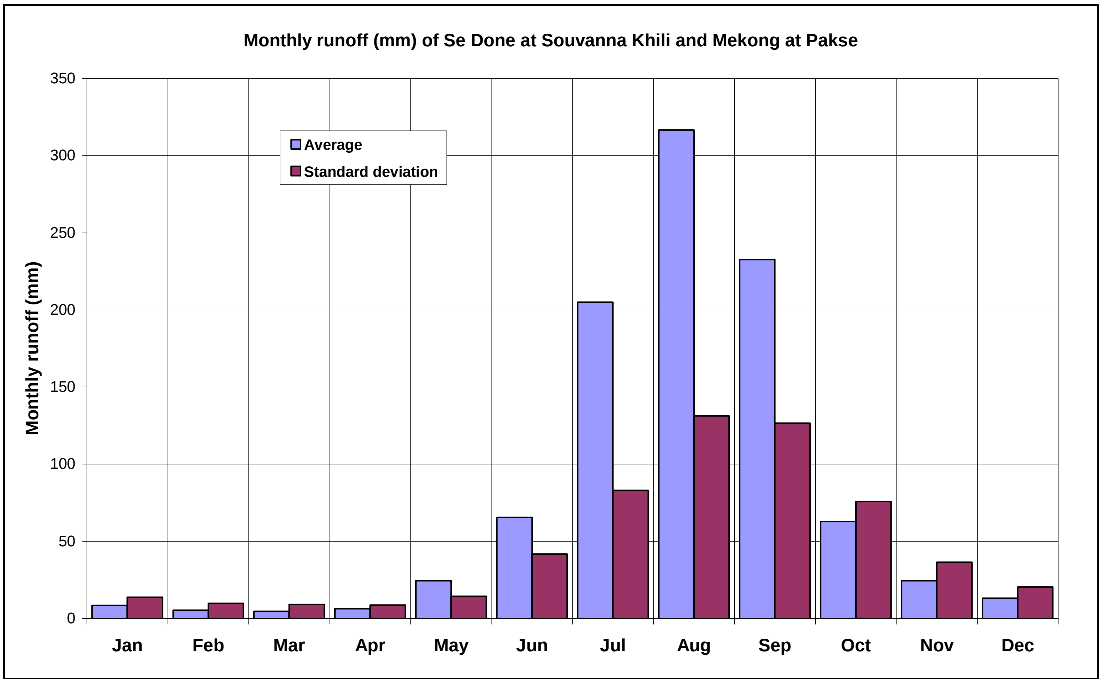

Figure 9.11 Average and standard deviation of Se Done at Souvanna Khili and Mekong at Pakse.

The characteristics of the flood hydrographs and their occurrence can be obtained from the daily discharge records and frequency curves for Souvanna Khili on Se Done (Figure 9.12 to Figure 9.14) and for the Mekong at Pakse (Figure 9.15 to Figure 9.17). From the figures the following can be observed:

- Floods on Se Done rise and fall fairly fast and last up to one or two weeks. Above average peak flows can be expected from July till mid-September. Note that Souvanna Khili is in the downstream part of the Se Done, hence upstream the rates of rise and fall will be more pronounced.
- The rate of rise and of fall of the flood levels on the main stream is less flashy and the above average annual floods (=37,500 m3/s) can be expected in the period from mid-July till mid-October.

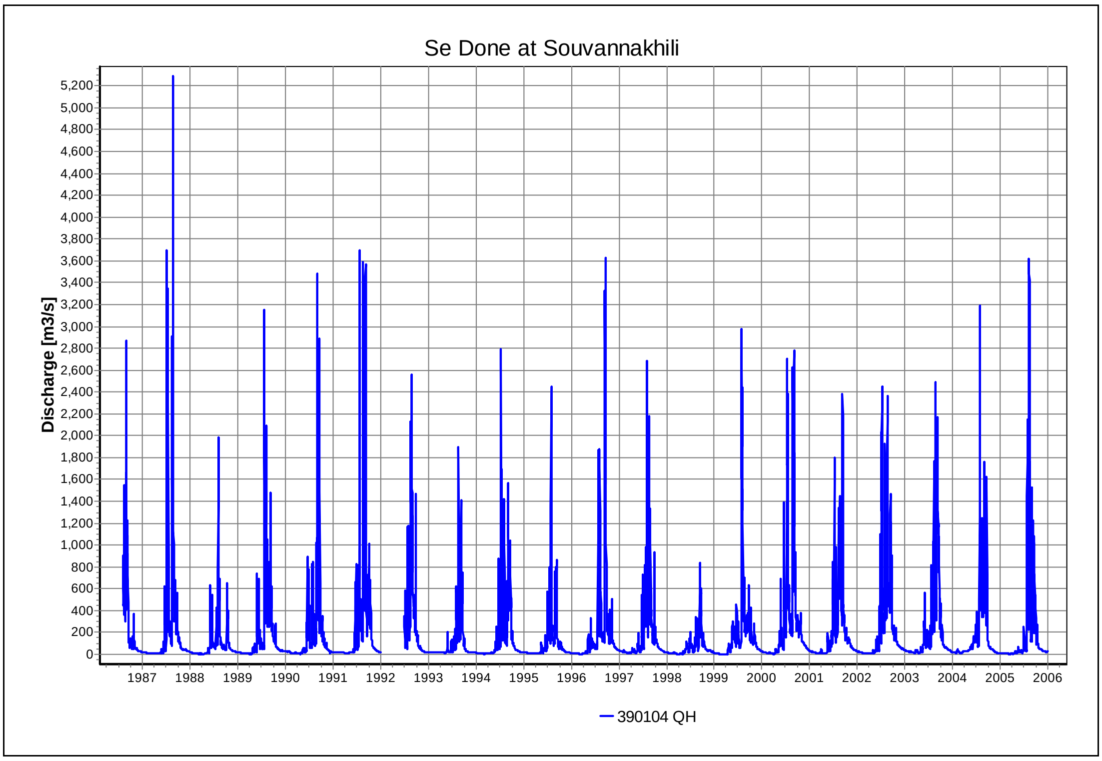

Figure 9.12 Discharge hydrograph of Se Done at Souvanna Khili.

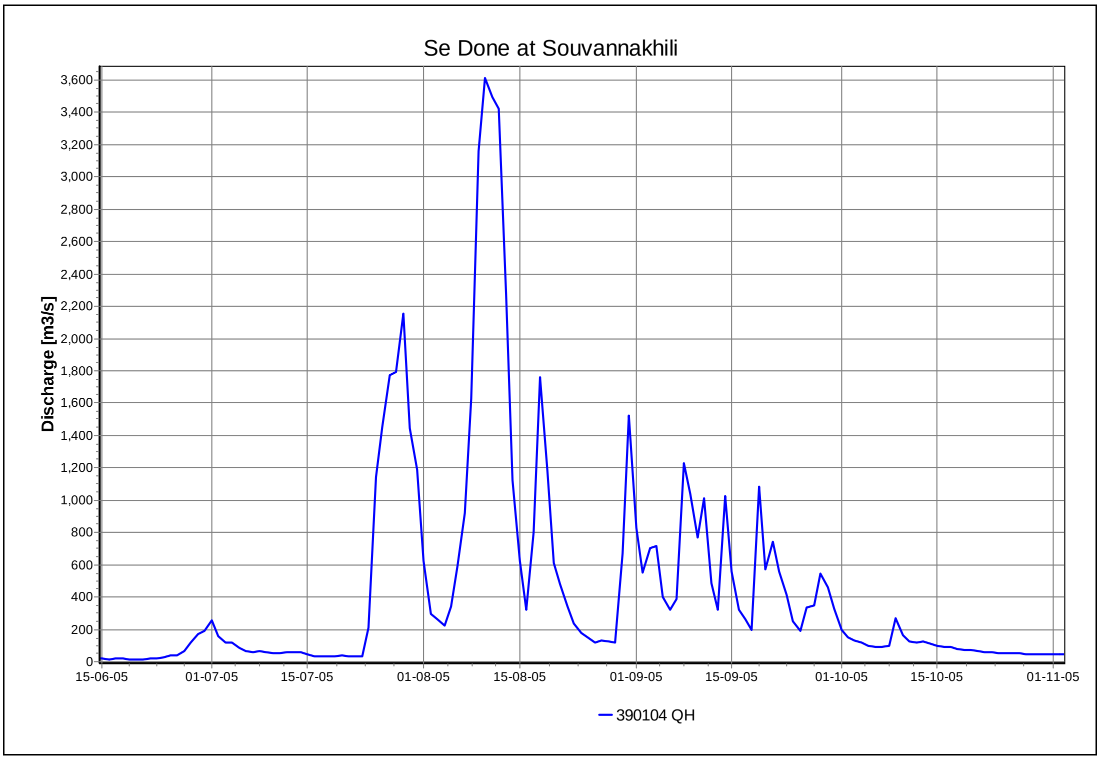

Figure 9.13 Discharge hydrograph of Se Done at Souvanna Khili, year 2005.

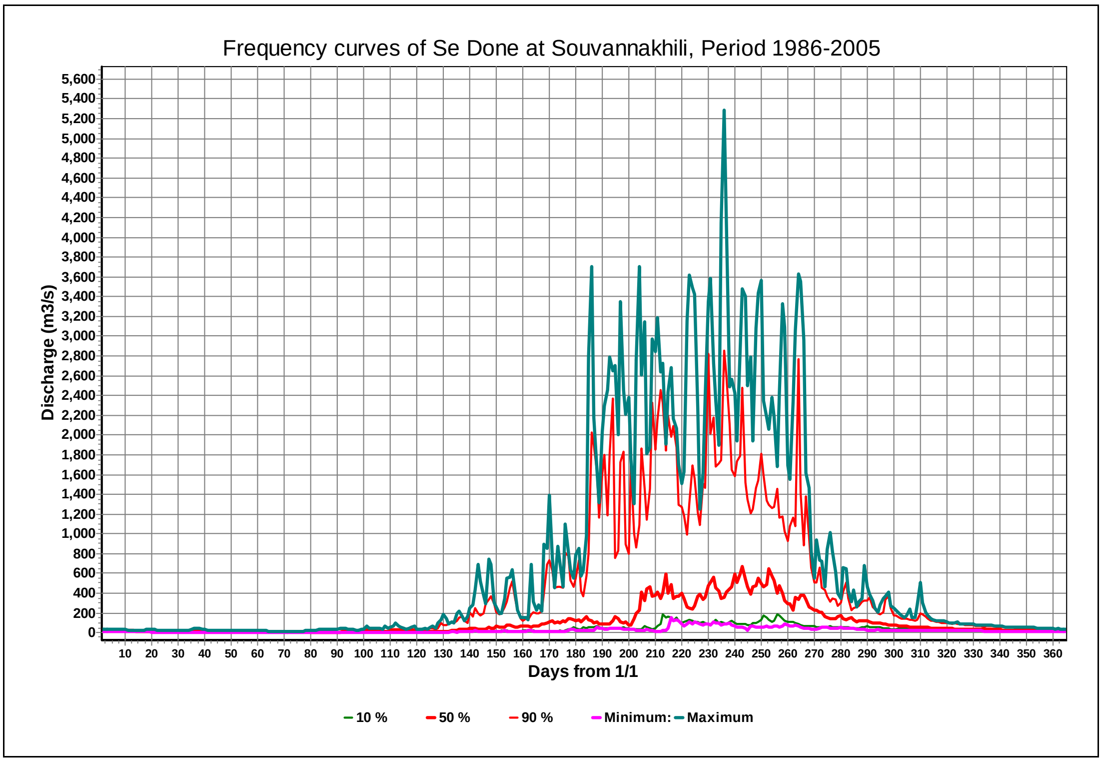

Figure 9.14 Frequency curves of Se Done at Souvanna Khili.

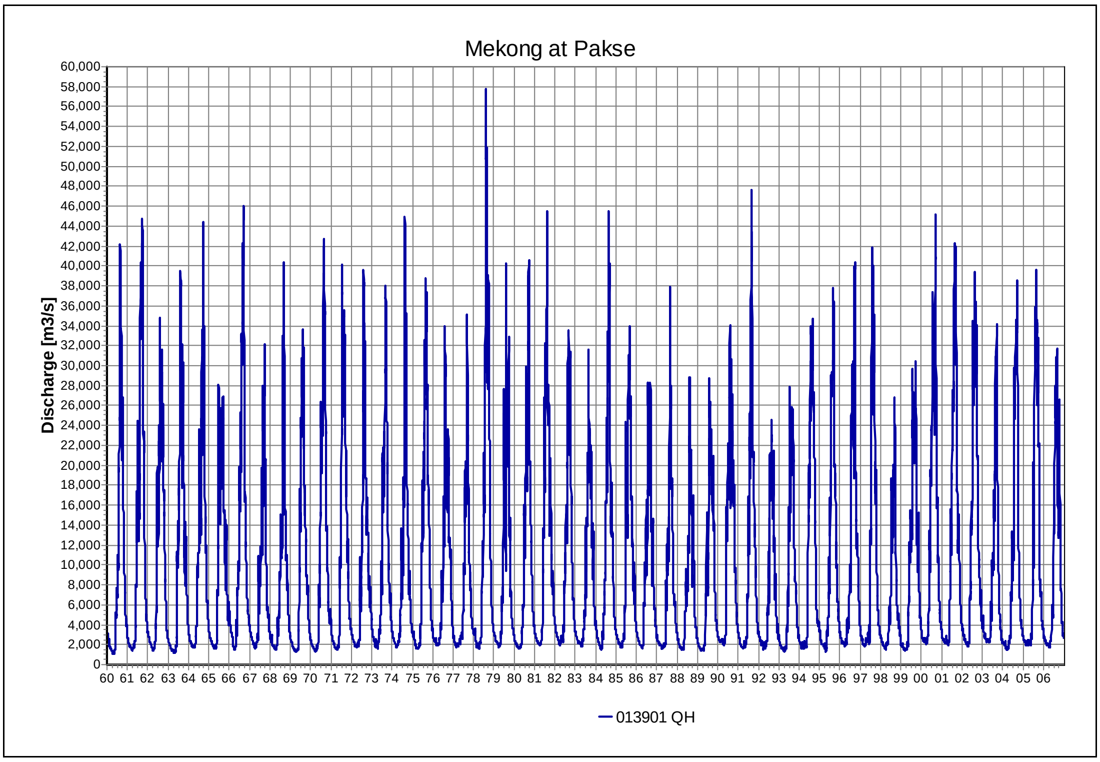

Figure 9.15 Discharge hydrograph of Mekong at Pakse.

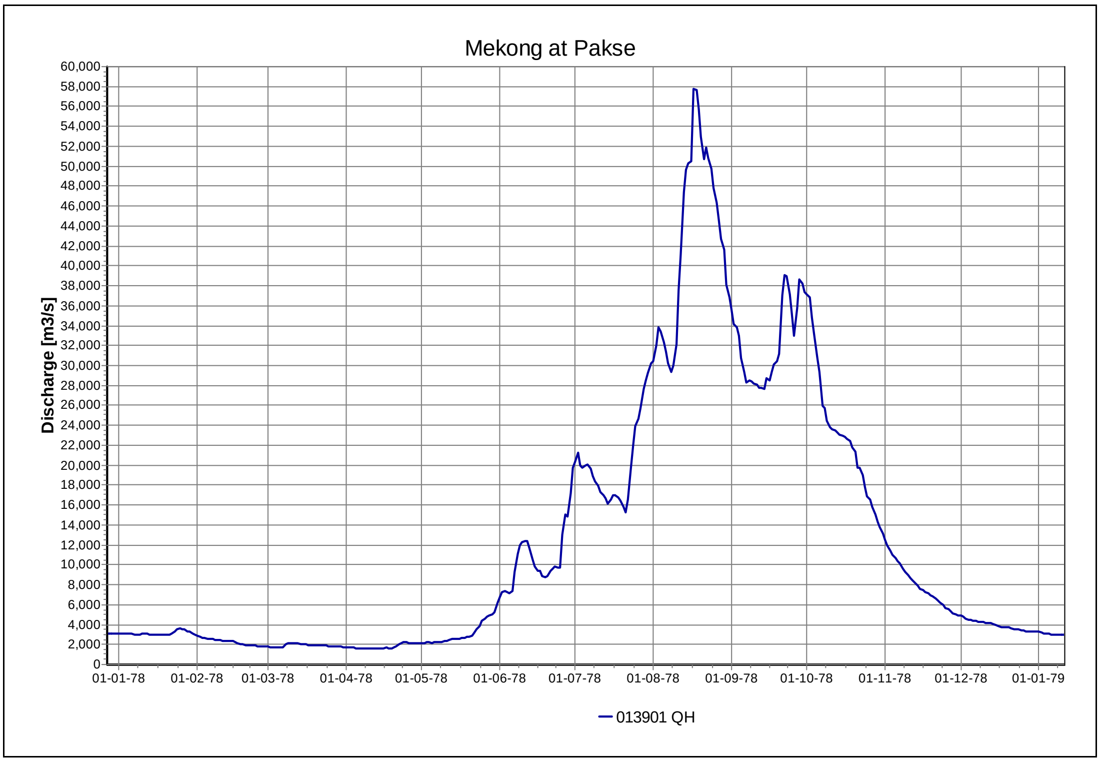

Figure 9.16 Discharge hydrograph of Mekong at Pakse, year 1978.

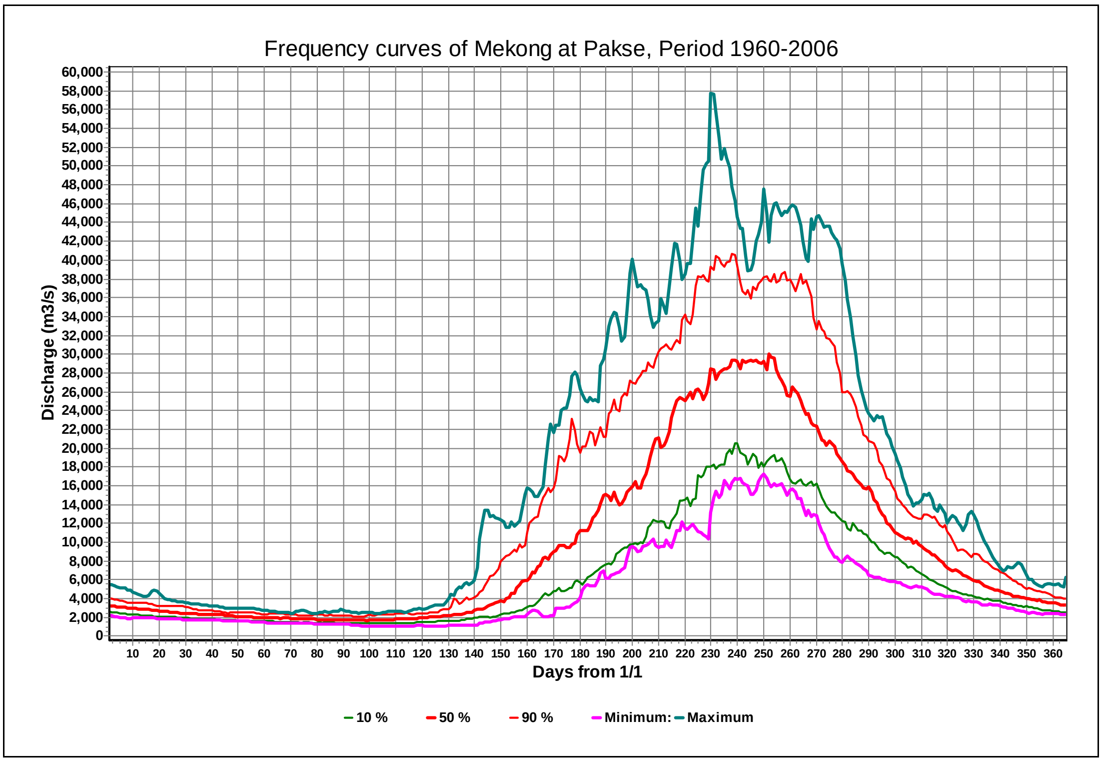

Figure 9.17 Frequency curves of Mekong at Pakse.

9.3 Developments in SA6 affecting the flow regime

The flow regime in SA6 is affected by developments of irrigation and hydropower.

Irrigation

About 2,000 irrigation schemes are in operation in SA6, making use of 60 dams, 13 reservoirs, some 2,000 pumps and 8 traditional weirs. The irrigation and domestic and industrial water demand is about 0.5 BCM annually (BDP, 2006). No figures are available on the storage capacity. A rapid increase of irrigation water requirement is expected as the irrigated area is planned to be doubled in about 10 years time.

Hydropower

An overview of the existing hydropower projects, the one under construction and those for which an MOU is available are presented in Table 9.7. It is observed that at present the storage capacity is small, hence the effect on the regime will be neglegible.

Table 9.7 Overview of major reservoirs in SA6 (source: MiMe, 2007).

Project	Basin	Basin area (km^2)	Capacity (MW)	Reservoir Storage (MCM)	Reservoir Area (km^2)
Existing					
Se Set 1	Se Set		45	2.3	0.6
Salabam	Se Done		5		
Under construction					
Se Set 2	Se Set		76	9.37	1.6
MOU					
Se Pon 3	Se Pon		75	406	29.5

With Se Pon 3 implemented the storage capacity still remains small compared to the basin runoff. Hence, it is expected that the effect on the regime will only be local, with limited possibilities for flood mitigation.

9.4 Floods

9.4.1 Tributary floods

A typical flood hydrograph of the Se Done at Souvanna Khili is presented in Figure 9.13. It shows a fairly rapidly rising and falling hydrograph, with a duration of 5 to 10 days. Since the station is in the downstream part of the basin in the upper part the flashiness will be more extreme. The annual maximum discharge in the Se Done is presented in Figure 9.18. It shows that the difference between the observed minimum and maximum value is about 5. The recent years were not particularly extreme, with the exception of 2005. The annual flood reports do not mention any severe flooding in the tributaries of SA6 in 2005 and 2006.

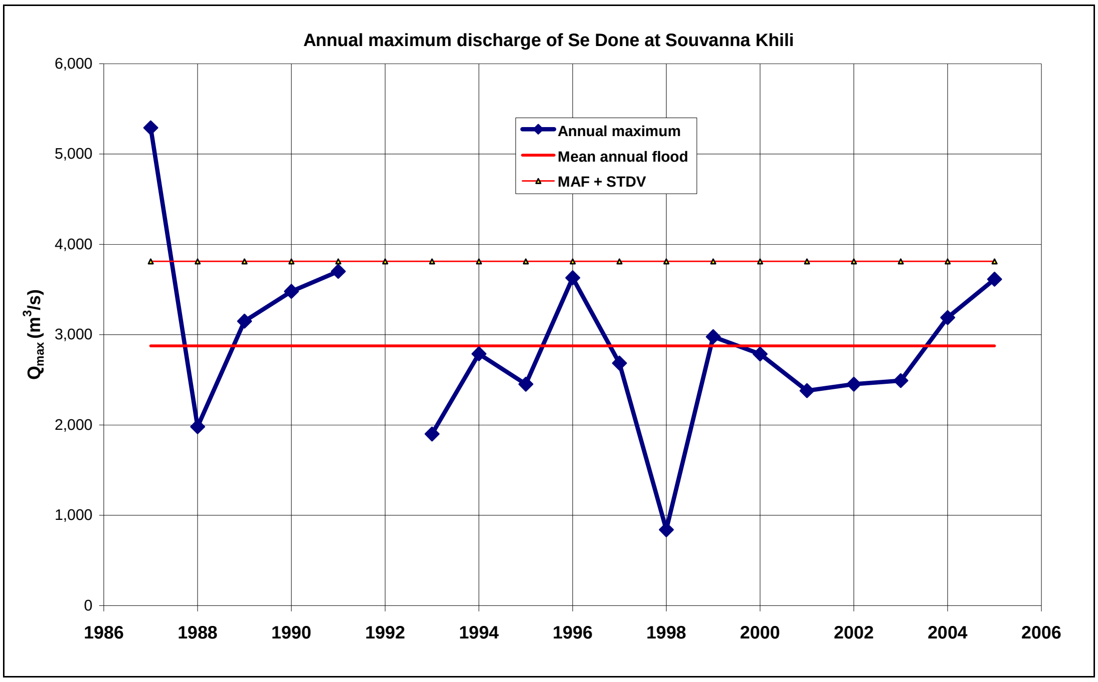

Figure 9.18 Annual maximum discharge in Se Done at Souvanna Khili.

Rainfall-runoff modelling based on available data in the HYMOS database will be cumbersome as the network density of rainfall stations is insufficient. It is expected though that from (pre)feasibility studies on hydrodams more information can be generated. The records of Souvanna Khili are sufficient for statistical analysis of extremes, provided that the discharge ratings have been acceptable, which is to be verified.

For flood modelling no data is available on the tributaries, hence hydrological hazards cannot be translated into flood hazards without field surveys.

9.4.2 Main stream floods

Main stream floods at Pakse do occur frequently. The record of annual maximum discharges in the Mekong in SA6 is presented in Figure 9.19. The largest flood occurred in 1978. Major flood prone areas are centered near Pakse just downstream of the confluence of the Se Done with the Mekong (BDP, 2006). The flood discharge level at Pakse is 38,500 m^3/s, which is just slightly above the 2-year flood discharge. Since 2000 this level was 5 times exceeded. Exceedance durations of various discharge levels for the period 2000-2006 are presented in Table 9.8. It is observed that the year 2000 has been most extreme in recent years.

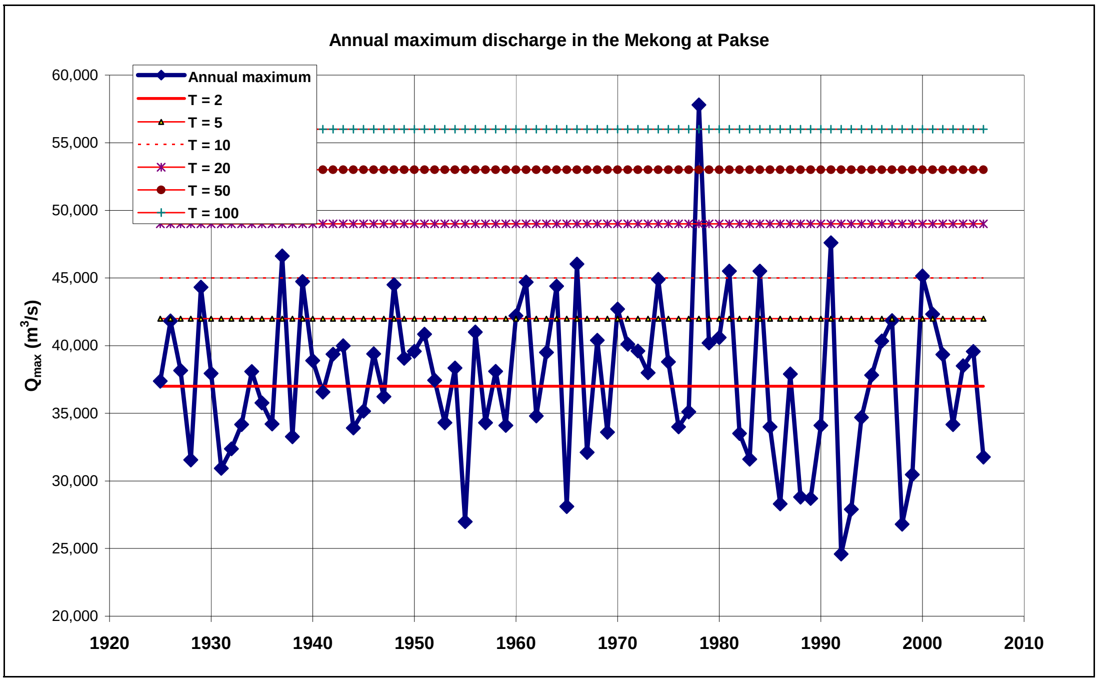

Figure 9.19 Annual maximum discharge in Mekong at Pakse.

Table 9.8 Exceedance duration (days) of flood levels with distinct return periods for Mekong at Pakse.

T (Years)	2	5	10	20	50	100
Q (m^3/s)	37,000	42,000	45,000	49,000	53,000	56,000
2000	17	6	2	0	0	0
2001	19	2	0	0	0	0
2002	6	0	0	0	0	0
2003	0	0	0	0	0	0
2004	4	0	0	0	0	0
2005	9	0	0	0	0	0
2006	0	0	0	0	0	0

9.4.3 Combined floods

Since the environs of the main stream are flat as can be observed from Figure 9.2 and Figure 9.3 flood water from the tributaries are backed up by the Mekong, particularly of the Se Done. The occurrence of flood on the Se Done coincide with those on the Mekong, as is observed from the frequency curves presented in Figure 9.20.

To reduce the flood risk in 2003 with an ADB loan 2,500 m of dikes and water gates were constructed focussing particularly on tributaries of the Se Done river. Flood water in these areas can now be discharged at 3 pumping stations.

Boundary conditions for combined flood analyses is available for the Se Done. However, no data is available on the dimensions of the Se Done. Hence, a bathymetric survey will be required to allow modelling of the lower reaches of the Se Done.

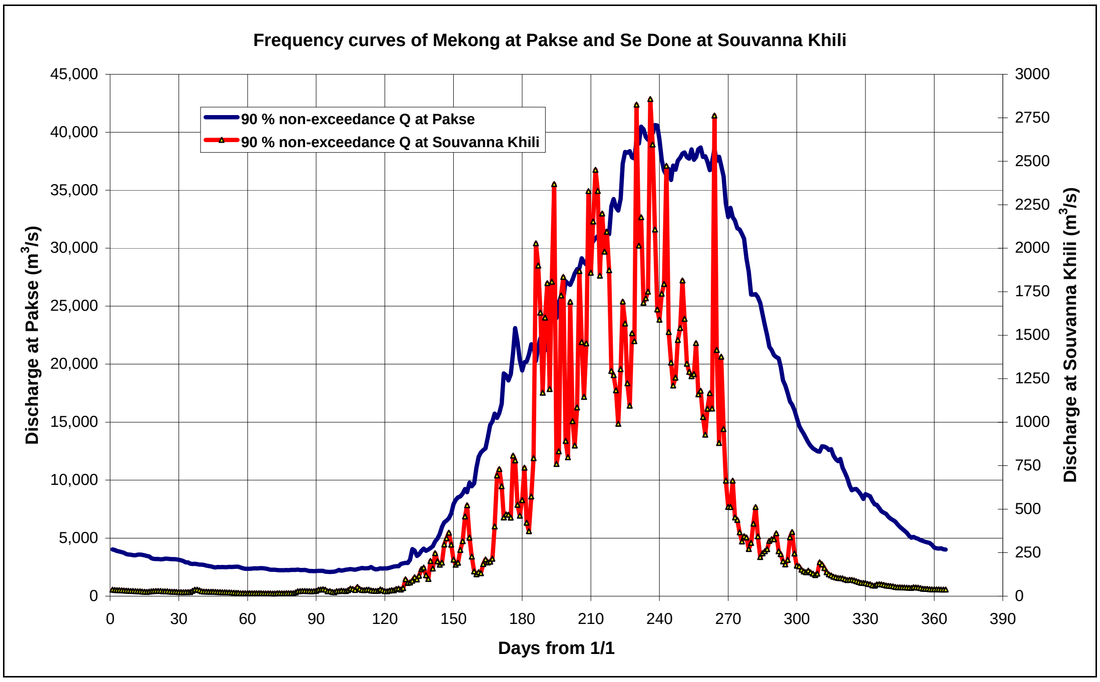

Figure 9.20 Frequency curves (90 %) of the Mekong at Pakse and the Se Done at Souvanna Khili.

9.4.4 Summing up

Major flood prone areas are centered 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 can be determined based on the available data. Flood hazard analysis will require a major effort on bathymetric surveys or flood maps from satellite imagery can be made available.

10 HYDROLOGICAL AND FLOOD HAZARD IN SUB-AREA 7

10.1 Basin characteristics

The basins of Sub-area 7 (SA7) draining to the Mekong at Stung Treng, see Figure 10.1, include the Se San, with the major tributaries Se Kong in the north and the Sre Pok south of it. The Sre Pok joins the Se San 40 km upstream of its confluence with the Mekong, whereas the Se Kong confluences 10 km upstream of the Se San mouth. The total basin area amounts 78,800 km^2, of which 22,850 km^2 is located in Laos, 29,950 km^2 in Vietnam and 26,000 km^2 in Cambodia. The basin population in 2003 was 2.86 million peaople of which 2.3 million lived in Vietnam, 370,000 in Laos and 190.000 in Cambodia.

The Se Kong covers an area of 32,200 km^2. It rises in the Annamite mountain range at the border between Laos and Vietnam, and drains also the eastern part of the Bolovens Plateau east of Pakse. The river travels for 344 km in Laos and some 125 km in Cambodia, before joining the Se San near Stung Treng. It includes the following main tributaries joining in Laos:

- Se Nam Noi
- Se Kaman and Se Xou, which drain near Attapeu
- Nam Kong
- Se Pian, and
- Houei Khampho.

The Sre Pok basin measures 29,800 km^2 . The river rises in Central Vietnam. The headwater are formed by the following rivers in Vietnam:

- Ea Krong
- Ea Soup
- Ea Hleo
- Ea Lop, and
- Ea Drang.

The Sre Pok joins the Se San 30 km upstream of the junction of the Se Kong with Se San

The Se San basin exclusive of Se Kong and the Sre Pok measures 17,300 km^2. It rises in the Truong Son Range of Central Vietnam and flows for over 200 km before entering Cambodia below the Yali falls. Major tributaries are:

- Dak Bla,
- Krong Poko
- Dak Hodrai, all entering in Vietnam
- Prek Liang, which joins downstream of the Vietnamese border.

The Se San joins the Mekong at Stung Treng at rkm 668.

The topography and slope map of the Se Kong-Se San-Sre Pok basin are presented in Figure 10.2 and Figure 10.3. It is observed that the north-eastern mountains, part of the Bolovens Plateau and the southern mountain in Dak Lak rise to over 1,100 m, whereas the downstream part in the west levels are below 150 masl. At Stung Treng the zero of the gauge is at 36.79 masl.

The land use map of SA7 is presented in Figure 10.4. Soime 65 % of the basin is covered with Forestlands, 16% by woodlands and less than 10 % is used for agriculture.

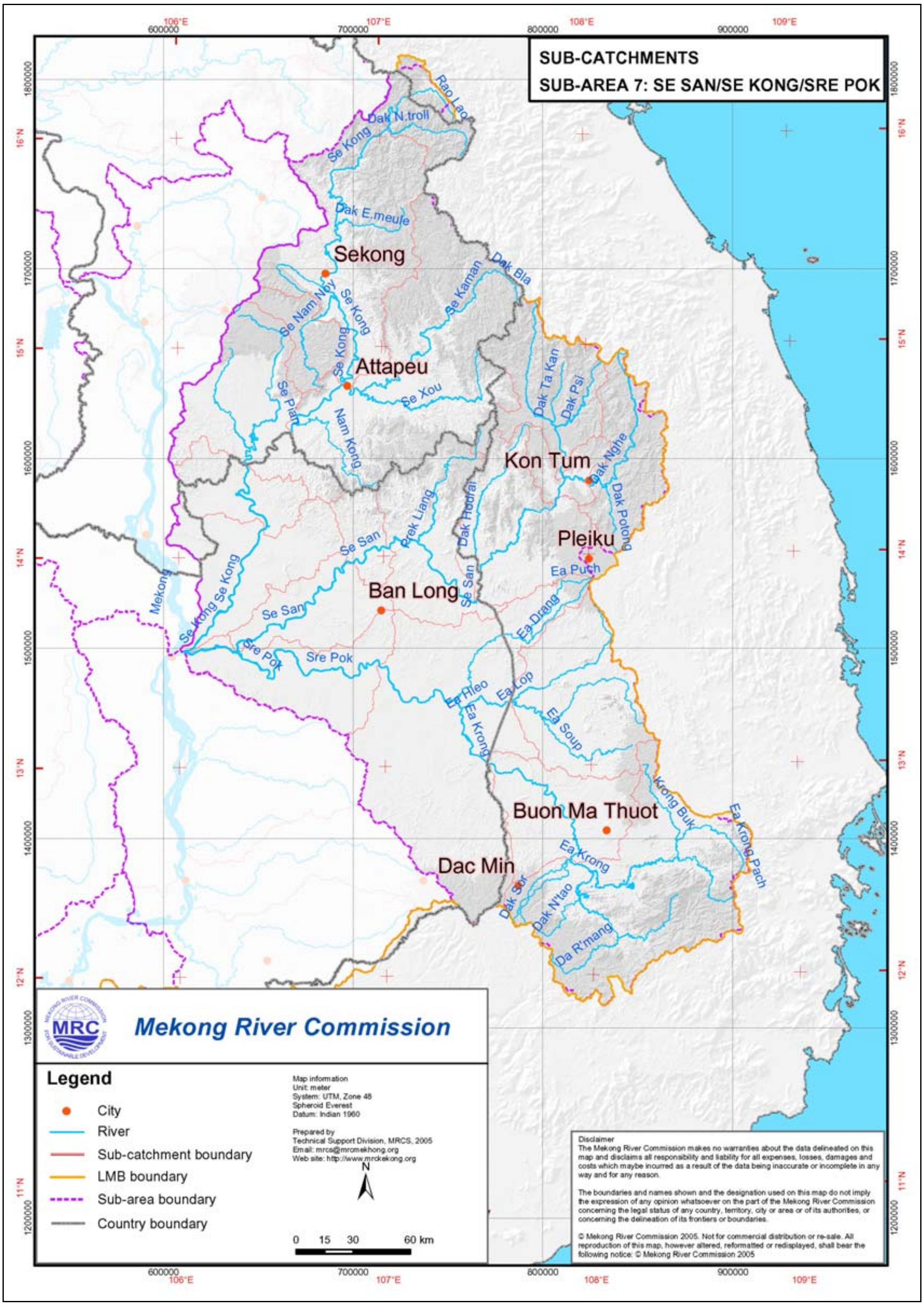

Figure 10.1 Layout of sub-basins in SA7 (BDP, 2006).

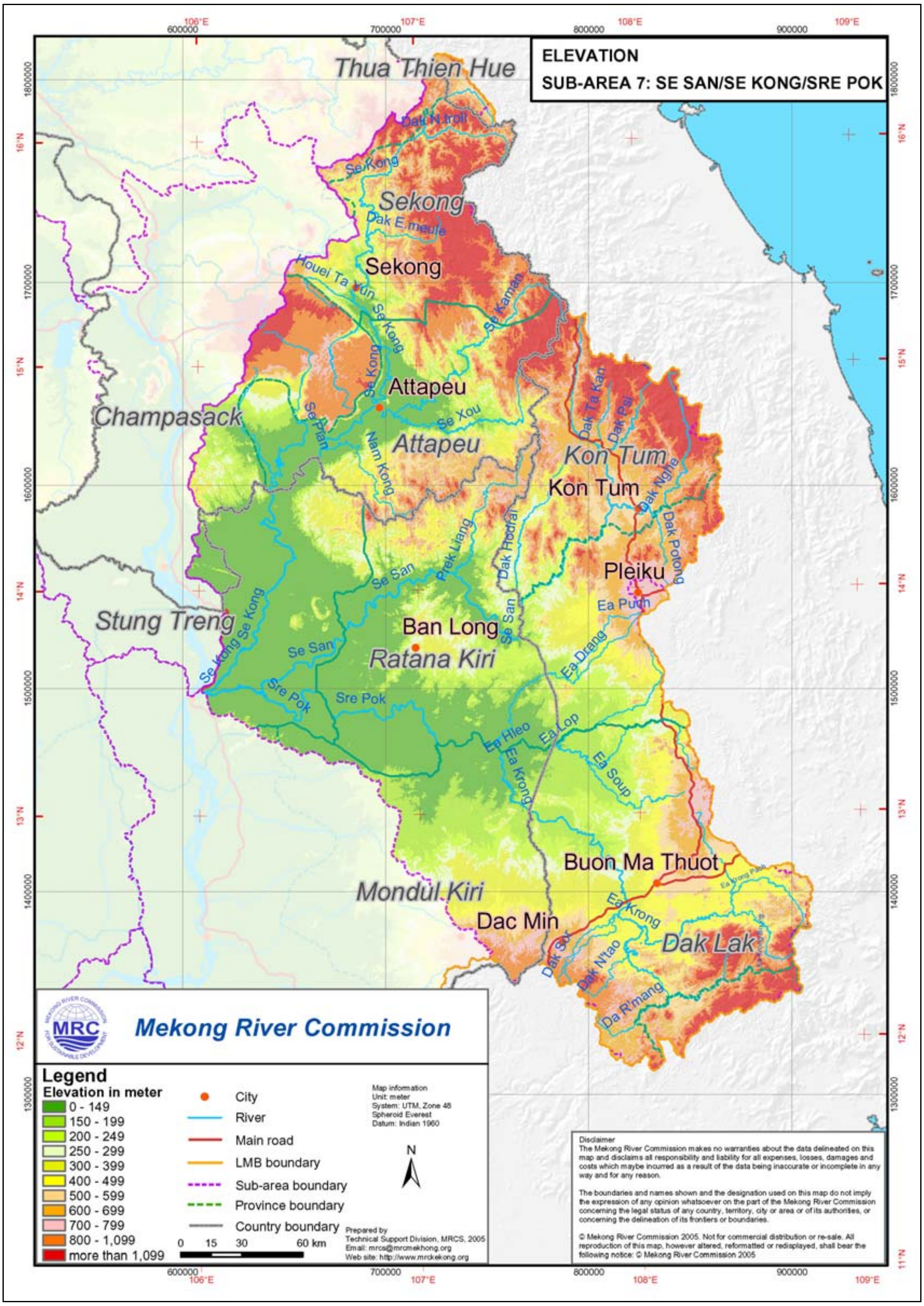

Figure 10.2 Elevation map of SA7 (BDP, 2006).

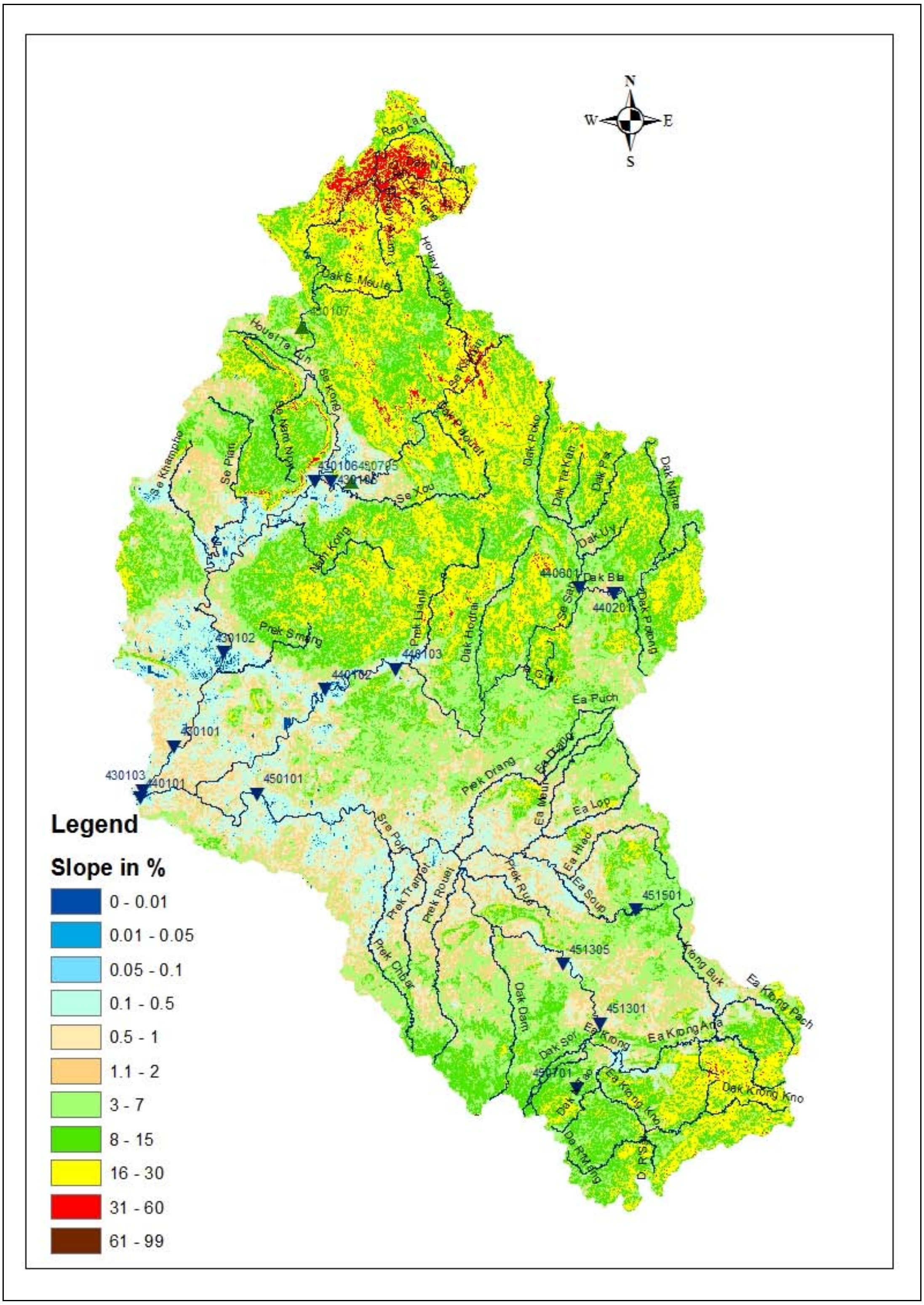

Figure 10.3	Slope map of SA7.

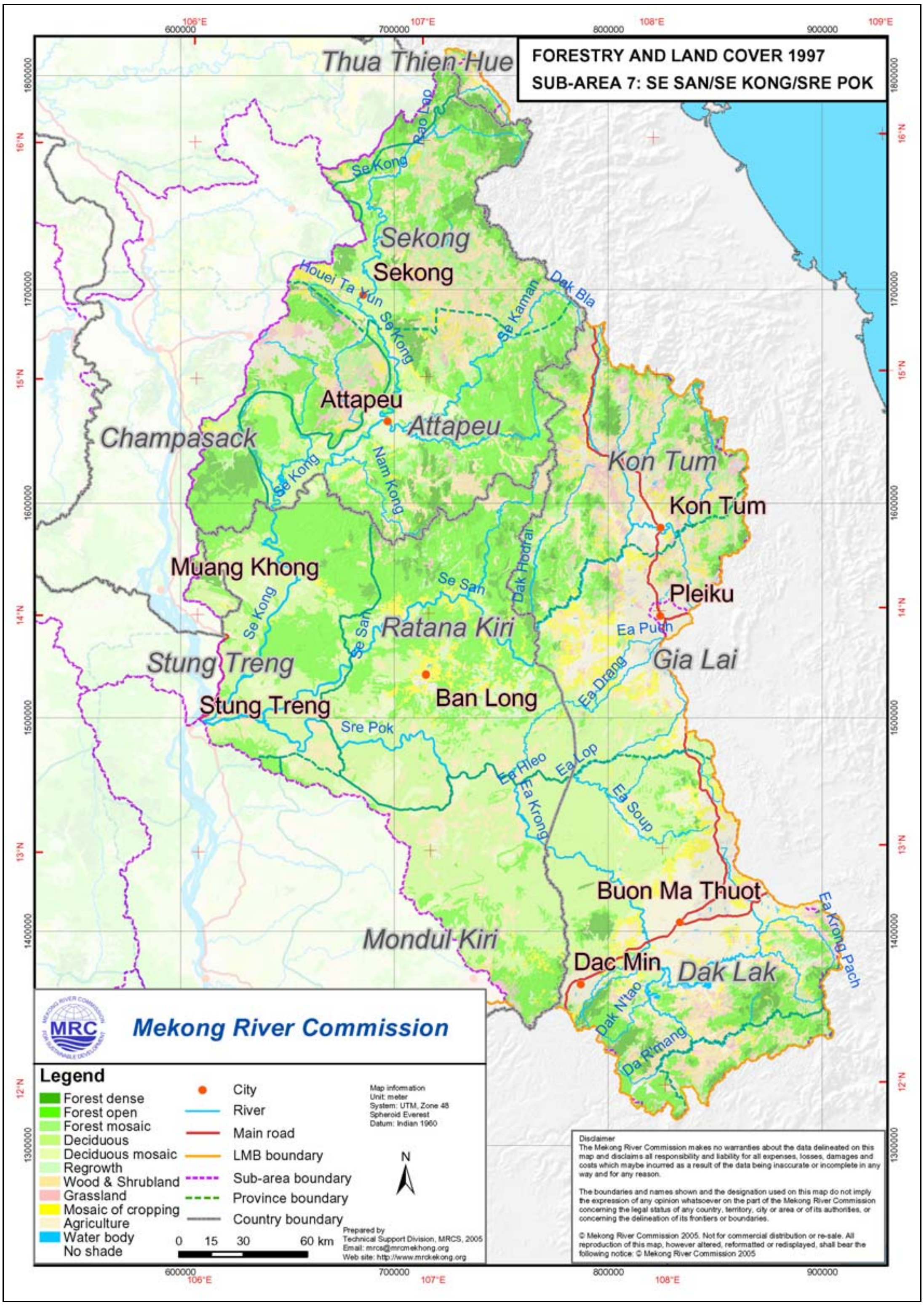

Figure 10.4 Land use in SA7 (BDP, 2006).

10.2 Hydrological characteristics

10.2.1 Data availability

The list of rainfall, water level and discharge stations is presented in respectively Table 10.1, Table 10.2 and Table 10.3. Their locations are shown in Figure 10.6.

With respect to rainfall, the tables and figure show that the MRC HYMOS-database of the basin includes only 20 stations, of which 4 in Laos, 6 in Vietnam and 10 in Cambodia. It implies that there is only one station per 4,000 km^2, which is insufficient for any hydrological modelling. A number of the series also have a very short record, particularly those of Cambodia with only some data in the sixties and since 2001, see Table 10.4, Table 10.5 and Table 10.6.

With respect to the water level and discharge data the situation is even worse. There is in Laos only one discharge station (Attapeu) with a record of 15-17 years, just enough for extreme value analysis. A similar situation exists in Cambodia where only the record of Ban Khampoun of 16 years would be long enough for some extreme value analysis. However, the validity of the applied stage-discharge relation, particularly the single relation for the recent years is very doubtful, see Figure 10.5: the station is under backwater of the Mekong, hence a single stage-dischre relation cannot be expected. A review of the discharge data for this station is required and the twin gauge approach is to be used to arrive at valid discharges. The conditions for Vietnam are better with 4 stations with discharge records of 15 to 22 years.

According to Halcrow (2001), who carried out a number of feasibilitystudies on hydropower schemes in the area, the river channels in the lower reaches of the Se Kong Se San and Sre Pok are very flat (see also Figure 10.3), wide, strongly meadering and have large out of bank storage. These conditions create large difficulties in gauging these streams properly.

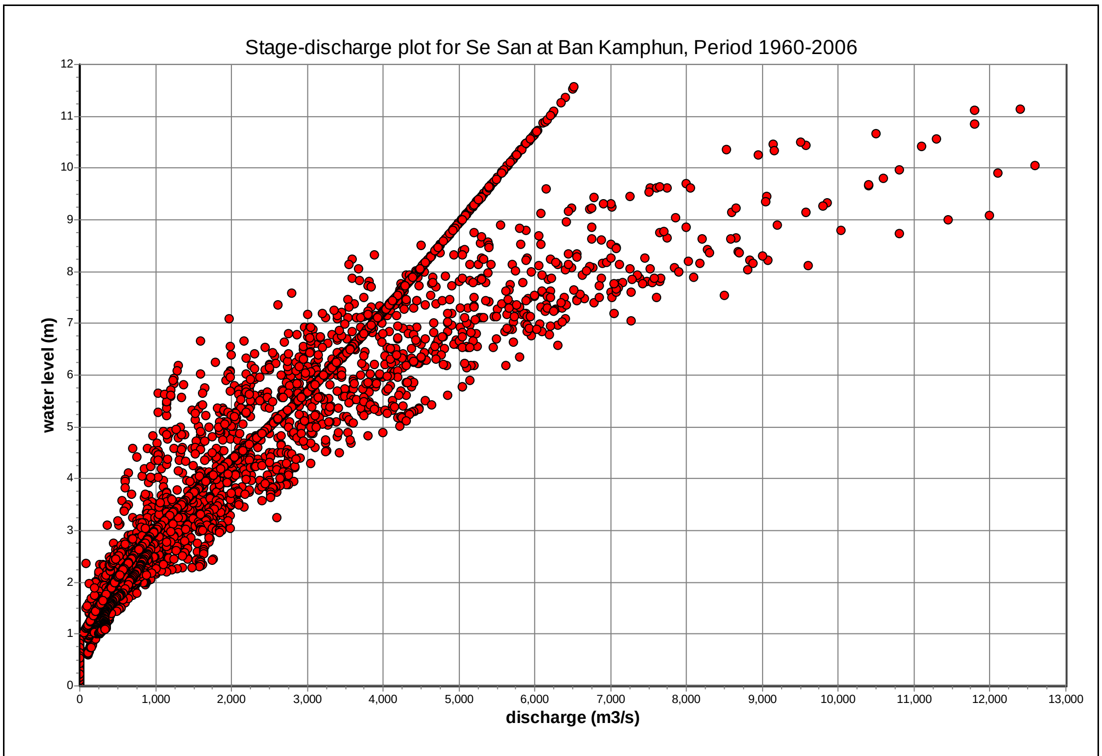

Figure 10.5 Stage-discharge relation applied in the discharge record of Se San at Ban Kamphun.

Reference is also made to hydrological and hydraulic model studies carried out by DHI (2005) for additional data.

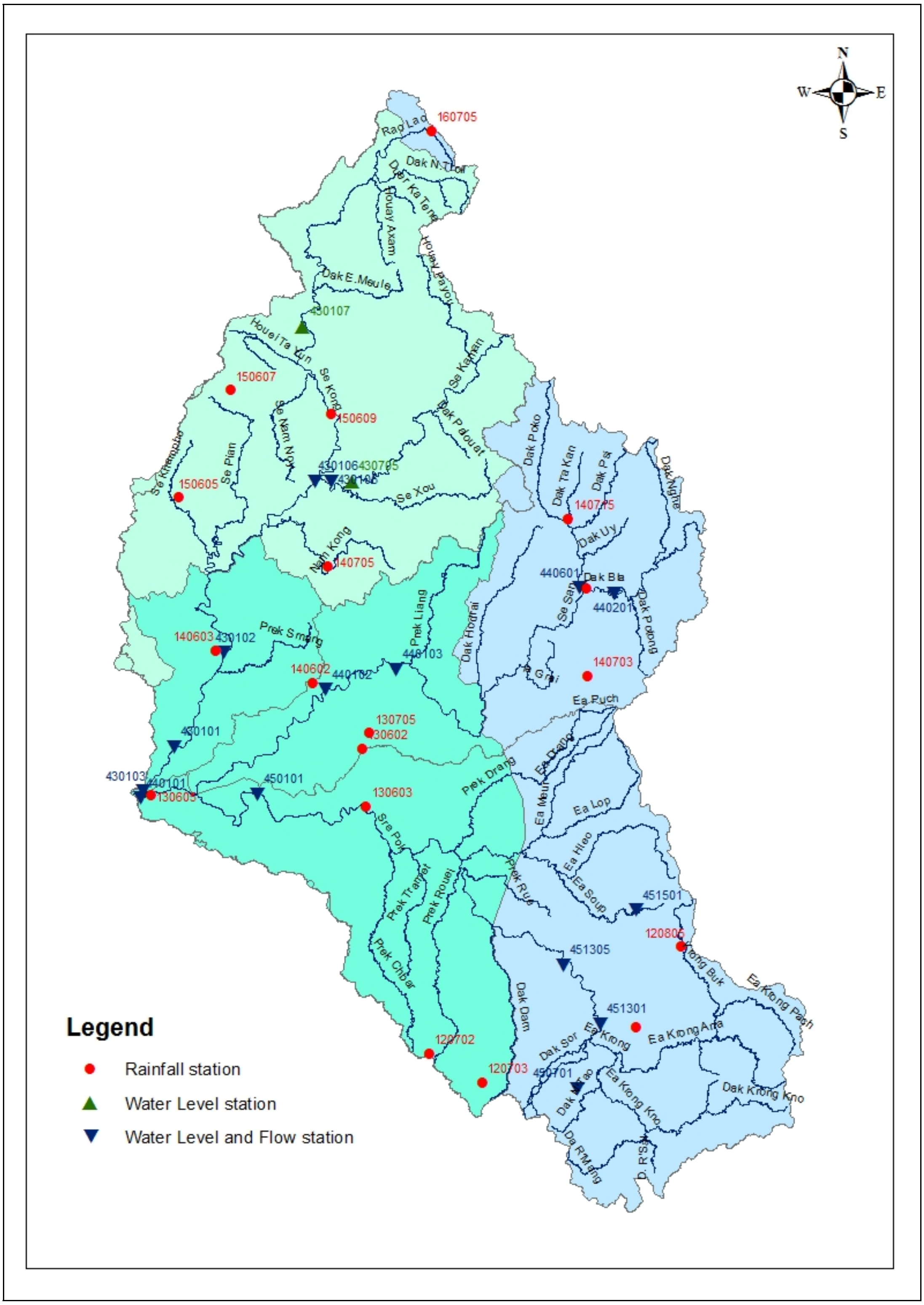

Figure 10.6 Layout of hydro-meteorological monitoring network.

Table 10.1 Overview of rainfall stations in SA7.

Station Location

Rainfall **7C**

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
120702	Sen Monorom	Sre Pok	12.5000	107.2334
120703	O Raing	Sre Pok	12.3834	107.4500
130602	Ban Lung	Se San	13.7334	106.9667
130603	Lumphat	Sre Pok	13.5000	106.9834
130605	Sesan	Se San	13.5520	106.0960
130705	O Chum	Se San	13.7950	107.0000
140602	Voeun Sai	Se San	14.0000	106.7667
140603	Seam Pang	Sekong	14.1334	106.3667
440101	Ban Kamphun	Sesan	13.5341	106.0464
440103	Andaung Meas	Sesan	14.0472	107.1070
	7L			
140705	Attopeu	Sekong	14.4667	106.8333
150605	Nonghine	Sekong	14.7500	106.2167
150607	Nikhom 34	Sekong	15.1833	106.4333
150609	Sekong	Sekong	15.0833	106.8500
	7V			
120801	Buon Me Thuot	Sre Pok	12.6000	108.0830
120805	Buon Ho	Sre Pok	12.9200	108.2700
140703	Pleiku	Se San	14.0170	107.9000
140704	Kontum2 (Lasar	Se San	14.3670	107.9000
140715	Dak To	Se San	14.6500	107.8300
160705	ALuoi	Sekong	16.2200	107.2800

Table 10.2 Overview of water level stations in SA7.

Water Level **7C**

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
430101	Ban Khmoun	Sekong	13.7410	106.1865
430102	Siempang	Sekong	14.1192	106.3935
430103	Chantangoy	Sekong	13.5641	106.0565
440101	Ban Kamphun	Sesan	13.5341	106.0464
440102	Voeun Sai	Sesan	13.9676	106.8141
440103	Andaung Meas	Sesan	14.0472	107.1070
450101	Lumphat	Sre Pork	13.5481	106.5285
	7L			
430105	M.May (Attope	Se Kong	14.8067	106.8433
430106	Veun Khene	Sekong	14.8098	106.7778
430107	Khoueng Sekon	Se Kong	15.4334	106.7334
430705	Ban Fang Deng	Se Kaman	14.8080	106.9330
	7V			
440201	Kontum	Dak Kla	14.3434	108.0083
440601	Trung Nghai	Krong Po Co	14.3667	107.8667
450701	Duc Xuyen	Krong Kno	12.3500	107.8334
451301	Cau 14 (Buon B	Ea Krong	12.6100	107.9334
451305	Ban Don	Vam Serepok	12.8500	107.7834
451501	Iahleo	Kinh Iahleo	13.0667	108.0834

Table 10.3 Overview of discharge stations in SA7.

Flow 7C

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
430101	Ban Khmoun	Sekong	13.7410	106.1865
430102	Siempang	Sekong	14.1192	106.3935
430103	Chantangoy	Sekong	13.5641	106.0565
440101	Ban Kamphun	Sesan	13.5341	106.0464
440102	Voeun Sai	Sesan	13.9676	106.8141
440103	Andaung Meas	Sesan	14.0472	107.1070
450101	Lumphat	Sre Pork	13.5481	106.5285
	7L			
430105	M.May (Attope	Se Kong	14.8067	106.8433
430106	Veun Khene	Sekong	14.8098	106.7778
	7V			
440201	Kontum	Dak Kla	14.3434	108.0083
440601	Trung Nghai	Krong Po Co	14.3667	107.8667
450701	Duc Xuyen	Krong Kno	12.3500	107.8334
451301	Cau 14 (Buon B	Ea Krong	12.6100	107.9334
451305	Ban Don	Vam Serepok	12.8500	107.7834
451501	Iahleo	Kinh Iahleo	13.0667	108.0834

Table 10.4 Availability of daily rainfall, water level and discharge data in Laos in SA7.

Daily Data Availability of BDP Sub-Area 7L (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
140705	Attopeu	Sekong																													+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150605	Nonghine	Sekong																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
150607	Nikhom 34	Sekong																																+	+	+	+		+	+	+	+	214	+	+	+	+	+	+
150609	Sekong	Sekong																																	+	+		+	+	+	+	+	+	+	+	+	+	+	+

Water Level

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
430105	M.May (Attopeu)	Se Kong																										85		244	142	+	+	+	182	+	+	+	+	303	+	+	+	+	+	+	+	+	+
430106	Veun Khene	Sekong																																										+	+	+	+	+	+
430107	Khoueng Sekong	Se Kong																																			151	+	+	+	+	+	+	+	+	+	+	+	+
430705	Ban Fang Deng (Att	Se Kaman																																	62									+	+	+	+	+	+

Flow

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
430105	M.May (Attopeu)	Se Kong																														+	+	+	182	+	+	+	+	303	+	+	+	+	+	+	+	+	
430106	Veun Khene	Sekong																																										+	+	+	+	+	

Notes:
+ = no missing
blank = missing
90 = number of missing days in a year

Table 10.5 Availability of daily rainfall, water level and discharge data in Cambodia in SA7.

Daily Data Availability of BDP Sub-Area 7C (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
120702	Sen Monorom	Sre Pok							+																																								
120703	O Raing	Sre Pok	62	+	+	+	+	+		+																																							
130602	Ban Lung	Se San																																									61	+	+		+	+	+
130603	Lumphat	Sre Pok		+	+	+	+	+		+																																	61	+	+		+	+	
130605	Sesan	Se San																																										+	+		+	+	+
130705	O Chum	Se San																																									92	+	+		+	+	
140602	Voeun Sai	Se San		+	+	+	+	+	+	+	+																																92	+	+			+	
140603	Seam Pang	Sekong																																							+	+	61	+	31		+	+	+
440101	Ban Kompoun	Se San																																							+	31	60						
440103	Andoung Meas	Se San																																									61	+	+		+	+	

Water Level

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
430101	Ban Khmoun	Sekong		12	+	1	+	+	+	+	+	+	306																																334				
430102	Siempang	Sekong						+	92	72	153																																	70	3	+	3	+	+
430103	Chantangoy	Sekong	67																																217	218	+	+	+	+	+	+	+	+	+	+	+		+
440101	Ban Kamphun	Sesan	69	+	+	+	+	+	+	+	+	+	278																							265	+	+	+	+	+	+	+	+	+	61	62	3	+
440102	Voeun Sai	Sesan						+	275	150	182	31																															274	+	+	+	31	31	
440103	Andaung Meas	Sesan																																									112	+	+	+	153	+	
450101	Lumphat	Sre Pork						83	92	59	91	+	275																														127	+	+	+	153	120	

Flow

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
430101	Ban Khmoun	Sekong		+	+	+	+	+	+	+	+	+	306																																				
430102	Siempang	Sekong						+	92	73	275																																						
430103	Chantangoy	Sekong	67																																	218	+	+	+	+	5	+	+	+	+				
440101	Ban Kamphun	Sesan	69	+	+	+	58	9	+	+	+	+	278																							334	+	+	+	+	+	+	+	+	+				
440102	Voeun Sai	Sesan						+	275	150	182	31																															274	+	+				
440103	Andaung Meas	Sesan						187																																				59	+				
450101	Lumphat	Sre Pork						83	92	59	91	+	275																														129	+	+	+	157		

Notes:
+ = no missing
blank = missing
90 = number of missing days in a year

Table 10.6 Availability of daily rainfall, water level and discharge data in Vietnam in SA7.

Daily Data Availability of BDP Sub-Area 7V (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
120801	Buon Me Thuot	Sre Pok	31	+		182	+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
120805	Buon Ho	Sre Pok																																										+	+	+	+	+	+
140703	Pleiku	Se San		+			+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
140704	Kontum2 (Lasan	Se San		31	59	+	+	+	+	90	122			+	122	91	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
140715	Dak To	Se San																																										+	+	+	+	+	+
160705	ALuoi	Sekong																																										+	+	+	+	+	+

Water Level

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
440201	Kontum	Dak Kla							+	+	+	+				+											+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
440601	Trung Nghai	Krong Po Co																																	+	+		+	+	+	122								
450701	Duc Xuyen	Krong Kno																										+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
451301	Cau 14 (Buon Bur)	Ea Krong							+	+	30	+					184										+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
451305	Ban Don	Vam Serepok																																	+	+	+	+		+	+	+	+	+	+	+	+	+	+
451501	Iahleo	Kinh Iahleo																															92		+	+	+												

Flow

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
440201	Kontum	Dak Kla								90	+	+	+	61	336	197	153										91	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
440601	Trung Nghai	Krong Po Co																																	+	+		+	+	+	122								
450701	Duc Xuyen	Krong Kno																										+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
451301	Cau 14 (Buon Bur)	Ea Krong								90	30	+				38	184										91		+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
451305	Ban Don	Vam Serepok																																	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
451501	Iahleo	Kinh Iahleo																															+		+	+	+												

Notes: + = no missing
blank = missing
90 = number of missing days in a year

10.2.2 Rainfall

Average annual rainfall in SA7 varies from 1600 mm in the the western part to 2,000 mm in the upper Sre Pok and to 2,500 mm in the upper Se San and Se Kong reaches. An example of the annual variation is given for Pleiku (long term average 2150 mm), which ranges between 1200 mm and 3200 mm. The seasonal variation can be observed from Figure 10.8 to Figure 10.10. Similarity exists between the monthly rainfall patterns: some 90 % of the rainfall occurs between May and October, with August generally the wettest month, though in the Se Kong area July appears to be equally wet. It appears though from Figure 10.11 that in the northern Se Kong rainfall particularly in July is relatively higher than in the Se San/Sre Pok area. In the following section it will be shown that this has some consequences for the timing of runoff.

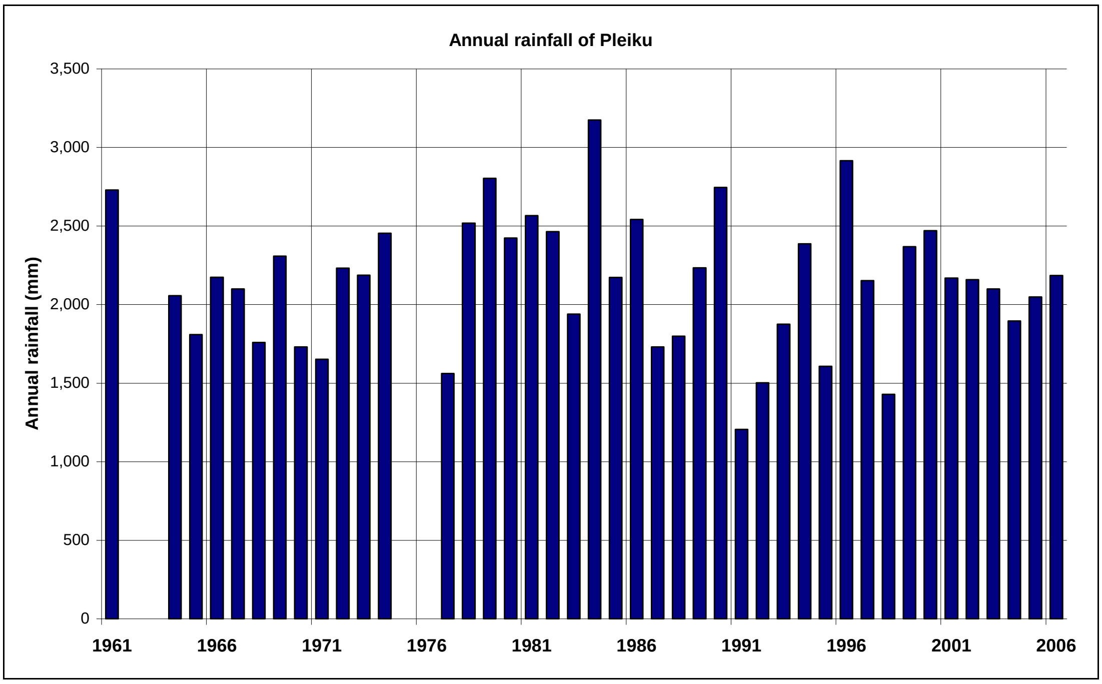

Figure 10.7 Annual rainfall of Pleiku (Vietnam).

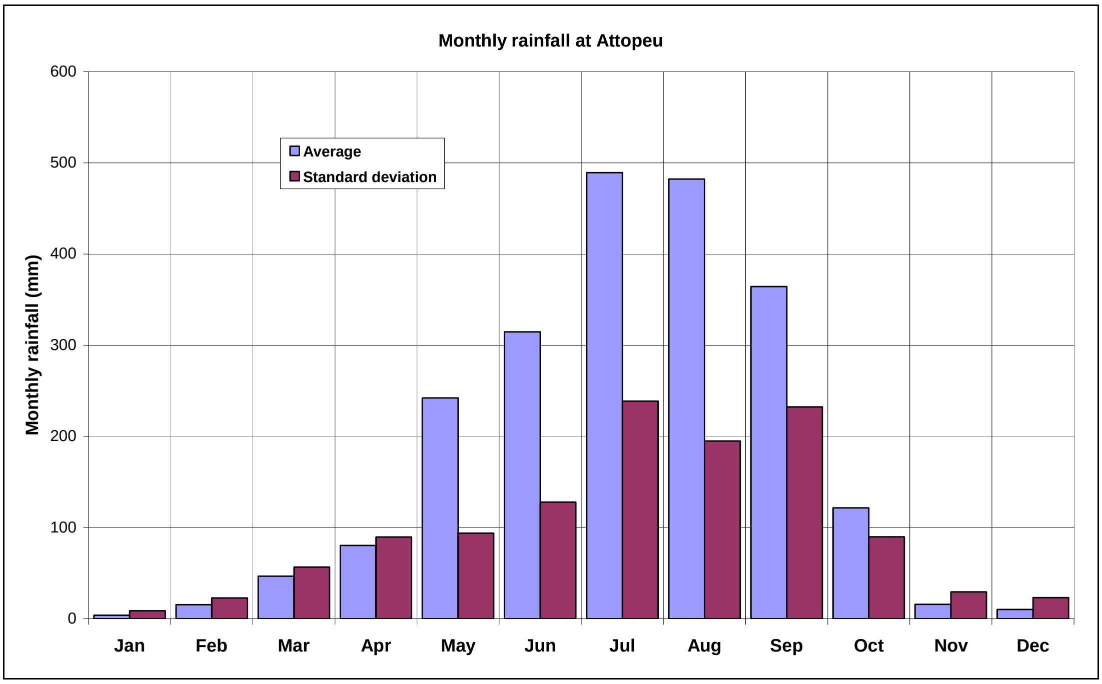

Figure 10.8 Monthly rainfall characteristics of Attopeu.

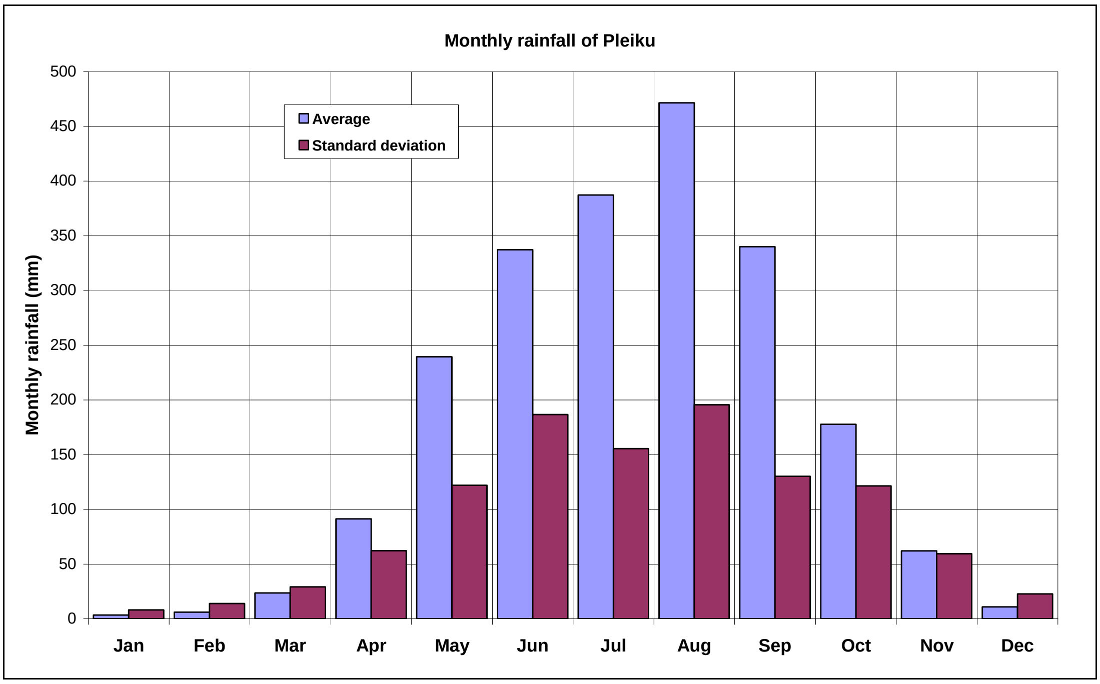

Figure 10.9 Monthly rainfall charcateristics of Pleiku.

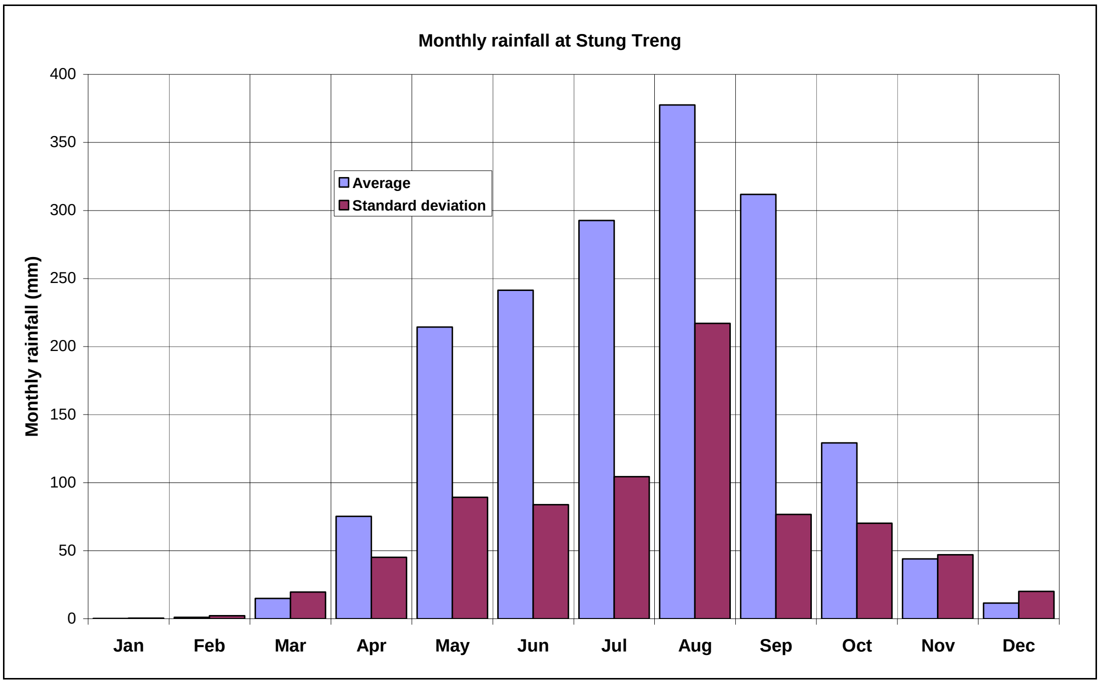

Figure 10.10 Monthly rainfall characteristics of Stung Treng.

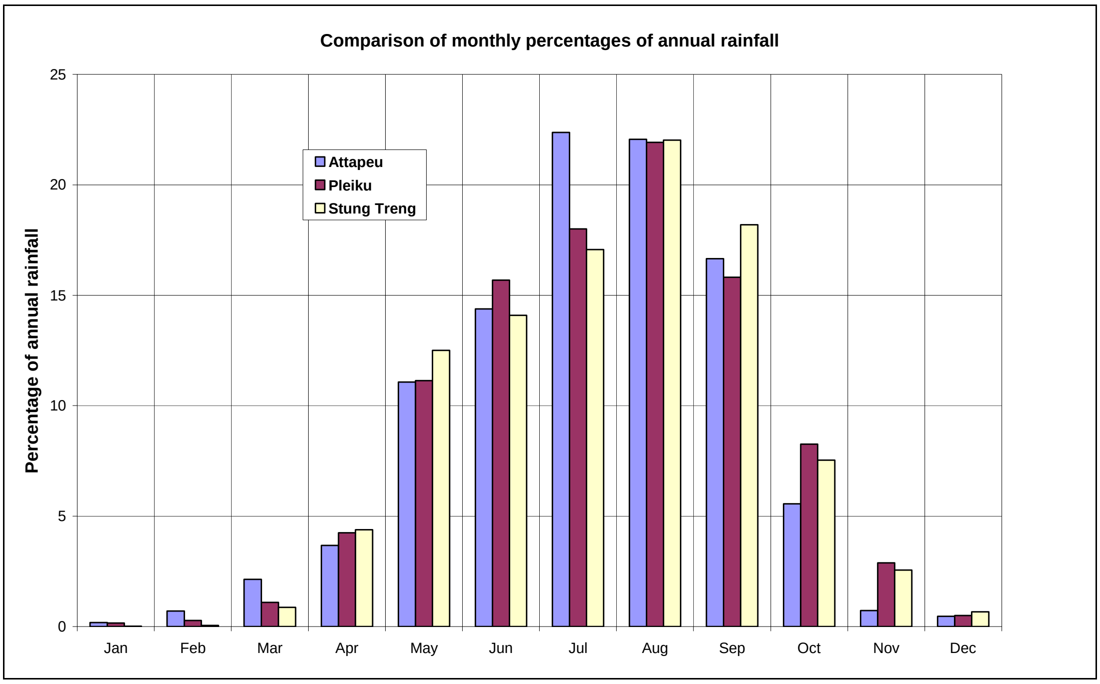

Figure 10.11 Monthly rainfall as percentage of annual total.

Though not particularly visible in the long term rainfall statististics, for 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 may be observed from Figure 10.12.

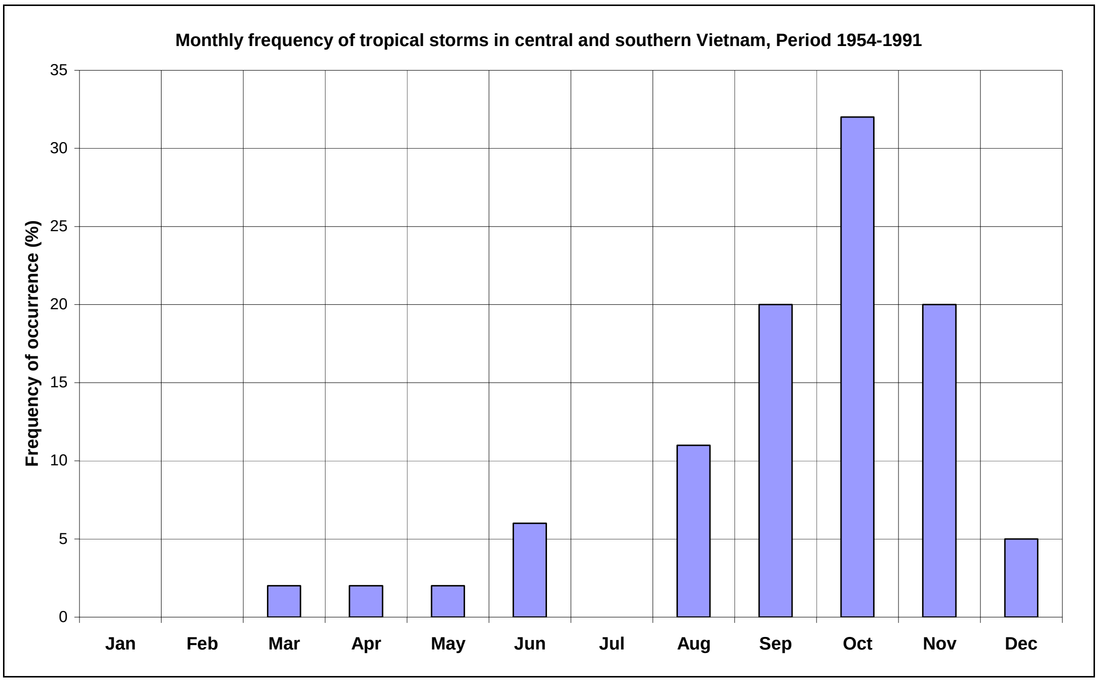

Figure 10.12 Monthly frequency of tropical storms and cyclones in central and southern Vietnam, Period 1954-1991 (ADPC, 2000).

10.2.3 Runoff

According to BDP (2006) the average run-off from SA7 amounts 90 BCM, of which nearly 28 BCM or 31 % is contributed by the basins located in Vietnam. Table 10.7 gives an overview of the annual contributions by the 3 systems. It shows that the runoff per unit area in the Se Kong is 1.5 times the runoff in the rest of the basin, in response to the higher rainfall in that area.

Table 10.7 Average annual runoff from Se Kong, Se San and Sre Pok basins (BDP, 2006).

Tributary	Area (km^2)	Volume (BCM)	Discharge (m3/s)	Runoff (mm)
Se Kong	32,200	43.14	1,368	1,514
Se San	17,300	17.25	547	1,009
Sre Pok	29,800	29.71	942	1,009

The average monthly flows for selected stations in the 3 basins are presented in Figure 10.13 to Figure 10.15, including Se Kong at Attapeu, Upper Se San at Kontum and Upper Sre Pok at Duc Xuyen. It observed that in the Se Kong the largest runoff is experienced in the months July and August. For the Se San and Sre Pok largest flows are occurring in September-October, i.e. two months later. This is remarkable as such large shifts in the monthly rainfall pattern is not available. From an analysis of the hydrographs it appears that the baseflow component for the Se San and Sre Pok tributaries is more important than in the Se Kong basin. This shift implies that the flood period on the Lower Se San will be quite long.

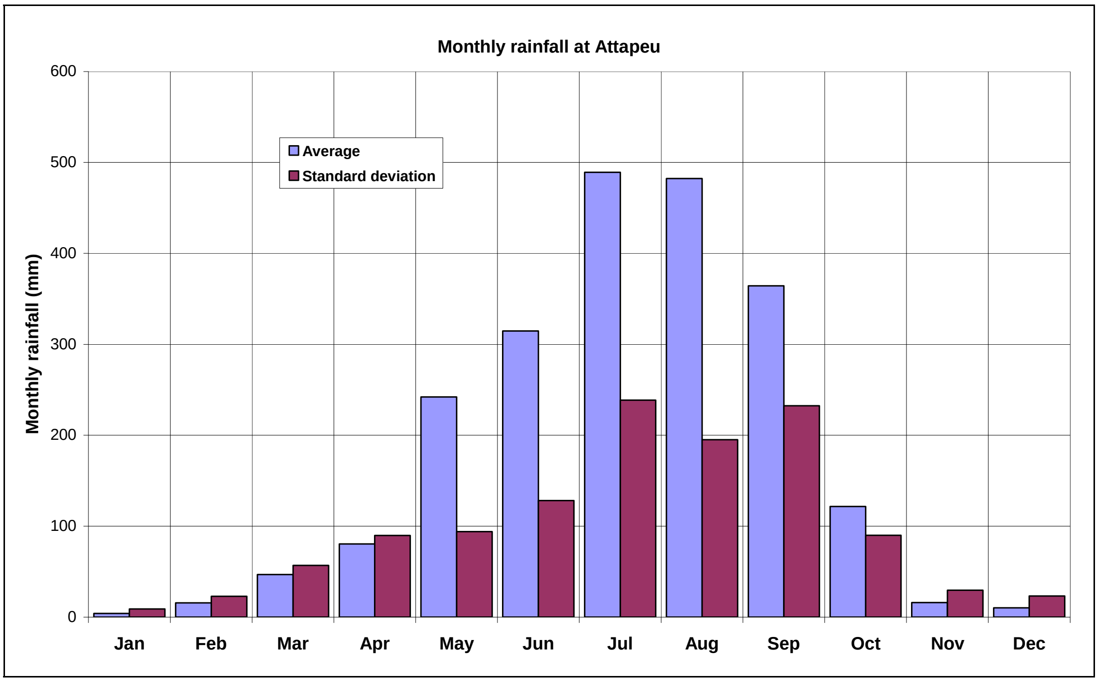

Figure 10.13 Monthly flow characteristics of Se Kong at Attapeu (Upper Se Kong).

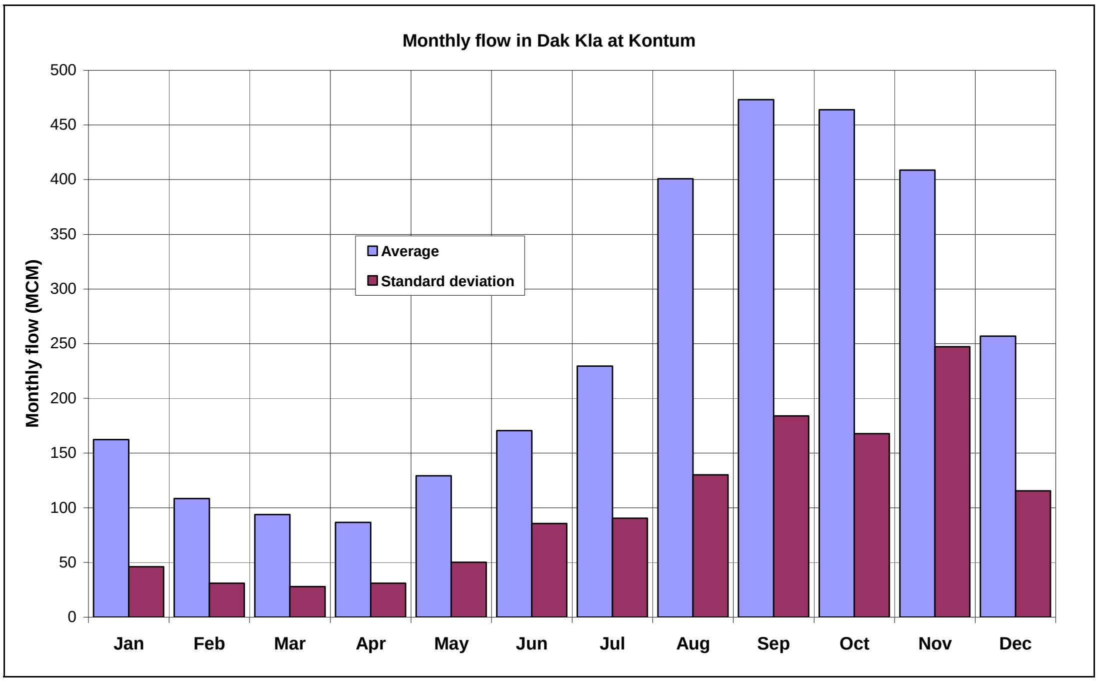

Figure 10.14 Monthly flow charcateristics of Dak Bla at Kontum (Upper Se San).

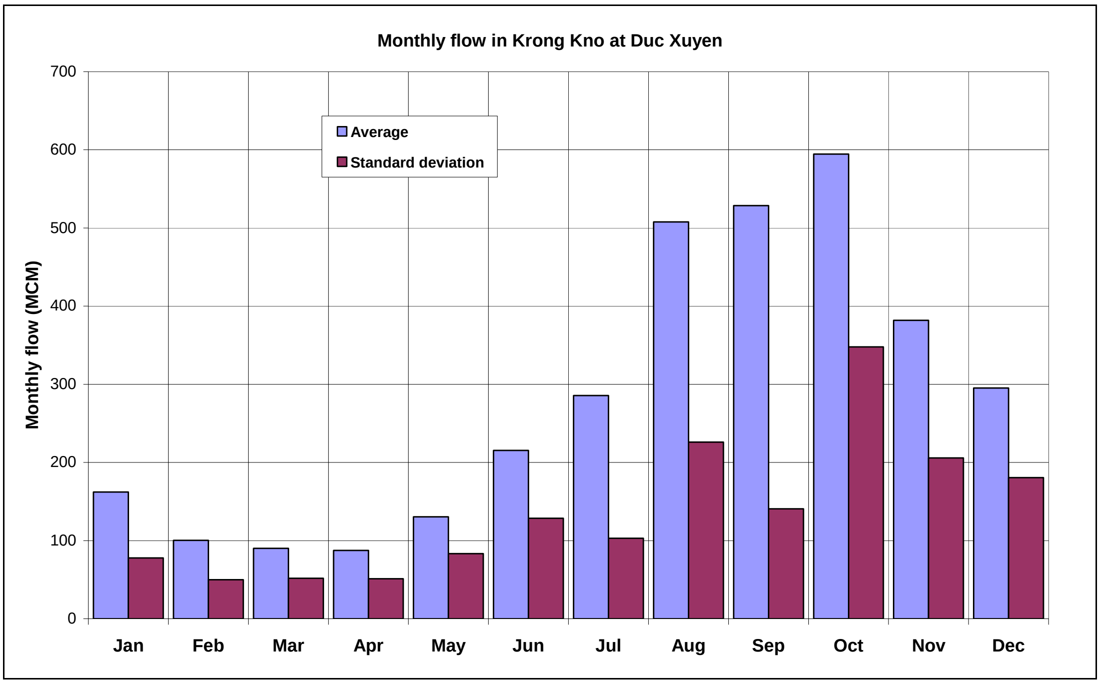

Figure 10.15 Monthly flow charcateristics of Krong Kno at Duc Xuyen (Upper Sre Pok).

The characteristics of the floods on the Se Kong, Se San and Sre Pok can be obtained from the discharge hydrographs and frequency curves of daily discharges of the selected stations discussed before, see Figure 10.16 to Figure 10.24. The following is observed:

- Floods on the Se Kong at Attapeu can rise quickly and may last 5 to 10 days. The mean annaul flood for Attapeu is estimated at 4,450 m^3/s, which value has been exceeded in the past in the period from mid-July to mid-September.
- Floods on Dak Bla can be very flashy. Peak values from one year to another may differ by a factor 5. The mean annual flood at Kontum is estimated at 900 m^3/s, which value has been exceeded in the period from September to November, i.e somewhat later than on the Se Kong. Here also the concentration of cyclones around October plays a role.
- Also at Duc Xuyen on the Krong Kno the floods are extremely flashy, and annual extremes differ by a factor 10. The mean annual flood amounts about 830 m^3/s, a value that was exceeded in the past between mid-June and end of November, which includes the periods of occurrence of extremes on the Se Kong and Se San.

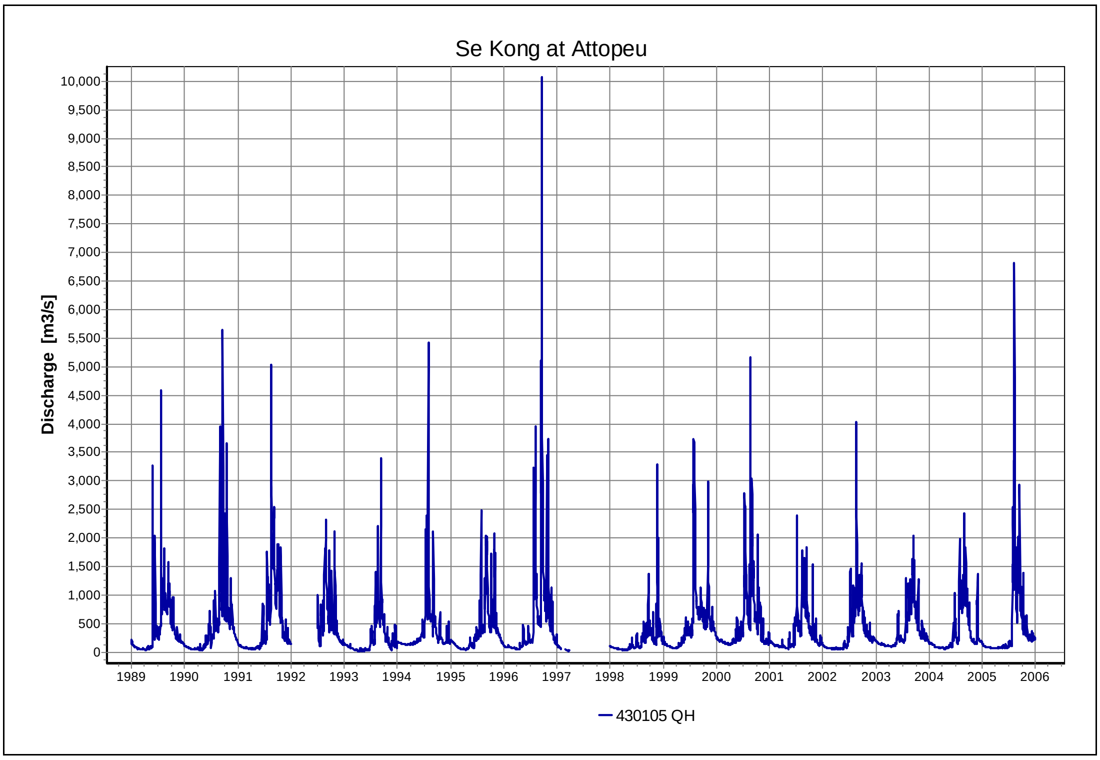

Figure 10.16 Discharge hydrograph of Se Kong at Attapeu.

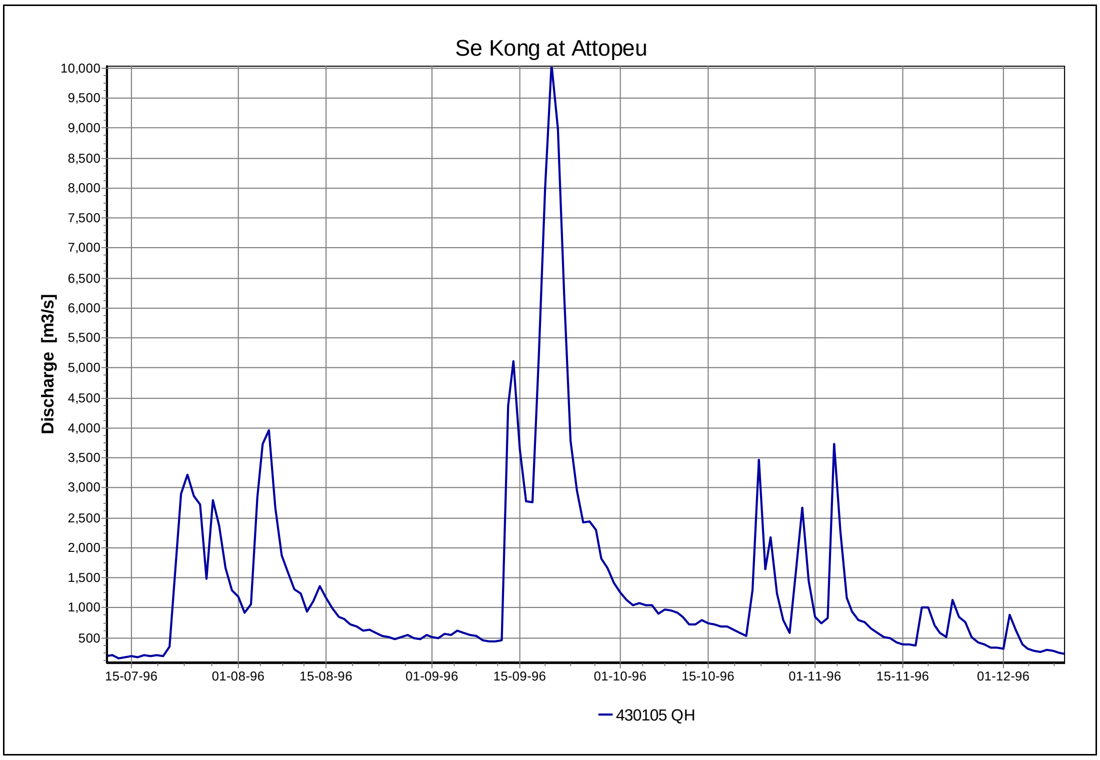

Figure 10.17 Discharge hydrograph of Se Kong at Attapeu, year 1996.

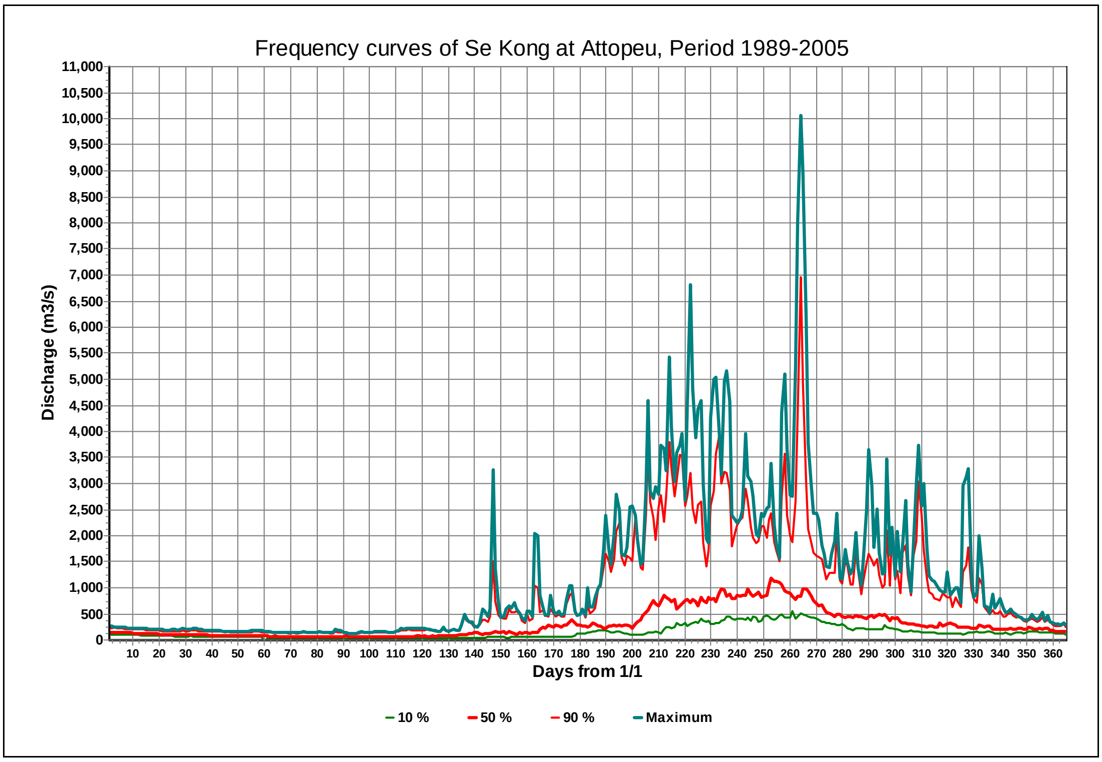

Figure 10.18 Frequency curves of Se Kong at Attapeu.

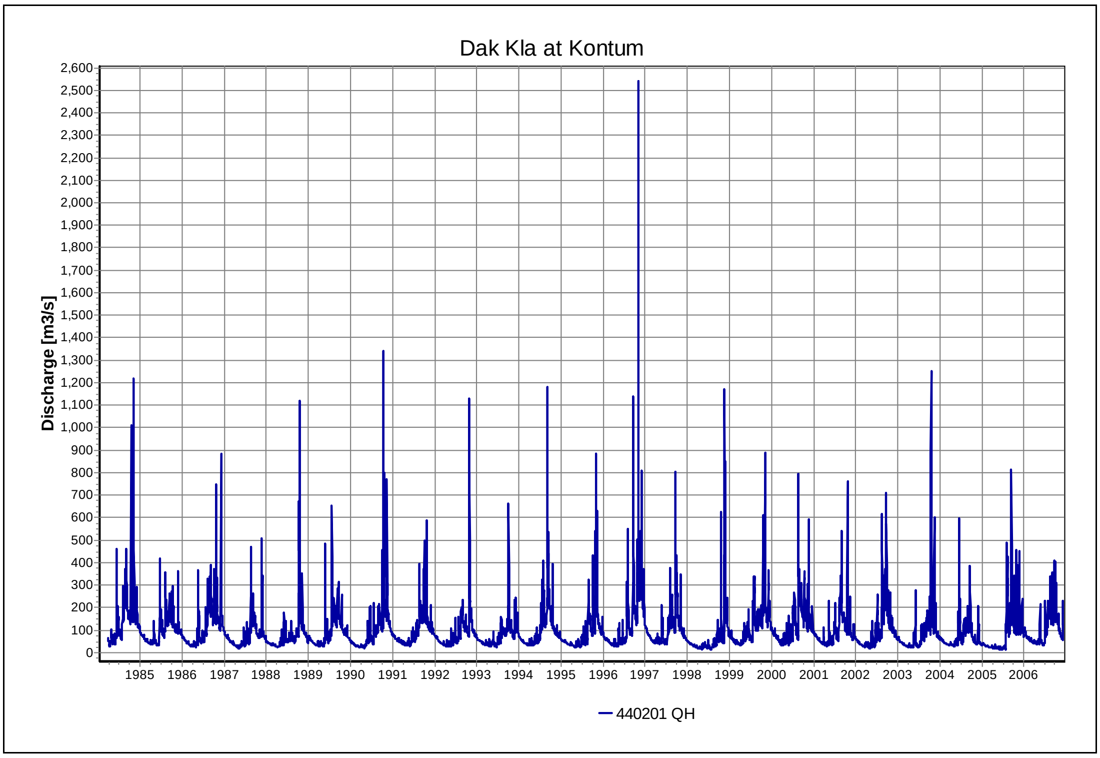

Figure 10.19 Discharge hydrograph of the Dak Bla at Kontum.

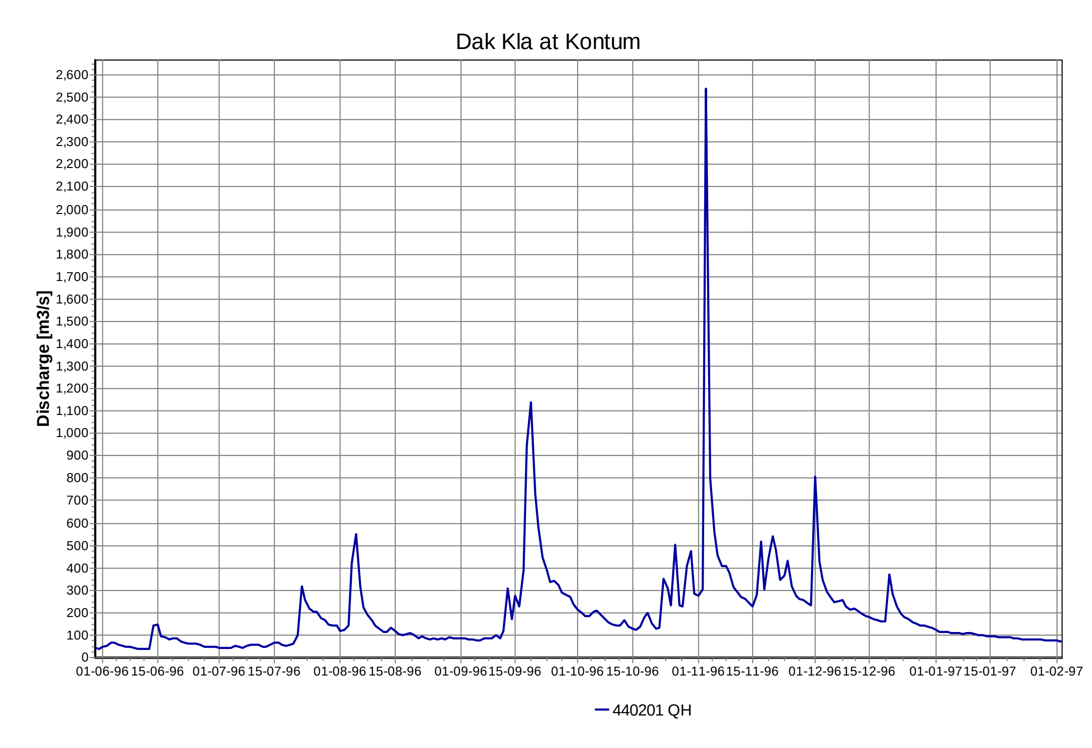

Figure 10.20 Discharge hydrograph of the Dak Bla at Kontum, year 1996.

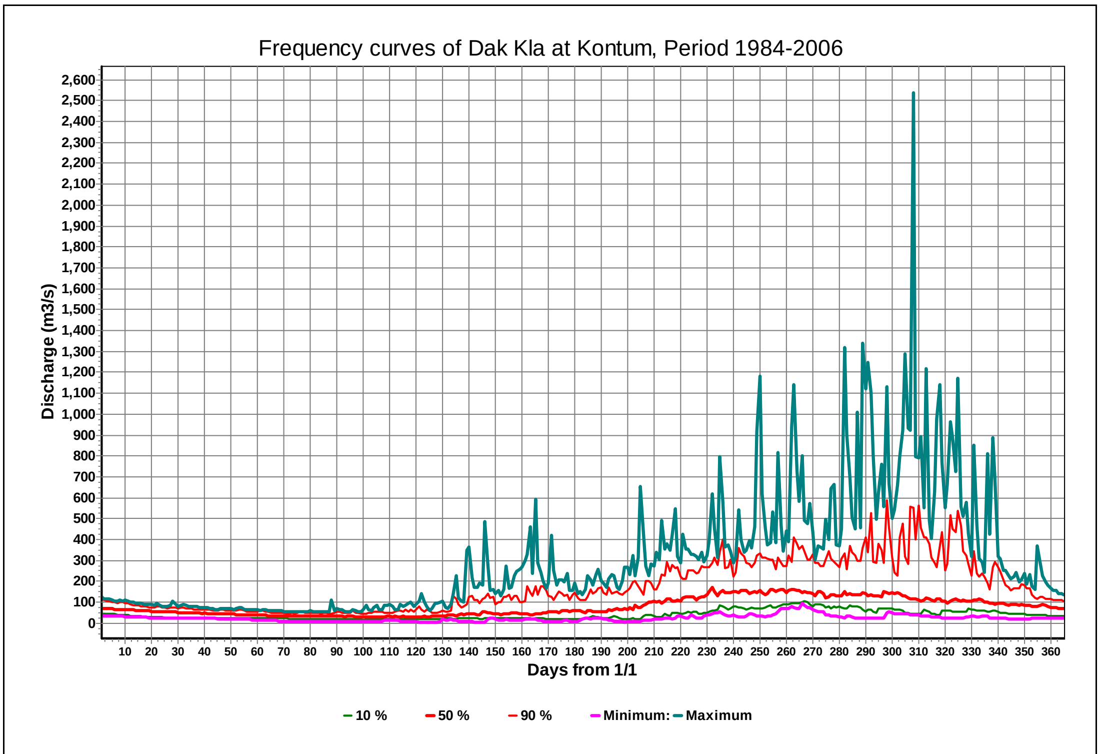

Figure 10.21 Frequency curves of daily discharge of the Dak Bla at Kontum.

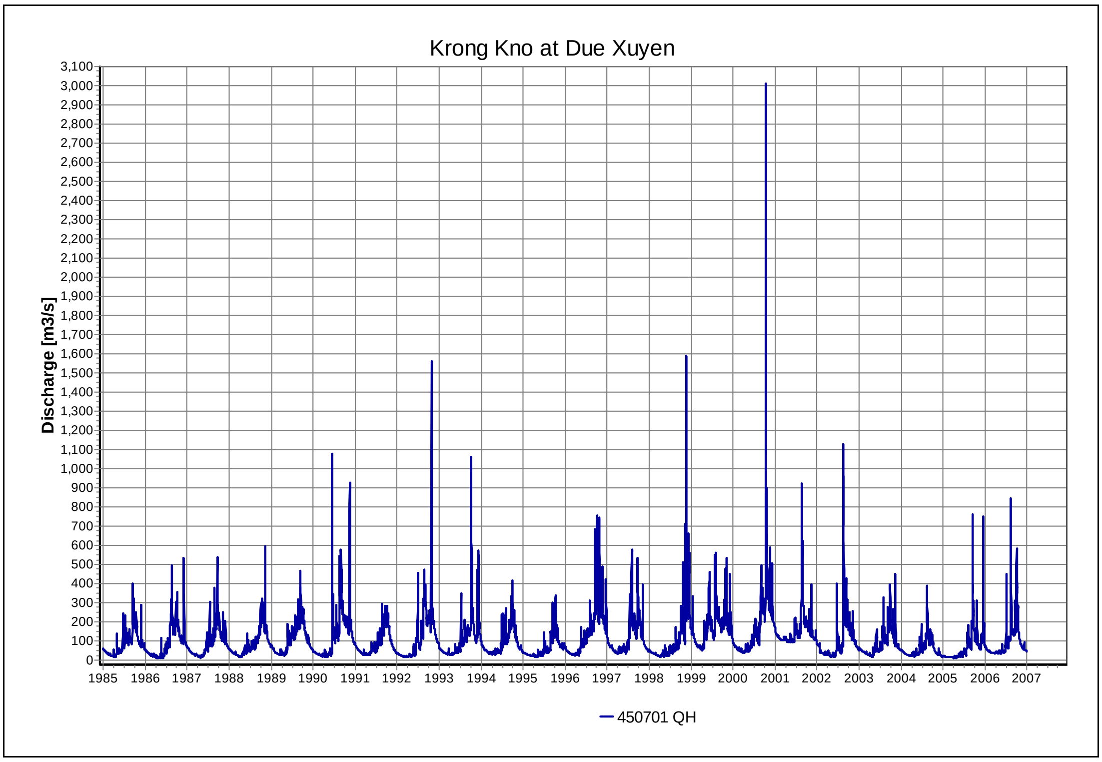

Figure 10.22 Discharge hydrograph of the Krong Kno at Duc Xuyen.

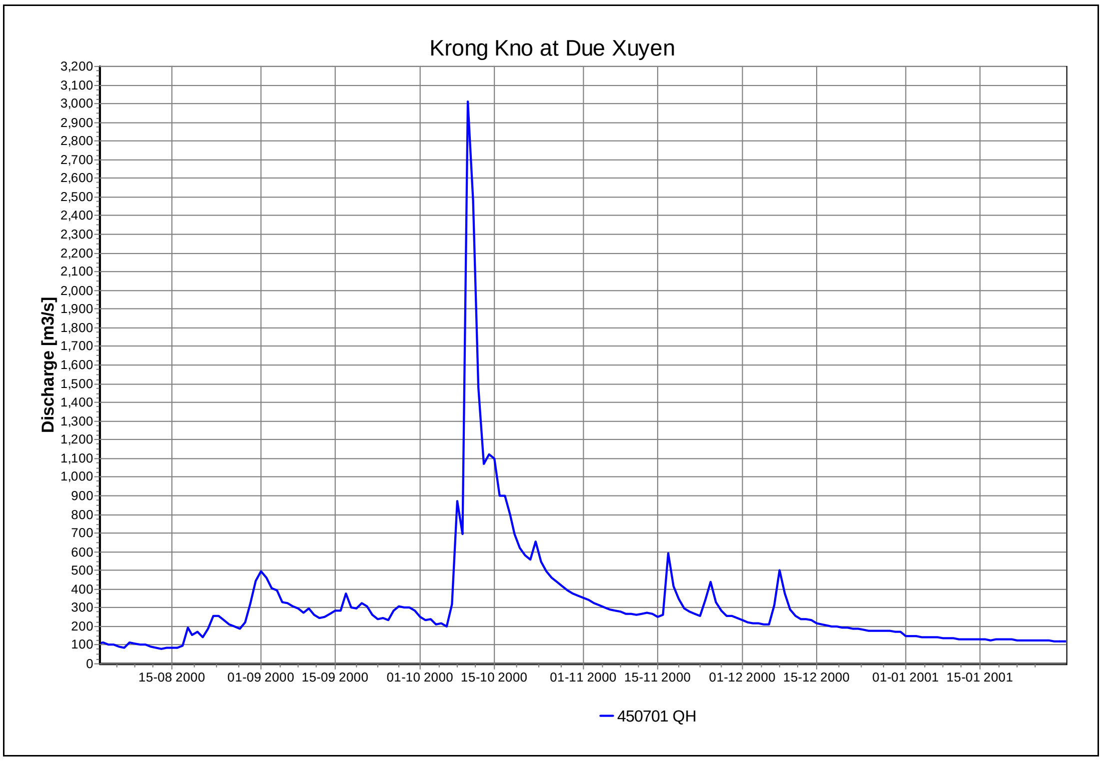

Figure 10.23 Discharge hydrograph of the Krong Kno at Duc Xuyen, year 2000.

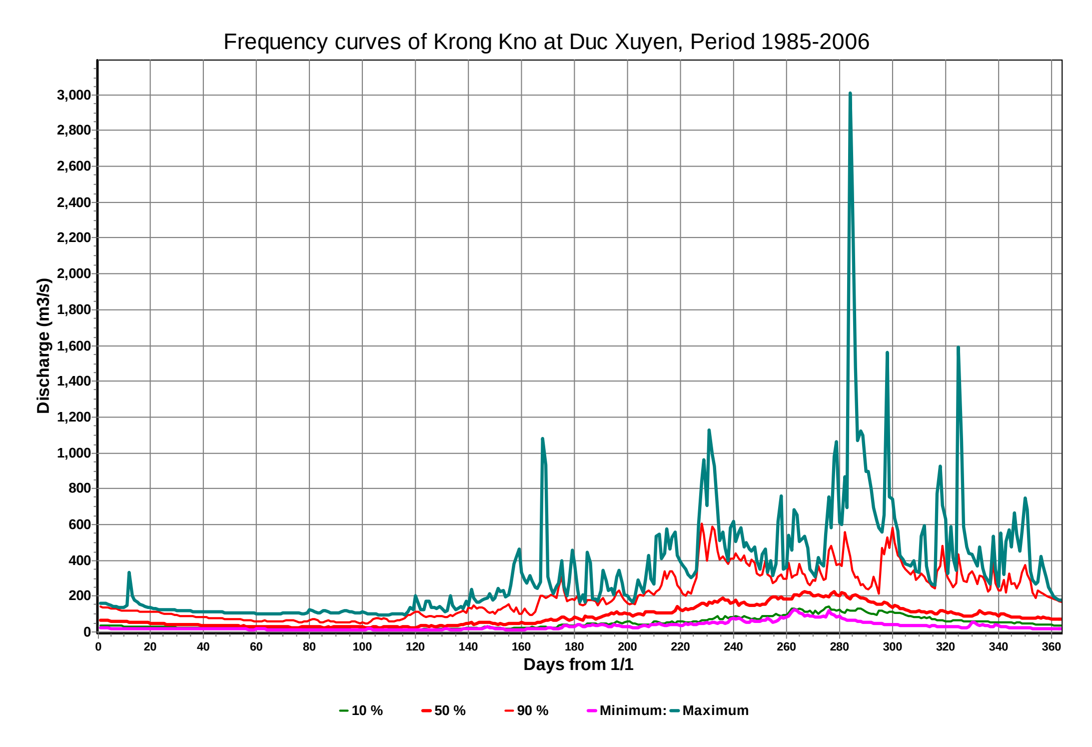

Figure 10.24 Frequency curves of daily discharge of the Krong Kno at Duc Xuyen.

10.3 Developments in SA7 affecting the flow regime

Irrigation

SA7 has more than 725,000 ha of agricultural land of which over 10 % is irrigated. The irrigation water requirement for Vietnam in 2004 was estimated at 2.8 BCM/yr, so the total requirement in the basin at present will be over 3 BCM/yr. There are 400 small irrigation schemes in the Laos part of SA7 with a total irrigated area of 11,000 ha. The irrigation areas are mainly located in the Se Kong around and downstream of Attapeu. In Vietnam in SA7 580 irrigation structures exists to serve 86,000 ha, heavily concentrated in the Upper Se San around Kontum and in the Sre Pok basin around Dac Min and Buon Ma Thuot. The storage structures are summarized below. The capacities at present are seen to be small and will have little capacity for flood control.

Table 10.8 Overview of existing irrigation storages in SA7 in Vietnam (BDP, 2006).

Basin	Project	Capacity (MCM)	Catchment area (km2)	Year of construction
Se San	Dak Uy Bien Ho 61 small & medium sized reservoirs	23 42	82.8 38	1975 1979
Sre Pok	Lower Krong Buk Ea Nhia Ea Kao Chu Kap Buon Triet 205 reservoirs	3.2 8.1 14 11.2 25	38 21 76 32	

Hydropower

The hydropower potential in SA7 is large. At present 3 major hydropower dams exist in SA7, one in Laos and two in Vietnam. An overview of the existing and planned development on hydropower in Laos and Vietnam is presented in Table 10.9 and Table 10.10.

The total storage capacity of the projects in Laos when all will be implemented amounts 22.5 BCM, which is about 50% of the average annual runoff of the Se Kong. Though active storage will be less, the development will certainly affect the regime of the river, and could be beneficial for flood mitigation. Storage capacity information on planned dams in Vietnam by NORPLAN (2004) reveales that including existing Yali, by 2025 the total active storage capacity will be 3.35 BCM. The dams are multipurpose with also a flood control function (BDP, 2006).

Table 10.9 Overview of major reservoirs in SA7 in Laos (source: MiMe, 2007).

Project	**Basin**	**Basin area (km^2)**	**Capacity (MW)**	**Reservoir Storage (MCM)**	**Reservoir Area (km^2)**
		Existing			
Houay Ho	Houay Ho		150	620	42
		Under construction			
Se Kaman 3	Am Paog-O		250	142	5
		MOU			
Se Kong 4	Se Kong		485	9,350	160
Se Kong 5	Se Kong		405	4,780	70
Se Pian/ Se Nam Noy	Nam Noy/ Se Pian		390	979	44
Se Kaman 1	Se Kaman		290	4,805	150
Se Kaman XanXay	Se Kaman		30	-	-
Se Kaman 4	Se Kaman		240	1,230	31
Nam Kong 1	Nam Kong		150	297	12
Nam Kong 3	Nam Kong		25	311	37

Table 10.10 Overview of major reservoirs in SA7 in Vietnam (BDP, 2006, NORPLAN, 2004).

Project	Basin	Capacity (MW)	Active reservoir storage (MCM)
	Existing		
Yali	Se San	720	780
Dray Ling	Ea Krong (Sre Pok)	12	?
8 small hydro in Se San		1.4	?
22 small hydro in Sre Pok		5.6	?
	Planned/Under Cconstruction		
Plei Krong (UC)	Se San	100	1,020
Se San 3 (UC)	Se San	108	<4
Buon Kuop	Sre Pok	280	<37
Upper Kontum (Planned)	Se San	220	120
Se San 3A (UC)	Se San	100	?
Se San 4 (UC)	Se San	330	470

Project	Basin	Capacity (MW)	Active reservoir storage (MCM)
Duc Xuyen	Sre Pok	58	480
Buon Tua Srah	Sre Pok	85	480
Chu Bong Krong	Sre Pok	23	?
Sre Pok 3	Sre Pok	180	?
Sre Pok 4	Sre Pok	40	?

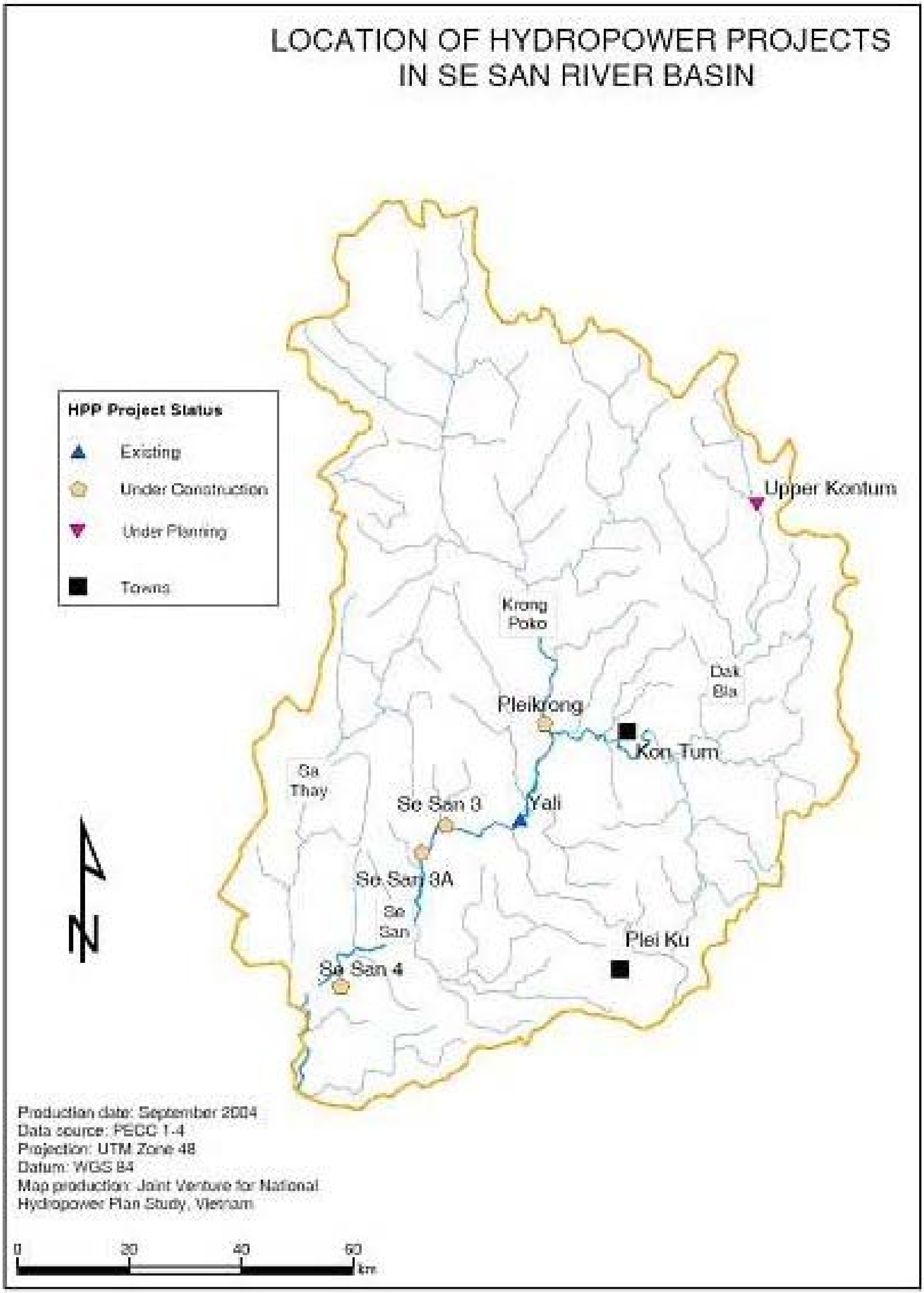

Figure 10.25 HPP in Se San in Vietnam: existing, under construction, planned (SWECO, 2006).

Regarding Cambodia Consultants have been informed by the Ministry of Industry, Mines and Energy that:

- On Se Kong there are no plans as yet
- On Se San the Lower Se San 1, 2 and 3 have recently been investigated by EVA (Energy Vietnam) in a Comprehensive Development Study of Hydropower in Se San River Basin in Cambodia (PECU Main Report, Hanoi, October 2006), with the following characteristics:

Table 10.11 Overview of major planned reservoir on Se San in Cambodia.

Parameter	Se San 1	Se San 2	Se San 3
FSL (m)	141	120	75
NOL (m)	140	119	74
Average Head (m)	18.6	27.4	25.9
Installed capacity (MW)	90	180	420
Area (km^2)	10.6	414	394

- On Sre Pok the Lower Sre Pok 3 and Sre Pok 4 pre-feasibility will be carried out by the Yunnan Copper Industry.

10.4 Floods

BDP (2006) states that on average, major floods in SA7 affect about 700 km^2. It blames reduced forest coverage for the occurrence of flash floods in recent years in Vietnam, whereas riverbank erosion in Lao PDR due to sand exploitation has contributed to frequent floods in the Se Kong region around Attapeu.

10.4.1 <u>Tributary floods</u>

Se Kong

From the available discharge record of Attapeu on Se Kong it is observed that the largest flood on record occurred in 1996, when a discharge of 10,000 m^3/s was reached in response to heavy rainfall (see Figure 10.27). From the rainfall pattern in relation to the peak it is observed that a lead time of 1 day is available to forecast the flow based on observed rainfall. Flooding in the region around Attapeu is a regular phenomenon, also in view of the topographical conditions, as may be observed from Figure 10.2 and Figure 10.3. In BDP (2006) reference is made to the 1996 and 2000 flood, causing large scale imundations and damages. Note, however, that the latter flood was peak-wise not extraordinary but volume wise considerable (5 BCM in 2000 against 8 BCM in 1996). In 2005 and also in 2006 again severe flooding with considerable damage is reported for the Se Kong in Laos (MRC, 2006) and MRC (2007). It is mentioned that river bank erosion due to sand mining has contributed to flooding.

Estimation of the hydrological hazard for the most affected area in Laos (the region around Attapeu) is possible based on the available discharge record, including design hydrographs. Transformation of the hydrological hazard into a flood hazard would require an hydraulic model, which is not available for this tributary. An alternative would be to determine the flood hazard from satellite imagery, provided sufficient images can be made available. For designing appropriate measures to cope with the flash floods in the upper reaches, unfortunately, little information is available. A regional approach as proposed for the other sub-areas could be used.

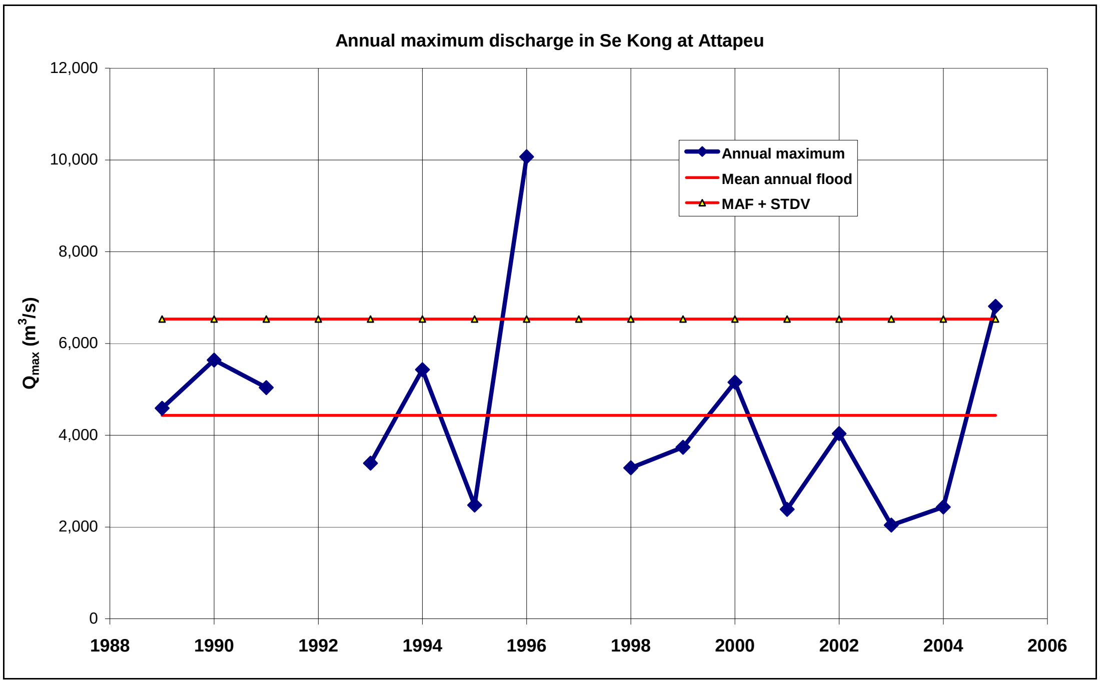

Figure 10.26 Annual maximum discharge in Se Kong at Attapeu.

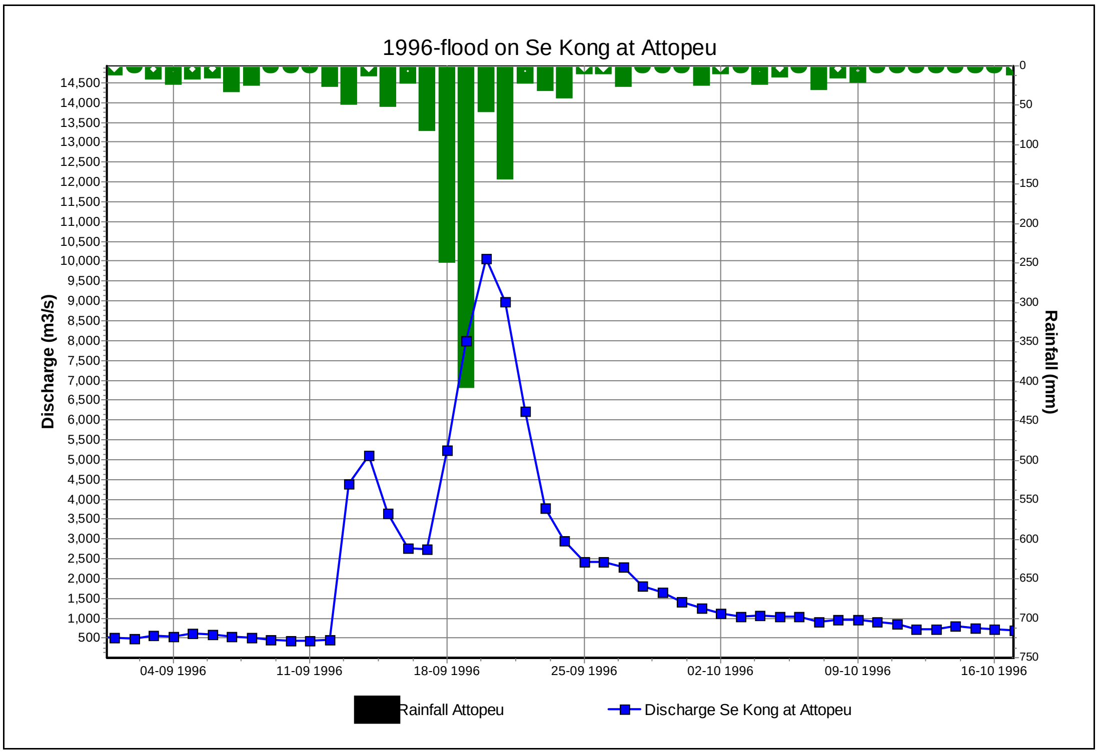

Figure 10.27 Rainfall and discharge hydrograph of the 1996 flood on Se Kong at Attapeu.

Se San

Floods in the Upper Se San do occur from June to November on the Krong Po Ko and from July to December on the Dak Bla (BDP, 2006). Annual large floods most frequently occur in October, where the concentration of cyclones around this month plays a role. Above mean annual floods have sofar experienced in the period from September to November. Floods in the upper reaches can be very flashy. Flood durations are typically 7 to 10 days, with a maximum 7-day flood volume at Kontum of 536 MCM. This is about 50% of the storage capacity of Yali dam. Apart from natural floods the region has suffered severely from unexpected dam releases, with large damages and casualties.

From the annual maximum discharge record of Kontum (see Figure 10.28) it is revealed that the maximum flood on record occurred in November 1996. In recent years moderate floods were recorded in the Upper Se San; only the flood of 2003 exceeded the mean annual flood level. The Annual Mekong Flood Reports of 2005 and 2006 (MRC 2006, 2007) did not report any widespread flooding in the Se San, but locally significant damages were encountered.

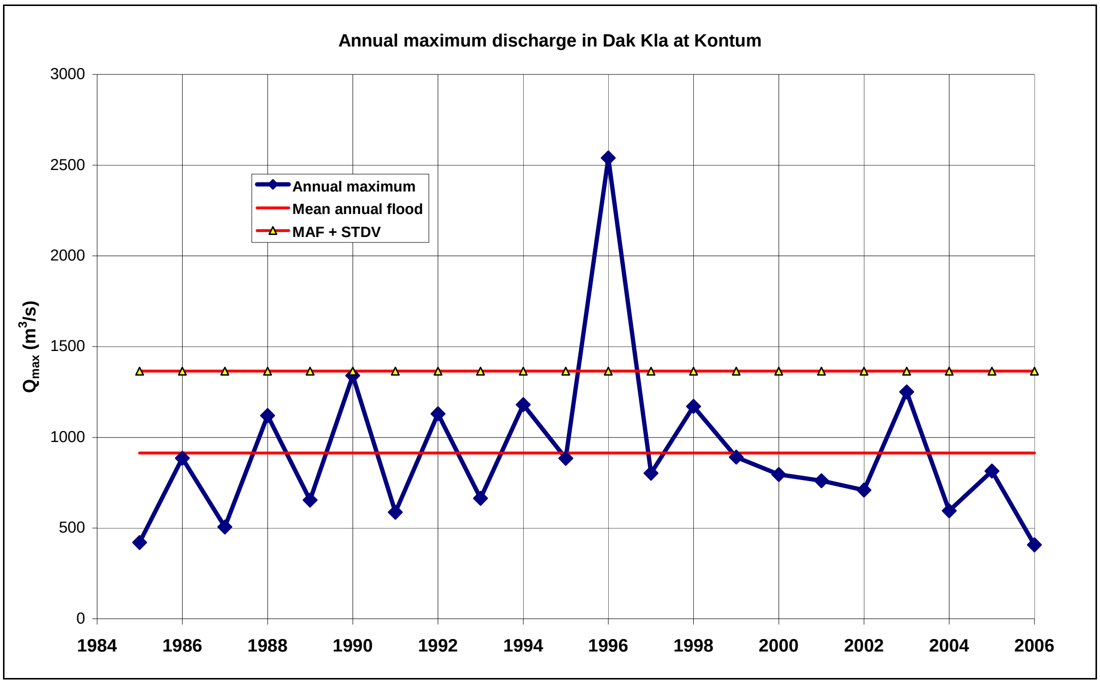

Figure 10.28 Annual maximum discharge of Dak Bla at Kontum.

Sufficient flow data is available for the Upper Se San to determine the hydrological hazard and design hydrographs. In 2005 DHI has developed hydrological and hydraulic models based on MIKE 11 of the Se San. The model system covers the Se San River from Kontum on Dak Bla River, Trung Nghia on Krong Poko and down to the confluence between Se San and Sre Pok rivers in Cambodia. A separate model has been established to describe the rainfall-runoff from the catchment. This model is used by CNMC for case studies. It implies that tranformation of hydrological hazard into flood hazard is possible for the Se San.

For the Lower Se San only at Ban Kamphun a record of sufficient length is available. However, a complete revision of the record will be required, including corrections for backwater, before this series can be applied.

Sre Pok

Like on the Upper Se San floods rise quickly on the Upper Sre Pok. At Duc Xuyen on the Krong Kno the higher floods were experienced between mid-June and end of November. Floods often last for 10-15 days creating long term flooding and water logging. The largest flood on record at Duc Xuyen occurred in 2000, when 4 times the mean annual flood discharge did occur.

Conditions with respect to data is such that hydrological hazards and design hydrographs can be determined, but tools to transform the hydrological hazard into flood hazards are missing.

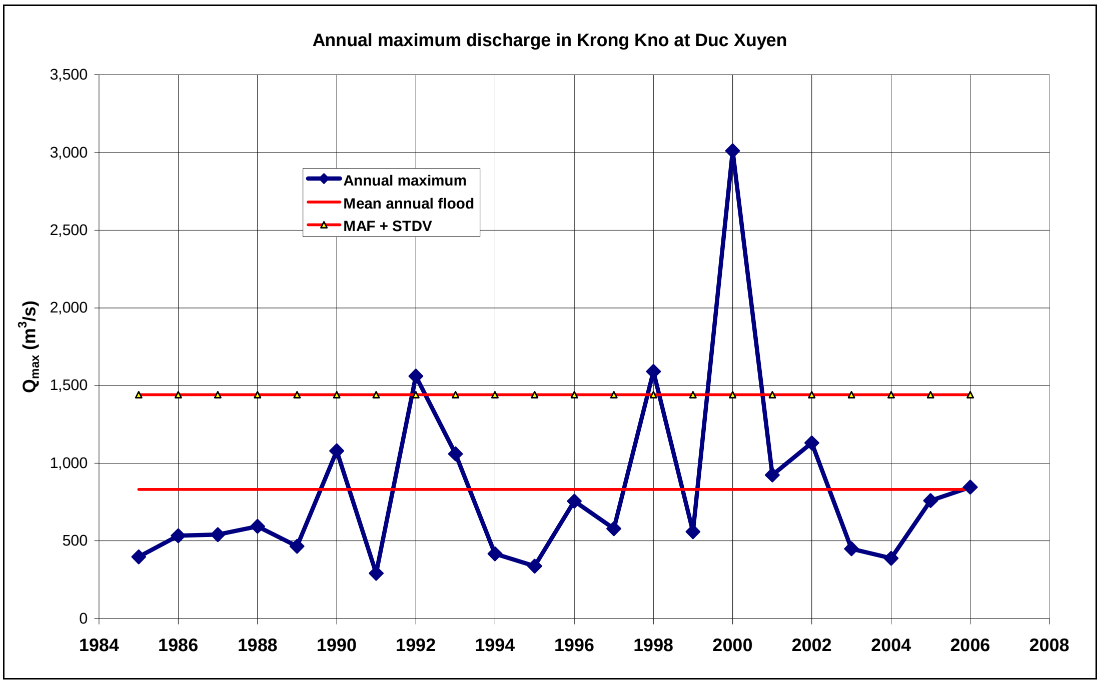

Figure 10.29 Annual maximum discharge in Krong Kno at Duc Xuyen.

10.4.2 Main stream floods

Flooding at the Se San river mouth in Stung Treng does occur. Reference is made to the description of the river flood in this reach in the report on SA8 in Section 11.4.2.

10.4.3 Combined floods

Flooding along the lower reaches of the Se San and tributaries does occur also due to backwater from the Mekong. As can be observed from the slope map Figure 10.3 the lower reaches of the Se Kong, Se San and Sre Pok are very flat, making the area vulnerable for combined floods, also because the period in which floods on the Se San and tributaries does occur is long with a high probability to coincide with floods on the main stream. To analyse the combined flood phenomenon the record of Ban Kamphun has first to be recomputed, as indicated in Section 10.4.1.

10.4.4 Summing up

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. However, hydraulic models for transformation of hydrological hazard into flood hazard are only available for the Se San, 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 hazrad. 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.

11 HYDROLOGICAL AND FLOOD HAZARD IN SUB-AREA 8

11.1 Basin characteristics

Sub-area 8 (SA8) covers the areas draining to the Mekong between Stung Treng at the confluence with the Se San to some 50 km downstream of Kratie at the border between Kratie and Kampong Cham provinces (Figure 11.1). The total area is 22,170 km^2 of which 98% is located in Cambodia and te rest in Vietnam. The Mekong is characterized by a braided channel with sand islands and deep-pool fish spawning refuges. Two-third of the sub-area is occupied by flood plain with elevations up to 100 m. The remaining area rises gently to levels of 200 m eastward and up to at maximum 500 m in the extreme south-east (Figure 11.2). The flatness of the major part of SA8 is also clearly observed from Figure 11.3. The Mekong reach covers the important gauging stations of Stung Treng and Kratie,which determine the inflow into the Tonle Sap system and the Mekong delta.

The following unmeasured tributaries drain to the Mekong in SA8:
- Siem Bok
- Prek Preah
- Prek Krieng
- Prek Kampi
- Prek Te
- Prek Chlong

About 80 % of SA8 is covered with forest, some 12% is woodland, agriculture takes 6 % and the rest is wetland (Figure 11.4). Land adjacent to the river is primarily alluvium soil.

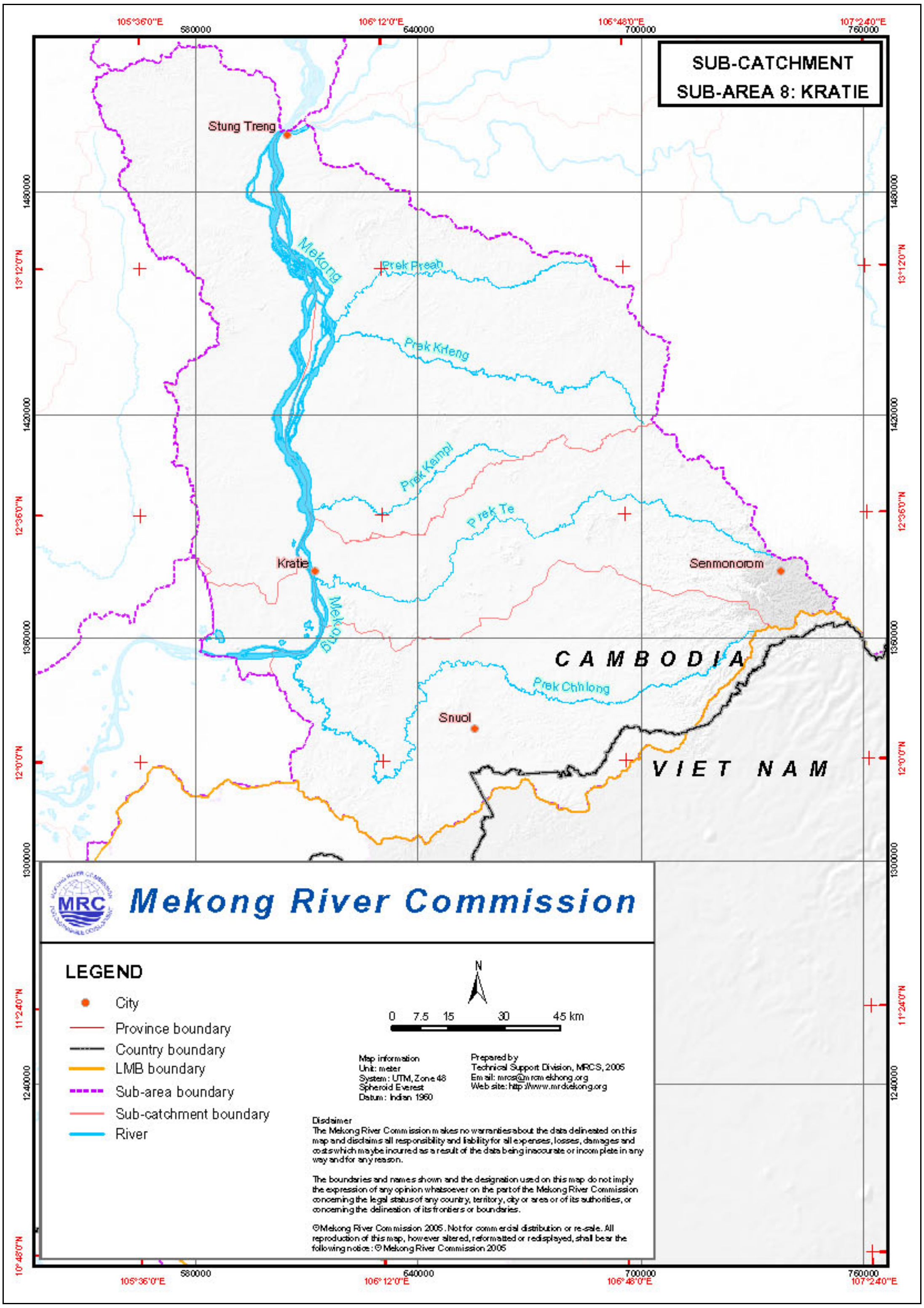

Figure 11.1 Layout of basins in SA8 (BDP, 2006).

Figure 11.2 Elevation map of SA8 (BDP, 2006).

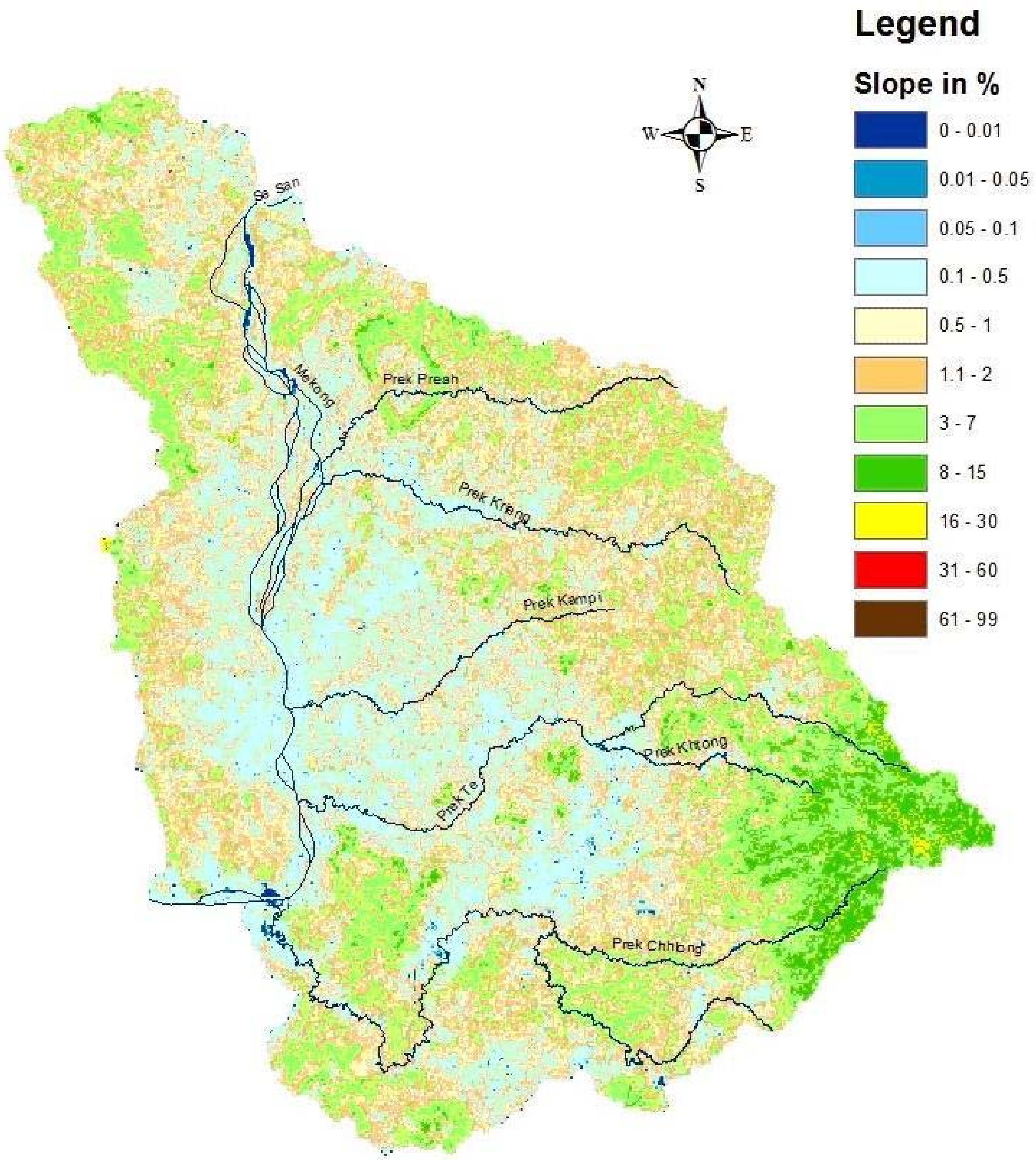

Figure 11.3 Slope map of SA8.

Figure 11.4 Land use map of SA8 (BDP, 2006).

11.2 Hydrological characteristics

11.2.1 Data availability

An overview of the available hydrological stations in SA8 for which data is available in the HYMOS database at MRC are presented in Table 11.1 and Figure 11.5. The availability of the data is presented in Table 11.2.

Rainfall data is available for some 13 stations in SA8, i.e. a density of 1 station per 1,700 km2, mainly concentrated along the Mekong mainstream. Though some of the stations have a record starting in 1920, the series contain many missing data. None is continuous for more than 10 years.

Water level series are available for Stung Treng as from 1910 onward till 2006. Part of it however is not measured data; the nineteen seventees has been filled in based on Pakse. A similar statement applies for the discharge data of Stung Treng.

The water level series for Kratie start in 1930 and has a gap between April 1974 and January 1980. Furthermore, the series shows that several times the gauge has been shifted. The flow series for Kratie in the HYMOS database of Mekong runs from 1924 to1969. A complete review will be required prior to the use of this series.

The flow series for Stung Treng and Kratie will be of high importance for any flow modelling in the delta as it determines the upstream boundary condition. It appears that different rating curves are in use for both stations:

- The rating curves for Stung Treng as applied in the Annual Flood report and according to the stage-discharge data available in HYMOS are presented in Figure 11.6. It is observed that the stage-discharge relation has not changed much in the course of time: the relation valid for the measurements in the sixties is also applicable after 2000.. Apparently the control section of Stung Treng is stable.
- For Kratie a large scale discharge measuring program was carried out in the years 2002-2003 by DHRW with financial support from MRC. It lead to a separate rating curve for the rising and falling stages, see JICA, 2004 and Annual Mekong Flood Report 2006 (MRC, 2007). These data and of earlier measurements are shown in Figure 11.7. It appears that the new rating deviates from the curve used by MRC in their calculation of the flood statistics. Particularly in the upper part the deviations are considerable. It appears that in the 2002-2003 measuring campaign, carried out with an ADCP, part of the flood plain flow has not been taken into consideration. If the flow at Stung Treng (shifted one day) is compared with the water level observed at Kratie then another rating can be established for Kratie, thereby assuming that the lateral inflow between the two stations as well as the attenuation is small. This has been shown in Figure 11.8. It appears that the Stung Treng curve fits well to the new rating at Kratie, however for the upper part, when h > 18 m, the flow estimated with the Stung Treng curve gives higher discharges and fits better to the MRC curve. The behaviour of the stage-discharge relation for the higher stages is of importance as this determines the inflow to the flood plain between Kratie and Kampong Cham. A thorough investigation is required, to apply the appropriate upstream boundary condition for the delta.

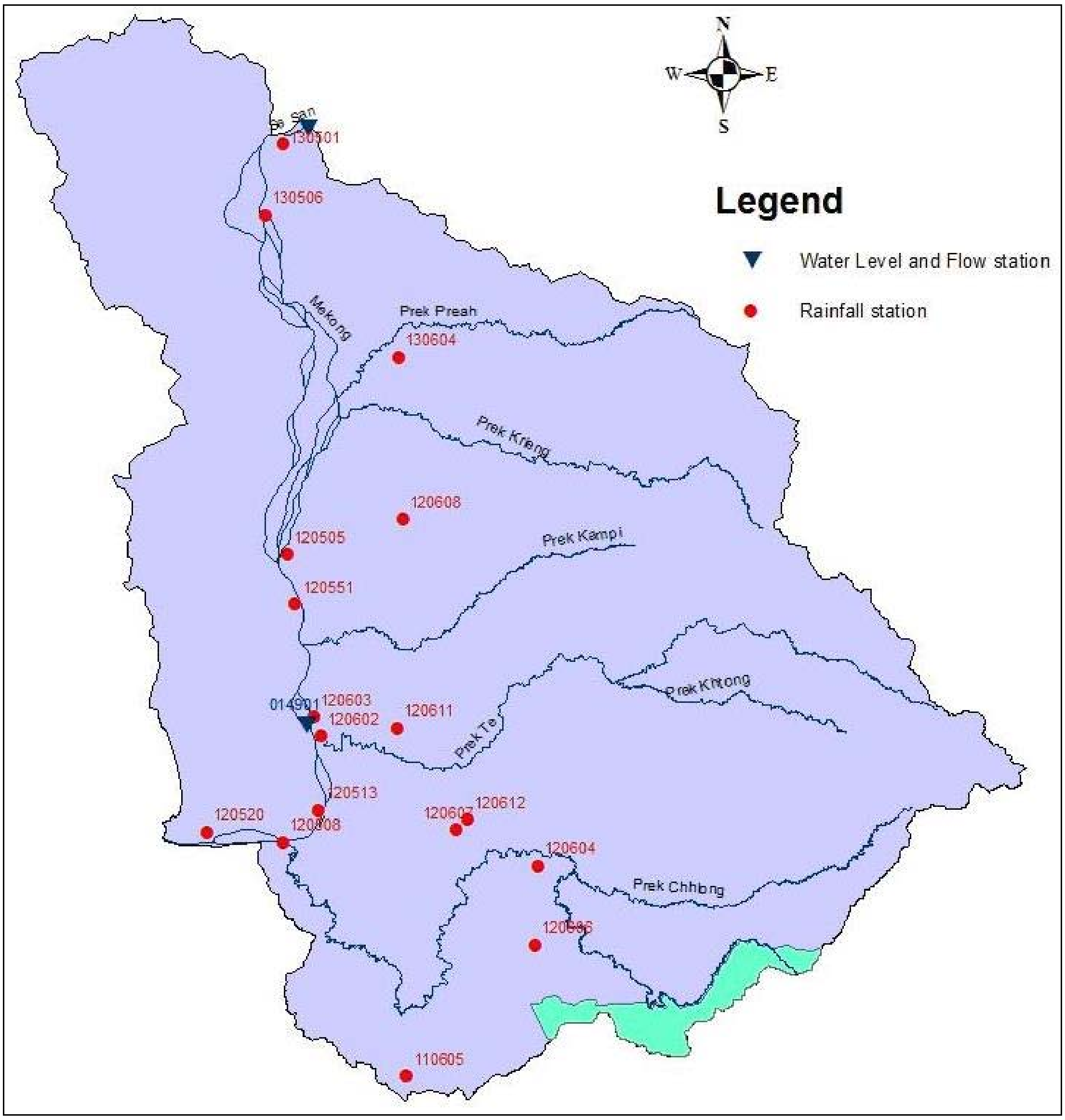

Figure 11.5 Hydro-meteorological network of SA8.

Table 11.1 Overview of rainfall, water level and discharge staions in SA8.

Station Location

Rainfall

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
110605	Mimot	Delta	11.8395	106.1902
120508	Chhlong	Mekong	12.2617	105.9667
120513	Prek Prasap	Mekong	12.3190	106.0334
120520	Cham Bac	Mekong	12.2812	105.8273
120551	Wattanak		12.6902	105.9905
120602	Peam Te		12.4532	106.0376
120603	Kratie		12.4871	106.0242
120604	Prek Chhlong		12.2167	106.4334
120606	Snoul		12.0748	106.4258
120607	Svay Chras		12.2834	106.2834
120608	Kbal Domrey		12.8423	106.1892
120611	Kantout		12.4670	106.1759
120612	Svay Chek		12.3012	106.3054
130501	Stung Treng		13.5192	105.9705
130506	Seam Bork		13.3900	105.9390
130604	O Krieng		13.1334	106.1834

Water Level

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
014501	Stung Treng	Mekong	13.5451	106.0166
014901	Kratie	Mekong	12.2398	105.9871

Flow

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)		Catchment Area, km2
			Latitude	Longitude	
014501	Stung Treng	Mekong	13.5451	106.0166	635000
014901	Kratie	Mekong	12.2398	105.9871	646000

Daily Data Availability of BDP Sub-Area 8C (before 1960)

Rainfall

Station ID	Station Name	River	1920										1930										1940										1950									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
120505	Sambor		+		+	31	+	+		+	+		+								+	+																				
120603	Kratie		+		+	+	+	+			+		+	+	+	+	+	+		+	+	+	+	+	+	+																
120604	Prek Chhlong																				+	28										1	+	+	+	+	62	62	30		+	+
120606	Snoul												+								+	28															+		30		204	61
130501	Stung Treng		31		+	90		73			60		31								31	59				+								31		59	122	59	151	31	243	90

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
120505	Sambor			+	+	+	+																																				+	+	+	+			+
120551	Wattanak																																										+	+	2	+			+
120602	Peam Te																																							92			+	+	+	+			+
120603	Kratie		+	+	+	+	+	+	+	+	+	+											+	+	+	+	+	+	+						254	+	+		+	+	+	+	+	+	+	+			+
120604	Prek Chhlong		+	+	+	+	+																																										
120606	Snoul		244	+	+	+	+	+	+	+	+	+	275																											+			61	+	+				+
120607	Svay Chras																																												+	+			1
120608	Kbal Domrey																																											+	+				
120611	Kantout																																											+	+	+			+
120612	Svay Chek																																																
130501	Stung Treng			+	+	+	+	+	+	+	+	+																	+	+					+		+					+	61	+	+		+	+	+
130506	Seam Bork																																											+	30		+		+
130604	O Krieng					+						+																															+	+	+	+			+

Water Level

Station ID	Station Name	River	1910										1920										1930										1940										1950									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
014501	Stung Treng	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
014901	Kratie	Mekong																								17	3	+	6	+	103	+	+	+	+	+	+	53	+	+	+	+	49	+	+	+	+	+	+	+	+	+

Water Level

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
014501	Stung Treng	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
014901	Kratie	Mekong	+	+	+	+	+	+	+	32	+	38	67	+	+	+	275						+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	19	+	1	+	+	+	+	+	+	+	+

Flow

Station ID	Station Name	River	1910										1920										1930										1940										1950									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
014501	Stung Treng	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
014901	Kratie	Mekong															+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	91	+	+	+	+	+	+	+	+	+	+	+	+	+

Flow

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
014501	Stung Treng	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
014901	Kratie	Mekong	+	+	+	+	+	+	+	+	+	38	67																																				

Notes:
+ = no missing
blank = missing
90 = number of missing days in a year

Table 11.2 Availability of rainfall, water level and discharge data in SA8.

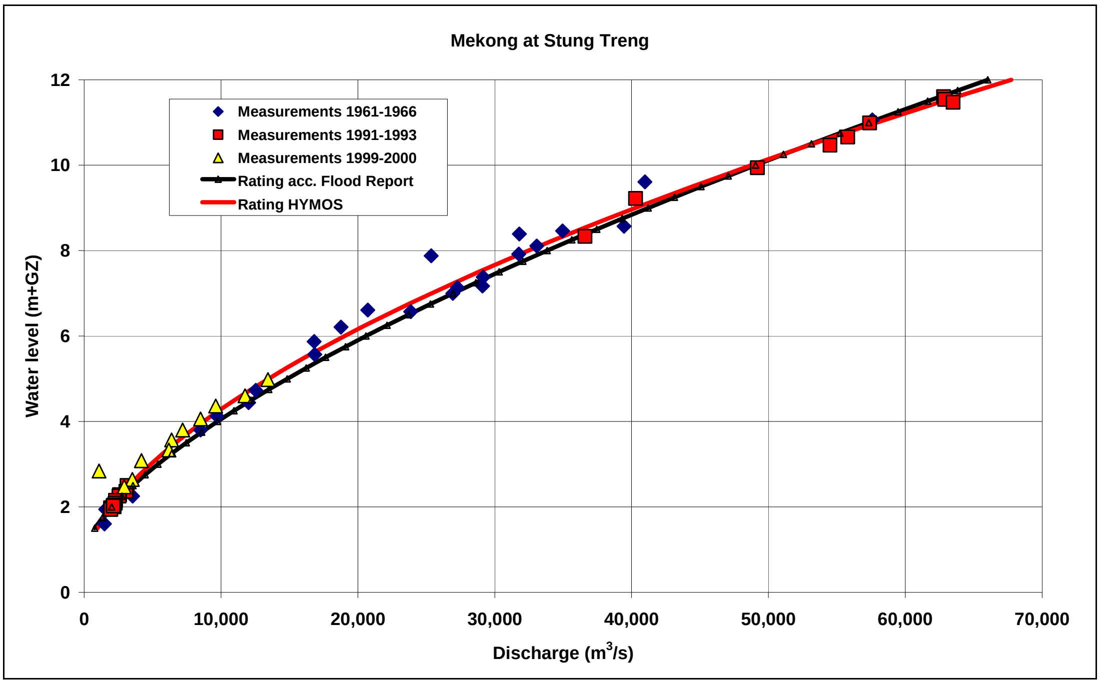

Figure 11.6 Stage-discharge rating for Stung Treng according to Annual Flood Report and HYMOS-data.

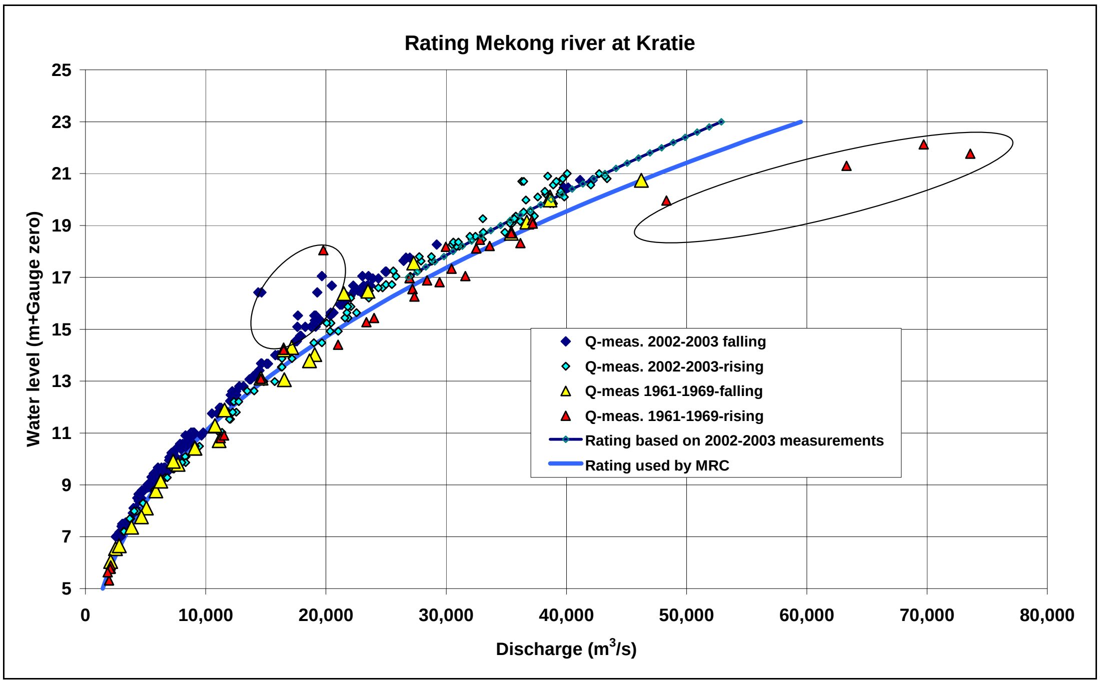

Figure 11.7 Stage-discharge rating for Kratie according to 2002-2003 meaqsurements and used by MRC.

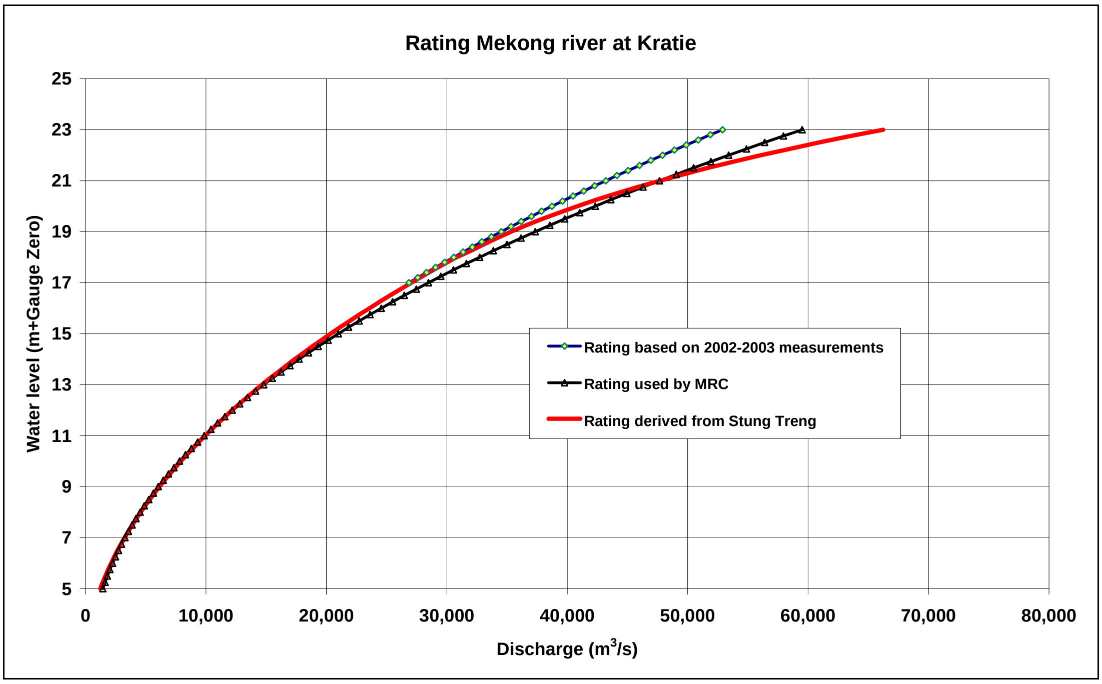

Figure 11.8 Ratings for Kratie: acc. to 2002-2003 measurements, MRC and derived from Stung Treng.

11.2.2 Rainfall

SA8 has a tropical monsoon climate. The annual rainfall is in the order of 1,600 to 1,800 mm, which predominantly falls in the months May to October. For Kratie 85% of the annual rainfall of is experienced in this period. It is observed that different from the more upstream sub-areas the rainfall in October becomes of importance in this region, also due to the landfall of cyclones in this part of the basin during this period.

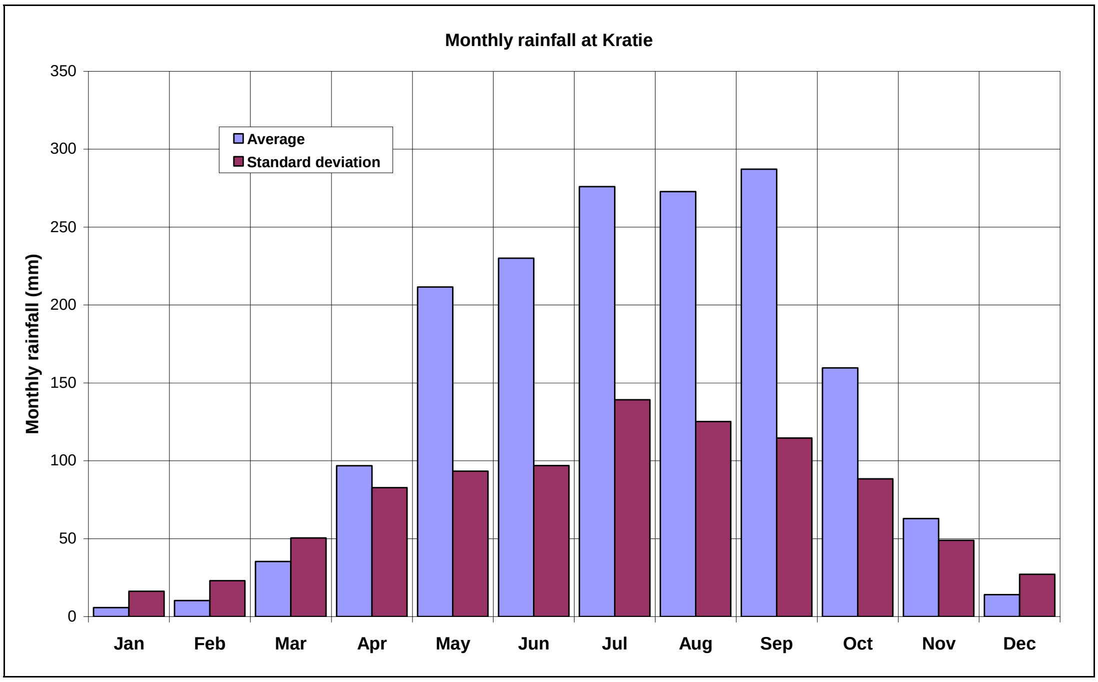

Figure 11.9 Monthly rainfall characteristics of Kratie.

11.2.3 Runoff

BDP (2006) estimates the runoff from SA8 at about 6 BCM/year with an annual runoff from the basin of 500 to 600 mm. This amount must have been derived from rainfall-runoff modelling as no discharge stations on the tributaries is available.

The annual flow and flood volume (June-November) in the Mekong at Stung Treng is presented in Figure 11.10, assuming that the rating curve of 1960-2000 is valid throughout.

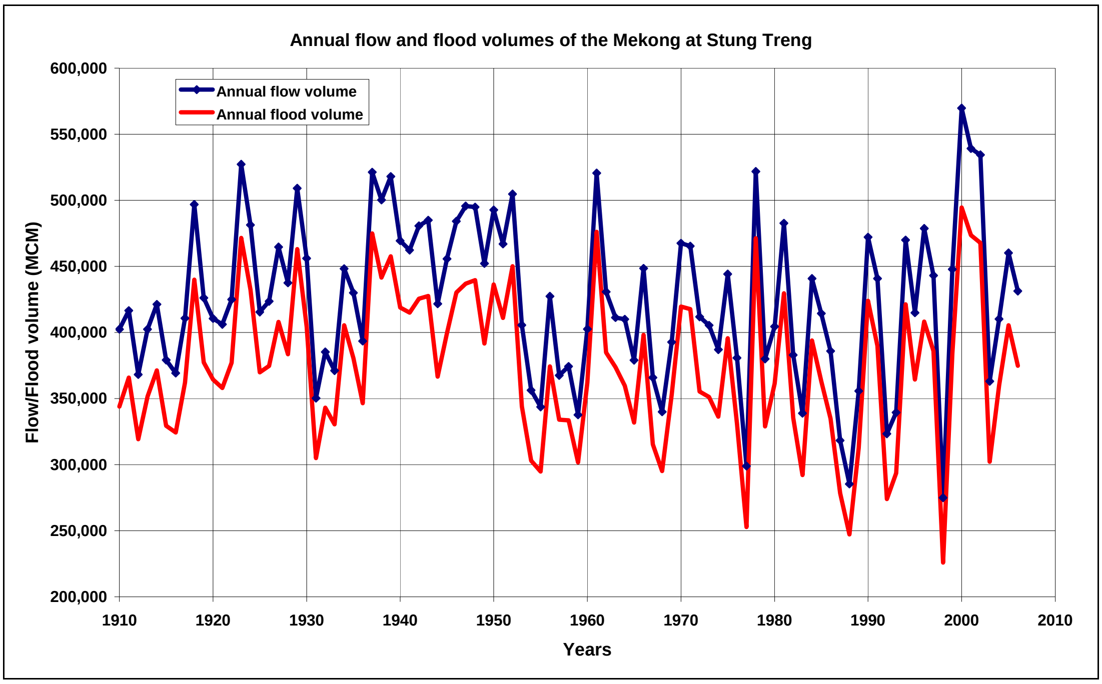

Figure 11.10 Annual flow and flood volume (June-November flow) of the Mekong at Stung Treng.

The long term average annual flow at Stung Treng amounts 425 BCM, with a standard deviation of 60 BCM. The annual average for the years prior to 1960 is 435 BCM against 415 BCM for 1960-2006. Hence, the runoff in the last period has been some 5% less compared to the first half of the last century. Under the assumption that the rainfall has not changed, this implies that deforestation has had no effect on the runoff. The expected effect of deforestation would have been an increase in runoff.

The monthly runoff characteristics of the Mekong at Stung Treng is shown in Figure 11.11. It is observed that the regime is almost symmetrical around 1st September. Comparison of the monthly flows for the periods prior to and after 1960 (see Figure 11.12) shows marginally lower values in the months July to September in the last period.

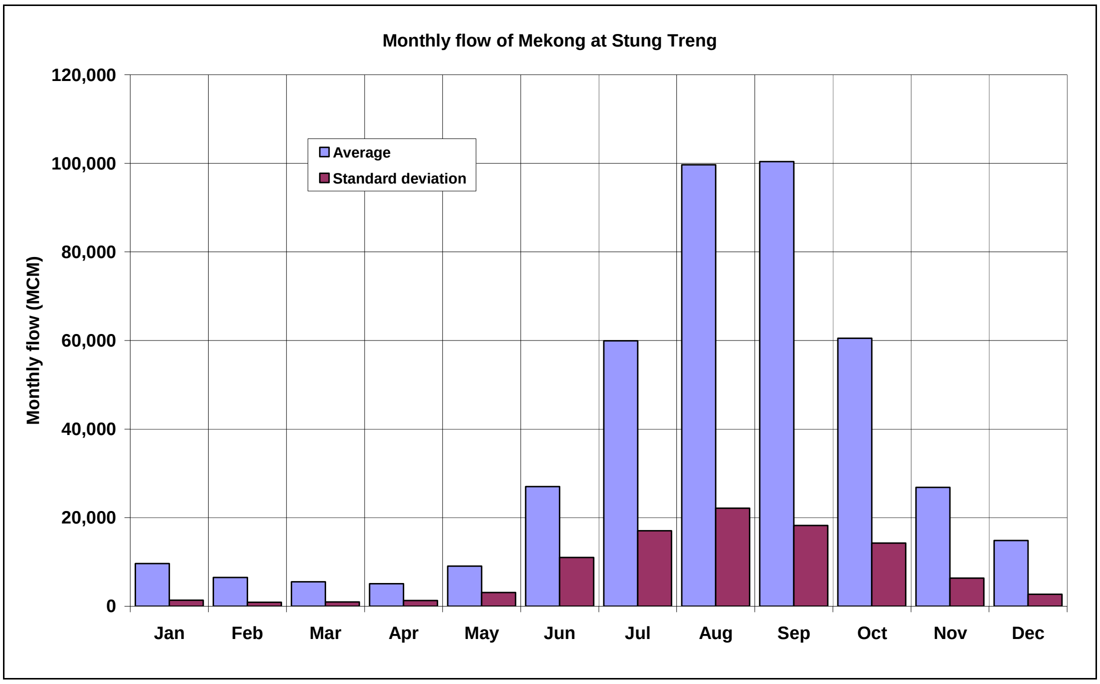

Figure 11.11 Monthly flow charcateristics of Mekong at Stung Treng.

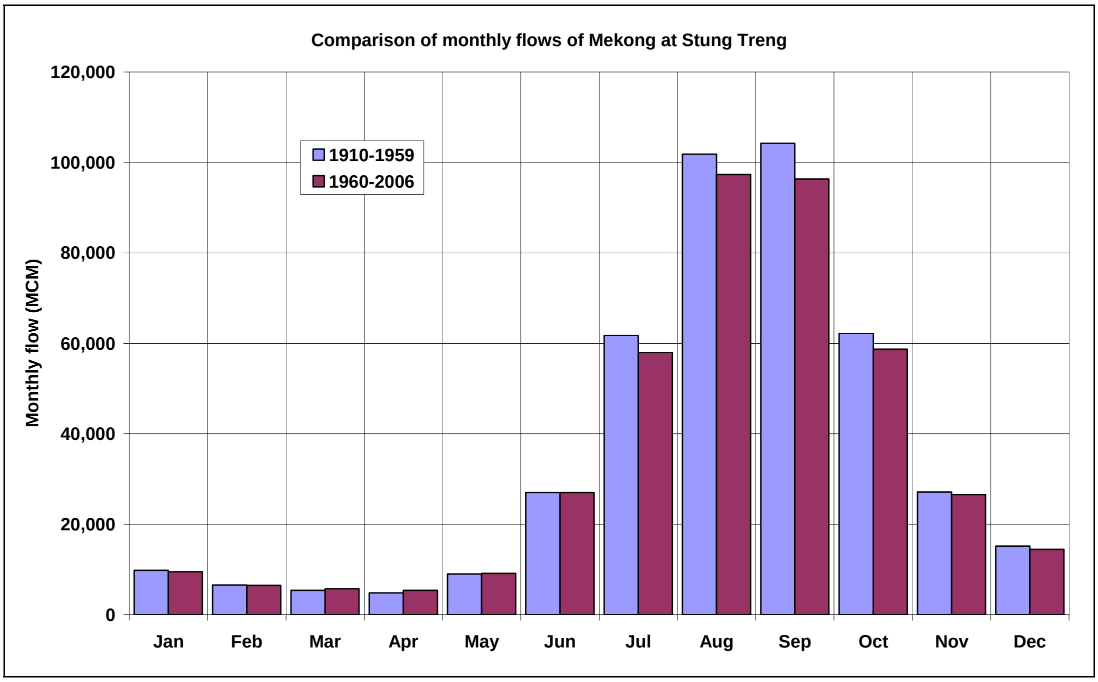

Figure 11.12 Comparison of monthly flows at Stung Treng of periods 1910-1959 and 1960-2006 The.

The flow regime is reflected in the frequency curve of daily discharges of the Mekong at Stung Treng, shown in Figure 1.13. The mean annual flood for Stung Treng amounts 52,000 m^3/s, which has been exceeded from mid-July till mid-October.

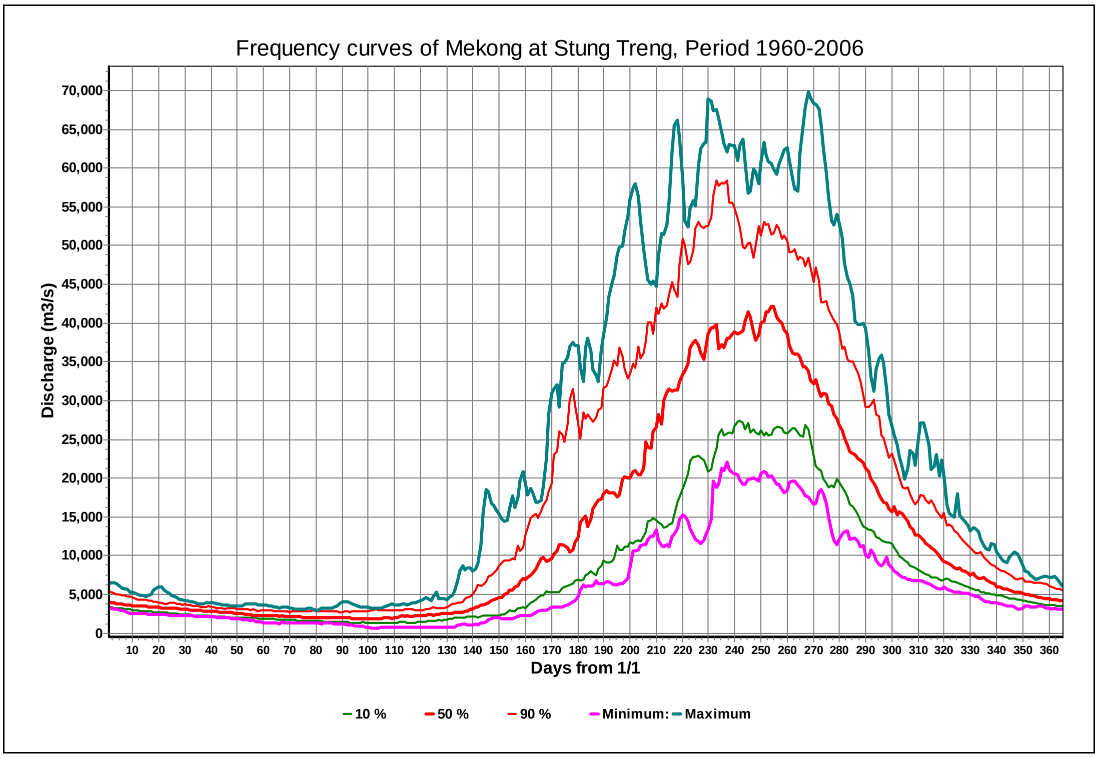

Figure 11.13 Frequency curves of daily discharge of the Mekong at Stung Treng.

11.2.4 Developments in SA8 affecting the flow regime

Irrigation

SA8 has about 90,000 ha of agricultural land of which in 2000 27,000 ha was irrigated in the wet season and over7,000 ha in the dry season. The irrigation water requirement together with domestic and industrial use is about 120 MCM/yr.

Hydropower

At present there is no hydropower project in SA8. According to MIME (pers. comm. 2007) at two locations HPP's are planned:

- At Stung Treng, where there is Russian interest for a pre-feasibility study
- At Sambor, just upstream of Kratie. A feasibility study is being made by the Chinese. There is no flood mitigation component being considered in the development of this dam. It was said that it would be a large dam and not just a run-of-river plant. Earlier there were two alternatives investigated for this location:
  - A large dam with an installed capacity of 3600 MW (Final Report of Review and Assessment of Water Resources for Hydropower and identification of priority projects. Cambodia, Annex, June 1995 by CPEC (Vienna) & ACI Consultants. The dam dimension considered were
    - Storage capacity 2.055 BCM,
    - Area 4,000 km^2, and
    - Dam height 54 m
  - Run-of-river plant with 465 MW installed capacity.

It is observed that the storage capacity given is very small compared to the volume of a Mekong flood, hence the flood control capacity will be small.

11.3 Floods

11.3.1 Tributary floods

There is no data available on tributary floods in SA8.

11.3.2 Main stream floods

Flood peaks

The annual maximum discharge at Stung Treng is presented in Figure 11.14. The mean annual flood discharge (MAF) for the period 1960-2006 amounted 52,000 m^3/s with a standard deviation of 9,000 m3/s. The annual maximum flood in 2000, 2001 and in 2002 is seen to have exceeded the MAF + STDV discharge.

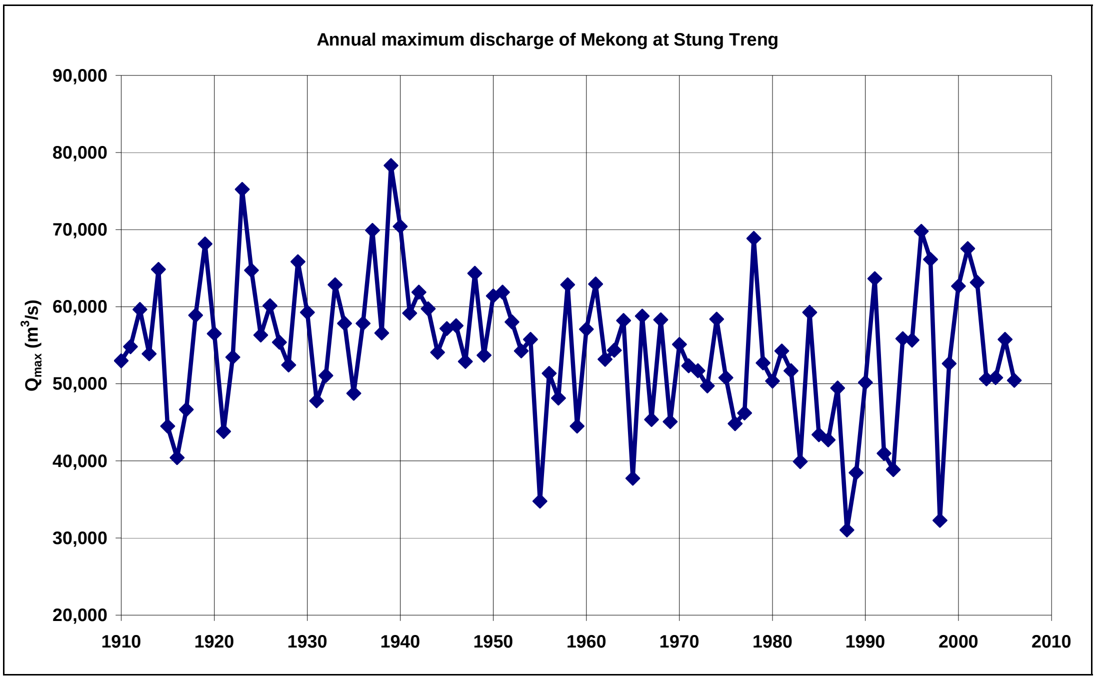

Figure 11.14 Annual maximum discharge of the Mekong at Stung Treng.

The duration of the exceedance of various flood discharge levels in recent years is presented in Table 11.3. The critical flood discharge level at Stung Treng is 66,000 m^3/s, which was only exceeded since 2000 in the year 2001 during 2 days.

Table 11.3 Exceedance duration of flood discharge level of given duration.

T (Years)	2	5	10	20	50	100
Q (m^3/s)	50,000	55,500	60,000	64,000	69,500	74,000
2000	28	21	8	0	0	0
2001	27	12	6	3	0	0
2002	21	7	4	0	0	0
2003	2	0	0	0	0	0
2004	3	0	0	0	0	0
2005	17	4	0	0	0	0
2006	2	0	0	0	0	0

The flood discharges presented for Stung Treng are also assumed applicable to Kratie. The critical flood discharge level in Kratie is 52,400 m^3/s, hence from the above table it may be observed that this level has been exceeded in 2000, 2001, 2002 and 2005. It follows that Kratie frequently has a serious flooding problem.

In the Annual Mekong Flood Report of 2005 (MRC, 2006) flood damages are reported for the provinces Stung Treng and Kratie. However, the normal annual floods, covering two-thirds of SA8, contribute to both agriculture and fisheries.

There is at present no hydraulic model available to translate the hydrological hazards into flood hazards. Only as from Kratie onward use can be made of model results. However, there is a large number of satellite images available for different flood levels, with which flood extent for different hazard levels can be estimated.

Flood duration

The duration of exceedance of a particular flood level is of importance to estimate the associated flood damage. This will be developed for all discharge gauging stations along the Mekong. As an example this has been elaborated for Stung Treng. It implies that for each hydrological year the accumulated duration of a discharge level exceedance is determined. The result is presented in Figure 11.15. It gives for different hazard levels the average exceeedance duration and the associated standard deviation of the range.The exceedance duration as a function of discharge can well be fitted by an exponential type of equation.

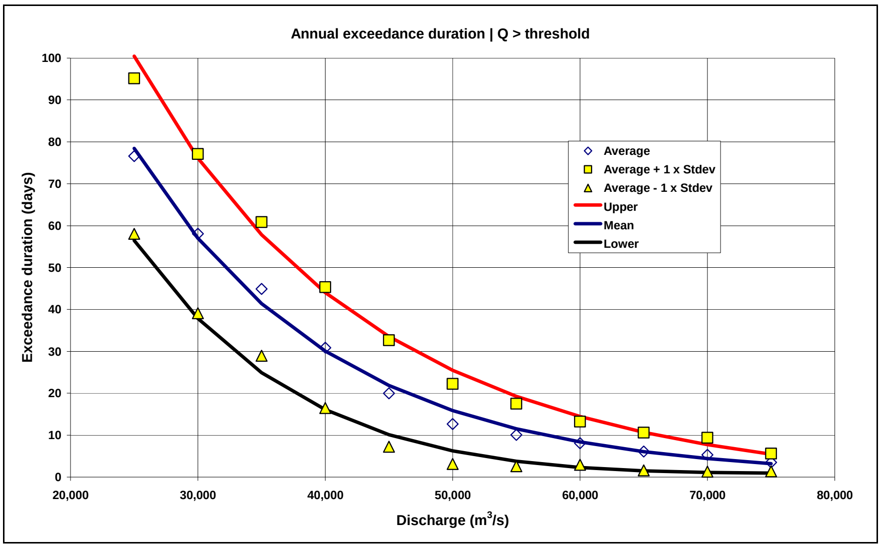

Figure 11.15 Annual exceedance duration for given flood discharge at Sung Treng.

It is noted that the volume is not explicitly taken into consideration as this is incorporated in the uncertainty of the exceedance duration.

Flood volume

For analysing the flooding downstream of Kratie in the delta and around Tonle Sap, the flood volume rather than the maximum discharge at Stung Treng/Kratie is of importance. The annual flood volume derived as the volume of water from June to November has been considered. For Stung Treng it is shown in Figure 11.10. The mean annual flood volume in Stung Treng for the period 1960-2006 is 364 BCM, with a standard deviation of 63 BCM.

A comparison of flood peaks and flood volumes for Stung Treng/Kratie is presented in Figure 11.16. It is observed that the flood of the year 2000, peakwise was not exceptional, but volume-wise is has been the largest on record. Similarly, the flood volumes of the floods of 2001 and of 2002 were among the highest.

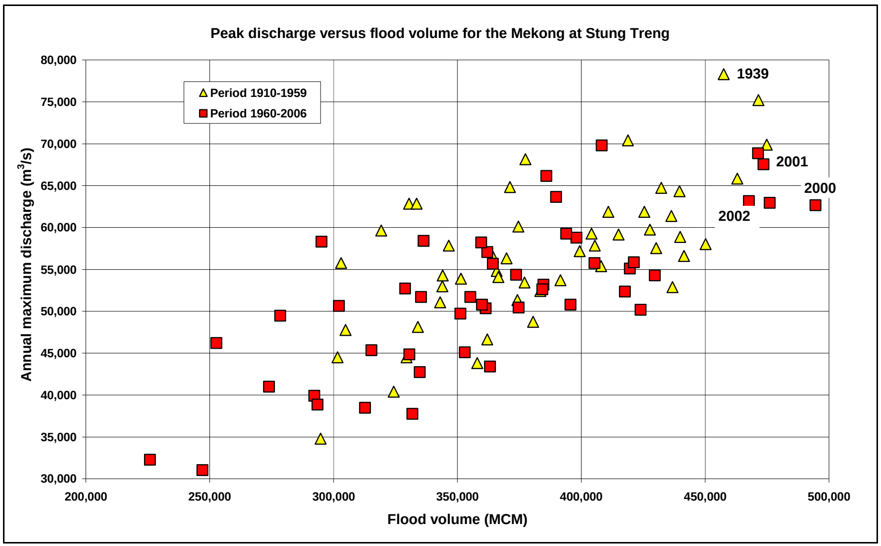

Figure 11.16 Peak discharge and flood volume for the Mekong at Stung Treng.

11.3.3 Combined floods

In view of the flatness of the major part of SA8, combined flooding will occur. However, both agriculture and fisheries welcome the annual flooding, except when the floods become extreme.

11.3.4 Summing up

In SA8 main stream flooding and combined flooding occurs. Apart from inundations of the cities, people welcome the normal floods as beneficial for agriculture and fisheries. 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. Prior to that a thorough review is required of the discharge ratings of Stung Treng and of Kratie. Exceedance duration can well be described by an exponential function of the discharge, including the uncertainty.

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 tranlation can be made. Downstream of Kratie satellite imagery as well as hydraulic models are available for the translation.

12 HYDROLOGICAL AND FLOOD HAZARD IN SUB-AREA 9

12.1 Basin characteristics

Sub-area 9 (SA9) covers the drainage area of the Tonle Sap Lake, see Figure 12.1. It covers an area of nearly 86,000 km^2, of which 81,818 km^2 is in Cambodia, and the rest in Thailand. The Tonle Sap basin is bordered by the Cardamon mountains in the west and south, shielding the basin from the Gulf of Thailand, and the Dangrek mountains in the north, which escarpment separates the basin from the Khorat Plateau. The Lake area in the dry season is about 2,750 km^2, whereas in the year 2000 (the highest year on record) the flood plain around the Lake rose to a level of 10.64 masl covering an area of 12,140 km^2, so the total area of open water at Tonle Sap for a very wet year may be as large as 14,900 km^2. This flood plain is part of the following main tributaries:

- Stung Chinit
- Stung Sen
- Stung Staung
- Stung Chikreng
- Stung Siem Reap
- Stung Sreng
- Stung Sisophon
- Stung Mongol Borey
- Stung Battambang
- Stung Sangker
- Stung Dauntri
- Stung Pursat
- Stung Baribo

The largest tributaries are the Stung Sen (16,359 km^2) and the Stung Mongol Borey (10,565 km^2). The remaining tributaries have areas between 2,000 and 10,000 km^2 (see also Table 12.8). The major part of SA9 are low lands with elevations below 100 masl and have gentle slopes (see Figure 12.2 and Figure 12.3). Levels rise in the southwest in the Cardamon mountains to over 1,500 m and in the north the steep escapment of the Dangrek mountains reaches to an average level of 500 m.

The land use map is presented in Figure 12.4. About 54% of the area is covered with forest of which 3 % is flooded forest, an important habitat for fish for reproduction and refuge. Some 25% of the land cover is agricultural land.

Figure 12.1 Layout of river basins in SA9 (BDP, 2006).

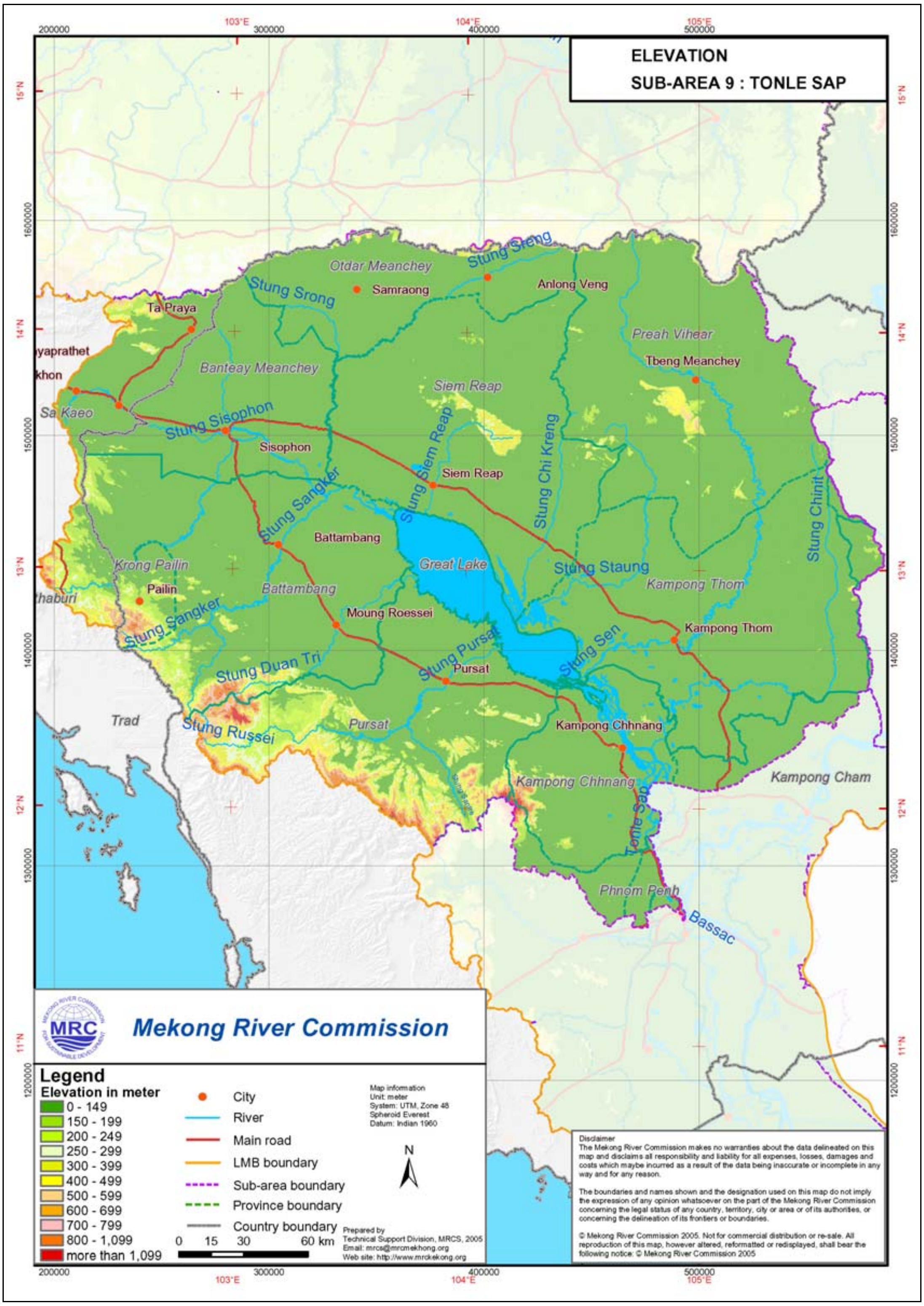

Figure 12.2 Elevation map of SA9 (BDP, 2006).

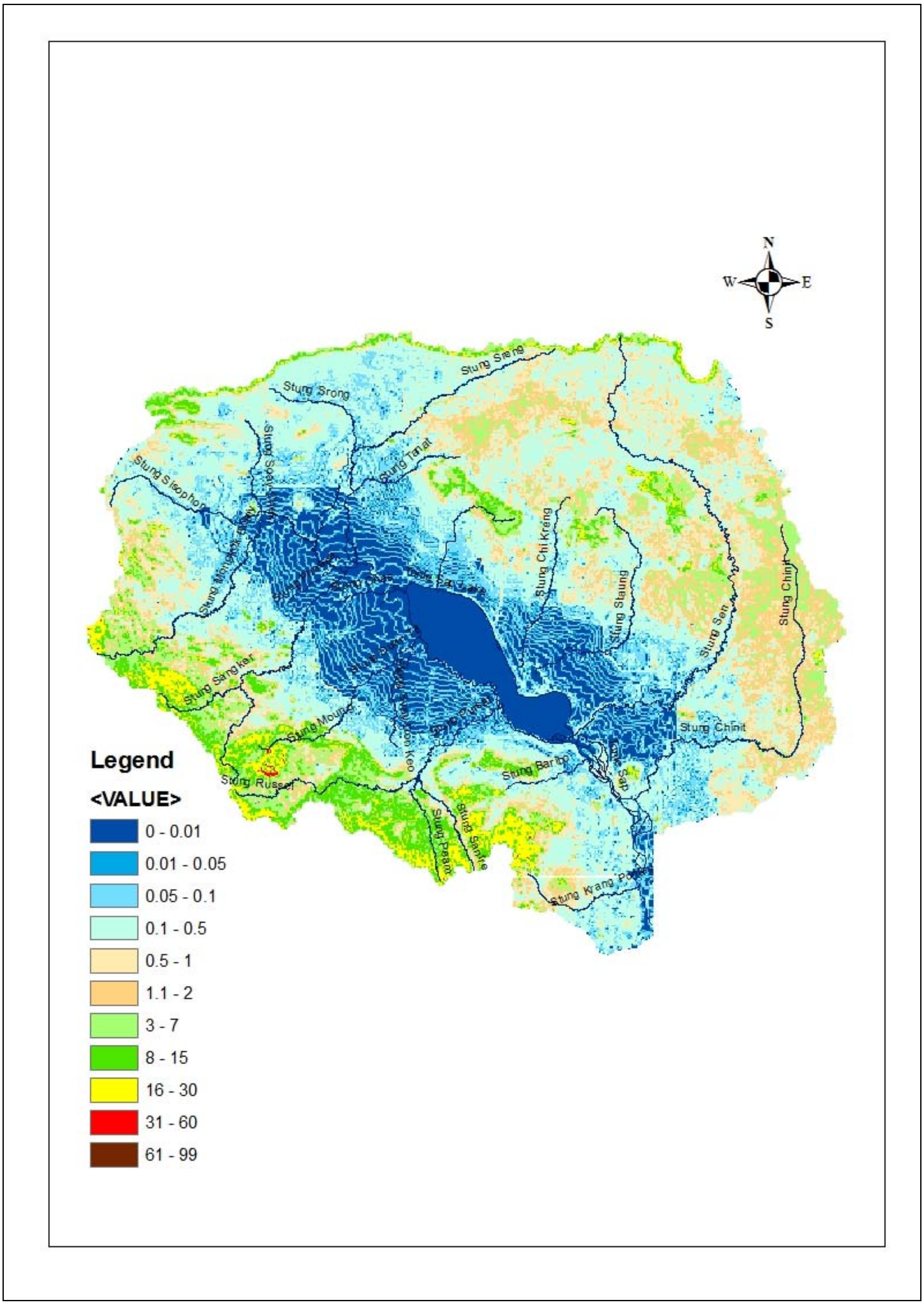

Figure 12.3 Slope map of SA9.

Figure 12.4 Land use map of SA9 (BDP, 2006).

12.2 Hydrological characteristics

12.2.1 Data availability

An overview of the rainfall, water level and discharge stations in SA9 is given in Figure 12.5 and Table 12.1 to Table 12.3.

The availability of rainfall data is presented in Table 12.4. A total number of 88 rainfall stations in Cambodia and 3 in Thailand exists in SA9, or on average 1 station per 950 km^2. The rainfall stations, however, are concentrated in middle and southern part of the area, whereas in the north-east no stations are available. The availability of rainfall data is very limited. Some 5 stations have longer series starting in the sixties, though with considerable gaps. Amother 8 stations have data in the sixties. The records of a number of stations start in the mid-nineties, and almost all have for a few years since 2000 data. The Thai stations have an almost complete record from 1980 till 2005, with one starting already in 1970.

Water level data is available for 5 stations on the Tonle Sap River and Lake, with 3 having records starting in 1960. The record for Prek Kdam is apparently completed as it is unlikely that in the second part of the seventies measurements have been taken. The major part of the water level stations refers to the Stungs, but their records generally cover a few years either in the mid-nineties or as from the late nineties onward. In general the records are very short.

The discharge records as available cover some 6 stations with a few complete years in the sixties and 17 stations with some years from the mid-nineties to 2002. Only for Kompong Thom on Stung Sen a longer record is available with 27 complete years.

There must be a larger database on rainfall and flow data available then present in the MRC HYMOS database, as can be deduced from the stations listed in CTI/DHI (2003) and WUP-FIN Phase II (2006). The latter present discharge data on the tributary inflow for the period 1997-2004 based on stations covering almost 60 % of the area draining to the Tonle Sap Lake. The database will therefore be extended with those completed and validated data.

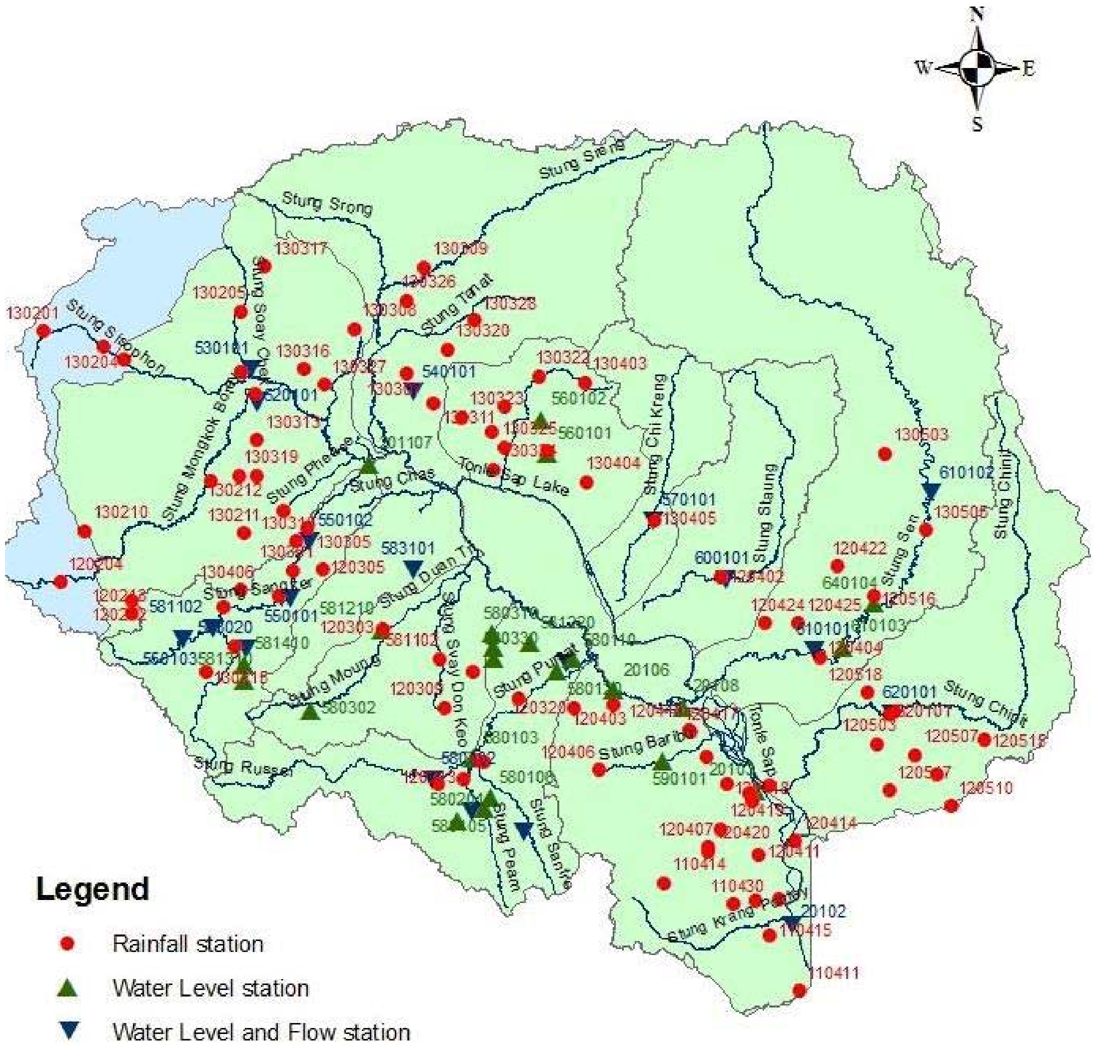

Figure 12.5 Lay-out of network of rainfall, water level and discharge stations in SA9.

Table 12.1 Overview of rainfall stations in SA9.

Rainfall

Station ID	Station Name	River	Coordinates (Indian 1960	
			Latitude	Longitude
110405	Kompong Tralach	Stung Baribo	11.9000	104.7667
110411	Phnom Penh (Ville)	Stung Baribo	11.6000	104.8334
110414	Tuol Khpos	Stung Baribo	11.9500	104.3834
110415	Oudong	Stung Baribo	11.7834	104.7334
110429	Boeung Leach	Stung Baribo	11.8938	104.6882
110430	Samaki Meanchey	Stung Baribo	11.8820	104.6120
120202	Pailin	Stung Monkol Borey	12.8587	102.6182
120205	Chamlong Kuoy	Stung Sangker	12.7134	102.9600
120206	Treng	Stung Sangker	12.8405	102.9205
120213	Rattanak Mondol	Stung Monkol Borey	12.8167	102.6167
120301	Tuol Krous	Stung Baribo	12.3610	104.5262
120302	Pursat	Stung Pursat	12.5500	103.9000
120303	Maung Russey	Stung Dauntry	12.7706	103.4500
120304	Dap Bat	Stung Pursat	12.3427	103.7870
120305	Raing Kesey	Stung Sangker	12.9667	103.2500
120306	Leach	Stung Pursat	12.3500	103.7667
120309	Talo	Stung Dauntry	12.5188	103.6591
120311	Cheang Meanchey	Stung Sangker	12.8772	103.1045
120312	Kravanh	Stung Pursat	12.6748	103.6477
120313	Peam	Stung Pursat	12.2865	103.7224
120320	Beoung Kantot	Stung Baribo	12.5167	104.0871
120401	Kompong Chhnang	Stung Baribo	12.2412	104.6667
120402	Staung	Stung Staung	12.9481	104.5722
120403	Krakor	Stung Baribo	12.5324	104.2174
120404	Kompong Thom	Stung Sen	12.6862	104.9000
120406	Bamnak	Stung Baribo	12.3167	104.1667
120407	Sdoc Ach Romeas	Stung Baribo	12.0667	104.5334
120410	Baribo	Stung Baribo	12.4500	104.4667
120411	Boeung Por	Stung Baribo	12.0428	104.7000
120414	Doun Pean	Tonle Sap / Great Lake	12.0878	104.8145
120415	Kompong Leang	Tonle Sap / Great Lake	12.2667	104.7334
120416	Rolear Phear	Stung Baribo	12.2177	104.6746
120417	Ponley	Stung Baribo	12.4432	104.4712
120418	Pong Ro	Stung Baribo	12.2746	104.5926
120419	Krang Tamoung	Stung Baribo	12.1263	104.5739
120420	Tuk Phos	Stung Baribo	12.0548	104.5284
120422	Prasat Balang	Stung Sen	12.9810	104.9588
120423	Stung Chinit	Stung Chinit	12.5102	105.1466
120424	Kondal Chrass	Stung Sen	12.7962	104.7147
120425	Prey Prous	Stung Sen	12.7984	104.8290
120426	Beoung Khnar	Stung Dauntry	12.6354	103.7506
120503	Baray	Stung Chinit	12.4040	105.0895
120507	Chamcar Andong	Stung Chinit	12.3667	105.2167
120509	Chamcar Leur	Stung Chinit	12.3041	105.2846
120515	Kompong Seam	Stung Chinit	12.4167	105.4429
120516	Prasat Sambo	Stung Sen	12.8857	105.0765

Rainfall

Station ID	Station Name	River	Coordinates (Indian 1960	
			Latitude	Longitude
120517	Taing Kok	Stung Chinit	12.2522	105.1295
120518	Taing Krasaing	Stung Chinit	12.5710	105.0572
130202	Sisophon	Stung Monkol Borey	13.6091	102.9705
130205	Svay Chek	Stung Monkol Borey	13.8020	102.9710
130208	Bovel	Stung Monkol Borey	13.2525	102.8772
130209	O Chrov	Stung Monkol Borey	13.6428	102.5839
130210	Komrieng	Stung Monkol Borey	13.0845	102.4617
130211	Komping Pouy	Stung Monkol Borey	13.0805	102.9909
130212	Roung Chrey	Stung Monkol Borey	13.2685	102.9708
130215	Samlot	Stung Sangker	12.6295	102.8635
130301	Banan	Stung Sangker	12.9615	103.1538
130304	O Taky	Stung Monkol Borey	13.1544	103.1174
130305	Battambang	Stung Sangker	13.1000	103.2000
130306	Air Port/Seam Reap	Stung Siem Reap	13.4183	103.8075
130307	Kralanh(Kealanh)	Stung Sreng	13.6043	103.5231
130308	Phnom Srok	Stung Monkol Borey	13.7500	103.3500
130309	Chong Kal	Stung Sreng	13.9500	103.5834
130310	Angkor Watt	Stung Siem Reap	13.4996	103.8517
130311	Sasar Sdam	Stung Sreng	13.5062	103.6170
130313	Tuol Samraung	Stung Monkol Borey	13.3853	103.0303
130315	Mongkol Borey	Stung Monkol Borey	13.5367	103.0231
130316	Pranet Preah	Stung Monkol Borey	13.6167	103.1834
130317	Thmar Pouk	Stung Monkol Borey	13.9492	103.0514
130318	Boeung Raing	Stung Monkol Borey	13.0570	103.1595
130319	Thmar Kol	Stung Monkol Borey	13.2691	103.0303
130320	Angkor Chum	Stung Sreng	13.6853	103.6592
130321	Prasat Bakong	Stung Siem Reap	13.3545	103.9909
130322	Banteay Srey	Stung Siem Reap	13.5981	103.9653
130323	Khum Lvear	Stung Siem Reap	13.4637	103.7103
130324	Phnom Krom	Stung Siem Reap	13.2939	103.8174
130325	Siem Reap Koktatry	Stung Siem Reap	13.3667	103.8500
130326	Srey Snam	Stung Sreng	13.8431	103.5231
130327	Svay Leu	Stung Monkol Borey	13.5667	103.2500
130328	Varin	Stung Sreng	13.7833	103.7500
130403	Phnom Koulen	Stung Siem Reap	13.5800	104.1170
130404	Dam Dek	Stung Siem Reap	13.2556	104.1250
130405	Kompong Kdei	Stung Chikreng	13.1300	104.3477
130406	Tbeng (Sdau)	Stung Monkol Borey	12.8982	102.9773
130503	Rovieng	Stung Sen	13.3500	105.1167
130505	Sondan	Stung Sen	13.1000	105.2500
520101	Mong Kolborey	Mongkol Borey	13.5037	103.0191
581102	Svay Donkeo	Stung Dauntry	12.7703	102.8791
	9T			
120204	PON NAM RON	Stung Monkol Borey	12.9167	102.3834
130201	WATTHANA NAKHON	Stung Monkol Borey	13.7334	102.3167
130204	ARANYAPRATHET	Stung Monkol Borey	13.6834	102.5167

Table 12.2 Overview of water level gauging stations in SA9.

Water Level

Station ID	Station Name	River	Coordinates (Indian 1960	
			Latitude	Longitude
020102	Prek Kdam	Tonle Sap	11.8133	104.8041
020103	Kg. Chhnang	Tonle Sap	12.2505	104.6859
020106	Kg. Luong	Tonle Sap	12.5752	104.2146
020107	Bac Prea	Tonle Sap	13.3087	103.3992
020108	Snoc Trou	Tonle Sap	12.5212	104.4453
520101	Mong Kolborey	Mongkol Borey	13.5037	103.0191
530101	Sisophon	Sisophon	13.6139	102.9981
540101	Kralanh	Stung Sreng	13.5436	103.5432
550101	Treng	Stung Sangker	12.8693	103.1390
550102	Battambang	Stung Sangker	13.0560	103.1986
550103	Sre Ponleu	Stung Sangker	12.7310	102.7799
551101	Mong Russey	St. Dauntry	12.8529	103.4396
560101	Bot Chhvear/Untac Brid	Siem Reap	13.3443	103.9956
560102	Prasat Keo	Siem Reap	13.4555	103.9709
570101	Kompong Kdei	St. Chikreng	13.1267	104.3393
580101	Pursat	Stung Pursat	12.6627	104.0543
580102	Taing Leach	Stung Pursat	12.2832	103.6130
580103	Bac Trakoun	Pursat	12.3535	103.7523
580104	Khum Viel	Stung Pursat	12.1794	103.7434
580105	Lo Lok Sar	Pursat	12.1911	103.7890
580106	Phum Kos	Pursat	12.2245	103.8074
580110	Kbal hong(up)	Pursat	12.6806	104.0798
580120	Kbal hong(down)	Stung Pursat	12.6366	104.0285
580201	Peam	Pursat	12.1500	103.7000
580301	Prey Klong(down)	Stung Pursat	12.1106	103.9136
580302	Prey Klong(up)	Stung Santre	12.5044	103.2144
580310	Sanlong(up)	Pursat	12.7575	103.8134
580320	Sanlong(down)	Pursat	12.7137	103.8159
580330	Svay At	Pursat	12.6750	103.8159
581102	Svay Don Keo	Pursat	12.7703	102.8791
581210	Kroch seuch (up)	St. Dauntry	12.7703	103.4449
581220	Kroch seuch (down)	St. Dauntry	12.7293	103.9372
581310	Wat Liep(down)	Pursat	12.6031	102.9914
581410	Wat Liep(up)	Pursat	12.6545	102.9914
583020	Thlea Maam(up)	Pursat	12.7034	102.9889
583101	Banteay Krang	St. Krakor	12.9660	103.5430
590101	Boribo	Stung Boribo	12.3476	104.3804
600101	Kompong Chen	Stung Staung	12.9375	104.5825
610101	Kg. Thom	Stung Sen	12.7075	104.8730
610102	Kompong Putrea	Stung Sen	13.2173	105.2635
610103	Panha Chi	Stung Sen	12.7173	104.9719
620101	Kg. Thmar	Stung Chinit	12.5010	105.1309

Table 12.3 Overview of discharge stations in SA9.

Flow

Station ID	Station Name	River	Coordinates (Indian 1960	
			Latitude	Longitude
020102	Prek Kdam	Tonle Sap	11.8133	104.8041
520101	Mong Kolborey	Mongkol Borey	13.5037	103.0191
530101	Sisophon	Sisophon	13.6139	102.9981
540101	Kralanh	Stung Sreng	13.5436	103.5432
550101	Treng	Stung Sangker	12.8693	103.1390
550102	Battambang	Stung Sangker	13.0560	103.1986
550103	Sre Ponleu	Stung Sangker	12.7310	102.7799
560101	Bot Chhvear/Untac Brid	Siem Reap	13.3443	103.9956
570101	Kompong Kdei	St. Chikreng	13.1267	104.3393
580101	Pursat	Stung Pursat	12.6627	104.0543
580102	Taing Leach	Stung Pursat	12.2832	103.6130
580103	Bac Trakoun	Pursat	12.3535	103.7523
580104	Khum Viel	Stung Pursat	12.1794	103.7434
580201	Peam	Pursat	12.1500	103.7000
580301	Prey Klong(down)	Stung Pursat	12.1106	103.9136
581102	Svay Don Keo	Pursat	12.7703	102.8791
583020	Thlea Maam(up)	Pursat	12.7034	102.9889
583101	Banteay Krang	St. Krakor	12.9660	103.5430
590101	Boribo	Stung Boribo	12.3476	104.3804
600101	Kompong Chen	Stung Staung	12.9375	104.5825
610101	Kg. Thom	Stung Sen	12.7075	104.8730
610102	Kompong Putrea	Stung Sen	13.2173	105.2635
620101	Kg. Thmar	Stung Chinit	12.5010	105.1309

Table 12.4 Availability of daily rainfall data in SA9.

Daily Data Availability of BDP Sub-Area 9C (before 60)

Rainfall

Station ID	Station Name	River	1910										1920										1930										1940										1950									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
110405	Kompong Tralach	Stung Baribo											+	+	+	+	+	+		+	+		+																													
120302	Pursat	Stung Pursat			+	+	+	+	+	+	+	+	+	+	+	+			+		+		+				+	+				+	+	+	+										+	+	+	+	+	+	+	+
120303	Maung Russey	Stung Dauntry																										+	+	+	+	+	+											+	+	+						
120305	Raing Kesey	Stung Sangker																														+	+																			
120306	Leach	Stung Pursat																															+	+	+																	
120401	Kompong Chhnang	Stung Baribo											+		+	+	+	+		+		+	+	+	+	+	+	+	+	+	+	+													+	+						
120402	Staung	Stung Staung																61														138	152	92																		
120403	Krakor	Stung Baribo																					+									+	+	+	+	+			+	+	+	+	+	+	+	+						
120404	Kompong Thom	Stung Sen											+		+	+	+	+		+	+	+	+	+	+	1	+	+	+	+	1	+	+	+	30	+										+	+	+	+			
120406	Bamnak	Stung Baribo																														+	+	+	+																	
120417	Ponley	Stung Baribo																					+																													
120503	Baray	Stung Chinit											32		+		90	14	+	+	+	+	+	+	+	+	+	+	+	+	+	28	+	+	+										93							
120507	Chamcar Andong	Stung Chinit																					+									+	+	+							182	+	+	276	+	+	+	+	31		92	59
120509	Chamcar Leur	Stung Chinit																													1																151	68	31		+	+
130305	Battambang	Stung Sangker											+		+	+	+	+	+	+	121	+	+	+	+	+	+	+	+	+	+	+	+											+	+	+	+	+	+		+	
130307	Kralanh(Kealanh)	Stung Sreng											+		+		+	+		+	+											+																				
130308	Phnom Srok	Stung Monkol Borey																													+	+	+																			
130313	Tuol Samraung	Stung Monkol Borey																									61		212	59	171	31	213																			
130315	Mongkol Borey	Stung Monkol Borey																														+	+																			
130325	Siem Reap Koktatry	Stung Siem Reap											+		+	+	+	+		+	+		+									+											+	+	+	+	+	+	+	+		

Daily Data Availability of BDP Sub-Area 9C (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
110405	Kompong Tralach	Stung Baribo		+	+	+	+																														+		+	+	+	+	+	+	123				+
110411	Phnom Penh (Ville)	Stung Baribo				+	+	+	+	+													+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	121	+	244									
110414	Tuol Khpos	Stung Baribo																																									+	30					
110415	Oudong	Stung Baribo																																					+	+	+	+	+	+	+	+	+	+	+
110429	Boeung Leach	Stung Baribo																																									+	+	+	+	+		
110430	Samaki Meanchey	Stung Baribo																																					+	+	+	+	+	+	+	+	+	+	+
120202	Pailin	Stung Monkol Borey	213	+	+	+	+	+	+	+	+	+	+	+	+	+	+																										+	+	+				
120205	Chamlong Kuoy	Stung Sangker																																									+	+	+				
120206	Treng	Stung Sangker																																									+	+	+				
120213	Rattanak Mondol	Stung Monkol Borey																																									+	+	+				
120301	Tuol Krous	Stung Baribo		+	+	+	+	+																																				+	+				
120302	Pursat	Stung Pursat	+	+	+	+	+									+								+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
120303	Maung Russey	Stung Dauntry		+	+	+	+																													+	+	+	+	+	+	+	+	+	+		+		+
120304	Dap Bat	Stung Pursat	+	+	+	+	+	+	+	+	+																																+	+	+		+	+	+
120305	Raing Kesey	Stung Sangker	+	+	+	+	+																																										
120306	Leach	Stung Pursat		+		+	+																																										

Daily Data Availability of BDP Sub-Area 9C (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
120309	Talo	Stung Dauntry																																										+	+	+	+	+	+	+	+
120311	Cheang Meanchey	Stung Sangker																																											+	+	+				
120312	Kravanh	Stung Pursat																																				+	+	+		+	+	+	+	+	+	2	1	+
120313	Peam	Stung Pursat																																											+	+	+		4	1	+
120320	Beoung Kantot	Stung Baribo																																				+	+	+			+	+	+	+	+	+	2	+
120401	Kompong Chhnang	Stung Baribo		+	+	+	+	+	+	+	+	+	280	+	+	+	214								+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+
120402	Staung	Stung Staung		150	121	90	91																																	+	+	+	+	+	+			+	+
120403	Krakor	Stung Baribo	+	+	+	+	+	+	+	+	+	+	+	+	+																						+	+	+			+	+	+	+	+	3	3	+
120404	Kompong Thom	Stung Sen	+	+	+	+	+	+	+	+		+	153											+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
120406	Bamnak	Stung Baribo		+	+	+	+																													31						+	+	+	+	+	+	+	+
120407	Sdoc Ach Romeas	Stung Baribo		+	+	+	+																																										
120410	Baribo	Stung Baribo		182	59	120	60																																							+	+		
120411	Boeung Por	Stung Baribo																																									+	+	+		+		
120414	Doun Pean	Tonle Sap / Great Lake																																									+	+	+				
120415	Kompong Leang	Tonle Sap / Great Lake																																			+		+	+	+	+	+	+	+	+	+		
120416	Rolear Phear	Stung Baribo																																			+		+	+	+	+	+	+	+	+	+	+	+
120417	Ponley	Stung Baribo																																			+		+	+	+			+	+	+	+	+	+
120418	Pong Ro	Stung Baribo																																									+	+	+	+	+		
120419	Krang Tamoung	Stung Baribo																																									+	+	+	+			
120420	Tuk Phos	Stung Baribo																																			+		+	61	+	+	+	+	+	+	+	+	+
120422	Prasat Balang	Stung Sen																																									+	+	+				
120423	Stung Chinit	Stung Chinit																																						+	+	+	+	+	+	+	+	+	
120424	Kondal Chrass	Stung Sen																																									61	+	+	+	+	+	
120425	Prey Prous	Stung Sen																																						61	+	+	+	+	+	+	+	+	
120426	Beoung Khnar	Stung Dauntry																																			+	+	+					+	+	+	+	+	+
120503	Baray	Stung Chinit			28	90	91																																	31	31	+	+	+	+	+	+	+	+
120507	Chamcar Andong	Stung Chinit	60	2	59	59	+																																										
120509	Chamcar Leur	Stung Chinit	+	+	+	+	+																																				+	+	+				
120515	Kompong Seam	Stung Chinit																																						61			+	+	+				
120516	Prasat Sambo	Stung Sen																																									+	+	+		+	+	
120517	Taing Kok	Stung Chinit																																						+	+	+	+	+	+	+	+	+	
120518	Taing Krasaing	Stung Chinit																																						+	275	+	+	+	+	+	+	+	
130202	Sisophon	Stung Monkol Borey		+	+	+	+	+	+	+	+	+	+	+	+															92	31	+	122	61	+	+	214	+	31				61	+	+	+		+	+
130205	Svay Chek	Stung Monkol Borey																																									31	+	+	+	+	+	

Daily Data Availability of BDP Sub-Area 9C (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
130208	Bovel	Stung Monkol Borey																																									+	+	1				+
130209	O Chrov	Stung Monkol Borey																																										61	+	+			
130210	Komrieng	Stung Monkol Borey																																									+	+	+				
130211	Komping Pouy	Stung Monkol Borey																																									+	+	+				
130212	Roung Chrey	Stung Monkol Borey																																									+	+	+				
130215	Samlot	Stung Sangker																																									+	+	+				
130301	Banan	Stung Sangker																																									+	+	+				
130304	O Taky	Stung Monkol Borey																																									+	+	+				
130305	Battambang	Stung Sangker	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+		+		
130306	Air Port/Seam Reap	Stung Siem Reap																																							+	+	+	+	+			+	+
130307	Kralanh(Kealanh)	Stung Sreng		+	+	+	+																																+	92	+	+	+	+	+	+	+	+	+
130308	Phnom Srok	Stung Monkol Borey		+	+	+	+																																			61	31	+	+	+	2	+	
130309	Chong Kal	Stung Sreng																																							+		+						
130310	Angkor Watt	Stung Siem Reap																																										+	+				
130311	Sasar Sdam	Stung Sreng																																										+	+			+	+
130313	Tuol Samraung	Stung Monkol Borey																																									+	+	+				
130315	Mongkol Borey	Stung Monkol Borey																																										+	+	+	+	+	
130316	Pranet Preah	Stung Monkol Borey																																										+	+	+	+	+	
130317	Thmar Pouk	Stung Monkol Borey																																										+	+	+	+	+	
130318	Boeung Raing	Stung Monkol Borey																																									+	+	+				
130319	Thmar Kol	Stung Monkol Borey																																			+	+	+		+	+	+	+	+				
130320	Angkor Chum	Stung Sreng																																						+	+			+	+	+		+	+
130321	Prasat Bakong	Stung Siem Reap																																						+	+	+		+	+	+		+	+
130322	Banteay Srey	Stung Siem Reap																																							61			+	+	+	+	+	+
130323	Khum Lvear	Stung Siem Reap																																										+	+				+
130324	Phnom Krom	Stung Siem Reap																																										+	+			+	+
130325	Siem Reap Koktatry	Stung Siem Reap		+	+	+	+					+												+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+						+	
130326	Srey Snam	Stung Sreng																																										+	+		+	+	+
130327	Svay Leu	Stung Monkol Borey																																										+	+			+	+
130328	Varin	Stung Sreng																																										+	+	+	+	+	+
130403	Phnom Koulen	Stung Siem Reap																																										+	+			+	+
130404	Dam Dek	Stung Siem Reap																													+	92	122					+	+	+		+	+				
130405	Kompong Kdei	Stung Chikreng		+	+	+	+	+	+	+	+	+	214																						153				+	+	92	+		+	+		+		
130406	Tbeng (Sdau)	Stung Monkol Borey																																											+				
130503	Rovieng	Stung Sen		214	+							+																																					
130505	Sondan	Stung Sen																																						61	+	+	+	+	+		+	+	+
520101	Mong Kolborey	Mongkol Borey																														31	122	92	92		61				92	61	91						
581102	Svay Donkeo	Stung Dauntry																																								+	+	+	+	+	+	+	+
	9T																																																
120204	PON NAM RON	Stung Monkol Borey																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	
130201	WATTHANA NAKHON	Stung Monkol Borey																							+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
130204	ARANYAPRATHET	Stung Monkol Borey											+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	

Table 12.5 Availability of water level data in SA9.

Water Level

Station ID	Station Name	River	1920										1930										1940										1950									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
020103	Kg. Chhnang	Tonle Sap					+	31	45	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
020106	Kg. Luong	Tonle Sap				31	+	31	45	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Water Level

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
020102	Prek Kdam	Tonle Sap	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
020103	Kg. Chhnang	Tonle Sap	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+						182	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	31
020106	Kg. Luong	Tonle Sap	122	+	90	+	+	+																															152	124	212	+	+	+	+	+	+	+	+
020107	Bac Prea	Tonle Sap			90	91																																				+	+	+	+	+	122		
020108	Snoc Trou	Tonle Sap			90	91																																											
520101	Mong Kolborey	Mongkol Borey			90	334																																		120	+	+	+	+	+	+			
530101	Sisophon	Sisophon			162																																			120	+	+	+	+	+	30			
540101	Kralanh	Stung Sreng			90																																			151	+	184	60	+	+	+	+	+	+
550101	Treng	Stung Sangker				+	14	5	+	+	+	+	+	+	+	183																										217	91	+	+				
550102	Battambang	Stung Sangker			90	275									113	163								151	31	+	+	+	163	31	177										71	+	+	+	+	+	+	+	+	+
550103	Sre Ponleu	Stung Sangker					+	+	+																																								
551101	Mong Russey	St. Dauntry																																										151	+				
560101	Bot Chhvear/Untac Br	Siem Reap																																						+	+	+	+	153	+				+
560102	Prasat Keo	Siem Reap																																								6	+	+	+	+	122		+
570101	Kompong Kdei	St. Chikreng			90	275																																		151	+	123	+	+	+	+	+	31	+
580101	Pursat	Stung Pursat			90	275									91	+	275																																
580102	Taing Leach	Stung Pursat						11	+	+	+	36																																					
580103	Bac Trakoun	Pursat																																			255	+	+	306				+	+	+			
580104	Khum Viel	Stung Pursat																																				120	+	306		+	+	+	+	+	+	+	+
580105	Lo Lok Sar	Pursat																																			90	+	+	306				+	+	+	12	+	+
580106	Phum Kos	Pursat																																			90	+	+	306									
580110	Kbal hong(up)	Pursat																																				120	+	306				+	+	+	+	+	+
580120	Kbal hong(down)	Stung Pursat																																				242				+	+	+	+	+	+	+	
580201	Peam	Pursat																																										+	+	+	+	+	+
580301	Prey Klong(down)	Stung Pursat																																			90	+	+	306				+	+	+	+	+	+
580302	Prey Klong(up)	Stung Santre																																			243	+	+	306				+					
580310	Sanlong(up)	Pursat																																				212	+	306									
580320	Sanlong(down)	Pursat																																				212	+	306									
580330	Svay At	Pursat																																			90	+	+	306									
581102	Svay Don Keo	Pursat			90	275																																90	+	306				+	+	+	+	+	73
581210	Kroch seuch (up)	St. Dauntry																																				212	+	306									
581220	Kroch seuch (down)	St. Dauntry																																				212	+	306									
581310	Wat Liep(down)	Pursat																																				212	+	306									
581410	Wat Liep(up)	Pursat																																				212	+	306									
583020	Thlea Maam(up)	Pursat																																			90	+	+	306									
583101	Banteay Krang	St. Krakor																																			90	+	+	306									
590101	Boribo	Stung Boribo																																							184	+	+	+	+	+	+		
600101	Kompong Chen	Stung Staung			90	275																																		91	+	92	182	+	+	+	+	+	+
610101	Kg. Thom	Stung Sen		124	+	+	+	+	+	+	+	+	245											138	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
610102	Kompong Putrea	Stung Sen						+	+	+	+	+																														69	+	182	61	+			
610103	Panha Chi	Stung Sen																																								273	+	+	+	+	+	+	+
620101	Kg. Thmar	Stung Chinit			90	275																																		94	+	+	+	+	+	+	+	3	31

Table 12.6 Availability of discharge data in SA9.

Flow

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
020102	Prek Kdam	Tonle Sap	185	2	1	+	+	+	1	4	35	+	+	+	+	199																																	
520101	Mong Kolborey	Mongkol Borey			90	275																																		120	+	+	+	+	+				
530101	Sisophon	Sisophon			160	275																																		86	+	+	+	+	+				
540101	Kralanh	Stung Sreng			90	275																																		151	+	184	60	+	+				
550101	Treng	Stung Sangker				+	15	5	+	+	+	+	+	+	+	183																											155	+	39				
550102	Battambang	Stung Sangker			90	275																																		71	+	+	+	+	+				
550103	Sre Ponleu	Stung Sangker					+	+	+																																								
560101	Bot Chhvear/Untac B	Siem Reap																																						+	+	+	+	153	+				
570101	Kompong Kdei	St. Chikreng			90	275																																		151	+	123	+	+	+				
580101	Pursat	Stung Pursat			90	275																																											
580102	Taing Leach	Stung Pursat						+	+	+	+	36																																					
580103	Bac Trakoun	Pursat																																			255	+	+	306				+	+				
580104	Khum Viel	Stung Pursat																																				120	+	306					+				
580201	Peam	Pursat																																										+	+				
580301	Prey Klong(down)	Stung Pursat																																			90	+	+	306					+				
581102	Svay Don Keo	Pursat			90	275																																											
583020	Thlea Maam(up)	Pursat																																			90	+	+	306									
583101	Banteay Krang	St. Krakor																																			90	+	+	306									
590101	Boribo	Stung Boribo																																							151	+	+	+	+				
600101	Kompong Chen	Stung Staung			90	275																																		91	+	92	182	+	+				
610101	Kg. Thom	Stung Sen		124	+	+	35	+	+	+	+	+	245												+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	214	+	+	+	+				
610102	Kompong Putrea	Stung Sen						+	+	+	+	+																																					
620101	Kg. Thmar	Stung Chinit			90	275																																		94	+	+	+	+	+				

Notes: + = no missing
blank = missing
90 = number of missing days in a year

12.2.2 Rainfall

Average annual rainfall in the area around Tonle Sap varies from 1,300 to 1,600 mm, increasing in easterly direction. An example of the annual variation is given for Aranyaprathet in the basin of Stung Mongol Borey in Thailand, with an average annual rainfall of 1380 mm and a standard deviation of 180 mm.

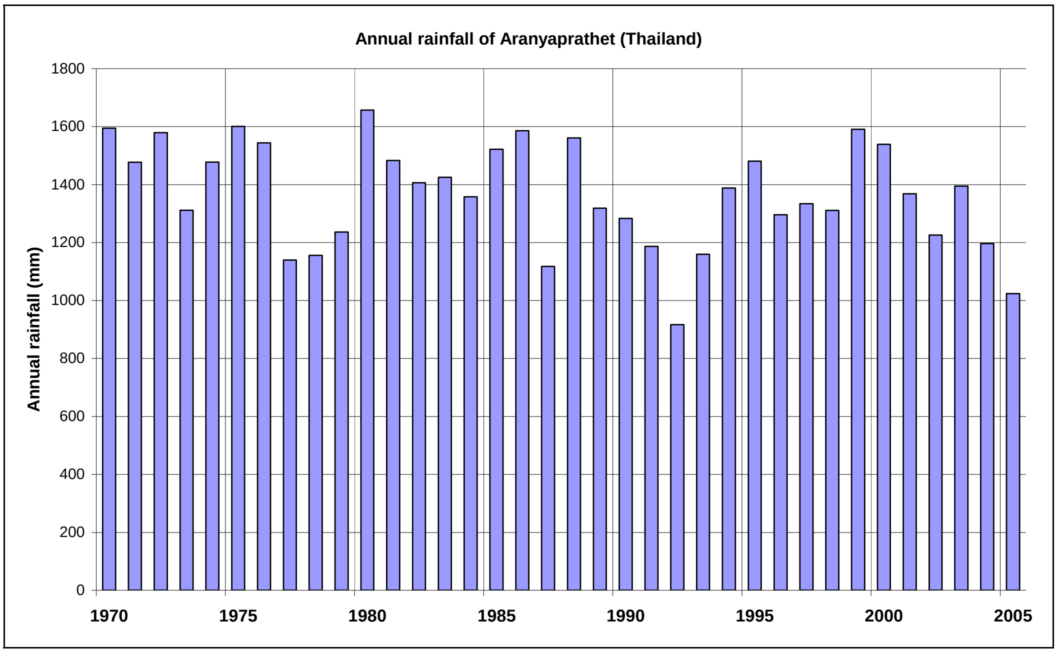

Figure 12.6 Annual rainfall of Aranyaprathet 1970-2005.

The seasonal variation for the Cambodian stations Kompong Chhnang and Battambang is shown in Figure 12.7 and Figure 12.8 and for Aranyaprathet in Figure 12.9. It is observed that the rainy period extends from May to October. It is noted that different from the northern sub-areas October is now among the wettest months.

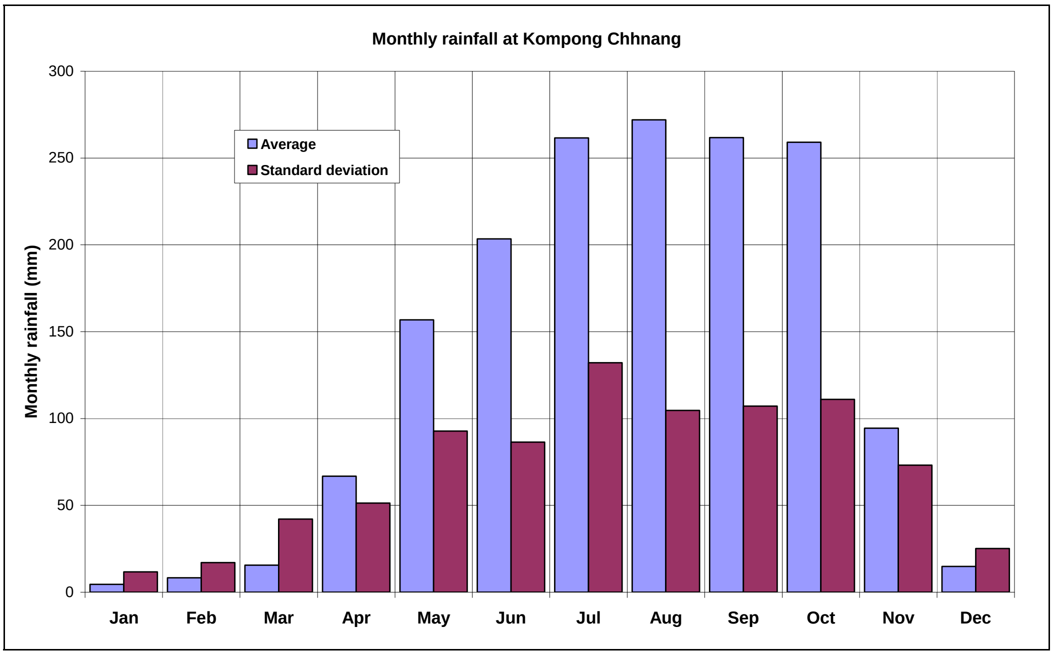

Figure 12.7 Monthly rainfall characteristics of Kompong Chhnang (Cambodia).

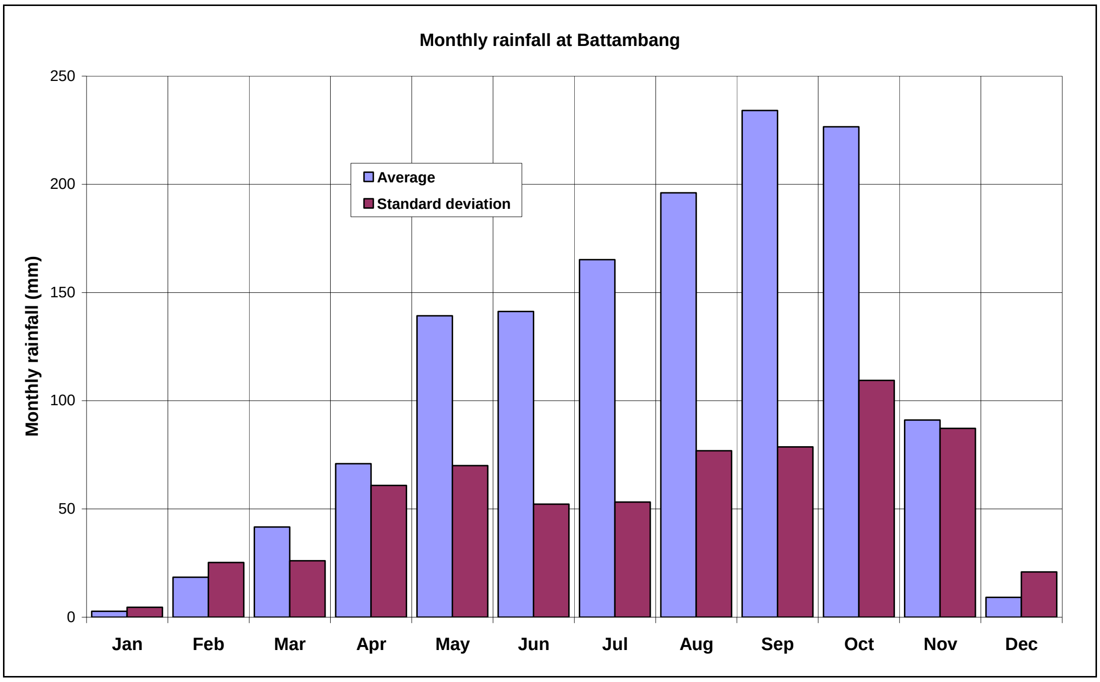

Figure 12.8 Monthly rainfall characteristics of Battambang (Cambodia).

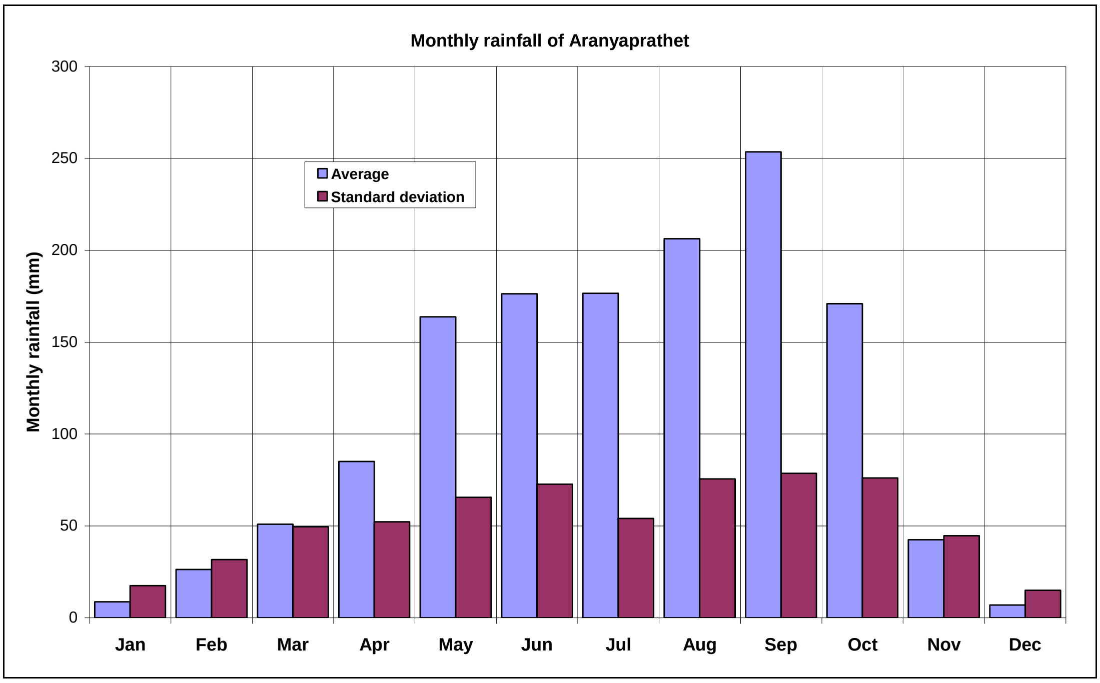

Figure 12.9 Monthly rainfall characteristics of Aranyaprathet (Thailand).

12.2.3 Water balance of Tonle Sap

The flows in the Mekong and Bassac downstream of Phnom Penh are affected by the filling and emptying of the Tonle Sap Great Lake. The water level of the Great Lake is lowest in April-May. When the river flows and levels start rising in May-June water flows via the Tonle Sap River into the lake. This flow can be estimated from the rating curve at Prek Kdam, corrected for backwater effects. If the flow at Kampong Cham exceeds about 25,000 m^3/s water starts spilling over both banks of the Mekong between Kampong Cham and Phnom Penh and part of the spill over the right bank reaches the lake as overland flow not measured at Prek Kdam. The flow towards the lake from the Mekong indicated as reverse flow continues generally till late September until the water level in the lake measured at Kampong Luong exceeds the level at Phnom Penh. Besides contributions from the Mekong water also enters the lake from the Tonle Sap tributaries mainly in the period May to November and the net precipitation on the lake. The outflow from the lake to the Mekong and Bassac rivers covers the period October-April/May.

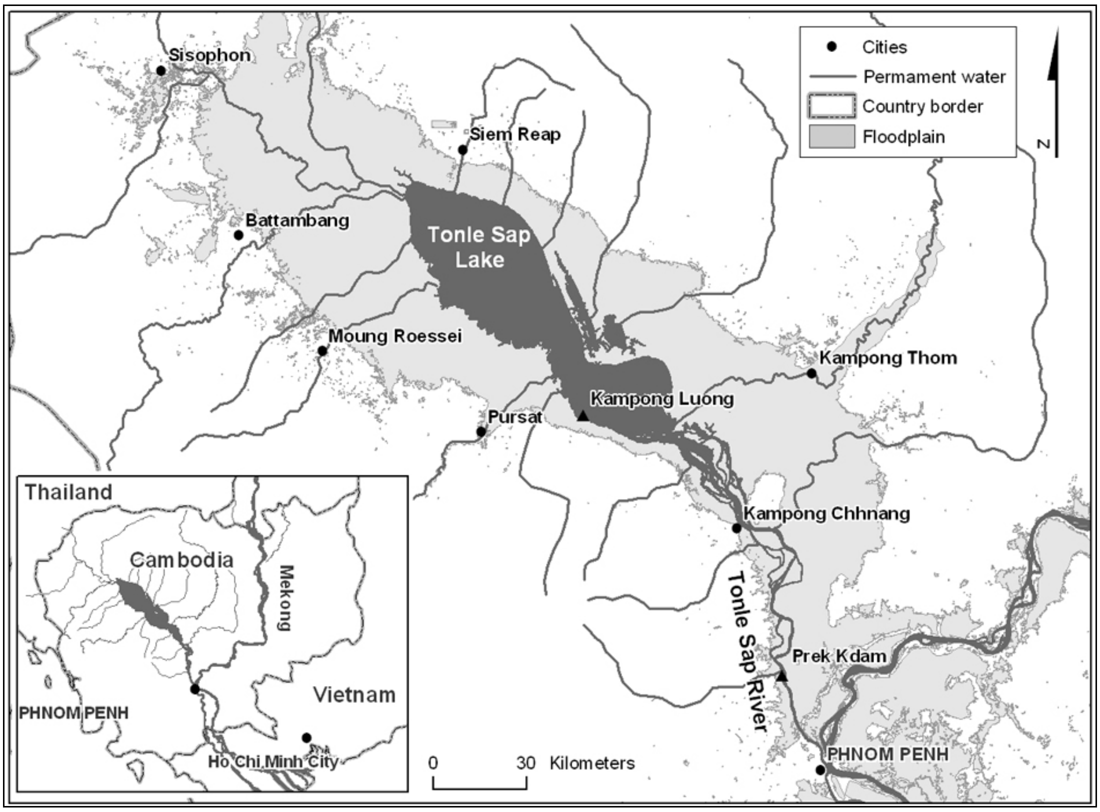

Figure 12.10 Tonle Sap Lake with permanent contour and flood plain and Tonle Sap River (MRC/WUP-FIN, 2006).

Water balance

The water balance components of Tonle Sap Great Lake include (with 1997-2001 averages):

- Storage change of Tonle Sap Great Lake
- Inflow from Mekong (40.7 BCM or 51% of inflow) and outflow to Mekong and Bassac (-70.4 BCM or 88 % of outflow) via Tonle Sap River, measured at Prek Kdam
- Overland flow from Mekong bypassing Prek Kdam (3.8 BCM or 5% of inflow) and vice versa
- Tributary inflow (25.1 BCM or 31 % of inflow)
- Lake rainfall (10.1 BCM or 13% of inflow) and evaporation (-9.2 BCM or 12 % of outflow)

Tonle Sap Lake

MRC/WUP-FIN has developed a DEM of the Tonle Sap based on a hydrographic survey of the dry season lake (CHO 1998/99), the Certeza survey map of 1993 for the flood plain and SRTM data (2003) for other areas. Area and volume as a function of lake level (masl Hatien) are:

$$A(km^2) = 30.053h^2 + 1094.19h + 716.65$$
$$V(km^3) = 0.73248h^2 - 0.31375h + 0.68578 \qquad (12.1)$$

where: A = lake area in km^2
V = lake volume in km^3 or BCM
h = water level at Kampong Luong (masl Hatien)

Based on the water levels observed at Kampong Luong the minimum and maximum lake areas and lake volumes for the period 1998 -2005 have been presented in Table 12.7.

Table 12.7 Minimum and maximum waterlevels, lake areas and lake volumes of Tonle Sap, Period 1998-2005.

Year	h_{max}	h_{min}	A_{max}	A_{min}	V_{max}	V_{min}
	(masl)	(masl)	(km^2)	(km^2)	(BCM)	(BCM)
1998	6.86	1.54	9,637	2,473	33.0	1.9
1999	8.96	1.24	12,933	2,120	56.7	1.4
2000	10.36	1.71	15,278	2,676	76.1	2.3
2001	9.89	1.42	14,478	2,331	69.2	1.7
2002	10.1	1.3	14,834	2,190	72.2	1.5
2003	8.26	1.36	11,805	2,260	48.1	1.6
2004	9.2	1.25	13,327	2,131	59.8	1.4
2005	9.29	1.26	13,475	2,143	61.0	1.5

Tonle Sap River

Lake inflow and outflow via the Tonle Sap River from the Mekong and towards the Mekong and the Bassac can be computed from the observed water level at Prek Kdam and a correction for backwater based on the water level difference between Phnom Penh Port and Kampong Luong. Recently, Forsius (2007) proposed the following discharge rating equation for Prek Kdam:

$$Q(m^3/s) = a\ f(h) \quad where: \quad f(h) = h_{PK}^{1.2}\left|h_{PP} - h_{KL}\right|^{0.5}$$
$$with:$$
$$for\ inflow: \quad a = 8.581 f^2(h) - 691.35 f(h) \qquad (12.2)$$
$$for\ outflow: \quad a = 6.608 f^2(h) + 476.21 f(h)$$

with: h_{PK} = water level at Prek Kdam (masl)
h_{PP} = water level at Phnom Penh Port (masl)
h_{KL} = water level at Kampong Luong (masl)

Note that the sign of the water level difference determines inflow or outflow conditions. Above equation has been presented as an improvement on previously applied discharge ratings for Prek Kdam. The application is shown in Figure 12.11 and Figure 12.12 for the extreme high flow volume year 2000 on Mekong River. The monthly water balance components for 2000 are presented in Figure 12.13. The range of reverse flows for the period 1996-2006 is presented in Figure 12.14.

Overland flow

The overland flow component contributing to the inflow varies with the size of the flood. Estimates vary from about 2 to 15 % of the total inflow volume, where the lower value applies to small flood and the higher one to large floods, see also Figure 12.13. Also during the outflow phase for normal to high floods an overland flow component upto about 3% of the total outflow is existing.

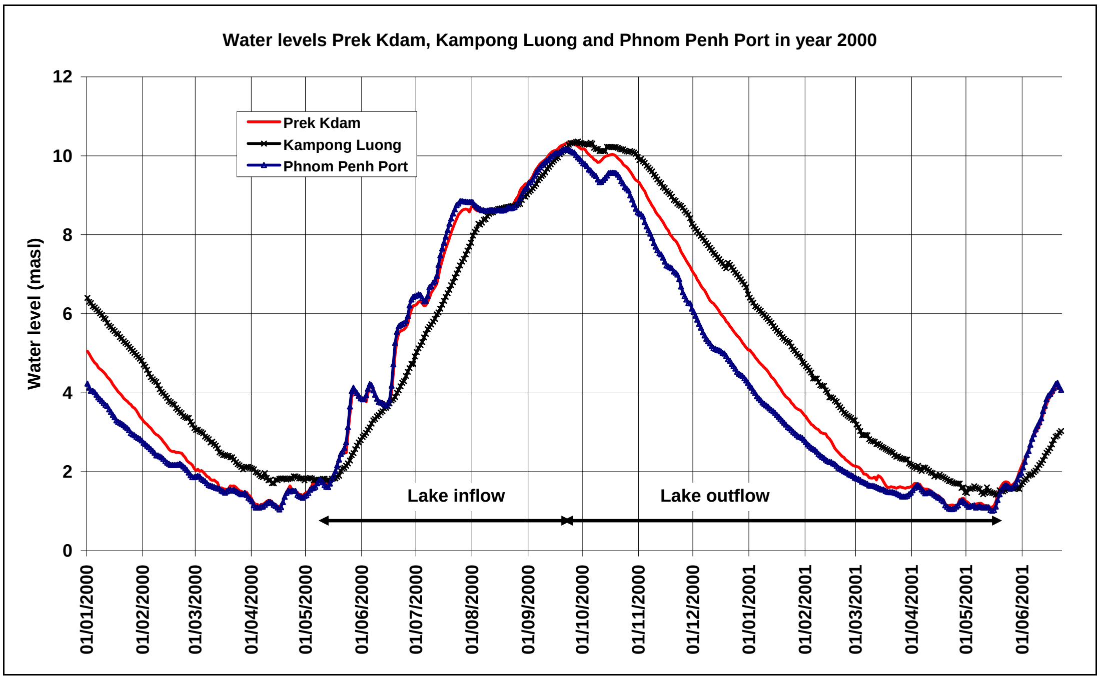

Figure 12.11 Water levels at Prek Kdam, Kampong Luong and Phnom Penh Port to determine Tonle Sap Lake inflow and outflow for year 2000.

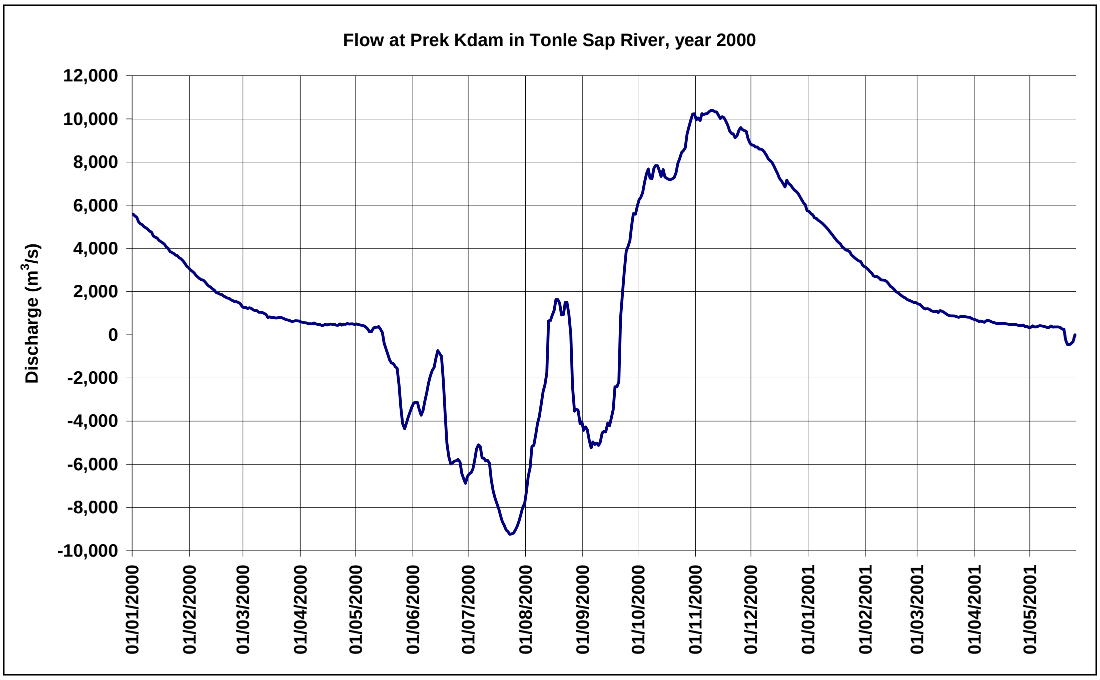

Figure 12.12 Discharge in Tonle Sap at Prek Kdam, year 2000.

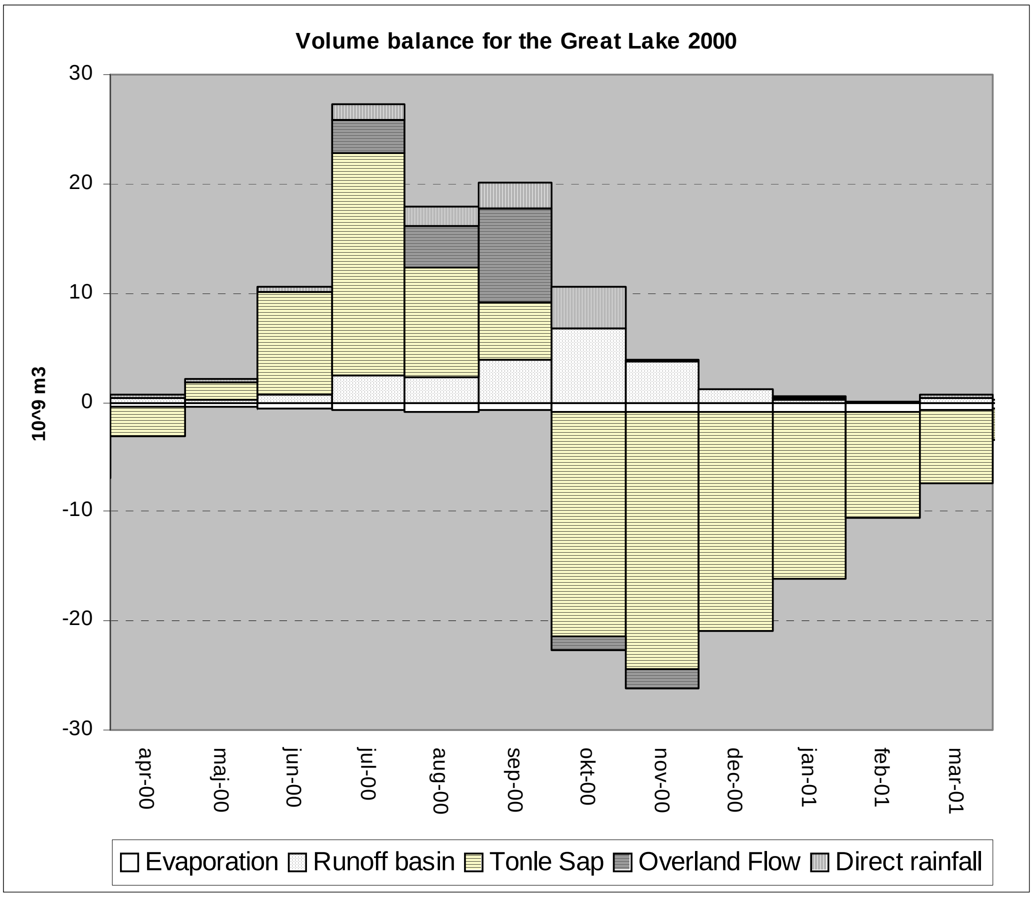

Figure 12.13 Monthly water balance components of Tonle Sap Lake for year 2000 (MRC, 2004).

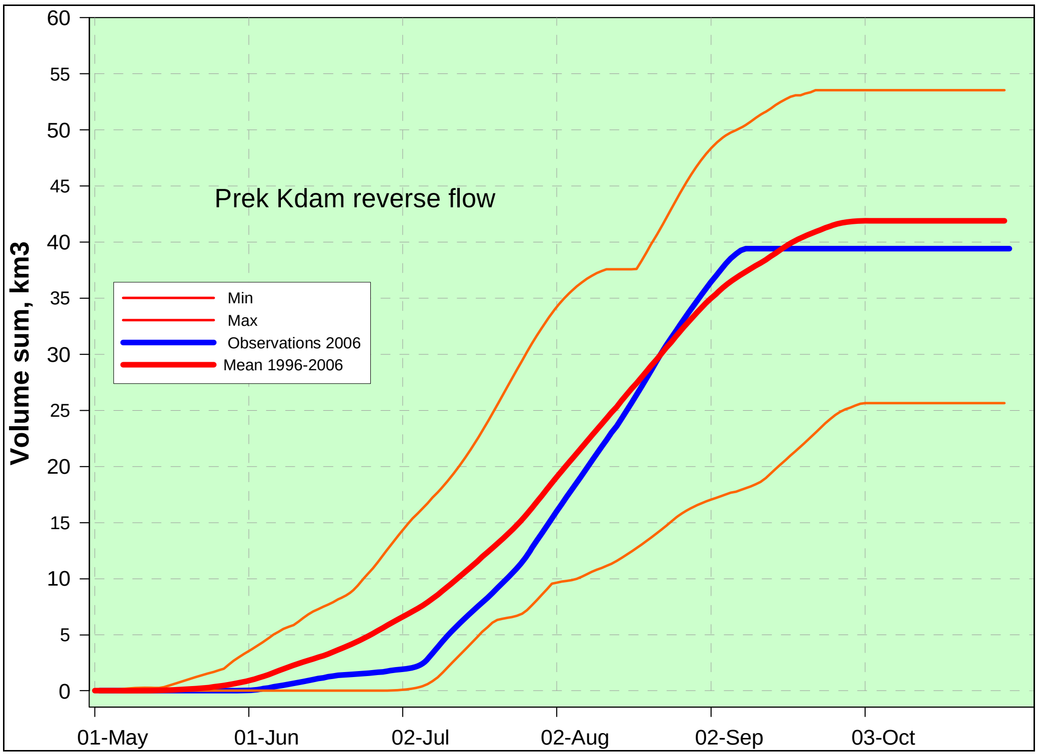

Figure 12.14 Reverse flow on Tonle Sap River at Prek Kdam (sourse: Forsius, 2007).

Tributary inflow

An overview of the mean annual runoff (period 1997-2004) of the basins draining to Tonle Sap Lake is presented in Table 12.8. The largest contribution is from the Stung Sen with 24 % of the total inflow, whereas Chinit, Battambang, Pursat and Boribo contribute each more than 10% or totally another 47 % to the inflow.

Table 12.8 Overview of main tributaries draining to Tonle Sap (MRC/WUP-FIN, 2006).

Nr	**Tributary**	**Total basin area (km^2)**	**Flooded area in 2000 (km^2)**	**% of total**	**Annual discharge (BCM)**	**Annual runoff (mm)**
1	Stung Chinit	8,236	1,876.5	22.8	3.46	486
2	Stung Sen	16,359	1,094.6	6.7	5.84	375
3	Stung Staung	4,357	1,128.6	25.9	1.00	276
4	Stung Chikreng	2,714	622.6	22.9	0.73	329
5	Stung Siem Reap	3,619	934.0	25.8	1.16	373
6	Stung Sreng	9,986	855.7	8.6	1.75	185
7	Stung Sisophon	4,310	39.2	0.9	0.57	133
8	Stung Mongol	10,565	1,513.1	14.3	1.34	134
9	Borey	3,708	396.4	10.7	2.73	462
10	Stung Battambang	2,344	1,560.5	66.6	Battambang	Battambang
11	Stung Sangker	3,695	998.3	27.0	0.44	140
12	Stung Dauntri	5,965	626.9	10.5	2.63	469
13	Stung Pursat	7,153	493.3	6.9	2.46	360
	Stung Baribo					
	Total	83,011	12,140	100	24.48	290
Tonle Sap Lake		2775*)	2775		Prec = 9.50 Evap = 9.33	
Grand total		85,786	14,915		24.65	

Some 80 % of the discharge is occurring in the period May to October, see Figure 12.15. The inflow is largest in August to October, particularly in October, when about 27 % of the annual total is experienced. In the table also the flooded areas relative to the total basin area is shown. It is observed that the total flooded area based on individual ratings for flooded area matches with flooded area presented in Table 12.7 (14,915 km^2 versus 15,278 km^2).

Table 12.9 shows the flow amounts calculated with equation (12.2) (index 2) and those calculated with the previously applied equations (index 1) (see Working Paper No 7 of MRC/WUP-FIN, 2006). As can be observed from the table equation (12.2) generally leads to higher inflow and outflow values. For both approaches, however, the balance does not exactly match. Note, however, that the overland flow from the Mekong, which is not measured at Prek Kdam, has not included in the table. Given the differences, it is concluded that further attention is to be given to the inflow and outflow calculation procedures for Tonle Sap.

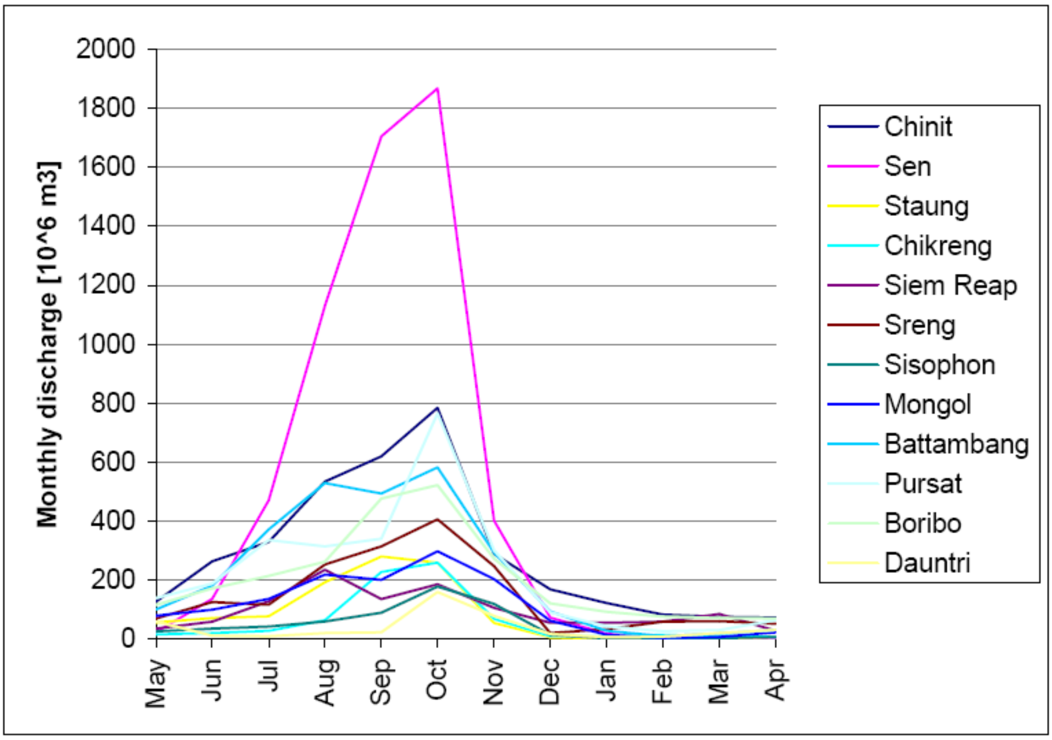

Figure 12.15 Average monthly flows into Tonle Sap Lake from tributaries (MRC/WUP-FIN, 2006).

Table 12.9 Water balance components for Tonle Sap (in BCM) with inflow and outflow based on old (1) and new (2) rating curve for Prek Kdam.

Year	Inflow tribs	Precip	Evap	TLS-in (1)	TLS-out (1)	TLS-in (2)	TLS-out (2)
199	23.14	6.01	8.67	40.41	55.86	-	-
7	12.77	5.19	6.71	24.14	37.46	-	-
199	28.16	11.5	10.4	38.74	67.64	27.5	70.3
8	39.92	2	5	44.75	81.65	45.5	91.8
199	27.77	11.9	11.4	47.10	75.52	49.4	83.1
9	22.34	9	7	49.70	72.90	53.5	81.5
200	15.35	12.4	10.4	30.97	51.53	39.8	49.3
0	-	4	9	-	-	44.9	60.6
200	-	11.3	10.0	-	-	52.6	62.1
1		7	0				
200		7.97	7.51				
2		-	-				
200		-	-				
3							
200							
4							
200							
5							
avg	24.28	9.50	9.33	39.40	63.22	44.7	71.2

12.3 Developments in SA9 affecting the flow regime

Irrigation

The receding flood water are an important irrigation water source. In the wet season some 500,000 ha are irrigated which reduce to about 10% of the area in the dry season. The annual irrigation, domestic and industrial water demand amounts about 4 BCM according to CNMC. Plans are mainly focussed on improvement of current schemes.

Hydropower

At present little hydropower is existing in SA9. According to MIME (2003) the following development plans regarding hydropower are presently considered in SA9:

- the Battambang I, II & III Projects, with installed capacity 73 MW
- Stung Pursat I & II Project, with installed capacity 92 MW
- Stung Sva Slap, with installed capacity 4 MW
- Upper and Lower Stung Reap, with installed capacities of resp. 0.6 and 2.0 MW.

No information is available on reservoir capacities so the effect on the river regime is difficult to judge.

Consultants were informed by MIME (2007) that for the Battambang I and II Projects a Korean Company showed interest in carrying out a feasibility study, to be completed in 6-8 months, and for Stung Pursat I the Chinese Company Xuangsi will carry out a feasibility study.

12.4 Floods

12.4.1 Tributary floods

Flash floods are a common phenomenon in following riverbasins (every year 1 or 2 times when rainfall exceeds 70 mm/day) in SA9:

- Stung Pursat
- Stung Sangker (Battambang)
- Stung Baribo (less frequent)
- Stung Mongol Borey, and
- Stung Sen

Flash floods typically occur at locations when the river slopes suddenly reduce to flat when leaving the mountains. General type of solutions for flash floods as proposed earlier is through reducing the hydrological hazard by reservoirs upstream and the flood hazard by dikes in the flood prone area. Some warning is given to the people in SA9, based on rainfall forecasts using information from Hongkong and Japan, though it does not seem to be very structured.

Since for all tributaries rainfall-runoff models (SWAT, NAM) are available and a rainfall data base have been completed by WUP-A/WUP-JICA/WUP-TLSV for the period 1985-2000 and updated till recent years by WUP-FIN it is possible to get a realistic estimate of the hydrological hazard. To translate the hydrological hazards into flood hazards hydrodynamic models are needed. Such models are only available for Stung Pusat and Stung Battambang as developed for case studies by CNMC. It appears that the Sung Pursat model is poorly calibrated. Another option is to make use of the flood maps available for Tonle Sap and surrounding.

12.4.2 Main stream floods

Main stream in SA9 means Tonle Sap Lake and River. Both are included in a number of hydraulic models including Mike-11, ISIS, WUP-FIN1 and 2 and VRSAP. It implies that the extent and duration of flooding for selected hydrological conditions can be estimated for historical conditions and as well as for design conditions. It is noted that a review is to be carried out taking into account the latest developments regarding the rating curves at Kratie and at Prek Kdam. Also, for creation of baseline conditions, the latest developments regarding embankments, road constructions and land fills should be included in the model to be used.

In addition to the modelling, a number of satellite images/flood maps are available for Tonle Sap Lake and River as from 1999 onward, which can be connected to observed water levels to calibrate the models and improve on the calculated flooded areas.

12.4.3 Combined floods

Since the lower parts of all tributary-basins form part of the flood plain of Tonle Sap Lake and hence combined floods will occur around the Tonle Sap by backwater from high stages in the lake, reducing the discharge capacity of the tributaries. Though the flood plain is covered by the models discussed in the previous section, the river reaches still in the backwater from the lake further upstream are not covered, with the exception of Stung Pursat and Stung Battambang (see Section 12.4.1). However, with the help of the satellite based flood maps of Tonle Sap flood plain options are available.

12.4.4 Summing up

Tributary, main stream 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.

For tributary and combined floods the hydrological hazards can be determined, but 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.

13 HYDROLOGICAL AND FLOOD HAZARD IN SUB-AREA 10

13.1 Basin characteristics

Sub-area 10 (SA10) covers the Mekong river basin from about midway Kratie-Kampong Cham to the river mouth in the South China Sea, excluding the drainage area of the Tonle Sap River and Lake. The total area amounts 58,500 km^2 of which 23,300 km^2 is in Cambodia 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 in SA10:

- From Kampong Cham to Chroy Chang Var (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;
- Mekong from Phnom Penh to the North Vam Nao River junction, with discharge stations Neak Luong in Cambodia and Tan Chau in Vietnam. The North Vam Nao River diverts part of the Mekong flow to the Bassac;
- 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;
- Bassac from Chaktomouk Junction to junction with North Vam Nao River, with stream gauging stations Chaktomouk in Cambodia and Chau Doc in Vietnam. Upstream of Chaktomouk the basin of the Prek Thnod discharges to the Bassac;
- 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.

In the area the flood plains and the road infrastructure play an important role in conveying the flood waters.

The elevation map and slope map are shown in Figure 13.2 and Figure 13.3, which shows a plane area with generally very low-lying grounds with very gentle slopes. An exception is the upper reach of the the Prek Thnot basin. In the Vietnamese part of the delta the average elevation is from 0.7 – 1.2 m masl, except the area at the boundary with Cambodia which has an elevation of about 2.0 – 4.0 m. In general the delta has a a deep hollow shape: high along river banks and low toward the inland.

Land use of SA10 is shown in Figure 13.4. It shows that agricultural paddy land heavily dominate the the delta, with some forest in the upper parts of SA10 in Cambodia. Soils in SA10 are the most fertile of LMB, brought in by the floods. Large quantities of gleysols exist suitable for rice farming. The land in the delta is also affected by saline soils and infertile acid sulphate soils in the Plain of Reeds.

Figure 13.1 Layout of SA10 (BDP, 2006).

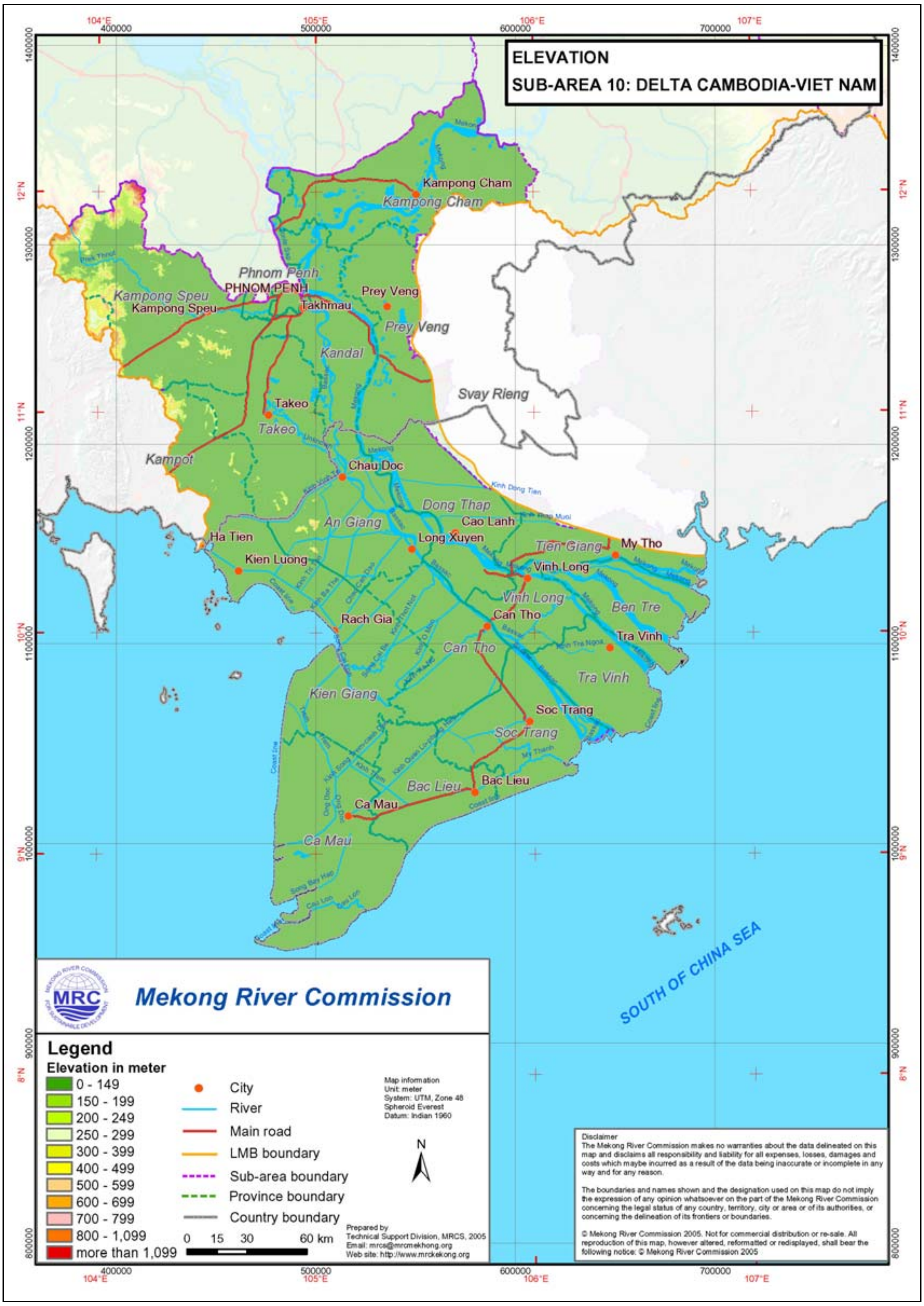

Figure 13.2 Elevation map of SA10 (BDP, 2006).

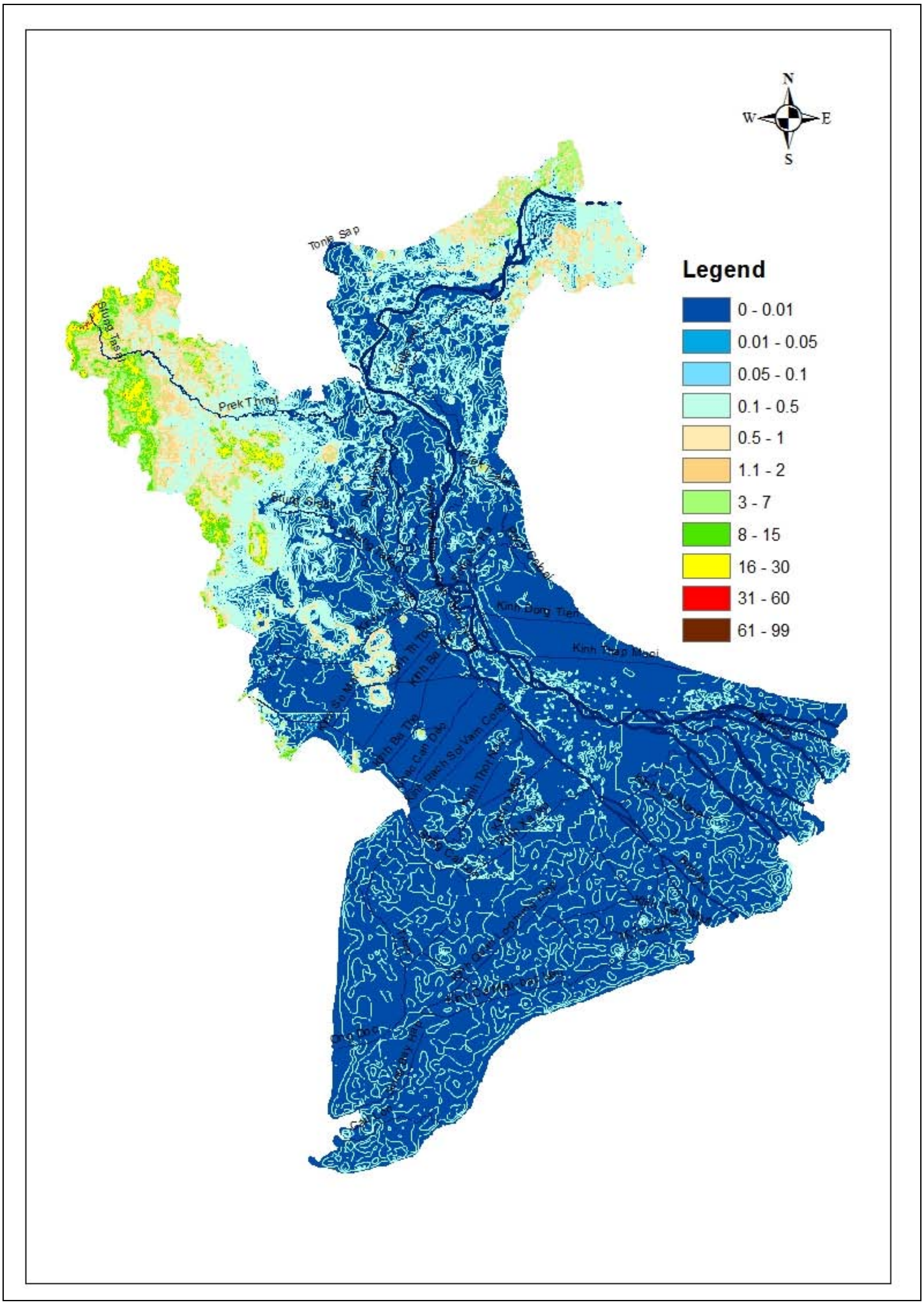

Figure 13.3 Slope map of SA10.

Figure 13.4 Land use map of SA10 (BDP, 2006).

13.2 Hydrological characteristics

13.2.1 Data availability

An overview of the stations for which data is available in the HYMOS database is presented in Table 13.1 to Table 13.3.

With respect to rainfall stations in Cambodia it is observed from Table 13.4 that apart from some 9 stations which have longer records, the majority of the rainfall records start in 2001. The situation in Vietnam is not very much different; here only for Can Tho and Chau Doc long series is available, but the reaimaining stations have only records as from 2001 onward. Much more rainfall data is however available for the Mekong delta in Vietnam. The Southern Regional Hydro-Meteorological Centre monitor rainfall at 121 stations of which the majority is located in the Mekong delta. Data availability comprises generally the period 1975/80-2007. Of a few stations much longer records is available starting in the French time.

Water level data is available in the HYMOS database for 16 stations in Cambodia and 21 stations in Vietnam. In Cambodia the records of Kampong Cham and Neak Luong start in 1930, 3 more stations start in 1960 and 1 stations in 1990, whereas the rest comprises just a few scattered years. In Vietnam the records of water levels start in 1980 and cover the main streams. Again the total number of water level stations in the Vietnamese delta for which data is available at the Southern Regional Hydro-Meteorological Centre. They monitor the water level at 40 stations in the Mekong basin and at 5 oceanic stations. The river stations are equipped with float type recorders and a few with staff gauges only. Of 20 stations data are reported to the Centre 1 x per day at 07:00 hrs and in flood period more frequent.

Discharge records are available for effectively 4 stations in Cambodia with records starting in the sixties, but only the record of Kampong Cham cover the full period. In view of the availability of rating curves established by WUP-JICA and the water level series a more extensive discharge database can be created.
Some 5 discharge stations along the Mekong and Bassac are available in Vietnam, with only data as from 2003 onward. But as for rainfall and water levels much longer records are available with the Southern Regional Hydro-Meteorological Centre. At the Vietnamese stations 4 times per year with an ADCP the full velocity profile is measured, whereas the rest of the time hourly observations are made at 1 vertical only.

From the above it is clear that the discharge record for the Vietnamese stations is insufficient for analysis. Data in the database of the Southern Regional Hydro-Meteorological Centre is available to Consultants, provided that an official request is made by the MRC and that funds are available for buying the data.

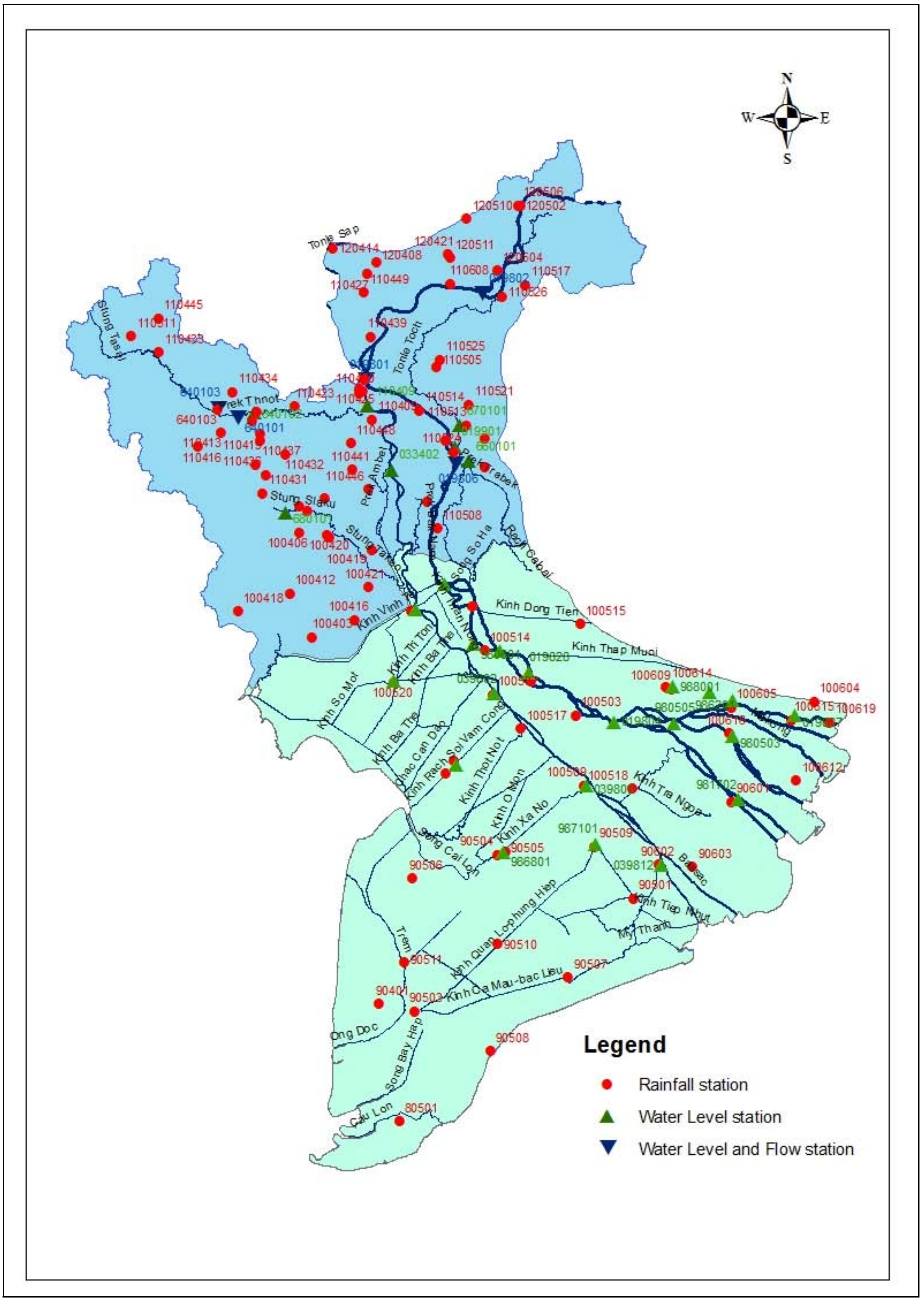

Figure 13.5 Layout of hydro-meteorological network in SA10.

Table 13.1 Overview of rainfall stations in SA10.

Station Location

Rainfall

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
033401	Bassac Chaktomouk	Bassac	11.5516	104.9330
100403	Kirivong	Delta	10.6000	104.7334
100406	Angtassom	Delta	11.0000	104.6834
100408	Takeo (Ville)	Delta	10.9833	104.8000
100412	Tani	Delta	10.7667	104.6500
100416	Bonteay Meas	Delta	10.6667	104.9000
100418	Dorng Tong	Delta	10.7000	104.4500
100419	Angkor Borey	Delta	10.9330	104.9660
100420	Doun Keo	Delta	10.9920	104.7910
100421	Koh Andet	Delta	10.7917	104.9500
110401	Chhouk	Delta	11.1000	104.6834
110402	Kompong Kantout	Prek Thnot	11.5334	104.7334
110403	Tonle Baty(Phnom Penh	Prek Thnot	11.3742	104.5262
110404	Kompong Speu	Prek Thnot	11.3439	104.0557
110406	Prek Leap	Tonle Sap	11.5834	104.9167
110407	Slakou	Delta	11.0834	104.7167
110408	Petit (Takeo)	Bassac	11.5334	104.9167
110409	Takhmao	Prek Thnot	11.4334	104.9667
110410	Bat Rocar	Delta	11.1334	104.7834
110413	Phnom Srouch	Prek Thnot	11.3844	104.3796
110416	Sre Khlong	Prek Thnot	11.3268	104.2906
110419	Kraing Ampil	Prek Thnot	11.3742	104.5262
110423	Thnal Tetung	Prek Thnot	11.4834	104.6667
110425	Pochentong	Bassac	11.5500	104.9167
110426	Chruy Changvar	Mekong	11.5834	104.9334
110427	Batheay	Siem Bok	11.9875	104.9479
110431	Baset	Delta	11.1502	104.5407
110432	Kong Pisey	Prek Thnot	11.2985	104.6318
110433	Oral	Prek Thnot	11.6875	104.1379
110436	Prey Dop	Delta	11.2204	104.5565
110437	Sdock	Delta	11.2602	104.5167
110438	Kampong Toul	Prek Thnot	11.4250	104.5000
110439	Prek Anchang	Siem Bok	11.7500	104.9600
110441	Samroung	Delta	11.2400	104.8900
110445	Trapeang Chor	Prek Thnot	11.8174	104.1372
110446	Prey Lvear	Delta	11.1667	104.9500
110448	Chambak	Prek Thnot	11.3417	104.8834
110449	Cholear	Siem Bok	11.9192	104.9339
110450	MRCS(Phnom Penh)	Bassac	11.5400	104.9279
110505	Snail Pol	Delta	11.6334	105.2167
110511	Prek Tameak	Prek Thnot	11.7500	104.0334
110512	Kamchay Mea	Delta	11.3598	105.4000
110513	Kanchreach	Delta	11.4100	105.3300
110514	Prey Veng	Mekong	11.4667	105.1500
110517	Sre Seam	Delta	11.9473	105.5581
110518	Peam Raing(Leuk Dek)	Delta	11.1200	105.1800
110519	Saang	Mekong	11.3500	105.2500
110520	Bar Phnom	Delta	11.2500	105.4000
110521	Kampong Leav	Delta	11.4900	105.3400
110524	Peam Ror	Mekong	11.3100	105.2800
110525	Pear Raing	Delta	11.6600	105.2300
110526	Chroy Thmar	Mekong	11.9022	105.4704
110605	Mimot	Delta	11.8395	106.1902
110608	Peam Chikang	Mekong	11.9507	105.2667
120408	Pha Ao	Siem Bok	12.0334	104.9834
120421	Prey Chhor	Siem Bok	12.0628	105.2581
120502	Stung Trang	Mekong	12.2500	105.5400
120504	Kompong Cham	Mekong	12.0020	105.4500
120506	Prek Kak	Mekong	12.2500	105.5334
120508	Chhlong	Mekong	12.2617	105.9667
120511	Prey Totung	Siem Bok	12.0500	105.2667
120513	Prek Prasap	Mekong	12.3190	106.0334
120520	Cham Bac	Mekong	12.2812	105.8273
640103	Peam Kley	Prek Thnot	11.4703	104.3662

0

Station Location

Rainfall

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
080501	Nam Can	Bassac	08.7500	105.0700
090401	U Minh	Bassac	09.2000	104.9900
090501	Soc Trang	Bassac	09.6000	105.9700
090503	Ca Mau	Bassac	09.1700	105.1300
090504	Vi Thanh	Bassac	09.7700	105.4500
090505	Kien Luong	Bassac	09.7800	105.4800
090506	Anbien	Bassac	09.6800	105.1200
090507	Bac Lieu	Bassac	09.3000	105.7200
090508	Ganh Hao	Bassac	09.0200	105.4200
090509	Phung Hiep	Bassac	09.8000	105.8200
090510	Phuoc Long	Bassac	09.4300	105.4500
090511	Thoi Binh	Bassac	09.3600	105.0900
090601	Tra Vinh	Mekong	09.9700	106.3500
090602	Dai Ngai	Bassac	09.7300	106.0700
090603	Tra Cu	Bassac	09.7200	106.2000
100502	Cao Lanh	Mekong	10.4300	105.5800
100503	Sa Dec	Mekong	10.3000	105.7500
100505	Chau Doc	Bassac	10.7000	105.1170
100507	Long Xuyen	Bassac	10.3800	105.4300
100509	Can Tho	Bassac	10.0330	105.7830
100513	Tan Chau	Mekong	10.7200	105.3500
100514	Cho Moi	Mekong	10.5500	105.4000
100515	Hung Thanh	Mekong	10.6500	105.7700
100516	Nui Sap	Bassac	10.1300	105.2800
100517	O Mon	Bassac	10.2500	105.5400
100518	Tam Binh	Bassac	10.0200	105.9700
100519	Tan Hiep	Bassac	10.0800	105.2500
100520	Tri Ton	Bassac	10.4300	105.0500
100604	Go Cong	Mekong	10.3500	106.6700
100605	My Tho	Mekong	10.3300	106.3500
100609	Cai Lay	Mekong	10.4000	106.1200
100612	Batri	Mekong	10.0500	106.6000
100614	Cai Be	Mekong	10.4100	106.1000
100615	Hoa Binh	Mekong	10.2800	106.5800
100616	Huong My	Mekong	10.2300	106.3400
100619	Vam Kinh	Mekong	10.2700	106.7300

Table 13.2 Overview of water level stations in SA10.

Water Level

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
019801	Chroy Chang Var	Mekong	11.5800	104.9388
019802	Kompong Cham	Mekong	11.9093	105.3877
019806	Neak Luong	Mekong	11.2609	105.2843
019901	Stung Slot		11.3255	105.2839
019910	Prek Koy	Prek Koy	11.8380	104.9880
019911	Spean Tras	Prek Koy	11.9010	104.9360
020101	Phnom Penh Port	Tonle Sap	11.5750	104.9228
033401	Bassac Chaktomouk	Bassac	11.5516	104.9330
033402	Koh Khel	Bassac	11.2396	105.0399
110409	Takhmao	Bassac	11.4818	104.9490
640101	Anlong Touk	St. Prek Thnot	11.4355	104.4434
640102	Thnous Loung/Kg. Speu	St. Prek Thnot	11.4564	104.5100
640103	PeamKhley-dam site	St. Prek Thnot	11.4704	104.3690
660101	Kompong Trabek		11.2708	105.3417
670101	Stung Banam	St. Banam	11.4082	105.3037
680101	Kompong Ampil	Stung Takeo	11.0763	104.6310

Water Level

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
019803	Tan Chau	Mekong	10.8034	105.2434
019804	My Thuan	Mekong	10.2734	105.9000
019805	My Tho	Mekong	10.3567	106.3567
019807	Cho Moi	Mekong	10.5450	105.4600
019827	Hoa Binh	Mekong	10.2950	106.5967
019828	Cao Lanh	Mekong	10.4670	105.3170
039801	Chau Doc	Bassac	10.7067	105.1334
039802	Long Xuyen	Bassac	10.3817	105.4384
039803	Can Tho	Bassac	10.0334	105.7900
039812	Dai Ngai	Bassac	09.7284	106.0784
980503	My Hoa	Ham Loung	10.2167	106.3550
980505	Cho Lach	Ham Loung	10.2700	106.1300
980601	Vam Nao	Vam Nao	10.5750	105.3567
981702	Tra Vinh	Co Chien	09.9750	106.3750
985203	Xuan To	Vinh Te	10.6000	104.9334
985401	Tri Ton	Kinh Tri Ton	10.4334	105.0500
986201	Long Dinh	Kinh Xang	10.3867	106.2684
986302	Tan Hiep	Kinh Cai San	10.1134	105.2884
986801	Vi Thanh	Kinh Xa No	09.7784	105.4717
987101	Phung Hiep	Kinh Cai Con	09.8084	105.8267
988001	Cai Lay	Ba Rai	10.4067	106.1250

Table 13.3 Overview of discharge stations in SA10.

Water Flow

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)		Catchment Area, km²
			Latitude	Longitude	
019802	Kompong Cham	Mekong	11.9093	105.3877	660000
019801	Chroy Chang Var	Mekong	11.5800	104.9388	663000
019910	Prek Koy	Prek Koy	11.8380	104.9880	
019911	Spean Tras	Prek Koy	11.9010	104.9360	
020101	Phnom Penh Port	Tonle Sap	11.5750	104.9228	
033401	Bassac Chaktomouk	Bassac	11.5516	104.9330	
640101	Anlong Touk	St. Prek Thnot	11.4355	104.4434	3650
640103	PeamKhley-dam site	St. Prek Thnot	11.4704	104.3690	

Flow

Station ID	Station Name	River	Coordinates (Indian 1960 geodetic datum)	
			Latitude	Longitude
019803	Tan Chau	Mekong	10.8034	105.2434
019804	My Thuan	Mekong	10.2734	105.9000
039801	Chau Doc	Bassac	10.7067	105.1334
039803	Can Tho	Bassac	10.0334	105.7900
980601	Vam Nao	Vam Nao	10.5750	105.3567

Table 13.4 Availability of rainfall data in SA10.

Daily Data Availability of BDP Sub-Area 10C (before 60)

Rainfall

Station ID	Station Name	River	1910										1920										1930										1940										1950									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
100408	Takeo (Ville)	Delta			+	+	+	+	+	+	+	+	+	+	+	+	90	+	+	+	+	+	1									59														+	89	62	92		+	+
110404	Kompong Speu	Prek Thnot								30	90	121	+	+	1	+	121	+	+	30	31	+	1									28																		212	30	30
110406	Prek Leap	Tonle Sap																																									+	+	21	30	10	17	8		+	+
110407	Slakou	Delta																														59	60	+	1																	
110409	Takhmao	Prek Thnot																																													151	59	92		93	59
110410	Bat Rocar	Delta																														+	+	+	1																	
110425	Pochentong	Bassac		59	31	59	31	59	91	61	59	121	31	60		28	91	28	90	28	62	+	+	28	31	59	90	59	+	+	60		31	31	28	32			120	91	31	31	30	28	+	+	29			30	31	59
110426	Chruy Changvar	Mekong																																									364	+	+		+	+	+		+	+
110427	Batheay	Siem Bok																																										+	+	+	+	+	+		+	+
110505	Snail Pol	Delta																														+	4	+	+																	
110514	Prey Veng	Mekong											32		+	+	90	1		60	+											28	60	31	1																	
120408	Pha Ao	Siem Bok																																											+	+	+	+	+		+	+
120504	Kompong Cham	Mekong											+		+			+		+	+	+	+	+	+	+			+		+	+		+	+	+				+												
120506	Prek Kak	Mekong																													+	+			+						+	27	2	+	+	+	+		+		+	+
120508	Chhlong	Mekong																													+	+											212	+	+	+	+	+	+		123	+

Daily Data Availability of BDP Sub-Area 10C (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
033401	Bassac Chaktomouk	Bassac																					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+									
100403	Kirivong	Delta																																										+	+	+	+	+	+
100406	Angtassom	Delta		+	+	+	+																																						59				
100408	Takeo (Ville)	Delta	+	31	+	+	+	+	+		+														+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+					+	
100412	Tani	Delta		212	+	+	+																																							+			
100416	Bonteay Meas	Delta																																										+	+	+	+	+	+
100418	Dorng Tong	Delta																																										+	+	+	+	+	+
100419	Angkor Borey	Delta																																										+	+	+	+		+
100420	Doun Keo	Delta																																										+	+	+	+	+	+
100421	Koh Andet	Delta																																										+	+	+	+	+	+
110401	Chhouk	Delta																																										+	+		+	+	+
110402	Kompong Kantout	Prek Thnot																																						+									
110403	Tonle Baty(Phnom Penh)	Prek Thnot																																										+			+		
110404	Kompong Speu	Prek Thnot	+	59	+	+	31								+										+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+	62	+	+	+
110406	Prek Leap	Tonle Sap	+	+	+	+	+																																										
110407	Slakou	Delta			+	+	+	+		+																																							
110408	Petit (Takeo)	Bassac									+																																						

Daily Data Availability of BDP Sub-Area 10C (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
110409	Takhmao	Prek Thnot	60	+	59	59	122																				+	+	+	+	+	+	+	+	+	+	+							+	+			+	
110410	Bat Rocar	Delta		1	+	+	+																																										
110413	Phnom Srouch	Prek Thnot																																					+	+	+	+	+	+	+	+	+	+	+
110416	Sre Khlong	Prek Thnot																																										+	+	+	+	+	
110419	Kraing Ampil	Prek Thnot																																											+		+		
110423	Thnal Tetung	Prek Thnot																																					31	+	+	31	+	+	+		+	+	+
110425	Pochentong	Bassac	+	+	151	58	92						+	+	+	+	214		336					+	+	+	+	+	+	+	+	+	+	+	3	+	+	+	+	+	+	+	+	+	+	184			
110426	Chruy Changvar	Mekong																						+	+	+	+	+	+	+	+			+	+	+	+	+	+	+			+						
110427	Batheay	Siem Bok	+	+																																							+	+	+				
110431	Baset	Delta																																					+	+	+	31	+	+	+	+	+	+	
110432	Kong Pisey	Prek Thnot																																				+	+	+	31	+	+	+	+		+	+	+
110433	Oral	Prek Thnot																																						+	+	+	+	+	+	+	+	+	+
110436	Prey Dop	Delta																																										+	+		+	+	
110437	Sdock	Delta																																										+	+		+	+	+
110438	Kampong Toul	Prek Thnot																																										+	+	+		+	
110439	Prek Anchang	Siem Bok																																										+	+	+	+	+	+
110441	Samroung	Delta																																							+	92	184	+	+	+	+		
110445	Trapeang Chor	Prek Thnot																																										+	+		+	+	
110446	Prey Lvear	Delta																																										+	+				
110448	Chambak	Prek Thnot																																										+	+				
110449	Cholear	Siem Bok																																									+	+	+				
110450	MRCS(Phnom Penh)	Bassac																																									91	+	3	+	+		
110505	Snail Pol	Delta					+																																										
110511	Prek Tameak	Prek Thnot																																										+	+	+	+	+	+
110512	Kamchay Mea	Delta																																										+	+	+	+	+	+
110513	Kanchreach	Delta																																										+	+	+	+	+	+
110514	Prey Veng	Mekong		+								+	245						336								+	+	+	+	+	+	+	+	+	+	+	+	+	+				+	+	+	+	+	+
110517	Sre Seam	Delta																																									+	+	+				
110518	Peam Raing(Leuk Dek)	Delta																																										+	+	+			
110519	Saang	Mekong																																										+	+		+		
110520	Bar Phnom	Delta																																										+	+	+	+	+	+
110521	Kampong Leav	Delta																																											+		+	+	
110524	Peam Ror	Mekong																																										+	+	+	+	+	+
110525	Pear Raing	Delta																																										+	+		+	+	+
110526	Chroy Thmar	Mekong																						+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	92	+	+		+	+			
110605	Mimot	Delta	62	59	28	89	62																																				+	+	+				
110608	Peam Chikang	Mekong																																									+	+	1				
120408	Pha Ao	Siem Bok	+	+	+	+	+																																										
120421	Prey Chhor	Siem Bok																																									+	+	+				
120502	Stung Trang	Mekong																										+	+	+					+									+	+				
120504	Kompong Cham	Mekong		+	+	+	+	+	+	+	+	+	+	+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	30	+	62	+	+			1	
120506	Prek Kak	Mekong	+		+	+	+																																										
120508	Chhlong	Mekong	+	59	243	59	91																																			+	+	+	+	+			+
120511	Prey Totung	Siem Bok	+	+	+	+	+																																										
120513	Prek Prasap	Mekong																																									+	+	+	+			+
120520	Cham Bac	Mekong																																									+	+	+	+			+
640103	Peam Kley	Prek Thnot																																										+	+		+	+	

Daily Data Availability of BDP Sub-Area 10V(before 1960)

Rainfall

Station ID	Station Name	River	1920										1930										1940										1950									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
100505	Chau Doc	Bassac	+	+	+	+	61	+		+	+	+	+																													
100509	Can Tho	Bassac	+	+	+	+	+	+		+	+	+	+									+										+	+	+	+	+	+	+	+			

Daily Data Availability of BDP Sub-Area 10V (1960-2006)

Rainfall

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
080501	Nam Can	Bassac																																										+	+	+	+	+	+
090401	U Minh	Bassac																																										+	+	+	+	+	+
090501	Soc Trang	Bassac																																										+	+	+	+	+	+
090503	Ca Mau	Bassac																																										+	+	+	+	+	+
090504	Vi Thanh	Bassac																																										+	+	+	+	+	+
090505	Kien Luong	Bassac																																										+	+	+	+	+	+
090506	Anbien	Bassac																																										+	+	+	+	+	+
090507	Bac Lieu	Bassac																																										+	+	+	+	+	+
090508	Ganh Hao	Bassac																																										+	+	+	+	+	+
090509	Phung Hiep	Bassac																																										+	+	+	+	+	+
090510	Phuoc Long	Bassac																																										+	+	+	+	+	+
090511	Thoi Binh	Bassac																																										+	+	+	+	+	+
090601	Tra Vinh	Mekong																																										+	+	+	+	+	+
090602	Dai Ngai	Bassac																																										+	+	+	+	+	+
090603	Tra Cu	Bassac																																										+	+	+	+	+	+
100502	Cao Lanh	Mekong																																										+	+	+	+	+	+
100503	Sa Dec	Mekong																																										+	+	+	+	+	+
100505	Chau Doc	Bassac	+	+	+	+	+	+	61	+					+	54	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
100507	Long Xuyen	Bassac																																										+	+	+	+	+	+
100509	Can Tho	Bassac																									+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
100513	Tan Chau	Mekong																																										+	+	+	+	+	+
100514	Cho Moi	Mekong																																										+	+	+	+	+	+
100515	Hung Thanh	Mekong																																										+	+	+	+	+	+
100516	Nui Sap	Bassac																																										+	+	+	+	+	+
100517	O Mon	Bassac																																										+	+	+	+	+	+
100518	Tam Binh	Bassac																																										+	+	+	+	+	+
100519	Tan Hiep	Bassac																																										+	+	1	+	+	+
100520	Tri Ton	Bassac																																										+	+	+	+	+	+
100604	Go Cong	Mekong																																										+	+	+	+	+	+
100605	My Tho	Mekong																																										+	+	+	+	+	+
100609	Cai Lay	Mekong																																										+	+	+	+	+	+
100612	Batri	Mekong																																										+	+	+	+	+	+
100614	Cai Be	Mekong																																										+	+	+	+	+	+
100615	Hoa Binh	Mekong																																										+	+	+	+	+	+
100616	Huong My	Mekong																																										+	+	+	31	+	+
100619	Vam Kinh	Mekong																																										+	+	+	+	+	+

Table 13.5 Availability of water level data in SA10.

Water Level

Station ID	Station Name	River	1920										1930										1940										1950									
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
019802	Kompong Cham	Mekong											+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
019806	Neak Luong	Mekong							16	15	31	+	+	+	+	7	3	+	+	6	+	+	+	+	+	+	+	126	210	25	166	+	+	+	351	131	+	1	+	+	+	+

Water Level

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
019802	Kompong Cham	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
019801	Chroy Chang Var	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
019806	Neak Luong	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
019901	Stung Slot	Stung Slot																												145	257													59	+		+		+
019910	Prek Koy	Prek Koy																																									204	72					
019911	Spean Tras	Prek Koy																																										271					
020101	Phnom Penh Port	Tonle Sap	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
033401	Bassac Chaktomouk	Bassac	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+						182	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
033402	Koh Khel	Bassac																															247	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
110409	Takhmao	Bassac																																									351						
640101	Anlong Touk	St. Prek Thnot				234	+	+	+	+	+	+	305																																				
640102	Thnous Loung/Kg. Speu	St. Prek Thnot																																						+	215			+	+	+	+		
640103	PeamKhley-dam site	St. Prek Thnot																																					244	+	125	+	+	+	+	+	+		
660101	Kompong Trabek	Kompong Trabek																																										+	+		31	+	5
670101	Stung Banam	St. Banam																												129																			
680101	Kompong Ampil	Stung Takeo																																									+	31	+	+	+	+	31

Water Level

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
019803	Tan Chau	Mekong																				98	+	+	+	+	+	+	6	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
019804	My Thuan	Mekong	181	16																		90	+	+	+	3	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
019805	My Tho	Mekong																										+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
019807	Cho Moi	Mekong																					91	+	+	+	+	5	29	15	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
019827	Hoa Binh	Mekong																										+	+	+	7	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
019828	Cao Lanh	Mekong																																				+	+	+	+	+	+	+	+	+	+	+	+
039801	Chau Doc	Bassac	180	111																		90	+	+	+	+	+	+	6	+	+	+	+	+	+	31	1	+	+	+	+	+	+	+	+	+	+	+	+
039802	Long Xuyen	Bassac																					91	+	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
039803	Can Tho	Bassac																				90	+	+	2	9	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
039812	Dai Ngai	Bassac																										+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
980503	My Hoa	Ham Loung																										+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+
980505	Cho Lach	Ham Loung																												+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
980601	Vam Nao	Vam Nao																										+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
981702	Tra Vinh	Co Chien																										+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	1	+	+	+
985203	Xuan To	Vinh Te																																	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
985401	Tri Ton	Kinh Tri Ton																																	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
986201	Long Dinh	Kinh Xang																												+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
986302	Tan Hiep	Kinh Cai San																										+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
986801	Vi Thanh	Kinh Xa No																										+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+
987101	Phung Hiep	Kinh Cai Con																										+	+	+	+	+	120	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
988001	Cai Lay	Ba Rai																												+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Table 13.6 Availability of discharge data in SA10.

Water Flow

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
019802	Kompong Cham	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+				
019801	Chroy Chang Var	Mekong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	275																																
019910	Prek Koy	Prek Koy																																															
019911	Spean Tras	Prek Koy																																															
020101	Phnom Penh Port	Tonle Sap																															+																
033401	Bassac Chaktomouk	Bassac					+	+	+	+	+	+	+	+	+	+	1																																
640101	Anlong Touk	St. Prek Thnot				234	+	+	+	+	+	+	305																																				
640103	PeamKhley-dam site	St. Prek Thnot																																					244	+	125	+	+	+	+				

Flow

Station ID	Station Name	River	1960										1970										1980										1990										2000						
			0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
019803	Tan Chau	Mekong																																												+	+	+	+
019804	My Thuan	Mekong																																												+	+	+	+
039801	Chau Doc	Bassac																																												+	+	+	+
039803	Can Tho	Bassac																																												+	+	+	+
980601	Vam Nao	Vam Nao																																												+	+	+	+

Notes: + = no missing
blank = missing
90 = number of missing days in a year

13.2.2 Rainfall

The Mekong delta has a monsoon climate. The average annual temperature is about 26°C and average rainfall varies from 1,200 to 2,000 mm. An example of the temporal variation of annual rainfall is presented in Figure 13.6 for Kampong Cham, which has an average annual rainfall of 1,430 mm. The seasonal distribution of the rainfall for Kampong Cham and for Tra Cu in Vietnam (average annual rainfall 1,570 mm) is shown in respectively Figure 13.7 and Figure 13.8. The rainfall is seen to be distributed into two seasons: 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%.

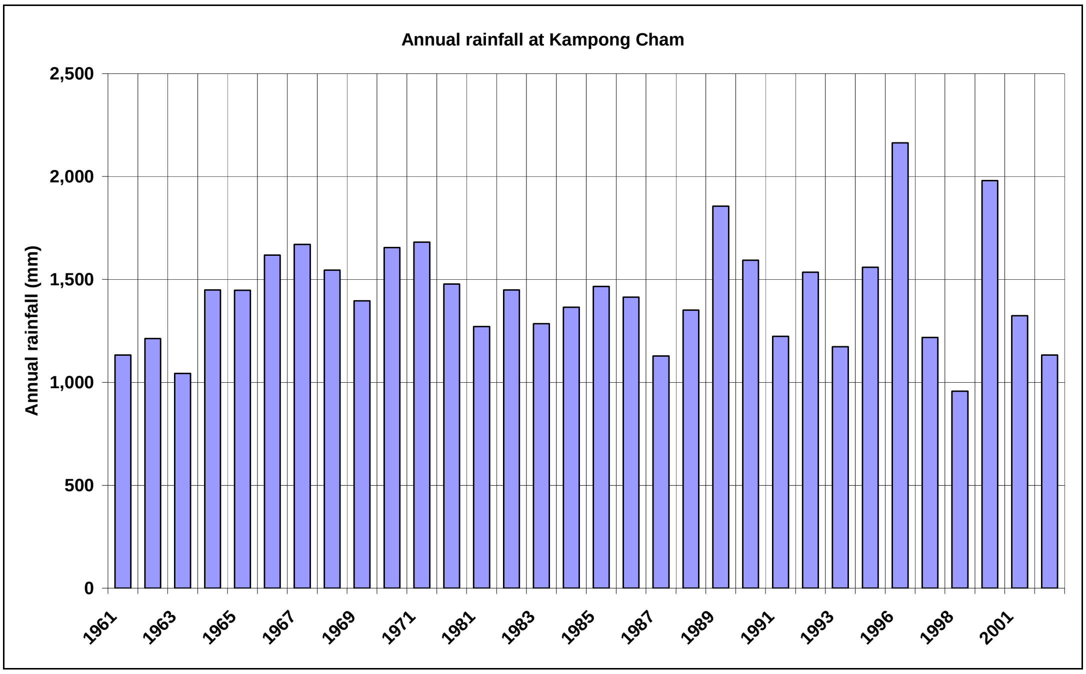

Figure 13.6 Annual rainfall at Kampong Cham.

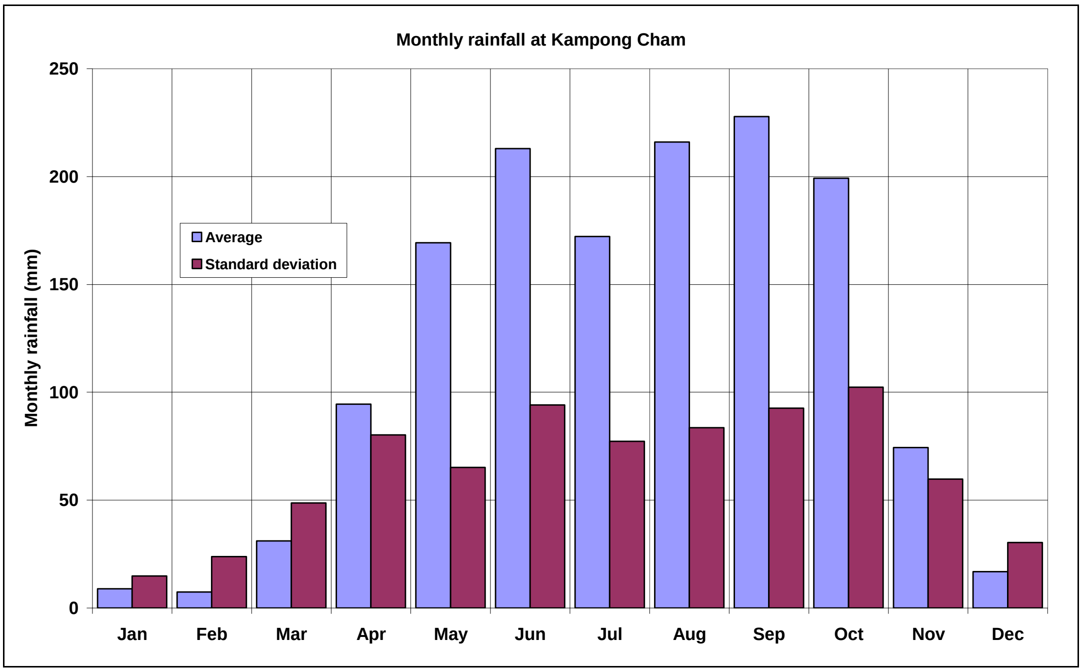

Figure 13.7 Monthly rainfall characteristics of Kampong Cham (Cambodia).

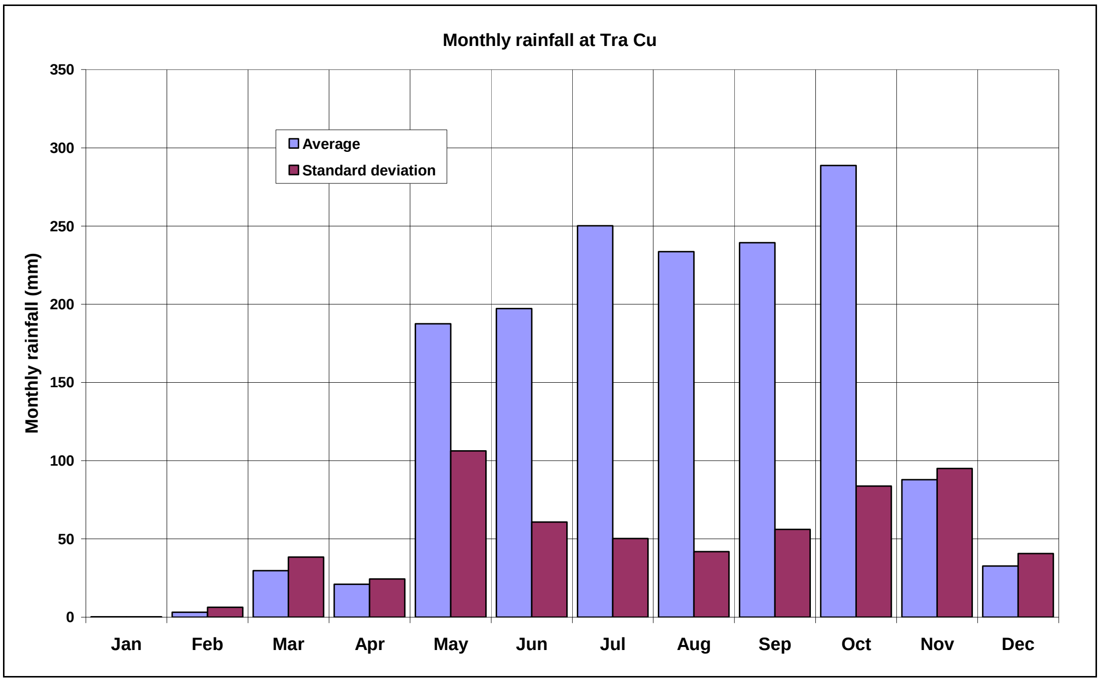

Figure 13.8 Monthly rainfall characteristics of Tra Cu (Vietnam).

13.2.3 Water levels and flow distribution

Estimates of the average annual outflow from SA10 to the sea range from 440 to 470 BCM. The exact amount is difficult to assess as part of it reaches the outlets as overland flow. From a hydraulic point of view the major part of SA10 can be considered as transition zone, where apart from the conveyance capacity the water levels are determined by the upstream discharge and the water levels at sea.

Upstream discharge boundary

The upstream discharge boundary for SA10 is the flow at Kratie (or equivalently Stung Treng). The first discharge station inside SA10 is at Kampong Cham. Dependent on the discharge rating curve applied for Kratie, an amount of water for the higher stages is entering the flood plain between Kratie and Kampong Cham along the left bank of the Mekong. This is illustrated in Figure 13.9.

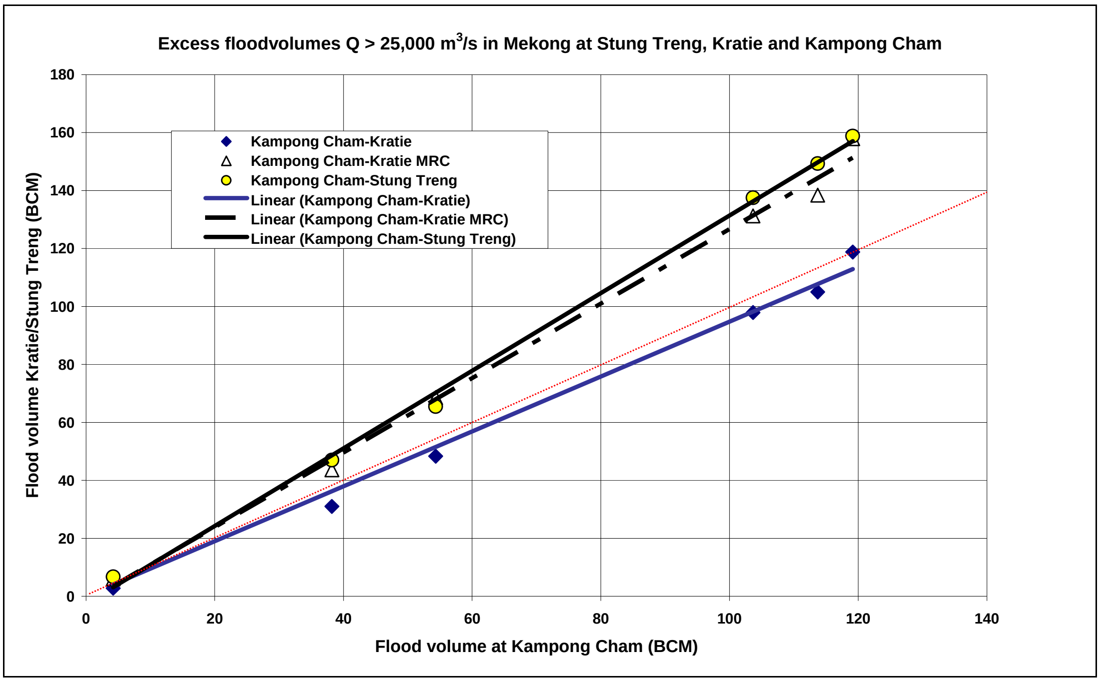

Figure 13.9 Flood volume above a discharge of 25,000 m^3/s at Kampung Cham as a function of the flood volume at Kratie/Stung Treng (period 1998-2003).

(Note that the rating for Kampong Cham like all other ratings in SA10 are a function of stage at the site times a correction factor for backwater given as a function of the fall with a downstream station, see WUP-JICA, 2004). Flood volumes at Kampong Cham and at Kratie/Stung Treng above the spill discharge level of 25,000 m^3/s are compared based on different discharge rating curves:

- Applying the rating curve at Kratie derived from the 2002-2003 discharge measurements at that site (applied by WUP-JICA, 2004), then the relation is according to the blue line in the figure; it implies no loss of water between Kratie and Kampong Cham.
- Applying the ratings according to MRC for Kratie or Consultant's rating curve for Stung Treng (see also chapter 11) then the relation is according to the black or dashed line in the figure, implying that in the years 2000-2002 there is a loss upstream of Kampong Cham of about 30 – 35 BCM, which enters the left bank flood plain upstream of Kampong Cham.

Particularly for the correct modelling of the flood plain inflow along the left bank of the Mekong (which enters the Plain of Reeds) it is of importance that the discharge ratings of Kratie/Stung Treng and at Kampung Cham are carefully reviewed as this is determining the correct boundary condition for the inflow into the flood plain of the Mekong. In the next phase of the Project Consultant's will give due attention to this.

Tidal conditions

The delta is affected by the tide in the South China Sea Mekong and Bassac and the part along the right bank of the Bassac draining southward to the Gulf of Thailand. These seas have different regimes:

- the semi-diurnal tide in the South Chine Sea with the high amplitude of 2.5 – 3 m, and
- the mixed tide with a dominant diurnal component in the Gulf of Thailand with a low amplitude of 0.4 - 1.2 m.

The tidal characteristics at the various outlets are of importance for a correct computation of the water levels in the flood season and of the salt water intrusion in the dry season.

According to IPCC a sea-level rise of 0.25 m to 0.50 m in 100 years time is to be taken into account to account for climate change (IPCC, 2007). The consequences of this change on the interventions in the delta will be taken into account.

Conveyance and storage capacity

In the flood season, a large part of the delta is inundated with water depths from 0.5 m to over 4.0 m at locations during 2 to 6 months per year, with the largest depths in the border area between Cambodia and Vietnam. The size of flooding is determined by the river flow and volume at Kratie, the water levels at sea and the conveyance capacities of the main hydraulic infrasructure of the Mekong, Bassac and Tonle Sap Rivers, the storage capacity of Tonle Sap Lake and storage and conveyance capacities of the flood plains adjacent to the main hydraulic infrastructure. These features are affecting the shape and timing of the water level and discharge hydrographs in SA10 as can be observed from Figure 13.10. It is observed that the levels and flows rise and fall rather quickly in the upper reaches of SA10 but due to the storage and redistribution of flood water in the flood plain and storage in Tonle Sap Lake a strong attenuation and stretching of the flood hydrograph takes place.

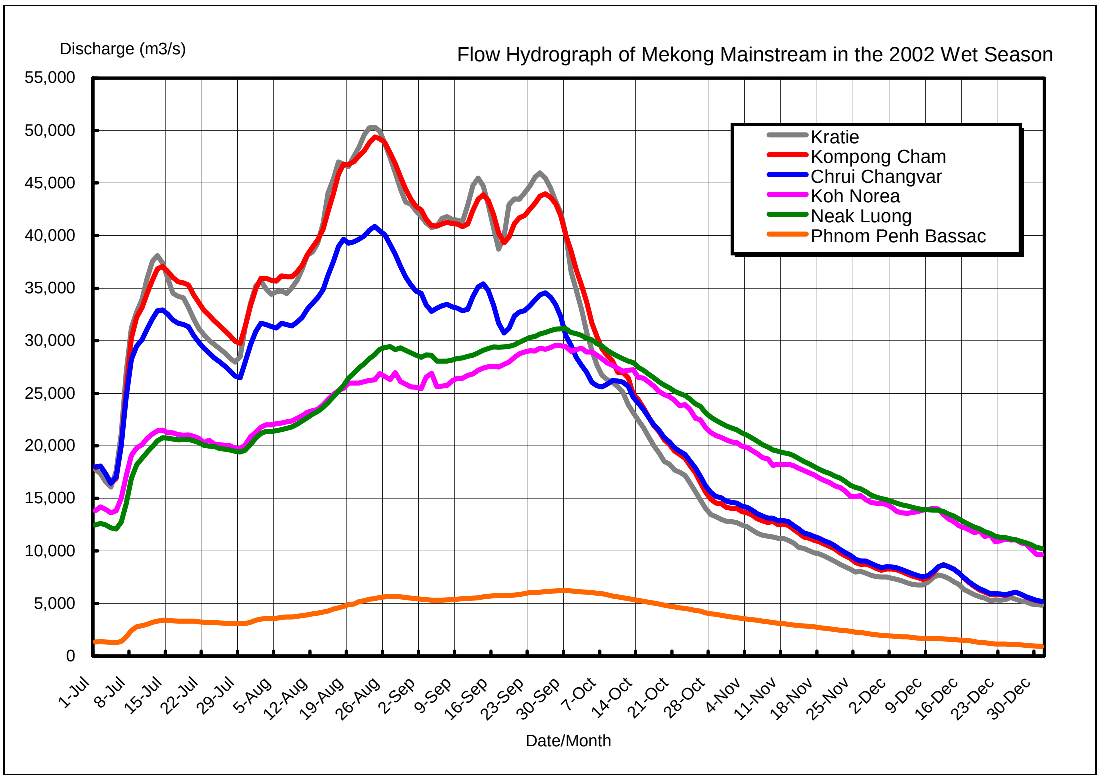

Figure 13.10 Discharge hydrograph of Mekong and Bassac in SA10 Cambodia, year 2002 (source: WUP-JICA, 2004).

It is observed that the year 2002 flood peak at Kampong Cham of 49,000 m^3/s has reduced to 41,000 m^3/s at Phnom Penk (Chroy Chang Var) and to some 30,000 m^3/s on the Mekong at the Vietnamese border, i.e to 60% of the original value due to storage and diversion to Tonle Sap and Bassac Rivers. From the figure it is also observed that in the WUP-JICA modelling the flows at Kratie and Kampong Cham are almost equal, and as discussed above this likely leads to an underestimation of the inflow to the flood plains along the left bank of the Mekong.

In the various documents available at MRC the inflow to the flood plains is described for particular years (WUP-JICA, 2004 and MRC, 2006). From Figure 13.11 it is observed that the size of flood plain flooding is dependent of the magnitude of the flood.

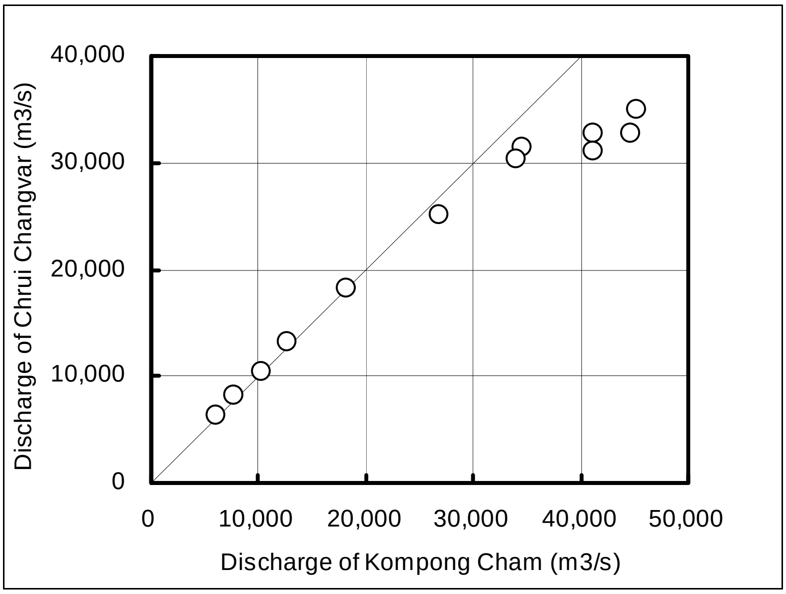

Figure 13.11 Relation between flow in the Mekong at Kampong Cham and at Chroy Chang Var (Phnom Penh).

At a discharge level of 25,000 m^3/s at Kampong Cham water is spilled to the flood plain in an increasing manner the more the spill level is exceeded. As an example the conditions according to WUP-JICA for the flood of 2002 is presented Figure 13.12.

From the above obser-vation of the spill level at Kampong Cham it follows that the volumes and per-centages given in this figure may be misleading for a general picture as they only apply to this par-ticular flood. It also shows that the storage of the Mekong flood volume in the Tonle Sap Lake is relatively small, though its importance for flood attenaution and augmen-tation of dry season flow is large. Illustrative for the complexity of the flood plain flooding in Cambodia is the water balance made for the flood of 2003 (which was a modest flood) of the period July-December (MRC, 2006).

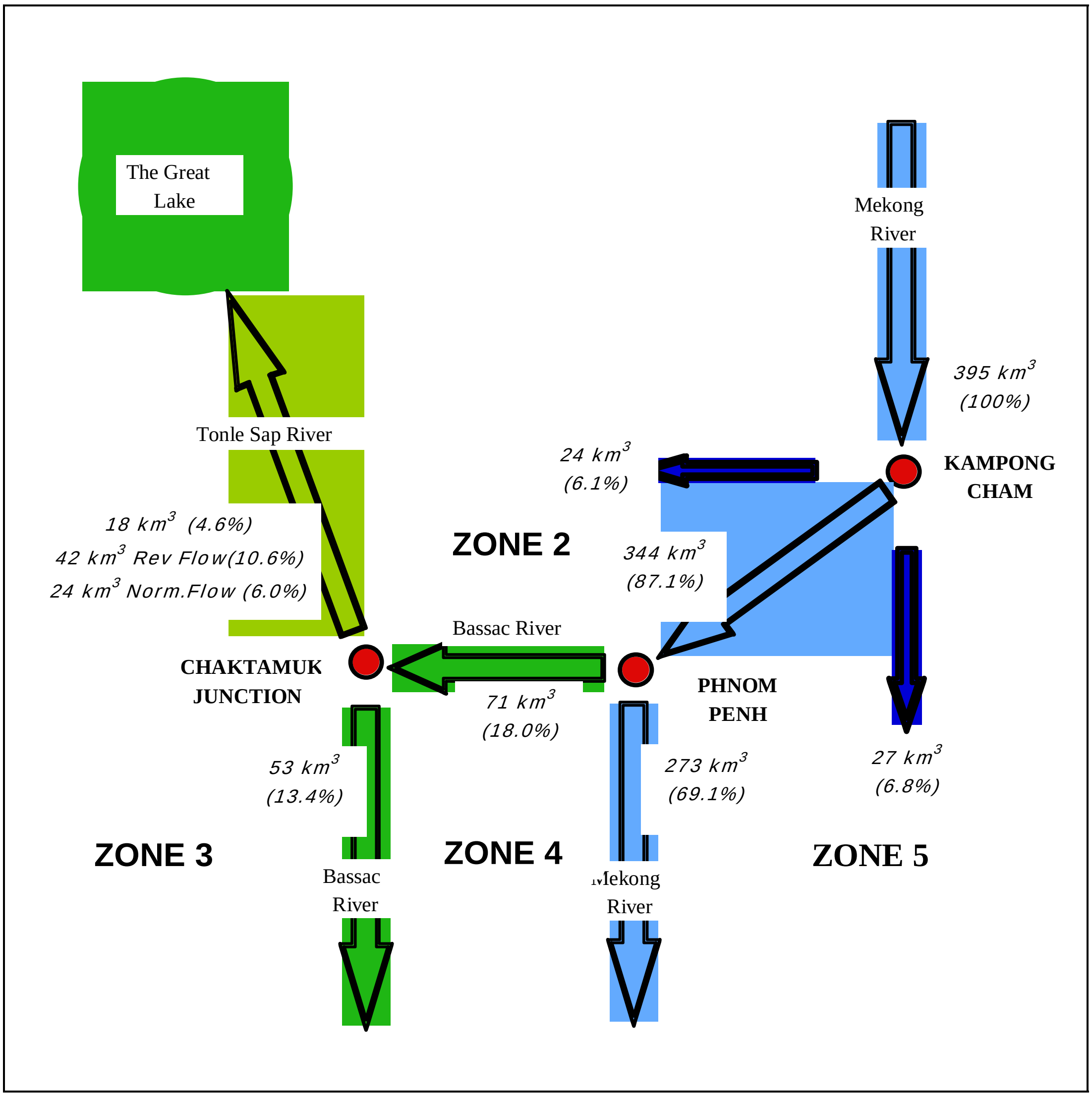

Figure 13.12 Distribution of flood volumes in Cambodian flood plain (MRC, 2006).

It is observed that considerable flooding takes place downstream of Kampong Cham along the Mekong right bank, of which a part returns upstream of Phnom Penh, a part enters Tonle Sap River upstream of Prek Kdam and part is conveyed via Road No 6 as overland flow to Tonle Sap Lake. A larger portion of the spill downstream of Kampong Cham enters the left bank flood plain further augmented with spill downstream of Phnom Penh, of which, however, a considerable amount returns to the Mekong near Neak Luong. The rest is conveyed through the flood plain to the Vietnamese border.Between Phnom Penh and Neak Luong water from the Mekong also enters the flood plain between te Mekong and Bassac, further augmented by water from the Bassac via colmatage canals. The colmatage canals also convey water with fertile sediments to the flood plain along Bassac's right bank. Hence at the Vietnamese border water enters the country via the Mekong and Bassac and via the flood plains, along the Bassac right bank, between the Bassac and the Mekong and along the Mekong left bank. In summary the following mechanisms describe the flooding in Cambodia (MRC, 2006):

- overbank flooding from the Mekong river along the right and left banks
- colmatage flooding from Bassac river to the flood plains along its banks, and
- floodway flooding, redistributing the flood waters across the flood plain via bypass channels.
- Tonle Sap Lake for storage of flood water, and
- the flood plains mainly for conveyance of flood water, whereas their storage function is of less importance.

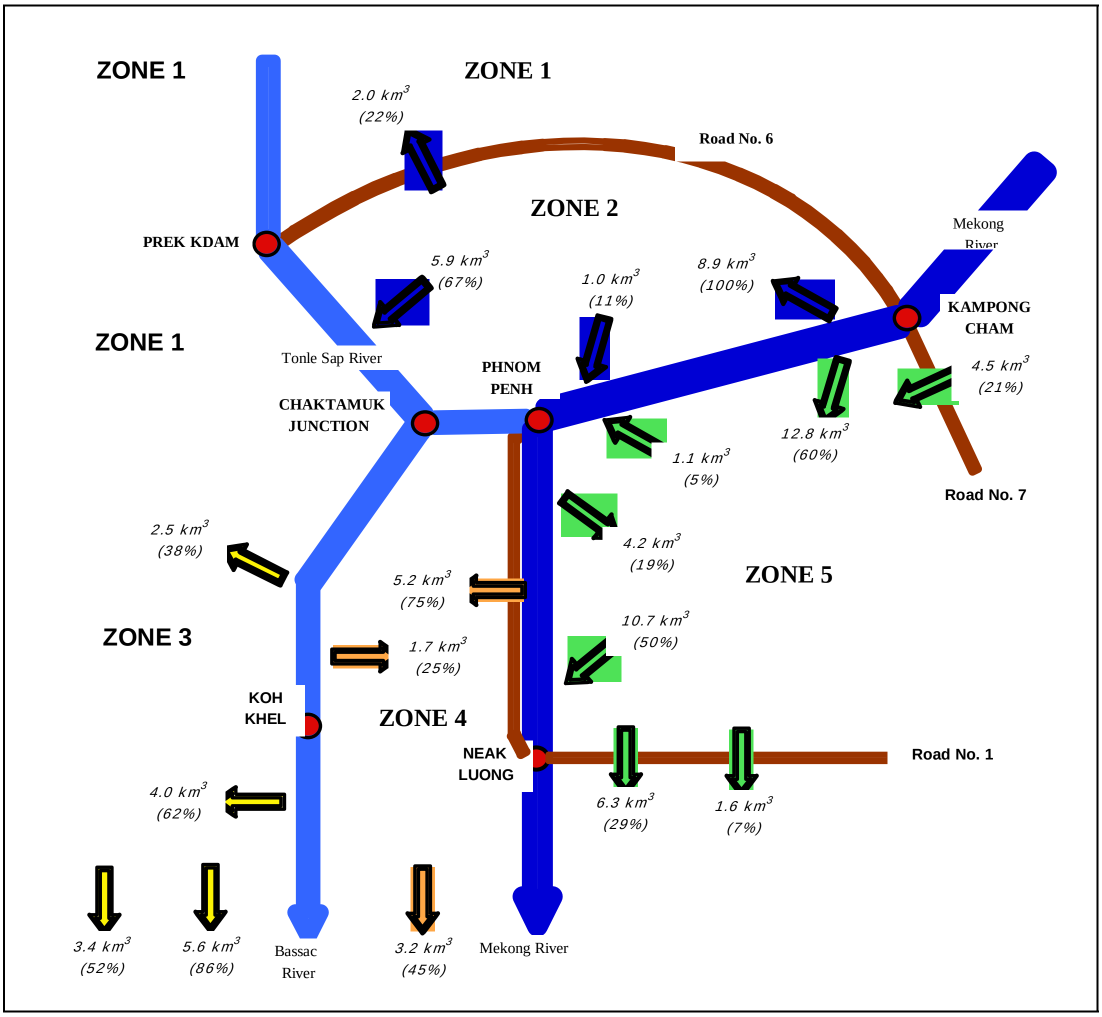

Figure 13.13 Distribution of flood volumes in the Cambodian flood plains along the Mekong and Bassac Rivers for 2003 flood July-December. (source MRC, 2006).

The distribution of the Mekong discharge at Phnom Penh to the Mekong and Bassac has an important role in the hydrologic regime of the Cuu Long Delta. The proportion during the flood season is about 80-20%, though a large part enters Vietnam also via the flood plains, as can be observed for the year 2000 flood volumes and discharges, the highest in living memory, see Figure 13.14. Further downstream the Vam Nao River redistributes the Mekong and Bassac flows and their discharges become almost equal thereafter. The average low-flow in the Mekong is about 2,500 m^3/s in April/May. During this period, salt water intrudes into half of the delta extending as far as 40 – 50 km from the sea boundary.

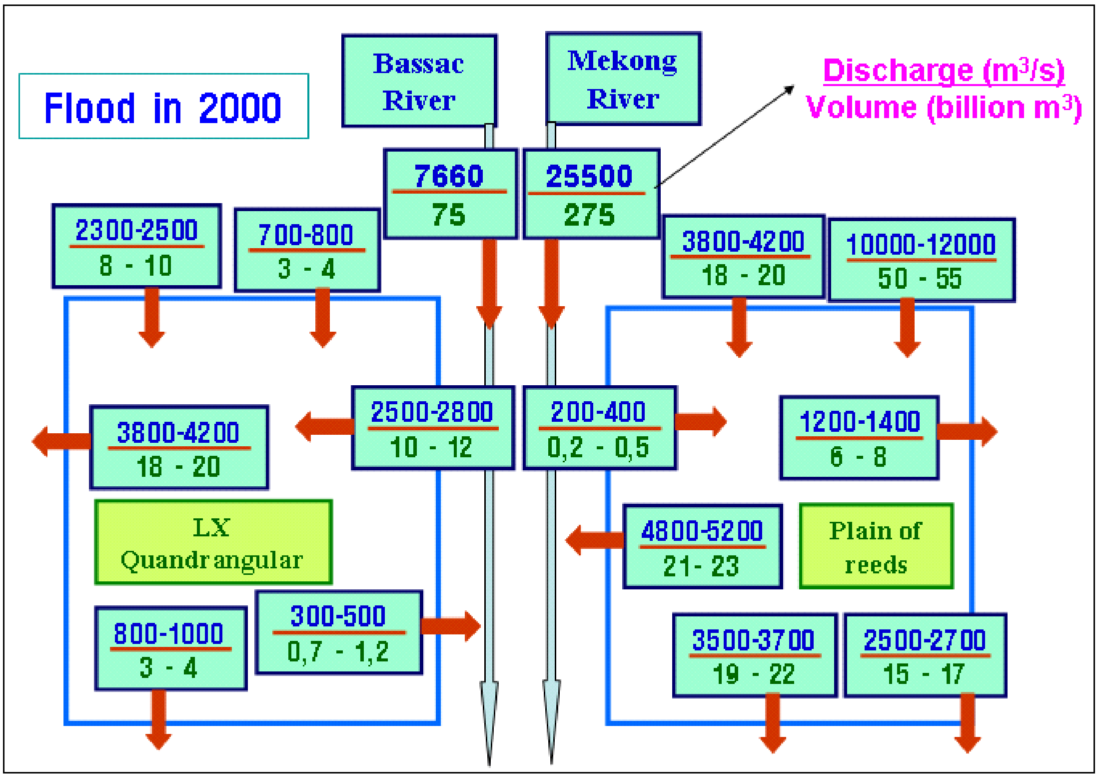

Figure 13.14 Distribution of flood flows in Cuu Long Delta (source: VNMC, 2007).

The hydraulic infrastructure of the Vietnamese part of the delta is characterised by a maze of natural and manmade waterways. The flooding in the border reach is widespread but decreases in intensity towards the sea. Based on the depth of flooding a zonation can be made for the Mekong or Cuu Long Delta (information from Southern Water Resources Planning Institute, 2007):

- Deep inundation areas (1.50 m - 4.00 m), which zone is mainly affected by the flood discharge. The areas include:
  - the Long Xuyen Quadrangle (Kien Giang, An Giang),
  - the Long An – Dong Thap area (Plain of Reeds), and
  - the area between Bassac and Mekong.
- Shallow inundation areas (< 1.50 m), whch are affected by the flood and the tide, further downstream
- Coastal zone, areas only affected by the tide and not by the floods

The inundation depths for the year 2000 is shown in Figure 13.15.

In the deep inundation area in the Long Xuyen Quadrangle the general strategy is to divert the floods to the West Sea (Gulf of Thailand), via existing and new channels, to block the (early) floods at the Cambodian border with structures (2 rubber dams, barrage, spillway), and with about 30 sluices along the coast to fight salinity intrusion. This strategy aims to support 2 crops/year in the area. Most of the structures have been completed. Floods are generally blocked at Cambodian border till middle of August to protect the harvest and only if a big flood arrives before that time the gates/dams/spillways will be opened.

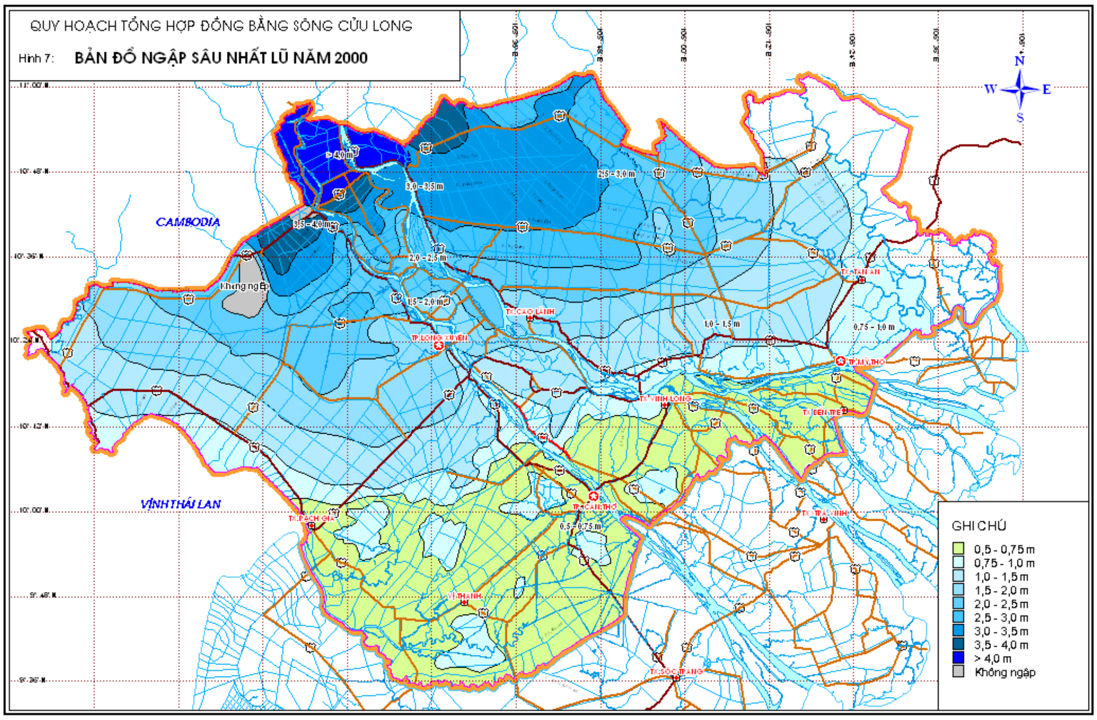

Figure 13.15 Flooding depth in Cuu Long Delta in year 2000 (source: VNMC, 2007).

In the deep inundation area in the Long An – Dong Thap area (Plain of Reeds), the strategy is to try to divert the floods to the Mekong and Vaico rivers. This is, however, difficult as there is no way to stop the big amounts of water from Cambodia into the Plain of Reeds. For instance a discharge of about 9,000 m^3/s should be diverted through a river with a normal discharge capacity of 900 m^3/s. The plan is now to construct 2 large structures at the border and try to find a diversion option. At present there are a number small scale polder type protection projects (200 to 500 ha), with dikes around the areas. This only protects against river floods and the floods from Cambodia, not against local floods as there are no pumping stations. The dikes (secondary embankments) are designed at a 10 % probability, studied and designed with mathematical models. The correct methodology to improve the flood conditions here has not been found yet due to the large amounts of water coming from Cambodia (80% of the flow). The total volume is about 40 to 50 billion m^3/year. Diversion to Vaico river is an option but also has its difficulties. A So Ha-Cai Co project is looking at a diversion to the Mekong. Upscaling of the small polders to bigger areas, making ring dikes and multiple structures to block the early floods (till half of August) in North-South direction and sluices in the Mekong River for West-East control. This will also need an improvement of internal drainage facilities. The question is if locking the early floods is/will be acceptable for Cambodia. Another question is if round-the-year flood control will be acceptable. The area has a population of about 3,5 million people, of which 800,000 live in cities or other settlement areas (about 500 small zone settled areas with raised houses) or ring dikes around the villages. The question is if blocking the early floods is/will be acceptable for Cambodia. Another question is if round-the-year flood control will be possible.

In the deep inundation area in the area between Bassac and Mekong between the rivers and above Vam Nao, full flood control is developed, with many structures, allowing controlled flooding for water quality control. The settlement areas have been raised as a Flood Proofing measure.

In the shallow inundation area (Kien Giang, Tien Giang, Vinh Long and Can Tho provinces), flood protection is designed based on the year 2000 flood with a probability of 3%, but only for the cities and settlements. Ring dikes provide full flood control to an area of 280,000 ha.

In the coastal zone the main strategy is to try to control the salinity intrusion and supply fresh water for agriculture, there is **no** flood control strategy. In the Tra Vinh province there is a special project with many structures on the river banks for intake and drainage control.

13.3 Developments in SA10 affecting the flow regime

Embankments

Since in the Cambodian flood plain and Cuu Long delta large amounts of water are conveyed via the flood plain, embankments of various kinds and road infrastructure will have a great influence on these conveyance capacities. The importance of the roads on the flood flows in the Cambodian flood plains has been investigated by WUP-JICA (2004). Roads constructed since the 1920 have decreased the overland flow to the Tonle sap lake, but increased the Tonle Sap River flows. It implies that the flood levels at Phnom Penh has increased since then. Similarly, the present land fills along the Mekong will reduce the spill to the flood plains and increase the water levels in the vicinity of Phnom Penh as well. In WUP-TLSV (2004) and WUP-A (2004) the impact of future embankments on the flood levels have been investigated, with effects on water levels ranging from 2 m lower to 1 m higher. Hence, changing the road/embankment infrastructure may have considerable effects and should be thoroughly studied. It was learned that in Cambodia third and lower grade roads are implemented without any consideration of effects on flood conveyance.

Widening of bridges and rehabilitation of colmatage canals

Besides the effects of embankment and roads on the flood levels also effects of widening of bridge openings and of rehabilitation of colmatage canals and polder systems have been studied (WUP-TLSV, 2004) has been investigated. Again, effects were locally substantial on flow distribution and flood levels, stressing the need for analysis with the help of hydraulic models.

Cuu Long Delta interventions

Similarly, proposed interventions in the Cuu Long Delta, also need to be accompanied with a detailed analysis of the hydraulic consequences, not only for the flood flows and levels but also for the low flows and the consequences for salinity intrusion. This is, however, practice in the delta since long time, using the VRSAP hydraulic model.

Irrigation

About 3 million hectares of agricultural land receive irrigation in SA10 (BDP, 2006) mainly in Vietnam. The irrigation water requirement (including domestic and industrial use) amounts about 6.0 BCM per year. This amount equals about the total catchment runoff of Sa10 (estimated at 5.7 BCM).

Hydropower

The flatness of SA10 makes the sub-area not suitable for large scale hydropower development, except for the upper reaches of Prek Thnot. Dams in the basin upstream of SA10, however, will have an impact on flood levels. For an extreme flood like in the year 2000 the effect is limited to some 5 cm, whereas for low floods the effect is in the order of a few decimeters (MRC, 2005).

13.4 Floods

13.4.1 Tributary floods

Only the Prek Thnot tributary can be considered separately from the rivers and flood plain system around Mekong and Bassac. On Prek Thnot flooding takes place from Krang Thum till Kampung Speu. Construction of dikes to protect the city seems to be a solution. Upstream reservoirs is not possible anymore in view of resettlement problem. The flooding problem is aggravated by flood plain landfill for industrial expansion near Phnom Penh. Because the river posed a threat to Phnom Penh, since 2007 water is diverted away from the city. Reconstruction works are taken up by JICA. Some 10-15 years of discharge data is available in the HYMOS database for analysis. No hydraulic model seems to be readily available for transformation of hydrological hazard into flood hazard. Flood maps when available for this area may be used instead.

13.4.2 Floods in Cambodian Flood and Mekong Delta

The mainstream and flood plain flooding in SA10 has been described in Section 13.2. Generally, people in the delta have adopted to live with the floods. Floods are generally considered as beneficial for the people, bringing fertile soils for agriculture and appropriate conditions for fish farming. Only very extreme floods pose a problem. The floods of the years 2000-2002, see Chapter 11, were among the largest on record, with 2000 as the highest one. In 2000 the level at Tan Chau on Mekong rose to 5.30 masl, which is 1.06 m higher than the average flood level of 4.24 masl. The levels at Chau Doc are slightly lower: here the average flood level is 3.88 masl and in 2000 5.06 masl ($H_{Han\ Zou} = H_{Hatien}$ -0.167 m).

The flooding in SA10 is complex and the local infrastructure affects the conveyance of the flow into and through the flood plains. Different models ranging from 1-D to quasi 2-D are available for the entire delta (VRSAP, ISIS and Mike 11) and real 2-D (WUP-FIN) for part of the delta. The quality of the models can easily be checked as stage measurements take place at a regular basis and detailed flow measurements have been carried out in 2002-2003, while furthermore a large amount of flood maps from satellite imagery is available. In the application of the models due attention is to be given that the proper infrastructure is incorporated as recently various roads through the flood plains have been constructed/ rehabilitated and land fills are taking place.

The present content of the hydro-meteorological database HYMOS at MRC for SA10 is insufficient to support appropriate modelling. Additonal databases have been developed by the various projects carried out for SA9 and SA10, but apparently have never been integrated to one reliable database. Therefore, it is strongly recommended that the HYMOS database is updated for SA9 and SA10 with rainfall, waterlevels, stage-discharge measurements and discharge data.

13.4.3 Summing up

Sufficient tools (hydraulic models and flood maps) are available for SA10 to describe the flooding in the area for various boundary conditions. The accuracy of the models for the present conditions is to be checked. The hydro-meteorological database needs to be updated/extended. Additional data is available from project databases and from the Southern Regional Hydro-Meteorological Centre in Ho Chi Minh City.

CHAPTER 14

STAGE DISCHARGE DATA AVAILABILITY

14 STAGE-DISCHARGE DATA AVAILABILITY

An overview of the stage-discharge measurements as available in the HYMOS database for the various sub-areas is presented in the following tables.

Table 14.1 Stage-discharge measurements available in the HYMOS database.

2T

Station ID	Station Name	River	Coordinates (Indian 1960)		Catchment Area, km²	1960										1970										1980										1990										2000						
			Latitude	Longitude		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
010501	Chiang Sean	Mekong	20.2734	100.0834	189000	22	21	20						111	105	95	84	90	76	53	19																			48	45	33	39	26	40	40	38	38	38	38		
040101	Ban Pa Yang	Nam Mae Kha	20.2334	99.8067	518																																37				34											
040201	Ban Huai Yano	Nam Mae Cha	20.1117	99.7850	203																																35				36											
050104	Chiang Rai	Nam Mae Kok	19.9184	99.8500	6060																																39	45														
050105	Ban Tha Ton	Nam Mae Kok	20.0600	99.3634	2980																																32				23											
050201	Ban Tha Mai Li	Nam Mae Fang	20.0200	99.3584	1800																																32				23											
050301	Ban Tha Sai	Nam Mae Lao	19.8534	99.8434	3080																																41				35											
051001	Dam Site	Nam Mae Suai	19.7000	99.5200	426																																137				40											
051101	Dam Site	Nam Mae Pun	19.4334	99.4584	258																																133				39											
070103	Thoeng	Nam Mae Ing	19.6867	100.1917	5700																																34				33											

3T

Station ID	Station Name	River	Coordinates (Indian 1960)		Catchment Area, km²	1960										1970										1980										1990										2000						
			Latitude	Longitude		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
011903	Chiang Khan	Mekong	17.8967	101.6684	292000								102	118	104		83	78	72	52	43																					32	38	41	41	40	38	38	38	38		
011904	Pa Mong Dam	Mekong	17.9850	102.4300	299000											38	33	72	114	51	59																															
012001	Nong Khai	Mekong	17.8767	102.7200	302000										98	76	52	82	122	116	63								34	30	32	34	35	33	33	33	33	31	44	36	32	32	38	38	41	39	39	42	42	44		
013101	Nakhon Phano	Mekong	17.3984	104.8034	373000	4	59	43	22	47	28		31	8	63	77	65	78	57	50	36																			23	30	31	36	38	42	41	42	37	37	35		
013402	Mukdahan	Mekong	16.5400	104.7367	391000	9	60	72	41	47	45	44	51	59	87	99	77	99	74	94	54								24				19	32	34	37	33	33	31	32	48	52	62	32	43	42	42	38	38	38		
140101	Ban Pak Huai	Nam Heung	17.7034	101.4150	4090																																									40	38	38	38	38		
140201	Dan Sai	Nam Man	17.2850	101.1517	401																																24				30			1								
140301	Dam Site	Nam San	17.4317	101.2700	703																																30				31											
150101	Wang Saphung	Nam Loei	17.2984	101.7800	1240																																31				29											
150102	Ban Wang Sai	Nam Loei	17.0517	101.5200	235																																31				32											
290102	Ban Tha Kok D	Nam Songkhra	17.8617	103.7800	4650																																26				58											
310102	Nam Kae	Nam Kam	16.9550	104.5084	2360																																37				36											
310201	Ban Tham Hai	Nam Pung	17.0800	104.2567	1070																																37				37											
330103	Ban Na Kham I	Huai bang Sai	16.7184	104.6250	1240																																35				37											

5T

Station ID	Station Name	River	Coordinates (Indian 1960)		Catchment Area, km²	1960										1970										1980										1990										2000						
			Latitude	Longitude		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
370104	Yasothom	Nam chi	15.7817	104.1417	43100																																36				33											
370122	Ban Chot	Nam Chi	16.1000	102.5767	10200																																36				39											
370210	Ban Kae (Si Ch	Nam Pong	16.8667	102.1850	1250																																79				44											
370805	Ban Tha Dua	Lam Choen	16.4934	102.1284	1520																																27	35			24											
371101	Ban Nong Kian	Huai Rai	16.1334	101.6667	1370																																36				38											
371203	Ban Tad Ton	Huai Pa Thao	15.9417	102.0300	326																																30	32			39											
371509	Ban Na Thorn	Nam Yang	16.0584	104.0384	3240																																30				27											
380103	Ubon	Nam Mun	15.2217	104.8617	104000																																36				33											
380127	Kaeng Saphu T	Nam Mun	15.2400	105.2484	116000																																48	50			45											
380134	Rasi Salai	Nam Mun	15.3350	104.1617	44600																																36				33											
381206	Ban Huai Khay	Huai Khayuong	15.0050	104.6384	2900																																36				33											
381503	Ban Fang Phe	Lam Dom Yai	14.6900	105.1600	1410																																36				33											

6T

Station ID	Station Name	River	Latitude	Longitude	Catchment Area, km²	1960										1970										1980										1990										2000						
						0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
013801	Khong Chiam	Mekong	15.3184	105.5000	419000						7	117	112		64			83	93	87	38																				22	26	39			38	38	38	38	38		
380111	Pak Mun	Nam Mun	15.3084	105.4950	117000																																36	37			32											

Notes:

blank = no measured flow

105 = number of measured flows in a year

1L

Station ID	Station Name	River	Coordinates (Indian 1960		atchment Area, km	1960										1970										1980										1990										2000						
			Latitude	Longitude		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
011201	Luang Prabang	Mekong	19.8917	102.1367	268000	8	105						31	84			15	8	2													12	28			45	34	27			28	46	41	40	36	29	33	25				
100102	Muong Ngoy	Nam Ou	20.7017	102.7583	19700																															51	42	67			39	63	72	80	40	38	46	33				
110101	Ban Sibounhom	Nam Suong	19.9700	102.2733	5800																															19		12			14	21	15	30	28	14	7	17				
110201	Ban Kok Van	Nam Pa	19.9533	102.2983	700																															13		11			9	17	17	25	21	8	13	11				
120101	Ban Mixay (Ban Mout)	Nam Khan	19.7867	102.1767	6100																																				8	19		30	28	21	21	18				
120102	Ban Pak Bak (downstream)	Nam Khan	19.7433	102.2800	5800																															46	32	39			31	44	29	30	23	22	20	18				

4L

Station ID	Station Name	River	Coordinates (Indian 1960		Catchment Area, km²	1960										1970										1980										1990										2000						
			Latitude	Longitude		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
011901	Vien Tiane	Mekong	17.9283	102.6200	299000	3	95						30	31	14	16	12		12														29				33			32	32	32	38	40	40	38	39	42	42	43		
013102	Thakhek	Mekong	17.3933	104.8067	373000																																			25	30	31	36	27	37	38	42	38	37	35		
013401	Savannakhet	Mekong	16.5617	104.7467	391000																																			32	32	32	38	41	41	42	42	38	38	38		
230101	Ban Pak Kanhoun	Nam Ngum	18.4183	102.5500	14300																															45	45	46	18	12	4	16	20	11	19	15	15	15			13	
230102	Tha Ngon	Nam Ngum	18.1350	102.6217	16500																																															
230104	Ban Tha Lat	Nam Ngum	18.5167	102.5167	14200																																															
230110	Ban Na Luang	Nam Ngum	18.9133	102.7783	5220																															100	95	69	5	9	3	34	35	39	37	35	37	37			19	
230201	Ban Hin Heup	Nam Lik	18.6600	102.3550	5115																															39	46	45	18	13	4	18	16	11	18	15	15	15			13	
230205	Muong Kasi	Nam Lik	19.2320	102.2570	374																															3	14	15	5	7	3	8	6	8	18	15	15	15			13	
230401	Vang Vieng	Nam Song	18.9230	102.4500	816																															19	20	19	5	7	4	11	5	8	18	16	15	15			13	
250101	Muong Mai	Nam Nhiep	18.5050	103.6583	4270																															19	20	15	5	5	3	9	8	8	15	18	20	13			13	
260101	Muong Borikhan	Nam Sane	18.5617	103.7367	2230																															19	20	20	5	5	3	9	8	8	15	18	20	14			13	
270101	Ban Phone Si	Nam Ca Ding	18.3017	104.0983	14200																																															
270901	Kham Keut	Nam Theun	18.2350	104.6620	5820																																															
270903	Ban Signo	Nam Theun	17.8450	105.0520	3370																															115	103	81	5	17	17	47	55	36	37	37	24	22			13	
320101	Se Bang Fai	Se Bang Fai	17.0720	104.9850	8560																																					36	25	13		13		26				
320107	Mahaxai	Se Bang Fai	17.4133	105.2020	4520																															104	68	80	5	17	17	26		37	36	37	37	37			13	
350101	Ban Keng Done	Se Bang Hieng	16.1850	105.3170	19400																															15	34	45	17		44	35	27	35	28	26	23	26				
350105	Tchepon (Sop Na	Se Bang Hieng	16.6867	106.2183	3990																															16	20	13	3	6	17	16	13	16	19	1	23	25				
350201	Muong Nong	Se La Nong	16.3700	106.5133	2011																															13	20			6		16	13	16	7	13	23					
350301	Ban Muong Chan	SePon	16.6600	106.2920	1979																															17	20	15		6	19	16	13	16	19	23	24	25				
350401	Highway Bridge	Se Thamouak	16.5770	105.9133	636																															16	11	16				15	13	11	17	17	23	14				
350501	Ban Phalane	Sexangxoy	16.6570	105.5680	882																															12	14	15		6		12	9	8	17	16	18	10				
350601	Kengkok	Se Champhon	16.4450	105.2030	2640																														13	2						5	14	19	18	21	23	16				
350602	Dong Hen	Se Champhon	16.6980	105.2920	1525																															12	15	8		5	2	11		11	17	17	23	17				

6L

Station ID	Station Name	River	Coordinates (Indian 1960		Catchment Area, km²	1960										1970										1980										1990										2000						
			Latitude	Longitude		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
013901	Pakse	Mekong	15.1167	105.8000	545000	9	108						18			1	12		16													8	28			22	26						29	42	32	34	34	38				
014301	Ban Chan Noi	Mekong	14.3167	105.8867	549000																																															
390102	Khong Sedone	Se Done	15.5750	105.8150	5151																															20	20	13	12	11	12	15									8	
390103	Saravanne	Se Done	15.7100	106.4500	1172																															21	19	26	3									7			10	
390104	Souvanna Khili	Se Done	15.3967	105.8250	5760																															46	37	40	26	13	21	22	20	10	15	19	20	20			12	

7L

430105	M.May (Attopeu	Se Kong	14.8067	106.8433	10500																															22	12	14		12	1			13	24						14	
430106	Veun Khene	Sekong	14.8098	106.7778																																											21	11			17	

Notes:

blank = no measured flow

105 = number of measured flows in a year

7C

Station ID	Station Name	River	Coordinates (Indian 1960		Catchment Area,	1960										1970										1980										1990										2000						
			Latitude	Longitude	km²	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
430101	Ban Khmoun	Sekong	13.7410	106.1865	29600				4	8	6																																									
430102	Siempang	Sekong	14.1192	106.3935	23500																																															
430103	Chantangoy	Sekong	13.5641	106.0565	29700																																	10	36						5	5						
440101	Ban Kamphun	Sesan	13.5341	106.0464	48200																																	9	14						10	10						
440102	Voeun Sai	Sesan	13.9676	106.8141	16300																																									24						
440103	Andaung Meas	Sesan	14.0472	107.1070																																										21						
450101	Lumphat	Sre Pork	13.5481	106.5285	25600																																									29	1					

8C

Station ID	Station Name	River	Coordinates (Indian 1960		Catchment Area,	1960										1970										1980										1990										2000						
			Latitude	Longitude	km²	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
14501	Stung Treng	Mekong	13.5451	106.0166	635000				1	9	11	5																									11	9	10						7	4		1				
014901	Kratie	Mekong	12.2398	105.9871	646000	101	9	11	4	24	22	11	1	1	2																																					

9C

Station ID	Station Name	River	Coordinates (Indian 1960		Catchment Area,	1960										1970										1980										1990										2000						
			Latitude	Longitude	km²	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
020102	Prek Kdam	Tonle Sap	11.8133	104.8041	84400																																	2	28			10	7	7	5		25	12				
520101	Mong Kolborey	Mongkol Borey	13.5037	103.0191	4170			8	30																																		2	9	6		11					
530101	Sisophon	Sisophon	13.6139	102.9981	4310			5	6																																		2	7	3		11					
540101	Kralanh	Stung Sreng	13.5436	103.5432	8175			8	23																																		1	8	6		15	1				
550101	Treng	Stung Sangker	12.8693	103.1390	2135		37	30																																					3	3	11	1				
550102	Battambang	Stung Sangker	13.0560	103.1986	3230			8	32																																		2	15	8		19					
550103	Sre Ponleu	Stung Sangker	12.7310	102.7799	566																																															
560101	Bot Chhvear/Untac Br	Siem Reap	13.3443	103.9956	670																																							2	5		16					
570101	Kompong Kdei	St. Chikreng	13.1267	104.3393	1920			5	19																																		1	9	4		16					
580101	Pursat	Stung Pursat	12.6627	104.0543	4480			10	21																																											
580102	Taing Leach	Stung Pursat	12.2832	103.6130	2080																																															
580103	Bac Trakoun	Pursat	12.3535	103.7523	4440																																							4	10	1	20					
580104	Khum Viel	Stung Pursat	12.1794	103.7434	4596																																							4	11	1	21					
580201	Peam	Pursat	12.1500	103.7000	243																																								13	10	22					
580301	Prey Klong(down)	Stung Pursat	12.1106	103.9136	421																																			12							14	1				
581102	Svay Don Keo	Pursat	12.7703	102.8791	805			7	10																																											
583020	Thlea Maam(up)	Pursat	12.7034	102.9889	322																																															
583101	Banteay Krang	St. Krakor	12.9660	103.5430	138																																															
590101	Boribo	Stung Boribo	12.3476	104.3804	869			9	19																																			6	6	1	16	1				
600101	Kompong Chen	Stung Staung	12.9375	104.5825	1895			6	21																																		2	10	9		15	1				
610101	Kg. Thom	Stung Sen	12.7075	104.8730	14000			5	24	10	4																																2	16	7		17					
610102	Kompong Putrea	Stung Sen	13.2173	105.2635	9,080																																										19					
620101	Kg. Thmar	Stung Chinit	12.5010	105.1309	4130			1																																			2	12	6		16					

10C

Station ID	Station Name	River	Coordinates (Indian 1960		Catchment Area,	1960										1970										1980										1990										2000						
			Latitude	Longitude	km²	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
019802	Kompong Cham	Mekong	11.9093	105.3877	660000		52																																						6	14	14	26	21			
019801	Chroy Chang Var	Mekong	11.5800	104.9388	663000				6	11	4																								8	34			22			17	6	5	5		51	102	51			
019910	Prek Koy	Prek Koy	11.8380	104.9880																																											30					
019911	Spean Tras	Prek Koy	11.9010	104.9360																																											33	2				
020101	Phnom Penh Port	Tonle Sap	11.5750	104.9228																																1				1							46	112				
033401	Bassac Chaktomouk	Bassac	11.5516	104.9330			40		9	10	2																																			1	1					
640101	Anlong Touk	St. Prek Thnot	11.4355	104.4434	3650				9	17	9																															1										
640103	PeamKhley-dam site	St. Prek Thnot	11.4704	104.3690																																				3		12	6	1	4	2						

Notes:

blank = no measured flow

105 = number of measured flows in a year

CHAPTER 15

CONCLUSIONS

15 CONCLUSIONS

Based on the description of the type of floods in the sub-areas 1 to 10 in the Lower Mekong Basin the following conclusions can be drawn:

Sub-area 1: Northern Laos

- The type of floods that occur in SA1 are:
  - flash floods on the tributaries, and
  - main stream 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 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 and 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.

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

- The type of floods that occur in SA2 are:
  - flash floods on the tributaries,
  - main stream 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 procedure proposed by Adamson (2007) is proposed as for SA1.
  - 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 main stream 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 satelitte 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

Sub-area 3: Nong Khai/Songkhram

- The type of floods that occur in SA3 are:
  - flash floods on the tributaries,
  - main stream 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 od 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 main stream flooding:
  - urban areas along the Mekong have been protected from main stream 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.

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,
  - main stream 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 duation 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 record larger then say 15 years can be derived from the available data. Extension with rainfall-runoff modelling is not an option in view of the limited available and partly unreliable rainfall data. A regional analysis, like the one proposed by Adamson, P.T. (2007) but extended with local rainfall and physical basin information as discussed in the previous sections, is an option.
  - For the Nam Ngum, Se Bang Fai 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 is not capable of tranforming hydrological hazard into flood hazard, however, 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.

Sub-area 5: Lower Esaan (Mun/Chi)

- Floods in the Mun-Chi system are flashy in the upper reaches and less rapid but much longer lasting in the midlle 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 (check) or a regional approach is being embarked on.
- For the main stream satellite imagery combined with hydraulic modelling (Mike-11) is an option, provided the model is properly calibrated.

Sub-area 6: Southern Laos (Khone Falls)

- Major flood prone areas are centered 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 main stream 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 or flood maps from satellite imagery can be made available.

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, 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.

Sub-area 8: Kratie

- Main stream 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. Prior to that a thorough review is required of the discharge ratings of Stung Treng and of Kratie.
- Exceedance duration can well be described by an exponential function of the discharge, including the uncertainty.
- 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 tranlation can be made.
- Downstream of Kratie satellite imagery as well as hydraulic models are available for the translation of hydrological hazard into flood hazard.

Sub-area 9: Tonle Sap

- Tributary, main stream 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.

Sub-area 10: Mekong Delta

- The hydro-meteorological database needs to be updated/ extended to derive the hydrological hazards Additional data is to be 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 the present conditions is to be checked.

CHAPTER 16

PROPOSED APPROACH

16 PROPOSED APPROACH

Based on the findings in the previous chapters and the summary in Chapter 15 in Table 16.1 an overview is given of the type of flood and their appearance in the sub-areas 1 to 10. For each of the sub-areas and flood type it has been indicated how the hydrological hazard will be/can be determined. From the table it is observed that the following options are generally available:

- from a statistical analysis of annual maximum flows making use of the HYMOS database or other databases if at least 15 years of data is available; this will require thorough screening of the available water level, stage-discharge and discharge data;
- regional analysis by scaling annual flood data according to their mean annual flood as proposed by Adamson (2007) and establishment subsequently of a relation between the mean annual flood and metorological and physical characteristics of the basin;
- for the main stream stations the hydrological hazard is available for the key stations from the Annual Flood Report of 2006;
- in a number of cases extension of the HYMOS database is necessary to arrive at series of sufficient length. It appears that such data is either available at MRC in various files or with the line agencies dealing with hydro-meteorological monitoring.

To translate the hydrological hazards into flood hazards two options are available:

- either use is made of a hydraulic model, which is run for discharges of the required return period
- satellite imagery of flooding is available for different river discharges, and interpolation (and extrapolation (if an accurate DEM is available)) is applied to determine the flood extent for discharges of the required return period

These options can also be combined to improve on the calculated flood extent by the model. Since also the flood duration is of importance relations will be established between flood level and average exceedance duration, based on the available data.

For locations where flood control measures are to be elaborated, design hydrographs will be developed to support the design. For this use will be made (when available) of historical discharge data if the time scale is commensurate with the temporal characteristics of the flood phenomenon, or use will be made of available rainfall-runoff models for tributary floods adjusted to the required time scale for the flood phenomenon or use will be made of empirical methods.

The impacts of envisaged basin development regarding irrigation and hydropower and effects of climate change will be investigated using the available computational tools.

It is proposed that in the first phase the procedures and possibilities for each sub-area are investigated and documented and thoroughly discussed with the line agencies and MRC, and based on the results it is determined to what extent these flood maps are developed in the second phase.

Table 16.1 Overview of flood type and their appearance in the sub-areas including procedures proposed for determination of hydrological and flood hazard based on available data, models and flood imagery.

Sub-area	Type of flood	Issue	Hydrological hazard	Flood hazard
SA1 Northern Laos	Tributary Main stream Combined	yes yes no	For some via statistics rest via regional approach Annual Flood Report -	No models available/satellite imagery? Satellite imagery -
SA2 Northern Thailand	Tributary Main stream Combined	yes yes yes	For some via statistics rest via regional approach Annual Flood Report HYMOS/other databases	No models available/satellite imagery? Satellite imagery No models available/satellite imagery?
SA3 Nong Khai/ Songkhram	Tributary Main stream Combined	yes yes yes	For some basins via statistics rest via regional approach Annual Flood Report HYMOS/other databases	Models available for Nam Loei, Huai Mong and Nam Songkhram Satellite imagery Models available for Nam Loei, Huai Mong and Nam Songkhram
SA4 Central Laos	Tributary Main stream Combined	yes yes yes	For some via statistics rest via regional approach Annual Flood Report HYMOS/other databases	Models available for Nam Ngum, Se Bang Fai and Se Bang Hieng Satellite imagery Models available for Nam Ngum, Se Bang Fai and Se Bang Hieng
SA5 Mun-Chi	Tributary Main stream Combined	yes yes no	For 12 via statistics, rest via RID data or regional approach HYMOS/RID/other databases	No models available, satellite imagery MIKE11+ satellite imagery
SA6 Southern Laos	Tributary Main stream Combined	yes yes yes	HYMOS/other databases Annual Flood Report HYMOS/other databases	Satellite imagery Satellite imagery Satellite imagery

Sub-area	Type of flood	Issue	Hydrological hazard	Flood hazard
SA7 Se San/ Sre Pok/ Se Kong	Tributary Main stream Combined	yes no yes	partly HYMOS/other databases, partly regional approach - HYMOS/other databases + review of Ban Kamphun data	Satellite imagery model for middle and lower Se San model Se San extension to Mekong
SA8 Kratie	Tributary Main stream Combined	yes yes yes	No data Annual Flood Report No data	- Satellite imagery u/s Kratie + model d/s Kratie -
SA9 Tonle Sap	Tributary Main stream Combined	yes yes yes	extension of database HYMOS/other databases extension of database	models for Stung Pursat and Stung Battambang + satellite imagery various models ISIS, WUP-FIN, MIKE11, VRSAP + satellite imagery models for Stung Pursat and Stung Battambang + satellite imagery
SA10 Mekong Delta	Tributary Cambodian flood plain and Mekong delta	yes yes	HYMOS/other databases extension of database updating rating curve Kratie/Stung Treng	models Prek Thnot?+satellite imagery various models ISIS, WUP-FIN, MIKE11, VRSAP + satellite imagery

CHAPTER 17

REFERENCES

17 REFERENCES

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