Mekong River Commission

Annual Mekong Flood Report 2007

May 2008

Published in Vientiane, Lao PDR in May 2008 by the Mekong River Commission

Cite this document as:

MRC (2008) Annual Mekong Flood Report 2007, Mekong River Commission, Vientiane.
86 pp.

Authors: P. A .Adamson and J. Tospornsampan

Editor: T.J. Burnhill

Graphic design: T.J. Burnhill

184 Fa Ngoum Road, Unit 18, Ban Sithane Neua, Sikhottabong District,
Vientiane 01000, Lao PDR
Telephone: (856-21) 263 263 Facsimile: (856-21) 263 264
E-mail: mrcs@mrcmekong.org
Website: www.mrcmekong.org

Foreword

It is my pleasure to introduce the third Annual Mekong Flood Report, a major output of the Mekong River Commission's Flood Management and Mitigation Programme (FMMP).

This 2007 Annual Flood Report is the second to combine a 'theme' with a review of flood conditions within the Lower Mekong Basin. The 2006 Report focussed upon the flood hydrology of the Mekong mainstream. The theme this year completes the evaluation of the regional flood hydrology by considering it within the major tributary systems, where flash floods are one of the principal natural hazards. As before, the report aims to draw together as much historical information as possible and provide insights into the temporal and geographic nature of the flood phenomenon.

Flash floods have been much in the news in recent years. It is widely held that their incidence and severity is increasing due to regional deforestation and landscape change. This is difficult to prove. The reality is that pressure on land resources and increased economic well being means that an increasing number of people are vulnerable to the hazard and the value of the property and goods exposed to damage and loss is increasing year by year. The socio-economic consequences of floods and flooding is certainly now much higher. The material presented here reveals just how difficult it is to forecast flash floods and underscores the need for continued research and planning if losses and damage are to be contained.

Another justification for the assessment of the flood hydrology of the Mekong tributaries is the accelerating pace of water resources development within their catchments, particularly with regard to hydropower. The associated dams and other structures require the estimation of design floods for spillways and other river works. Here a regional procedure is presented which enables such estimates to be made based upon several hundred station-years of hydrological data, thereby improving upon many current practises. In so doing the 'theme' material becomes of real value to design engineers.

The four country reports from Cambodia, Lao PDR, Thailand and Viet Nam are summarised to reveal the extent of national loss and damage during the year. This information that in time will accumulate as key reference material.

The report should be seen therefore as a collaborative effort between the Mekong River Commission Secretariat (MRCS) and the riparian countries towards achieving a much better understanding of the nature of the regional flood hazard. The annual 'theme' is formally agreed between the countries and future subjects include the costs and benefits of the annual Mekong flood and the potential impacts of climate change.

Jeremy Bird
Chief Executive Officer
Mekong River Commission Secretariat

Table of Contents

Table of Figures

Table of Tables

Acknowledgements

This report was prepared within the framework of the Flood Management and Mitigation Programme (FMMP) of the Mekong River Commission Secretariat (MRCS). The authors wish to thank the National Coordinators at the National Mekong Committees of Cambodia, Lao PDR, Thailand and Viet Nam for their support and guidance in the drafting of the report.

Summary

1. Introduction

As in 2006, the 2007 Annual Flood Report aims to fill two primary roles, (i) to provide a summary of flood conditions in the Mekong Region over the year, and (ii) to collate the relevant data and information. The report also has an annual 'theme'. Having contributed significantly to the understanding of Mekong mainstream floods and flooding in the 2006 Report, this document has made the logical progression and taken the flood hydrology of the tributaries as its theme, with flash floods meriting particular attention.

2. The flood hydrology of the major tributaries in the Lower Mekong Basin

2.1. An introductory note on the impacts of land-use change and deforestation on the flood regime of the Mekong tributary rivers

The belief that deforestation causes an increase in the frequency and severity of major floods and compounds the damage that they do appears to be widespread. This view is as widely held within the Mekong Basin as it is throughout the tropical world. However, an authoritative Report from the UN's Food and Agriculture Organization (FAO) and the Centre for International Forestry Research (Cifor) says that the evidence shows no link. That flood damage is increasing is unquestioned; however this is not linked to the increasing magnitude of events but is due to the growing global population and the consequent expansion of human settlements into areas which had once been marginal. As a result, each flood claims more lives than it would have done a century ago. In addition the human diversion of watercourses and the construction of flood protection works often moves the problem from upstream to downstream areas.

There are arguments and some evidence to suggest that the actual frequency of floods is beginning to increase, possibly in response to climate change, a major consequence of which, it is generally agreed, will be an increase in the incidence of extreme events.

2.2. The geography of the major tributary contributions to the flood hydrology of the Mekong

The physical geographical region defined by the Lower Mekong Basin (LMB) is a variable one in terms of its topography, land cover, and rainfall. These three factors obviously have a major impact on regional hydrological response and its spatial variability, which is reflected in the contributions that the major tributaries make to the mainstream flows. These major tributaries are identified and, recognising the geographical distinctions in tributary hydrology, three reaches of the mainstream and their tributaries are considered: Chiang Saen to Vientiane, Vientiane to Pakse and Pakse to Kratie.

2.3. Chiang Saen to Vientiane — the regional history of tributary floods and flooding

In northern Thailand and northern Lao PDR flash floods have been much in the news in recent years with locally catastrophic events particularly in 2000 and 2001. Flash floods in these regions feature in the hydrological landscape to some extent virtually every year and there is a long history of extreme events. For example, the years between 1918 and 1920 each featured devastating events, as did 1953. Even further back in time the original capital of the Lanna Kingdom had to be moved to Chiang Mai at the end of the 13th Century because of frequent flood inundation. These events obviously occurred long before the regional forests were reduced by logging, which has been blamed for a supposed increase in the frequency of the flood hazard since the 1960s. The logging of natural forests was banned in Thailand following the national flood emergency of 1988.

In the northern Lao provinces of Huaphan, Pongsaly, Luangnamtha and Luang Prabang significant flooding has been similarly frequent, having occurred in 1991, 1995, 1996, 2000, 2002, 2005 and 2006. Prior to that the largest regional flood was in September 1966, which was associated with the incursion of Cyclone Phyllis over the large northern tributaries.

2.4. Chiang Saen to Vientiane — the regional tributary systems

A schematic of the regional tributary rivers is presented along with summaries of their areas and the hydrological data that are available.

- The reach comprises a complex of right bank tributaries in north and northeast Thailand, principally the Nam Mae Khan, Nam Mae Ing, Nam Mae Kok and Nam Loei and a number of generally larger left bank tributaries in northern Lao PDR. Of these the Nam Ou is by far the most significant in terms of drainage area and discharge.

- The total tributary area is 110,000 km^2, of which stream-flow data are available for almost 60,000 km^2.

- Annual tributary runoff is less than in other parts of the Lower Mekong Basin to the south, particularly from the large left bank tributary systems downstream of Vientiane.

- The sub-reach between Luang Prabang and Vientiane is unique in the LMB in that there are no large left bank tributaries, a fact which largely explains the small contribution it makes to the overall flow of the Mekong.

- Flash floods in this area of the Lower Mekong Basin have been a key feature of its hydrological history. It has also been an area where deforestation and 'slash and burn' agriculture have been widespread, leading to arguments that the consequent landscape changes have been a major contributory factor to flooding.

2.5. Chiang Saen to Vientiane — are flash floods becoming more common?

The view that deforestation has increased the frequency and severity of flash floods is widely held, particularly in northern Thailand. There appears to be sufficient evidence on the basis of the analyses undertaken that extreme floods have become more frequent over the last 15 years or so. Whether this is a response to external influences such as climate change is arguable. It may simply be part of the natural periodicity of such processes — the fact that there were no significant events at all during the 1980s might be evidence in this regard. However, the timescale for which data are available is far too short to establish any such possible periodic patterns one way or the other. Nevertheless, it seems reasonable to conclude that after the logging ban in Thailand during the late 1980s, deforestation appears not to be a factor in the increased frequency of events post 1990.

2.6. Chiang Saen to Vientiane — the hydrological assessment of extreme regional tributary flood events

It is proposed that there are two weather processes linked to the occurrence of floods, one that generates average and significant floods and one that generates floods that are far more extreme. This distinction may be linked to:

- typical monsoonal storms and average antecedent catchment conditions that result in the more typical or basic events, and;

- more extreme weather systems, such as intense tropical depressions, severe tropical storms and typhoons, which combine with wet or saturated antecedent catchment conditions to generate extreme or outlier events.

The picture that emerges from the assessment of the most extreme historical regional flood events is that, except for the larger catchments in Lao PDR such as the Nam Ou, they are of short duration, typically three to four days. In addition:

- times to peak are extremely rapid, typically less than one day;

- antecedent flow conditions are often not linked in any significant way to the peak magnitude, though such is the rapid rate of recession of the flood hydrograph this may not of itself be a meaningful indication of the actual state of the catchment in terms of wetness and its ability to generate maximum rates of runoff during a storm.

2.7. Vientiane to Pakse — the regional tributary systems

In this reach the large left bank tributaries in Lao PDR begin to exert their dominant influence on the flood hydrology of the Mekong, starting with the entry of the Nam Ngum 50 km downstream of Vientiane. The combined mean annual flow of all tributaries between Vientiane and Pakse is 171 km^3, almost 40% of the total for the Mekong. The major contributions to this figure are made from the left bank by the Nam Ngum, Nam Kading/Nam Theun and the Se Bang Hieng, while the Mun – Chi Basin accounts for by far the greater part of the floodwater arising from the right bank in Thailand. Within this reach:

- The tributary catchment areas are generally very large, such that flash floods do not dominate the flood hydrology as they do in the tributaries upstream of Vientiane. They are locally important on some of the smaller, steeper, tributaries and in the upper reaches of the larger rivers, and on the larger tributaries conditions may arise where extremely rapid increases in discharges are followed by equally fast flood recessions.

- In their lower reaches backwater effects from the confluence with the Mekong mainstream can extend very considerable distances upstream and exacerbate the depth and duration of inundation during extreme events.

- The accelerating development of hydropower schemes in this sub-region of the LMB will in time significantly modify the flood regime of many of the major tributaries. The impact upon flood peaks and volumes will depend upon the scale of reservoir development and whether any such storages are operated in a way that mitigates the flood hazard, for example by the provision of operational flood storage during the flood season.

- It is anticipated that one of the major changes to the flood regime will be a delay in the start of the flood season and the onset of the higher discharges associated with it. Early season flood water will be withheld in the reservoirs which will typically be drawn down at the end of the dry season.

- The cumulative impacts of the numerous proposed schemes will in time modify the flood regime of the Mekong mainstream itself.

2.8. Vientiane to Pakse — the hydrological assessment of extreme regional tributary flood events

Because the major tributaries in this Mekong hydrological sub-region are large, flood risk should be assessed both in terms of flood peak and volume, thereby acknowledging the importance of both the depth and duration of flood inundation. A highly variable flood hydrology both within and between years is characteristic of the large left bank tributaries and there is, in effect, nothing that can be defined the 'typical' flood season hydrograph. Extremely rapid increases and decreases in flood discharge, generally associated with severe tropical storms can, even in very large catchments, cause flash flood conditions.

Due to the flat landscape, the lower rainfall and to some extent the presence of large reservoirs, flash floods are not a feature of the hydrology of the Mun – Chi Basin, except in the far upstream reaches. In recent years the events of 2000, 2001 and 2002 were the largest both in terms of flood peak and volume. On the Nam Mun the highest peak discharge occurred in 1978, corresponding with the year that the largest flood peak was observed on the Mekong mainstream at Kratie since records began in 1924.

The evidence from the Nam Chi Basin suggests that below 'normal' flood years, when peak and volume are significantly less than average, tend to cluster. During the 13 years between 1967 and 1979, eight of the most extremely deficient annual floods were observed.

With a total basin area of 120,000 km^2 , equivalent to 22% of the Mekong drainage area at Pakse, the Mun – Chi system contributes only 10% to the average flood volume at that point on the mainstream and 6% to the total at the Delta.

2.9. Vientiane to Pakse — the estimation of flood risk at ungauged locations

The accelerating pace of hydropower development in the LMB means that there is a growing need for the development of a reliable procedures for the estimation of design flood risk at ungauged dam sites. Over recent years 'best practice' has involved the use of regional methods based upon the pooling of data in regions and sub-regions that might be considered to be homogenous with respect to their flood hydrology. The Mekong between Vientiane and Pakse can be considered to be one such, though the left and right bank tributaries require separate treatment. A statistical procedure is developed.

2.10 Pakse to Kratie — the regional tributary systems

This reach of the Mekong, which accounts for 18% of the total basin drainage area, the tributary contribution to the mean annual flood volume at the Delta is about 20%. At Kratie 90% of floodwater has already entered the system; downstream of there most of the balance is made up by the contribution of the Tonle Sap Basin in Cambodia. Of this 20% around 18% is accounted for by the combined Se Kong, Se San and Sre Pok Basins, which combined make the largest single contribution to the total Mekong flood in most years.

The major constraint to hydrological analysis in this sub-region is a lack of representative data, which are distributed amongst only seven sites. With the exception of the gauge on the Se Done at Kong Se Done, which records the flows from 65% of the basin, and the gauge on the Se Kong at Attapeu, the others on the Se Kong and Sre Prok are far upstream and only provide information about the hydrology of the headwaters. Meaningful estimates of the flood hydrology of these key regional river systems is therefore dependent upon hydrological modelling.

2.11. Pakse to Kratie — the hydrological assessment of extreme regional tributary flood events

This lack of representative data means that only a limited assessment of the tributary flood hydrology is possible, which is unsatisfactory given the pivotal role of the Se Kong, Se San and Sre Pok in the generation of extreme flood conditions across the Cambodian floodplain and in the Mekong Delta. Their contribution to the extreme regional flood of 2000 was a major one. This event was characterised by a peak flow at Kratie on the mainstream of the Mekong that was only marginally above average. It was the total flood volume over the flood season that was extreme, being the highest observed since 1924.

3. The 2007 flood season

3.1. Hydrological aspects — the mainstream of the Mekong

In terms of peak discharges and seasonal flood volumes, conditions along the Mekong mainstream during the 2007 flood season were comparable to those that occurred during 2006. As then, both variables fell below their long-term average values; the degree to which they did so became more pronounced downstream, so that at Kratie both flood peak and volume were significantly below normal. In fact, flood conditions at Kratie during 2006 and 2007 are amongst the eight lowest observed since 1924.

These below average flood conditions were not, however, the definitive hydrological feature of the 2007 season. This lies with the fact that throughout the mainstream the start of the flood season was generally the latest observed over the last 80 to 90 years. Typically, the season begins in the last week of June or the first week of July in those reaches above Kratie and a week or two later at Phnom Penh and in the Delta in Viet Nam. As a consequence of the three week to one month delay in 2007, water levels at the end of July were amongst the lowest ever observed.

3.2. Hydrological Aspects — The Cambodian Floodplain and Mekong Delta

Self evidently, hydrological conditions over the Cambodian floodplain and within the Delta during the 2007 flood season — indicated in terms of water level rather than discharge — reflected those that prevailed upstream. Water levels were considerably below average throughout most of the years and amongst the lowest observed at the end of July. Only in October did they increase to anywhere near average.

3.3. The 2007 Flood Season — Meteorological Aspects

With the exception of most of Cambodia and the Delta region, rainfall during the SW Monsoon of 2007 over the Mekong region was moderately below average, with only one extensive storm system that was large enough to bring the Mekong up to average discharges and water levels. This was Sever Tropical Storm 'Lekima', which passed over the central regions of Lao PDR and Thailand during the first week of October.

4. Lao PDR 2007 Country Report

The central and southern parts of Lao PDR were the most affected by floods in 2007, which were mainly associated with impacts of Tropical Storm 'Lekima'. The resultant national damage and loss exceeded that for 2006, particularly with respect to the rice crop. Elsewhere in the country the only events of note in 2007 were heavy rainfall during mid-September in Luangnamtha Province and a local storm in Vientiane during April which caused some damage. Two people were killed and over 600 villages were affected in some way by the floodwater. Almost 160,000 ha of rice crop was damaged to some extent by prolonged submergence along with 30% of the planted vegetable crop.

5. Thailand 2007 Country Report

The southern parts of the Mun and Chi River Basins around Nakon Phanom, Kalasin Mukdahan, Roi Et Yasothon and Ubonrachatani were the most affected by the storm rainfall associated with 'Lekima'. Most rainfall occurred on the 4th and 5th of October, by which time the event had been downgraded to a tropical depression. Rainfall decreased from in excess of 250 mm in the east of the Mun Chi Basin to less that 150 mm in the west during the first week of October as the intensity of the system decreased as it tracked westwards. Flooding in NE and central Thailand during October 2007 was described by the *Bangkok Post* as the worst in 40 years, with troops and rescue workers dispatched to assist stranded residents. A number of people died as a result of being swept away and thousands of hectares of crop lands were inundated to a depth of 1 m and more. There was widespread disruption of road links and many communities were cut off. Other reports suggest that the total number of people killed was as high as 67 and that 17,000 people had to be evacuated.

6. Cambodia 2007 Country Report

Events in Cambodia during 2007 centred around the flooding caused by Tropical Storm 'Pabuk' in the northern and coastal areas of the country on the 4th and 5th of August. Otherwise, the fact that the annual flood on the Mekong mainstream was a month late in starting and that water levels, once it had, remained significantly below average until October following 'Lekima', meant that levels in the Great Lake were considerably lower than average. This delay in the increase in lake levels until early August and the fact that inundation of the riparian forest covered a much smaller area than usual resulted in a large fall in the annual fish catch. Reports from those provinces affected by 'Pabuk' during August indicate that more than 160,000 persons were affected, 5 people were killed, 37 km of rural roads were seriously eroded, along with some locally significant damage to public building, temples and residential areas. A number of dykes and irrigation canals eroded or filled with sediment. Over 8000 ha of rice and other crops were damaged or altogether lost due to prolonged submergence.

7. Viet Nam 2007 Country Report

Seven typhoons and three tropical depressions, originating in the South China Sea, affected the Vietnamese regions of the LMB during 2007, of which those designated Numbers 2 ('Pabuk' in Cambodia) and 5 during August and November caused major flash floods in the Upper Se San and Sre Pok Basins. Flooding in the Delta was minimal, except during spring tides when areas of Can Tho City are inundated. Serious damage to infrastructure, agricultural production, and human settlements resulted from Typhoon No. 2 during early August. In Dak Lak Province 23 people died and losses to the provincial economy estimated at US$5 million. Over 10,000 properties were inundated, more than 41,000 ha of agricultural lands flooded and 70 water control projects destroyed or damaged. The flash floods, landslides and debris flows that took place in November as a result of Typhoon No. 5 caused extensive damage in the upper Se San catchment. In Kon Plong one person died, four bridges were either damaged or completely destroyed and several villages flooded and cut off. The remoteness of many of the villages made rescue and repair operations challenging.

8. Summary conclusions and recommendations

In many ways the flood season of 2007 mirrored that of 2006, with below average peak discharges, water levels and flood volumes, which at Kratie were significantly so. The definitive feature of the year was the exceptionally late start to the flood season throughout the Lower Mekong region. It generally starts during the early weeks of July but in 2007 the onset was as late as early August in Cambodia and Viet Nam. This delay caused discharge and water levels towards the end of July to be some of the lowest observed since hydrological records began in the early 20th Century. The major impact of a shorter flood season, significantly low water levels over most of the season and the fact that maximum water levels were unseasonably late, not occurring as that did until October, reduced the annual fish in the Great Lake by a reported 35%.

The only major regional storm event to cause widespread flooding over the central areas in Lao PDR and Thailand was Tropical Storm 'Lekima', which occurred in October and resulted in considerable loss of life. This provided the only flood runoff during the year on a scale large enough to cause Mekong water levels to increase to anywhere near average.

Elsewhere, flash floods in Cambodia and Viet Nam during August and again in Viet Nam in November caused considerable damage and loss of life, particularly in the Upper Se San and Sre Pok Rivers.

The principal recommendations are:

- In 2007 the incidence of flash flooding and the death and damage that it causes once again drawn particular comment, particularly through the National Flood Reports. There is general consensus that they are not well understood and that reducing the number of people and their property that is exposed to them is amongst the priorities for regional flood management and mitigation.

- Because storm rainfall is spatially very variable and the highest rainfall areas are in the remoter mountainous regions it is often not possible to find any storm data from ground observations to link to many extreme flash floods that have occurred. This seriously limits efforts to understand them in terms of cause and effect. Satellite and weather radar are the obvious means of gaining this better understanding and efforts should be made to pursue such studies, perhaps under the remit of the FMMP.

- Unlike the mainstream data, those for the tributaries are not up to date so no analysis of conditions during 2007 is possible. Consideration should perhaps be given to the provision of current hydrological data for those rivers that contribute major volumes of flood water to the Mekong. These have been identified as part of this report. Such data would add substantially to understanding current flood conditions, particularly in the event of an extreme flood year.

- Another data issue that drew comment is the lack of consistency between national water level datums and those held in the database at the MRCS. The latter should be audited in order to ensure that the water levels reported in documents such as this agree with the official national figures.

- Finally, it has been recommended that consideration be given to the translation of the Annual Flood Report into the languages of the MRC member countries so that it can be more widely read and understood by the relevant stakeholders and line agencies and make a meaningful contribution to institutional strengthening and the available reference material.

1. Introduction report structure and summary of contents

1.1 Introduction

This Annual Mekong Flood Report for 2007 follows the structure, format and content that was agreed during the preparation of the 2006 report. The regional flood hydrology and meteorological conditions form the nucleus of the material that is presented complimented by an overview of the four National Flood Reports for 2007. Appendices provide the relevant reference data.

Having contributed significantly to the understanding of Mekong mainstream floods and flooding in the Annual Mekong Flood Report 2006, this document has made the logical progression and taken the flood hydrology of the tributaries as its theme.

1.2 Report structure and summary of contents

As with the 2006 report, the 2007 report is laid out with the theme material presented first in Chapter 2. Here the tributary flood hydrology is considered within three mainstream reaches: Chiang Saen to Vientiane, Vientiane to Pakse and Pakse to Kratie, which reflects some important geographical distinctions. The theme is introduced with a short note upon the impacts of land-use change and deforestation upon the flood hydrology of the tributaries, of which there is no significant evidence. This is followed by an overview of the geography of the major tributary contributions to the Mekong mainstream. In considering the nature of the tributary flood regimes, flash flooding has been given particular attention. Losses from flash floods, including related hazards such as landslides and debris flows, appear to be increasing due to pressure on land resources. There is also widespread agreement that under global warming storm rainfall intensities will increase. The point is made that the location, type, and value of human activities that appear to be expanding into more hazardous areas needs to be reassessed on the basis of a better understanding of the flash flood phenomenon, which regionally is not confined to small, steep, river basins.

A particular effort has been made to present reference schematics that reveal the location of 'functional' tributary data, that is data that of sufficient length and reliability for meaningful analysis. In the past this has not been a straightforward task. Amongst the analyses undertaken here using these data is the provision of a methodology for estimating flood risk at un-gauged sites. Such estimates are required increasingly, as regional water resources development accelerates. For example, they are required for the estimation of design spillway floods for hydropower schemes.

Chapter 3 reviews regional flood conditions during 2007 and the major storm events of the year. A number of standard diagrams that were developed during 2006 are once again employed and some new ones presented.

Chapters 4 to 7 contain overviews of the four National Flood Reports, the aim being to be concise and emphasise the major flood and storm events that occurred over the year, the types of damage caused, and the principal lessons that have been learnt.

Chapter 8 presents the conclusions of the 2007 report and some recommendations. The document closes with selected data appendices.

2. The flood hydrology of the major tributaries in the Lower Mekong Basin

2.1 An introductory note upon the impacts of land-use change and deforestation on the flood regime of the Mekong tributary rivers

The belief that deforestation causes an increase in the frequency and severity of major floods, and compounds the damage that they cause, appears to be widespread. This view is as widely held within the Lower Mekong Basin as it is throughout the tropical world. However, an authoritative report from the UN's Food and Agriculture Organization (FAO) and the Centre for International Forestry Research (Cifor) says that the evidence shows no link. Citing evidence from Bangladesh, Nepal, South Africa, Thailand and the United States it shows that the frequency and extent of major floods has not changed over the last century or two, despite drastic reductions in forest cover. Loss of forest cover does play a role in the generation of smaller floods and in the loss of fertile topsoil but, because forests do help to reduce floods in small areas, people assume that the effect must also apply to severe floods over large catchment areas.

According to the report, after a review of specific scientific studies worldwide, the clear indication is that changes in land-use and land-use cover have only a minor impact upon the risk and severity of large-scale flood events. The local effect from forests disappears as the catchment scale becomes larger and larger. That flood damage is increasing is unquestioned. However, this is not linked to the increasing magnitude of events, but is instead due to the growing global population and the consequent expansion of human settlements into areas that had once been marginal. As a result, each flood claims more lives than it would have done a century ago. In addition, the diversion of watercourses by human activity and the construction of flood protection works often moves the problem from upstream to downstream areas.

There are arguments and some evidence to suggest that the actual frequency of floods is beginning to increase, possibly in response to climate change, a major consequence of which, it is generally agreed, will be an increase in the incidence of extreme events. However, the evidence is as yet inconclusive. One scenario, based on the outputs of global climate modelling, is that periods of storm rainfall (and the causal climatic conditions) will be more variable with an increase in the occurrence of extremes. This, it is proposed, will be combined with longer dry spells between such events.

These observations and conclusions provide an important prelude to this overview of the flood hydrology of the major tributaries of the Mekong, where the damage and loss of life from flash floods has been very much in the news in recent years. However, this increase in damage is the result of increased regional prosperity and the consequent expansion of the infrastructure and its economic value that is at risk. A return to this theme is made in Section 2.5 where the potential impacts of climate change are also briefly examined.

2.2 The geography of the major tributary contributions to the flood hydrology of the Mekong

The physical geographical region defined by the Lower Mekong Basin is a variable one in terms of its topography, land cover, and rainfall climate. These three factors obviously have a major impact on regional hydrological response and its spatial variability, which is reflected in the contributions that the major tributaries make to the mainstream flows. The principal feature of the hydrology of the basin in this respect is that, despite the fact that it is by far the largest Mekong tributary system in terms of area, the Mun-Chi Basin in Thailand accounts for less than 6% of mainstream flow, a figure that is matched by the Nam Kading and Nam Ngum, the catchment areas of which amount to only 12% of that of the Mun-Chi (Figure 1).

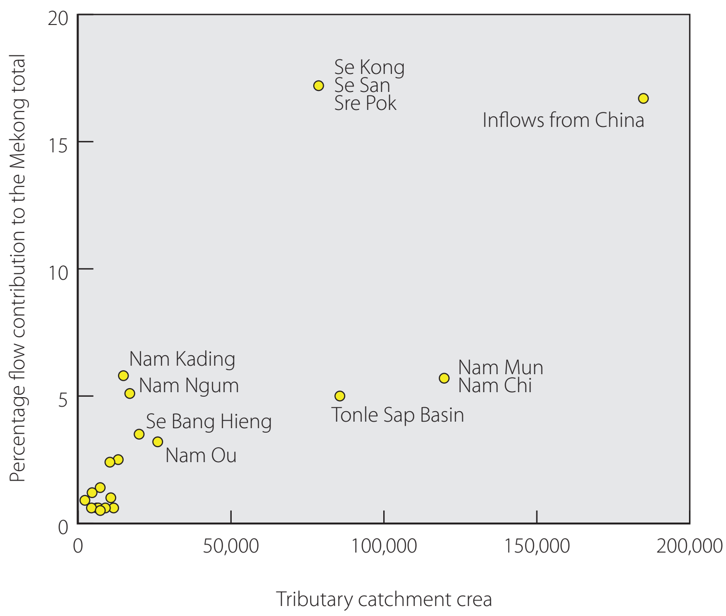


Figure 1. Percentage contribution of the major Mekong tributary systems to mainstream annual flow, as a function of catchment area.

This distribution of annual rainfall is the main factor that controls the geographic variability of river runoff, though topography also plays an important role. The mean annual rainfall over the Mun–Chi Basin varies between 1000 and 1500 mm, compared to 2500 to more than 3000 mm over a number of the large left bank tributaries in Lao PDR (Figure 2). The landscape of the Mun–Chi is also very flat, such that only between 25 and 50% of the rainfall is translated into stream flow, which compares to up to 75% over the much wetter and steeper left bank tributary basins. The geographical distribution of tributary runoff is shown in Figure 3.

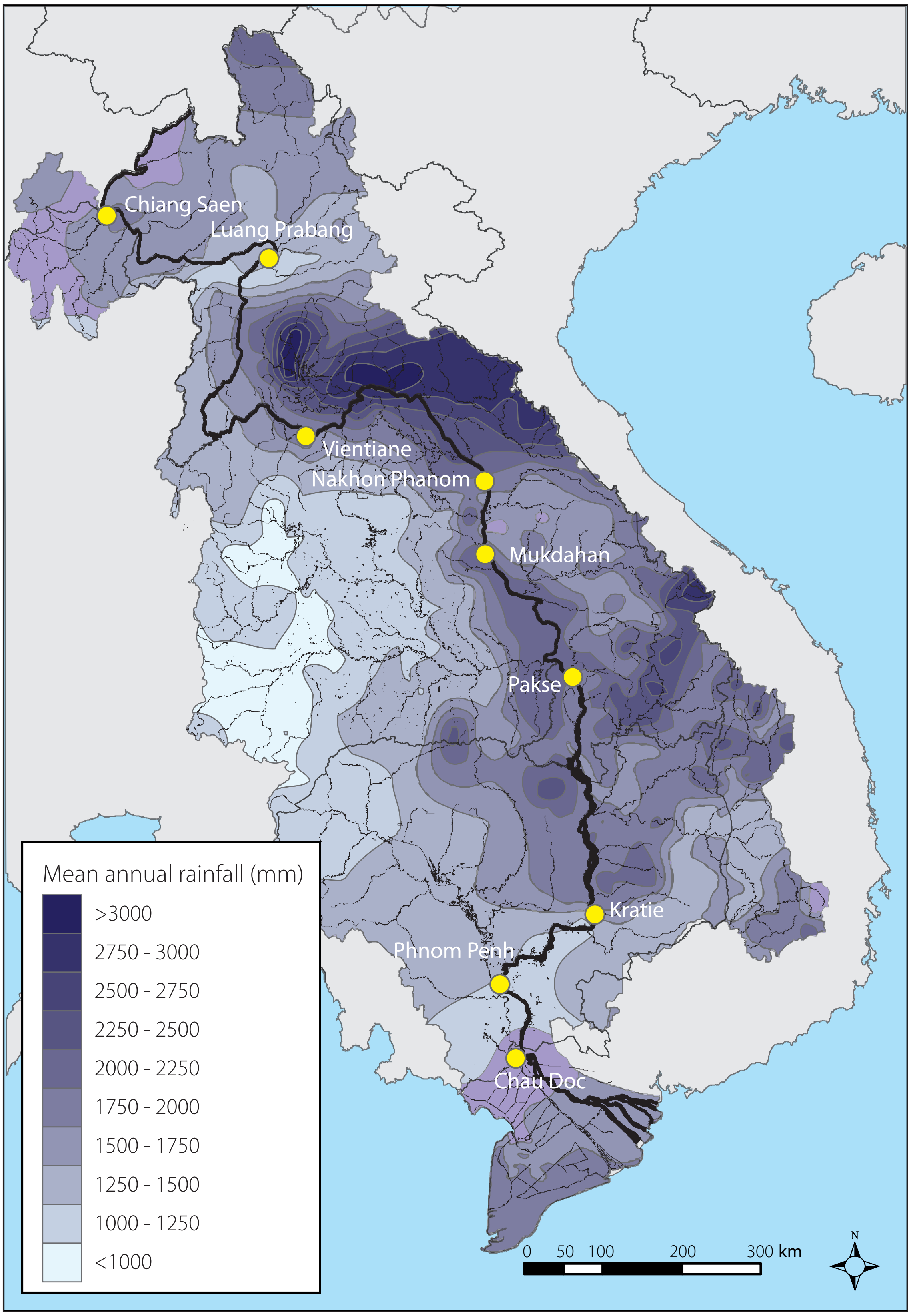


Figure 2. Lower Mekong Basin — mean annual rainfall (mm).

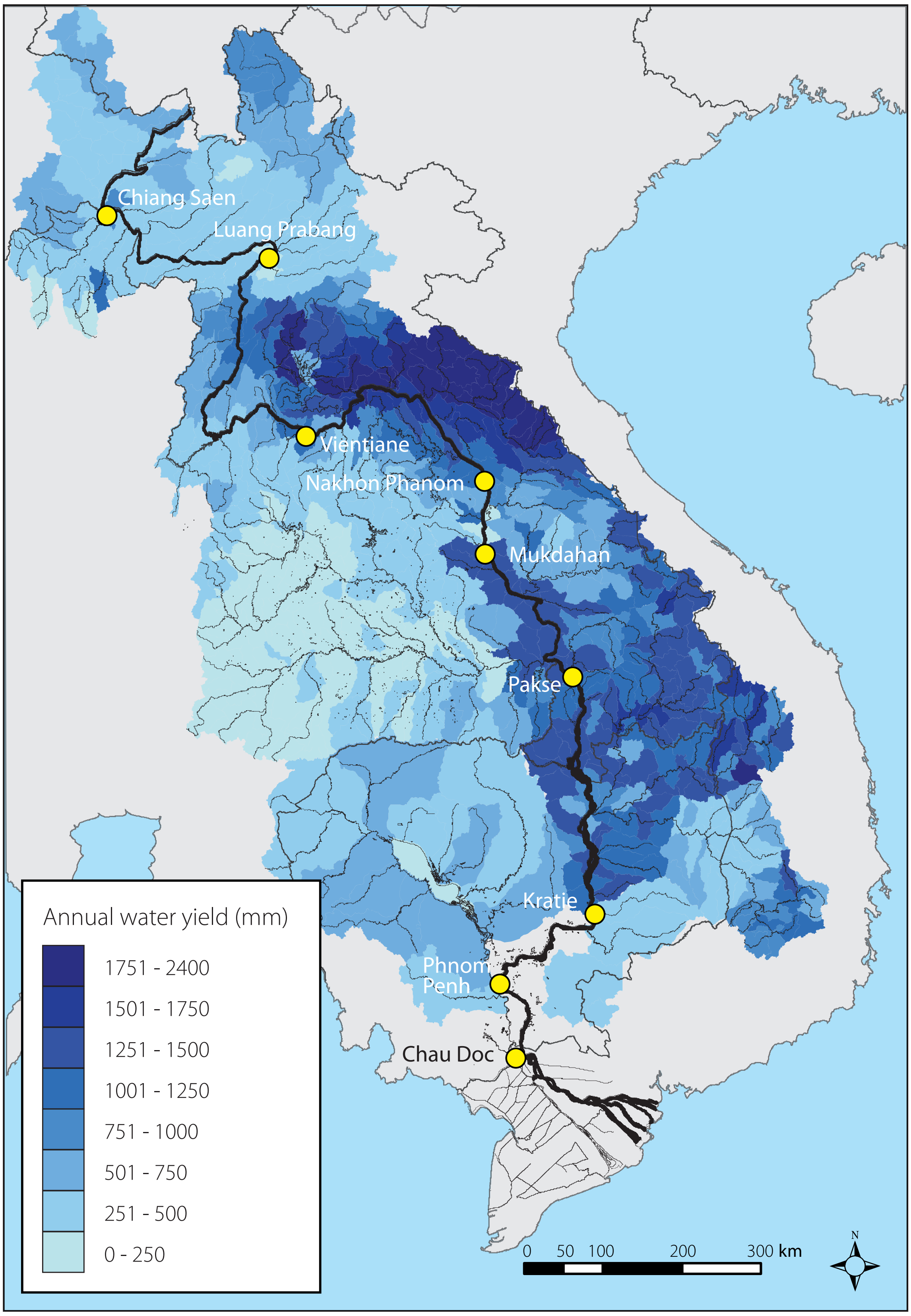


Figure 3. Lower Mekong Basin — mean annual runoff by tributary sub-basin (mm).

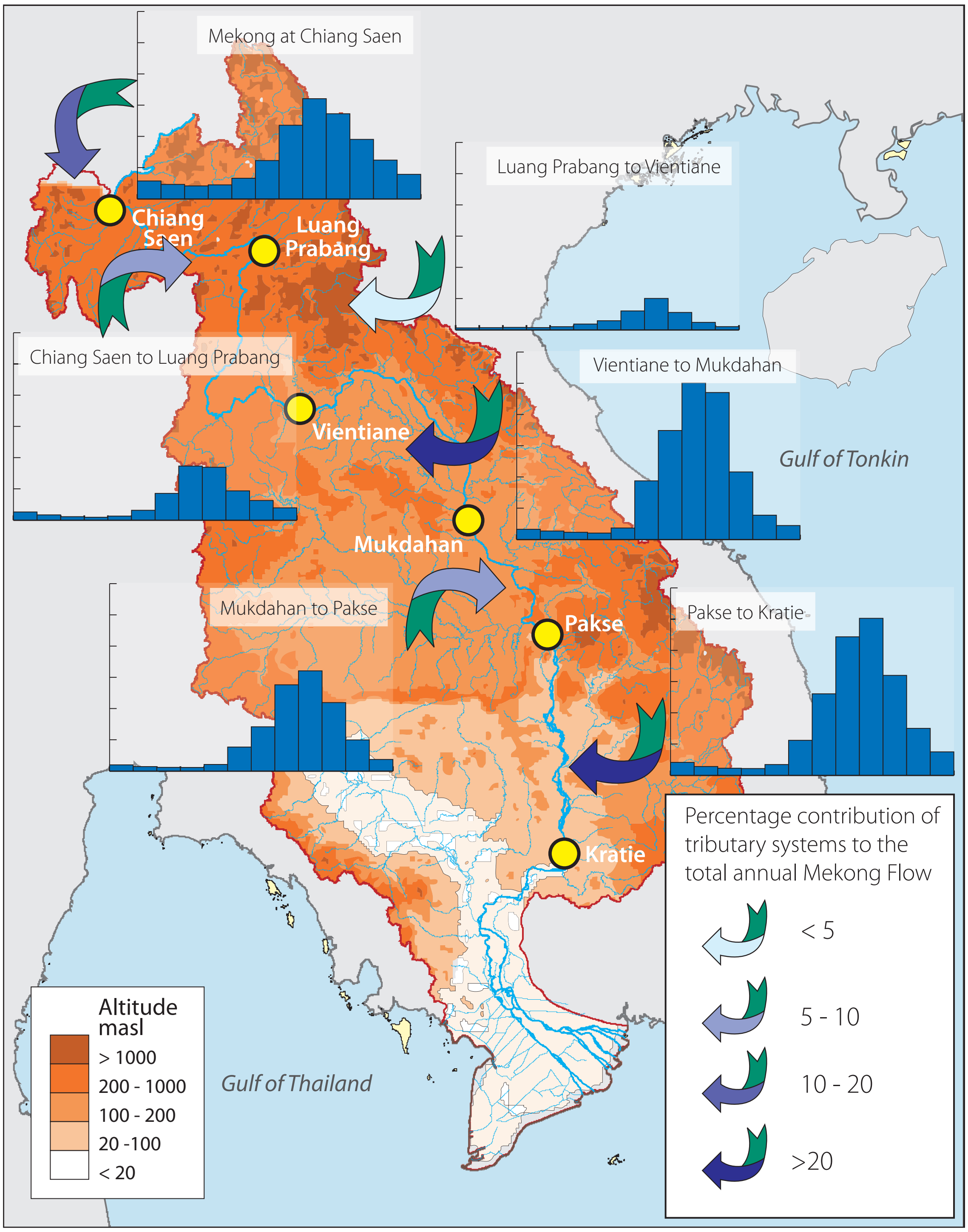


Figure 4. Mean monthly and annual tributary system contributions to Mekong mainstream discharge. *Note*: Vertical scales on the bar charts is 0 to 12,000 cumecs.

The mean annual and monthly tributary flow contributions to the mainstream are summarised in Figure 4, these being set out geographically between key locations along the mainstream itself. For the sake of consistency we consider the Upper Mekong in China as the ‘tributary’ at Chiang Saen:

- Here the average annual flow is about 18% of the total flow at Kratie, at which point 90% of overall Mekong flow is already in the system. Downstream of Kratie the Tonle Sap Basin contributes most of the remaining 10%.

- Between Chiang Saen and Vientiane tributary inflows are modest, particularly those downstream of Luang Prabang. The Nam Ou, Nam Tha and Nam Khan rivers contribute most of the mainstream flows in this reach.

- It is downstream of Vientiane that the major hydrological contributions occur. The tributary systems between Vientiane and Mukdahan and between Pakse and Kratie are the major sources of floodwater. Those between Mukdahan and Pakse provide rather less, a fact explained by the low relative levels of runoff in the Mun – Chi Basin, which although it is the largest Mekong tributary system in terms of area, it drains a flat landscape over which annual rainfall is significantly lower than that for the wider region (Figure 2).

The mean annual tributary contributions to the mainstream are summarised in Table 1, reach by reach. In order to simplify matters for the detailed assessment of the tributary flood hydrology, the number of mainstream reaches was reduced to three between Chaing Saen and Kratie: Chiang Saen to Vientiane, Vientiane to Pakse and Pakse to Kratie. These three tributary groups broadly reflect the regional distinctions in tributary flood hydrology.

Table 1. *Mean annual tributary system contributions to total Mekong flow.*

Tributary System.	Mean Annual Flow (km^3)	As % of total Mekong
Yunnan component at Chiang Saen	84.5	18
Chiang Saen to Luang Prabang	38.5	8
Luang Prabang to Vientiane	17.6	4
Vientiane to Mukdahan	104.8	23
Mukdahan to Pakse	65.9	14
Pakse to Kratie	106.2	24
Kratie to Delta	39.8	9
Totals	457.3	100

2.3 Chiang Saen to Vientiane—the regional history of tributary floods and flooding

The recent history of flood events in northern Thailand is summarised in the figure below, which illustrates their annual frequency and the exposure of the region to the flood hazard.

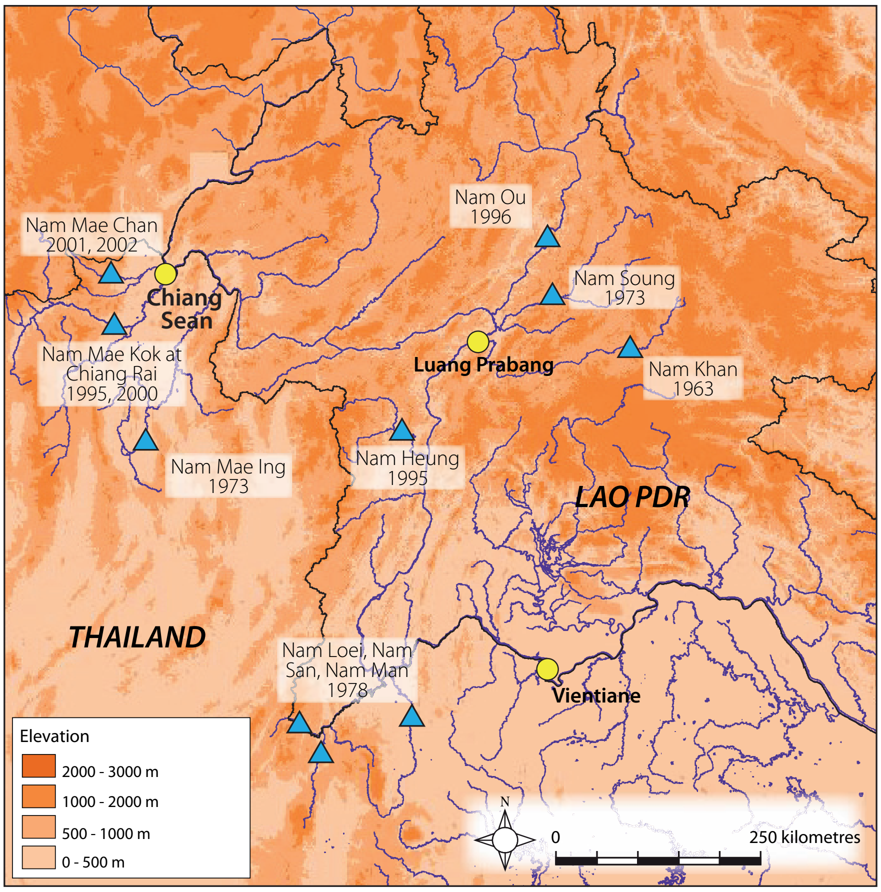


Figure 5. Northern Thailand and northern Lao PDR—flash flood events of recent years.

Of these regional flood events in recent years, that of 2002 in Chiang Rai and Loei provinces in Thailand was amongst the most severe with 40 people reported killed . Five thousand people had to be evacuated and three thousand properties were damaged. The flood of 2001 was responsible for over 100 deaths.

Going back even further in history each of the years from 1918 and 1920 featured devastating events, as did 1953. Even further back in time the original capital of the Lanna Kingdom had to be moved to Chiang Mai at the end of the 13th Century because of frequent flood inundation. These events obviously occurred long before the regional forests were reduced by logging, which has been blamed for a supposed increase in the frequency of the flood hazard (see below) since the 1960s. The logging of natural forests was banned in Thailand following the national flood emergency of 1988.

In the Northern Lao PDR provinces of Huaphan, Pongsaly, Luangnamtha and Luang Prabang significant flooding has been similarly frequent, having occurred in 1991, 1995, 1996, 2000, 2002, 2005 and 2006. Prior to that the largest regional flood to have occurred historically was that of September 1966, associated with the incursion of Cyclone Phyllis over the large northern tributaries.

2.4 Chiang Saen to Vientiane — the regional tributary systems.

A schematic of the regional tributary rivers is presented in Figure 6 and Tables 2 and 3 summarise their areas and the hydrological data that are available. In the latter case the information only refers to those sites where the records are longer than a few years and considered to be reasonably reliable.

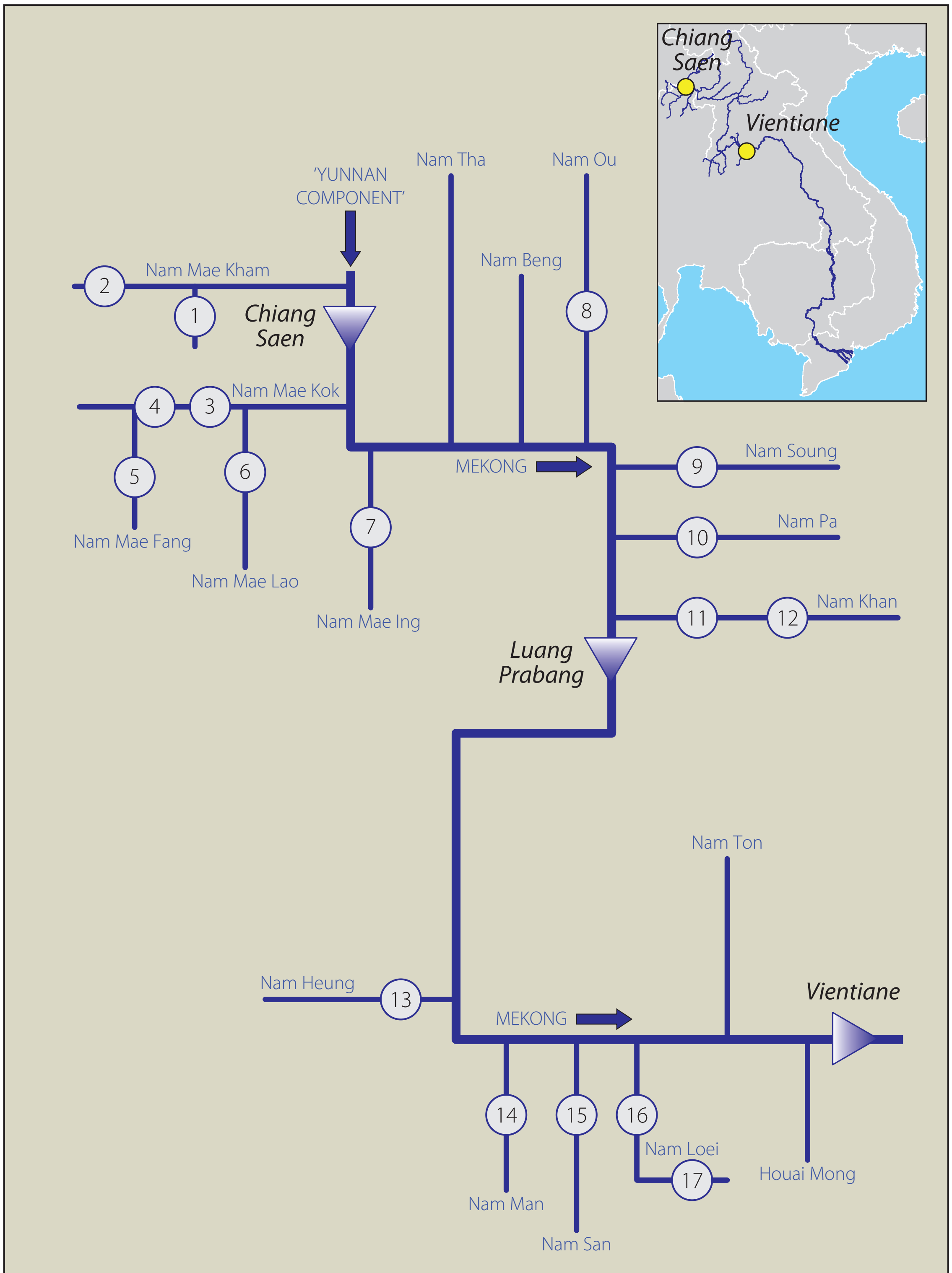
Table 2. *Major tributaries to the Mekong mainstream — Chiang Saen to Vientiane.*

Major Tributary (catchment > 1000 km²)	Catchment Area (km²)	Mainstream	Major Tributary (catchment > 1000 km²)	Catchment Area (km²)
		CHIANG SAEN		
Nam Mae Khan	4095			
Nam Mae Kok	10,870			
Nam Mae Ing	7180		Nam Tha	8690
			Nam Beng	2500
			Nam Ou	25,810
			Nam Soung	6670
		Luang Prabang	Nam Khan	7400
Nam Houng	1920			
Nam Heung	4900			
Nam Loei	3900			
Houai Mong	2720			
		VIENTIANE		

- The reach comprises a complex of right bank tributaries in north and northeast Thailand, principally the Nam Mae Khan, Nam Mae Ing, Nam Mae Kok and Nam Loei and a number of generally larger left bank tributaries in northern Lao PDR. Of these the Nam Ou is by far the most significant in terms of drainage area and discharge.

- The total tributary area is 110,000 km^2 of which stream flow data are available for almost 60,000 km^2.

- Annual tributary runoff is less than in other parts of the Lower Mekong Basin to the south, particularly from the large left bank tributary systems downstream of Vientiane (Figure 3).



Total tributary catchment area	Percentage of LMB area	Total mean annual flow of all tributaries	Average annual sub-basin runoff
110,000 km^2	19.5%	56 km^3	510 mm

Figure 6. Schematic of the major Mekong tributary systems between the Chinese border and Vientiane, indicating the sites at which discharge data are available. (Numbers refer to the right hand column in Table 3.)

- The sub-reach between Luang Prabang and Vientiane is unique in the LMB in that there are no large left bank tributaries, a fact which largely explains the small contribution it makes to the overall Mekong flow (Figure 4).

- Flash floods in this area of the Mekong basin have been a key feature of its hydrological history. It has also been an area where deforestation and slash and burn agriculture have been widespread, leading to arguments that the consequent landscape changes have been a major contributory factor to flooding.

Table 3. *Tributary sites between Chiang Saen and Vientiane at which functional hydrometric data are available. (Sequence numbers refer to those in Figure 3.)*

Sketch	Station No.	River	Site	Catchment (km^2)	Mean annual flow (cumecs)
1	040201	Nae Mae Chan	Ban Huai Yano Mai	200	5
2	040101	Nam Mae Kham	Ban Pa Yang	520	11
3	050104	Nam Mae Kok	Chiang Rai	6060	122
4	050105	Nam Mae Kok	Ban Tha Ton	2980	69
5	050201	Nam Mae Fang	Ban Tha Mai Liam	1800	27
6	050301	Nam Mae Lao	Ban Thai Sai	3080	28
7	070103	Nam Mae Ing	Theong	5700	64
8	100102	Nam Ou	Muong Ngoy	19,700	417
9	110101	Nam Soung	Ban Sibounhom	5800	90
10	110201	Nam Pa	Ban Kok Van	700	9
11	120101	Nam Khan	Ban Mixay	6100	96
12	120102	Nam Khan	Ban Pak Bak	5800	92
13	140101	Nam Heung	Ban Pak Huai	4090	40
14	140201	Nam Man	Dan Sai	400	6
15	140301	Nam San	Dam Site	700	9
16	150101	Nam Loei	Wang Saphung	1240	17
17	150102	Nam Loei	Ban Wang Sai	235	7

2.5 Chiang Saen to Vientiane — are flash floods becoming more common?

The view that deforestation has increased the frequency and severity of flash floods is widely held, particularly in northern Thailand. Defining a significant event as a flood that was more than one standard deviation above the mean annual maximum flood peak, Figure 7 shows the regional incidence of such events between 1970 and 2003. Even if the figures are corrected for the number of station years available in each decade, the increased proportion and incidence of such events remains apparent from 1990 onwards. Of the 25 significant events observed since 1970, 16 or 65% occurred after 1990. Interestingly, none at all occurred during the 1980s. The regional median annual maximum event remained unchanged over the period as a whole.

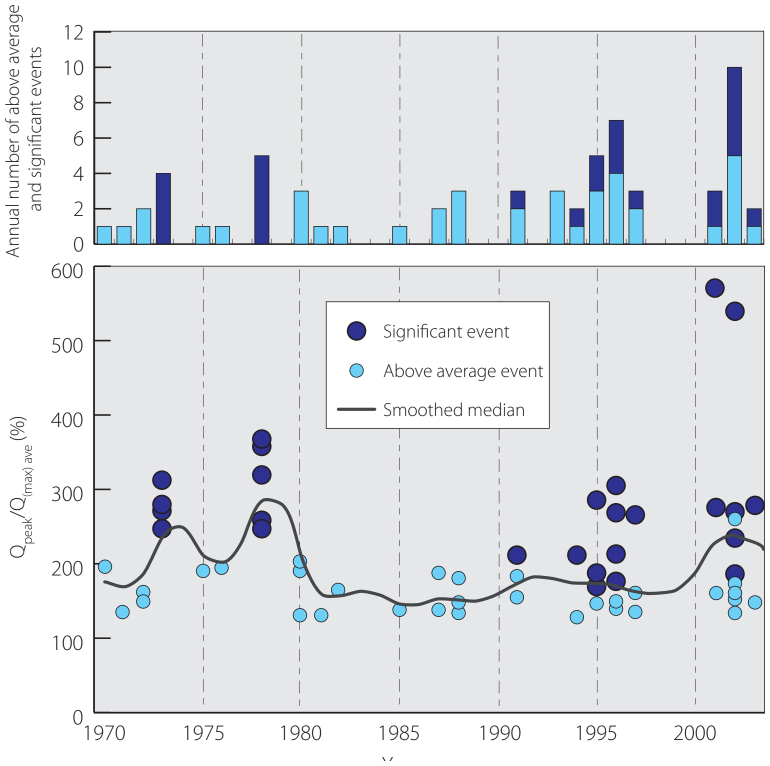


Figure 7. Regional annual number of significant and extreme flood events — 1970 to 2003. (See text for definitions).

There appears to be sufficient evidence on the basis of this simple analysis to suggest that significant floods have become more frequent over the last 15 years or so. Whether this is a response to external influences such as climate change is arguable. It may simply be part of the natural periodicity of such processes — the fact that there were no significant events at all during the 1980s might be evidence in this regard. However, the timescale for which data are available is far too short to establish any such possible periodic patterns one way or the other. Nevertheless, it seems reasonable to conclude that after the logging ban in Thailand during the late 1980s, deforestation would appear not to be a factor to the increased frequency of events post 1990.

2.6 Chiang Saen to Vientiane — the hydrological assessment of extreme regional tributary flood events

Figure 8 shows a plot of the annual maximum flood events of 2001 and 2002 on the Nam Mae Chan at Ban Huai Yano Mai in northern Thailand. These are by far the largest on record for the river over the 24 years for which data are available (1980–2003), with peak discharges three standard deviations above the mean annual flood over the same period. Such events are quite distinct from the rest of the sample, which might be classified into significant events (greater than one standard deviation above the mean) and extreme events (greater than two standard deviations above the mean). Clearly the suspicion is that there are two weather processes at work, one that generates average and significant floods and one that generates those that are far more extreme.

This distinction may be linked to:

- typical monsoonal storms and average antecedent catchment conditions that result in the more typical or basic events, and;
- more extreme weather systems, such as intense tropical depressions, severe tropical storms and typhoons, which combine with wet or saturated antecedent catchment conditions to generate extreme or outlier events.

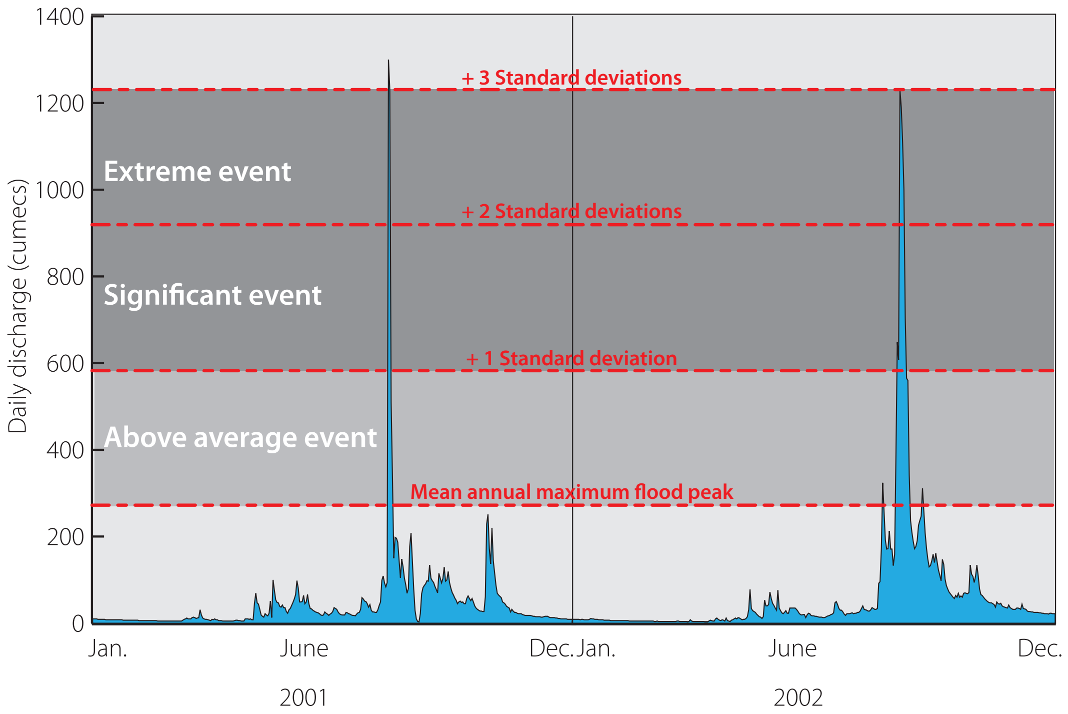


Figure 8. Nam Mae Chan at Ban Huai Yano Mai. Definition of significant and extreme floods in the context of the events of 2001 and 2002.

The picture that emerges from the following assessment of the most extreme historical regional flood events is that, except for the larger catchments in Lao PDR such as the Nam Ou, they are of short duration, typically three to four days. In addition:

- times to peak are extremely rapid, typically less than one day;

- antecedent flow conditions are often not linked in any significant way to the peak magnitude, though such is the rapid rate of recession of the flood hydrograph this may not of itself be a meaningful indication of the actual state of the catchment in terms of wetness and its ability to generate maximum rates of runoff during a storm.

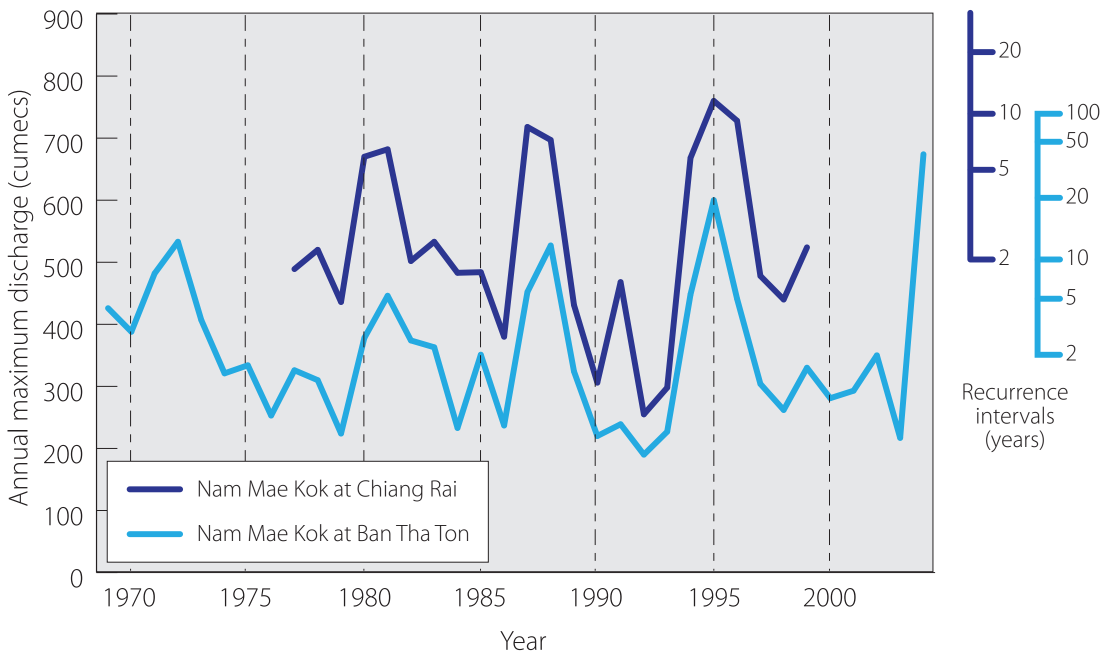


Figure 9. Nam Mae Kok at Chiang Rai and at Ban Tha Ton. Annual maximum peak discharges for the periods of available data and their annual recurrence intervals.

Figure 9 shows the annual maximum discharges on the Nam Mae Kok at Chiang Rai and upstream at Ban Tha Ton over the years for which data are available. The indication is that flood peaks in excess of ten years occurred in 1972, 1988, 1995, and 2004, the latter being greater then the 1:30 year event at Ban Tha Thon (no data are available for Chiang Rai). Of the observed data at Chaing Rai, the largest event occurred in 1995 (though the 2004 event would have exceeded it significantly if the flows upstream at Ban Tha Ton are scaled accordingly). This 1995 event at Chiang Rai is shown in detail in Figure 10:

- It was not a flash flood in any real sense, the overall flood season hydrograph being quite coherent, with several independent peaks superimposed upon it rather than rising rapidly from a relatively low flow state. The associated daily rainfalls are also shown, with the maximum daily depth of 130 mm occurring on the 5th August. This depth has estimated annual recurrence interval of 1:5 years.

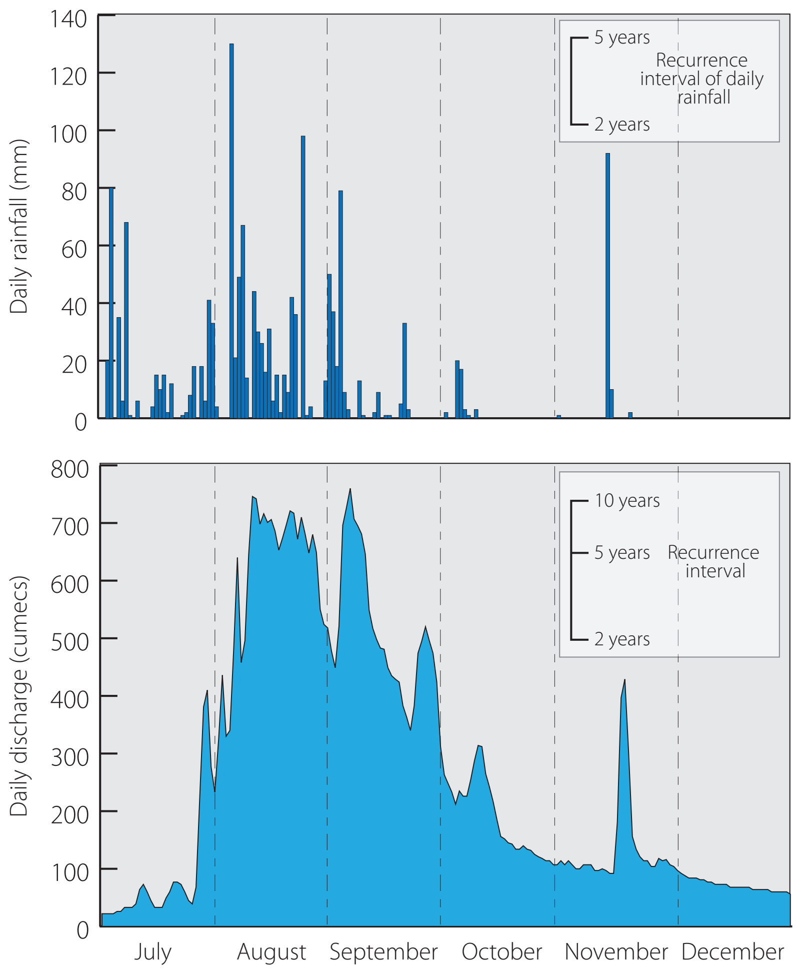


Figure 10. Nam Mae Kok at Chiang Rai — 1995 flood hydrograph with associated daily rainfall.

- It is the accumulated daily rainfalls that were responsible for the relative severity of the event, with the 5- and 10-day totals observed at Chaing Rai being exceptional, with recurrence intervals of 20 years.

Table 4. *Chiang Rai — cumulative rainfall, 5th to 14th August, 1995 and their recurrence interval.*

Storm duration	Dates August 1995	Cumulative depth (mm)	Recurrence interval
1 day	5th	130	5 years
2 day	5–6th	150	10 years
3 day	5–7th	200	10 years
5 day	5–9th	280	20 years
10 day	5–14th	400	20 years

The later period of storm rainfall at the end of August and during the first few days of September produced a slightly higher flood peak. However, the cumulative depth over five days of 200 mm was unexceptional in terms of its recurrence interval, but it was far more effective in runoff terms since flows in the river were already high and the upstream catchment saturated.

The 2004 event in the Nam Mae Kok was much more severe with a flood peak of 650 cumecs at Ban Tha Thon. The corresponding peak discharge at Chiang Rai could have been anywhere between 800 and 1000 cumecs, possibly therefore as high as a 1:50 year event. It takes on much more of the appearance of a flash flood with discharges rising by over 400 cumecs in two days from a relatively modest initial flow condition (Figure 11). Finding daily rainfall conditions to link to the event proved a problem, indicative of the highly localised nature of intense storm rainfall bursts. The only 'local' site with a storm rainfall pattern consistent with the flood runoff during September was that at Mae Chan, though even here the daily rainfalls were anything but extreme, even in terms of the accumulated total over five days. The later period of storm rainfall at the end of August and during the first few days of September produced a slightly higher flood peak. However, the cumulative depth over five days of 200 mm was unexceptional in terms of its recurrence interval, but it was far more effective in runoff terms since flows in the river were high and the catchment saturated.

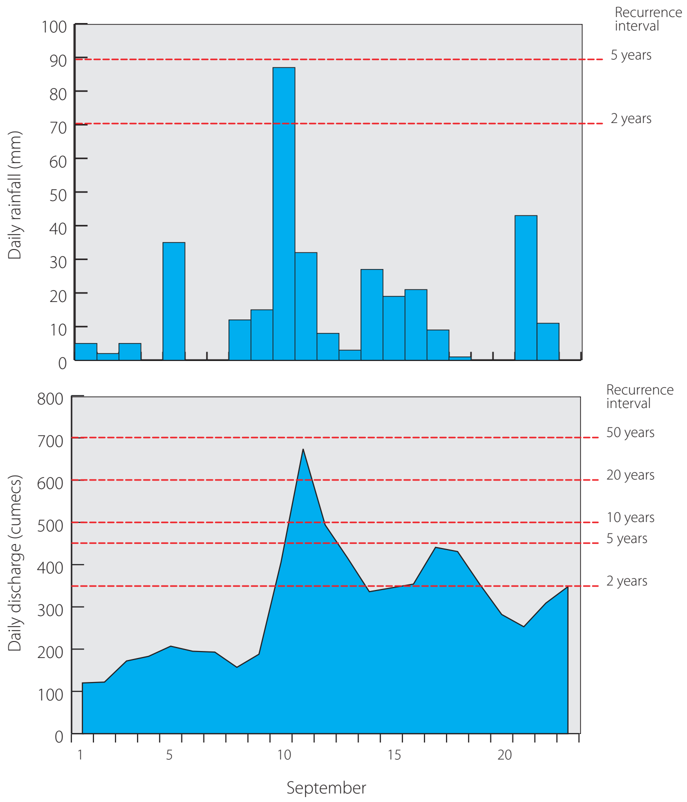


Figure 11. Nam Mae Kok at Ban Tha Ton — the 2004 flood hydrograph with associated daily rainfall at Mae Chan.

The classic regional example of the extreme flash flood is provided by events on the Nam Loei, Nam San and Nam Man during August 1978 (Figure 12):

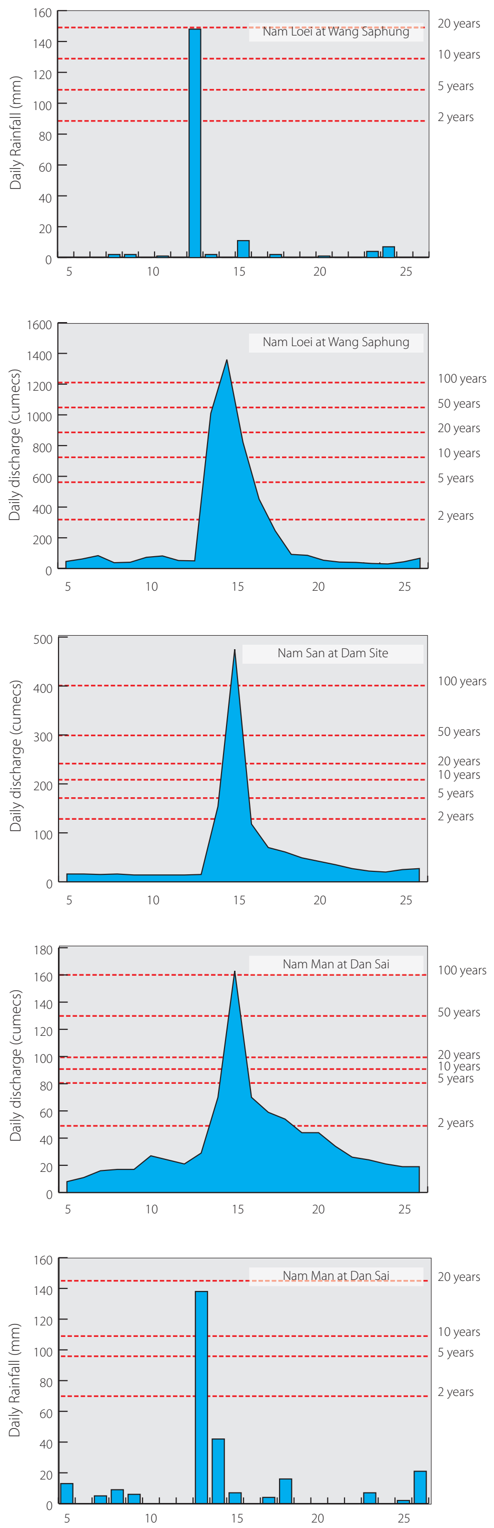


Figure 12. The classic flash flood. Events on the Nam Loei, Nam San and Nam Man during August 1978, with the associated daily rainfall at Loei and at Dan Sai.

- On all three rivers the flood is estimated to have had a peak discharge with a recurrence interval of at least 1:100 years.

- The hydrographs indicate extreme rates of flood rise from initial flow conditions that were very low. From the start of the event to the peak discharges increased by as much as 25 orders of magnitude over two days.

- Almost as quickly as flows rose to the peak they declined, such that the hydrograph overall had a small volume to peak ratio—typical of the flash flood event.

- In itself this points to an extremely intense period of storm rainfall, but one with a relatively short duration.

- This is confirmed by the associated storm rainfalls at Loei and at Dan Sai which reveal that they were essentially confined to a single day, with none of any significance in the previous ten. The observed amounts, however, were not large enough to explain the event, unless the intensities were extreme and they occurred within a few hours. Clearly elsewhere in the local area depths of greater magnitude and exceptional intensity must have occurred.

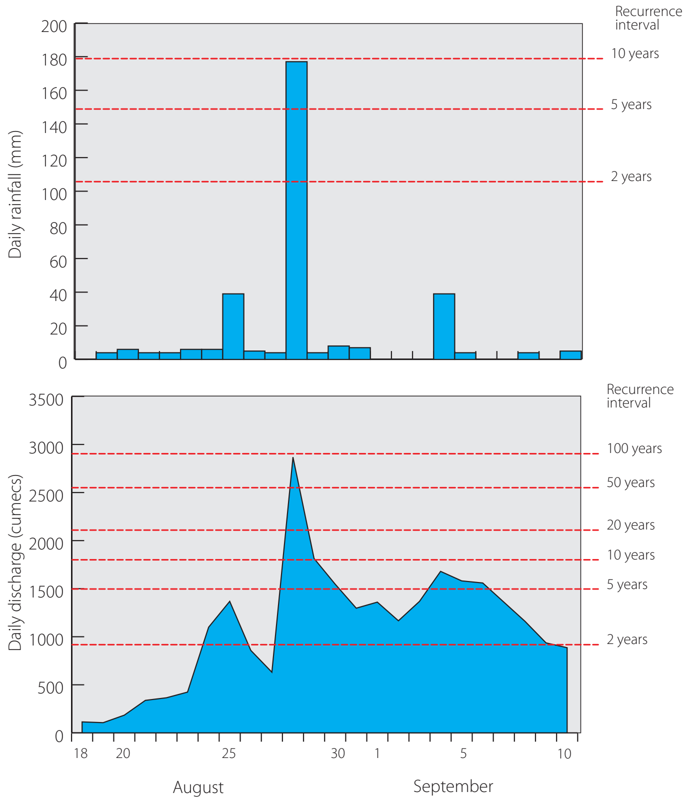


Figure 13. The flash flood event on the Nam Soung in Lao PDR during August 1973, with indicative rainfall at Xiengkhoung.

A flood of similar character and recurrence interval and with the associated rainfall again apparently confined to a single day occurred on the Nam Soung in Lao PDR in August 1973 (Figure 13), though in this case the river was relatively high at the start of the event. Once again, the available observed daily rainfall data do not contain the local storm conditions that would have generated the event, only an indication of them.

Even quite large catchment areas within the region can develop classical flash flood conditions as Figure 14 illustrates for the Nam Khan at Ban Mixay in Lao PDR, where the upstream catchment area is over 6000 km^2. Here the event of July 1963 had an estimated recurrence interval of over 100 years in terms of its peak discharge. The observed rainfall conditions at the time at Luang Prabang are hardly related at all to the magnitude of the flood event. The storm depths and intensities responsible would have occurred far up in the catchment towards the headwaters — where no data are observed.

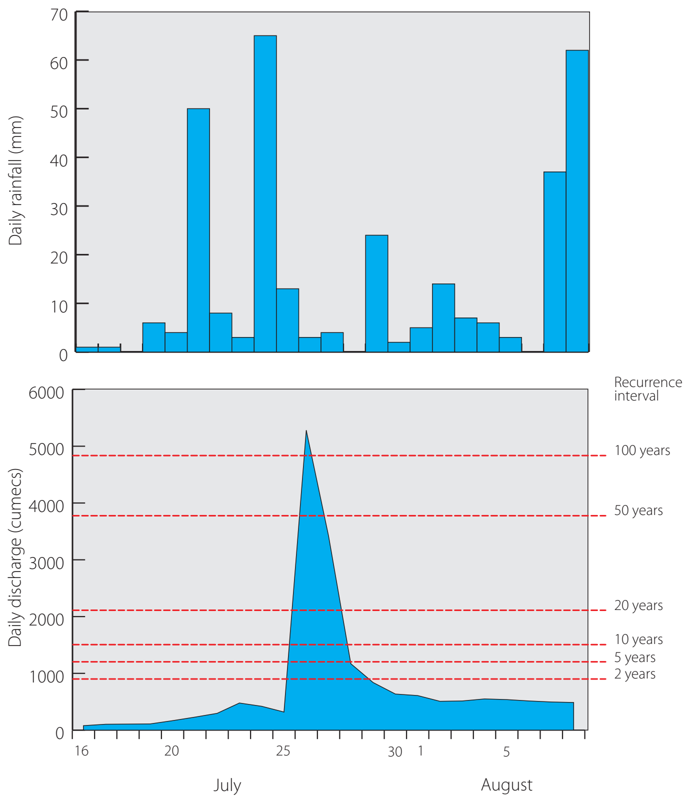


Figure 14. The flash flood event on the Nam Khan at Ban Mixay in Lao PDR during July 1963. Rainfall at Luang Prang was hardly related at all to the flood. This would have occurred in the headwater reaches of the catchment and was unrecorded.

No representative rainfall data at all are available for some of the largest extreme flash floods that have been observed, most particularly the outlier events on the Nam Mae Chan during 2001 and 2002 (see Figure 8), once again underscoring the conclusion that the storm events that cause them are highly localised, high intensity events of short duration. The details of the flood hydrographs for three such floods are shown in Figure 15, again illustrating the characteristic time distribution of flash flood runoff.

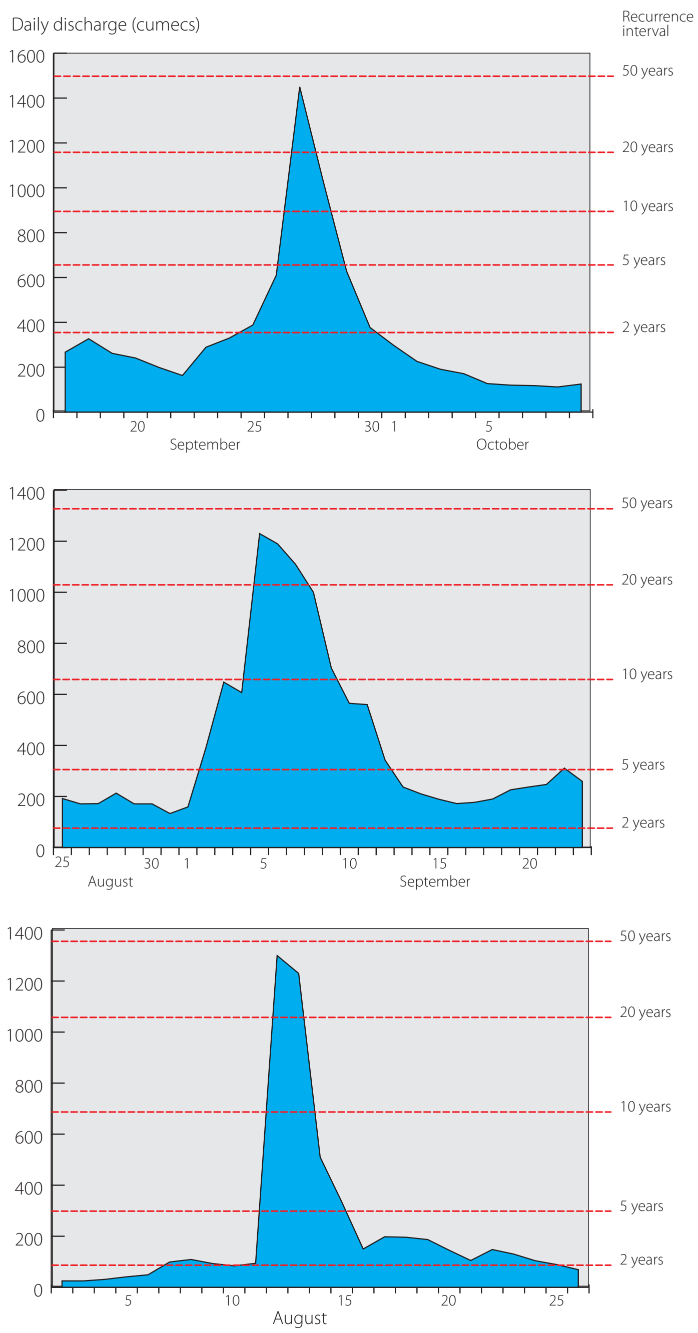


Figure 15. The largest observed flash flood events on the Nam Heung (1995) and Nam Mae Chan (2001 and 2002). No explanatory or indicative rainfall data are available from the records for these events.

Not all of the largest events observed regionally are of the flash flood type. Longer duration storms can produce flood runoff distributed in a different and far less 'peaked' pattern while catchment landscape in terms of less steep slopes can be a significant influence on hydrograph shape. An example, is that for the most extreme event recorded on the Nam Mae Ing at Theong during September 1973, which although the time to peak is very short the recession time is not. If the distribution of the storm rainfall that is associated with the event shown in Figure 16 is a reasonable approximation to the actual temporal pattern (if not to the amounts) then none occurred after the peak discharge was reached. Physical factors and natural catchment storage would then largely explain the longer flood recession time.

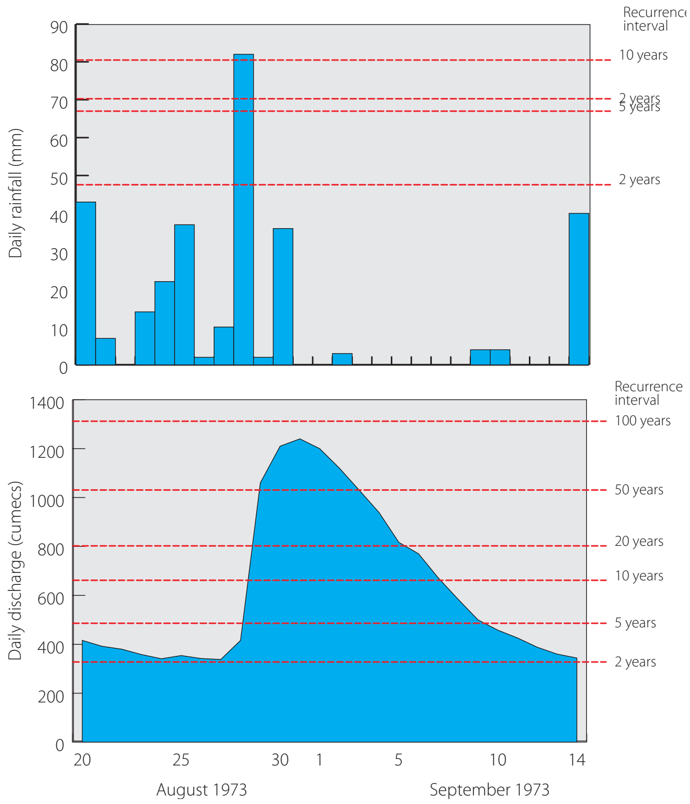


Figure 16. The largest observed flood event on the Nam Mae Ing. If the indicative temporal pattern of the 'local' storm rainfall is accurate then none occurred after the peak and the longer flood recession time would be explained by catchment factors such as natural flood storage.

Catchment scale is another factor influencing the shape of the characteristic flood response hydrograph. The Nam Ou at Muong Ngoy in Lao PDR has a drainage area of almost 20,000 km^2. In this case the time of concentration of the floodwater would typically be longer than within a smaller basin area such that flood rise would be less rapid. Recessions would also tend to be slower due to scale effects. The largest recorded event on the Nam Ou occurred in 1996 and is shown in Figure 17. It was a significant 'outlier', being almost twice the magnitude of the second rank ordered event in terms of peak discharge[1]. The hydrograph shows a time to peak of

1 The 1966 flood, for which no data are available, would almost certainly have been higher. It would have corresponded with the largest peak observed on the Mekong mainstream since 1913 at Vientiane, which was the result of Cyclone Phyllis which moved across the northern tributary systems in Lao PDR during September. If it were possible to include this event in the sample then the estimated risk of the 1996 event would probably not be of the order of 1:100 years – such are the implications of sample effects and therefore the need to adopt regionalised approaches to flood risk analysis.

six days and a recession time of more than a week, which is probably a typical pattern for the larger tributaries within the Lower Mekong Basin. The number of 100 year events estimated within the region might appear be an issue. However, three of these occurred on the same date, associated with the same storm event. So collectively, they should be counted as one. The rest are independent events in time. This gives five 100 year floods within a total regional sample size of 534 station years of data, which is the statistical expectation.

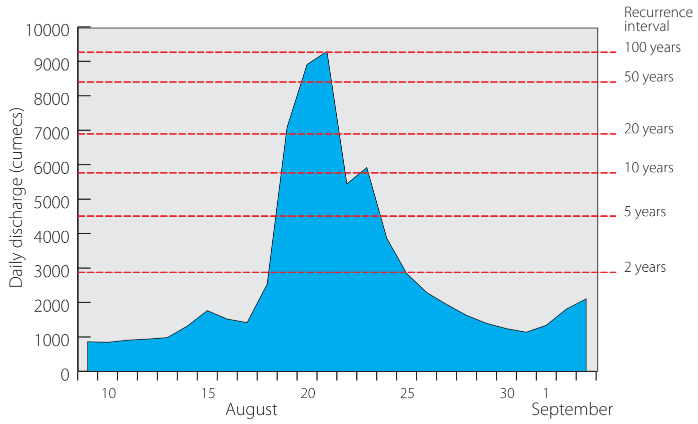


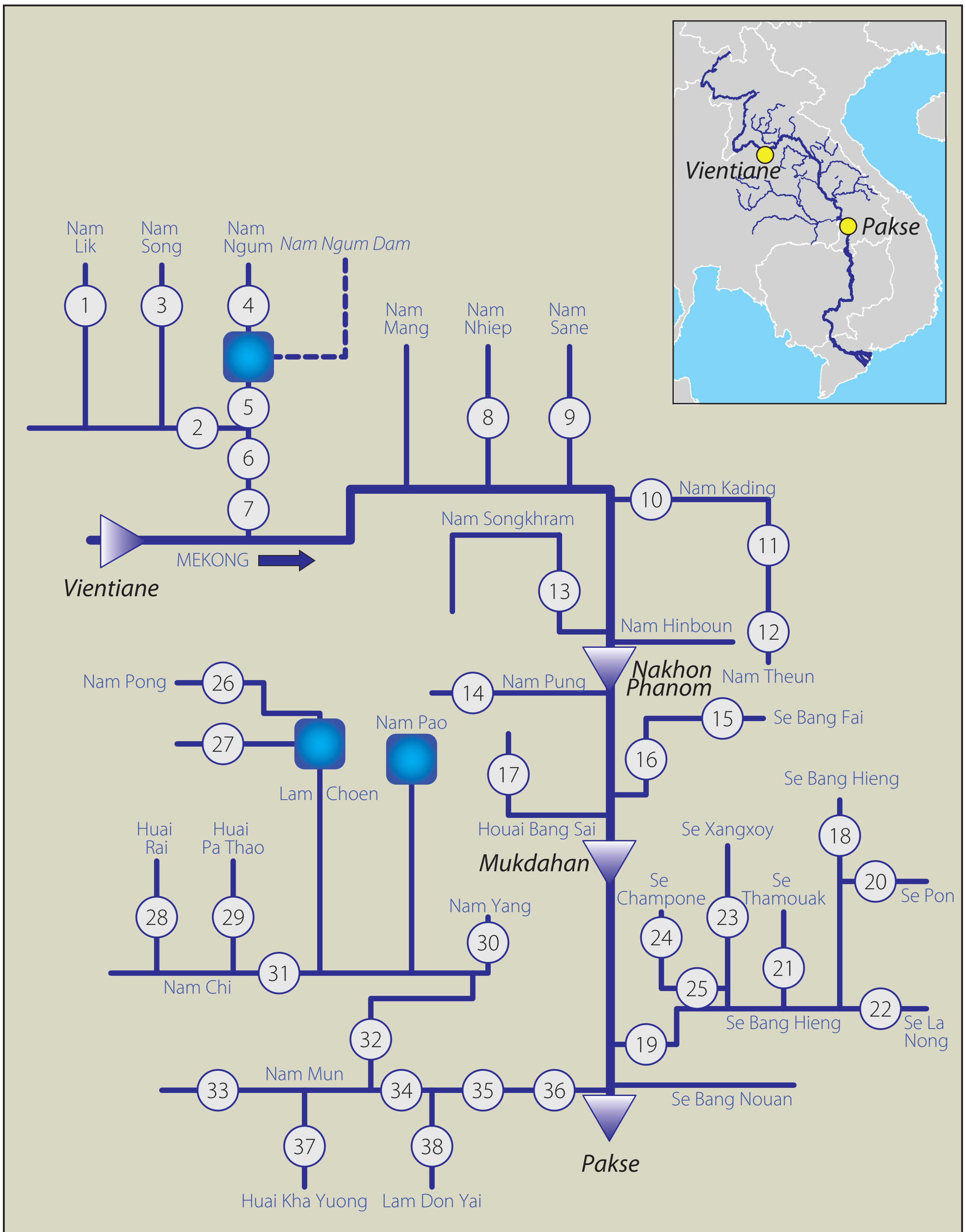
Figure 17. The hydrograph of the largest flood event observed on the Nam Ou since 1985, while illustrates the effects of catchment scale upon hydrograph shape.

2.7 Vientiane to Pakse——the regional tributary systems

In this reach the large left bank tributaries in Lao PDR begin to exert their dominant influence on the flood hydrology of the Mekong, starting with the entry of the Nam Ngum 50 km downstream of Vientiane. The combined mean annual flow of all tributaries between Vientiane and Pakse is 171 km^3, almost 40% of the Mekong total. The major contributions to this figure are made from the left bank by the Nam Ngum, Nam Kading/Nam Theun and the Se Bang Hieng, while the Mun–Chi Basin accounts for by far the greater part by far of the floodwater arising from the right bank in Thailand. The major tributary systems are indicated schematically in Figure 18, which also shows the functional hydrometric network. Tables 5 and 6 provide further summary information.

Within this reach:

- The tributary catchment areas are generally very large such that flash floods do not dominate the flood hydrology as they do in the tributaries upstream of Vientiane. They are locally important on some of the smaller, steeper tributaries and in the upper reaches of the larger rivers and conditions can arise on the larger tributaries of extremely rapid increases in discharges, followed by equally fast flood recessions.



Total tributary catchment area	Percentage of LMB area	Total mean annual flow of all tributaries	Average annual sub-basin runoff
246,000 km^2	43%	171 km^3	700 mm

Figure 18. Vientiane to Pakse — schematic of the major Mekong tributary systems indicating the sites at which discharge data are available. (Numbers refer to those in Table 6.)

Table 5. *Major tributaries to the Mekong mainstream — Vientiane to Pakse.*

Major Tributary (catchment > 1000 km²)	Catchment Area (km²)	Mainstream	Major Tributary (catchment > 1000 km²)	Catchment Area (km²)
		VIENTIANE		
Nam Huai Luang	4120			
			Nam Ngnum	17,170
			Nam Ngiep	4500
			Nam Sane	2220
			Nam Kading	14,900
Nam Songkhram	13,100			
			Nam Hinboun	2700
		Nakhon Phanom		
			Se Bang Fai	10,240
Houai Bang Sai	3500			
		Mukdahan		
			Se Bang Hieng	19,300
			Se Bang Nouan	3100
Nam Mun/Nam Chi	120,000			
		PAKSE		

- In their lower reaches backwater effects from the confluence with the Mekong mainstream can extend very considerable distances upstream and exacerbate the depth and duration of inundation during extreme events.

- The accelerating development of hydropower schemes in this sub-region of the LMB will in time significantly modify the flood regime of many of the major tributaries. The impact upon flood peaks and volumes will depend upon the scale of reservoir development and whether any such storages are operated in a way that mitigates the flood hazard, by the provision of operational flood storage during the flood season, for example.

- It is anticipated that one of the major changes to the flood regime will be a delay in the start of the flood season and the onset of the higher discharges associated with it. Early season flood water will be withheld in the reservoirs which will typically be drawn down at the end of the dry season.

- The cumulative impacts of the numerous proposed schemes will in time modify the flood regime of the Mekong mainstream itself.

Table 6. *Vientiane to Pakse — tributary sites at which functional hydrometric data are available. (Sequence numbers refer to those in Figure 18.)*

Sketch	Station No.	River	Site	Area (km^2)	Mean annual flow (cumecs)
1	230205	Nam Lik	Muong Kasi	375	15
2	230201	Nam Lik	Ban Hin Heup	5115	265
3	230401	Nam Song	Vang Vieng	865	50
4	230110	Nam Ngum	Ban Na Luong	5220	130
5	230104	Nam Ngum	Ban Tha Lat	8280	590
6	230101	Nam Ngum	Ban Pak Kanhong	14,300	600
7	230102	Nam Ngum	Tha Ngon	21,995	680
8	250101	Nam Nhiep	Muong Mai	4305	170
9	260101	Nam Sane	Muong Borikhane	2230	130
10	270101	Nam Kading	Ban Phone Si	14,200	340
11	270901	Nam Theun	Kham Kheut	5650	290
12	270903	Nam Theun	Ban Signo	3370	220
13	290102	Nam Songkhram	Ban Tha Kok Daeng	4650	150
14	310201	Nam Pung	Ban Tham Hai Br	1070	10
15	320107	Se Bang Fai	Mahaxai	4520	230
16	320101	Se Bang Fai	Se Bang Fai	8560	440
17	330103	Huai Bang Sai	Ban Na Khom Noi	1220	15
18	350105	Se Bang Hieng	Tchepon	3990	170
19	350101	Se Bang Hieng	Ban Keng Done	19,400	520
20	350301	Se Pon	Ban Muong Chan	1980	65
21	350401	Se Thamouak	Highway Br	636	20
22	350201	Se La Nong	Muong Nong	2,010	80
23	350501	Se Xangxoy	Ban Phalane	880	25
24	350602	Se Champone	Dong Hen	1525	45
25	350601	Se Champone	Ban Keng Kok	2640	60
26	370210	Nam Pong	Si Chompu	1260	10
27	370805	Lam Choen	Ban Tha Dua	1500	10
28	371101	Huai Rai	Ban Non Kiang	1370	15
29	371203	Huai Pa Thao	Ban Tad Ton	326	4
30	371509	Nam Yang	Ban Na Thom	3240	30
31	370122	Nam Chi	Ban Chot	10,200	55
32	370104	Nam Chi	Yasothon	43,100	230
33	380134	Nam Mun	Rasi Salai	44,600	175
34	380103	Nam Mun	Ubon	104,000	610
35	380127	Nam Mun	Kaeng Saphu Thai	116,000	770
36	380111	Nam Mun	Pak Mun	117,000	backwater
37	381206	Huai Khayuong	Ban Huai Khayuong	2900	35
38	381503	Lam Dom Yai	Ban Fang Phe	1410	20

2.8 Vientiane to Pakse — the hydrological assessment of extreme regional tributary flood events

Because the major tributaries in this Mekong hydrological sub-region are large, flood risk should be assessed both in terms of flood peak and volume, thereby acknowledging the importance of both the depth and duration of flood inundation.

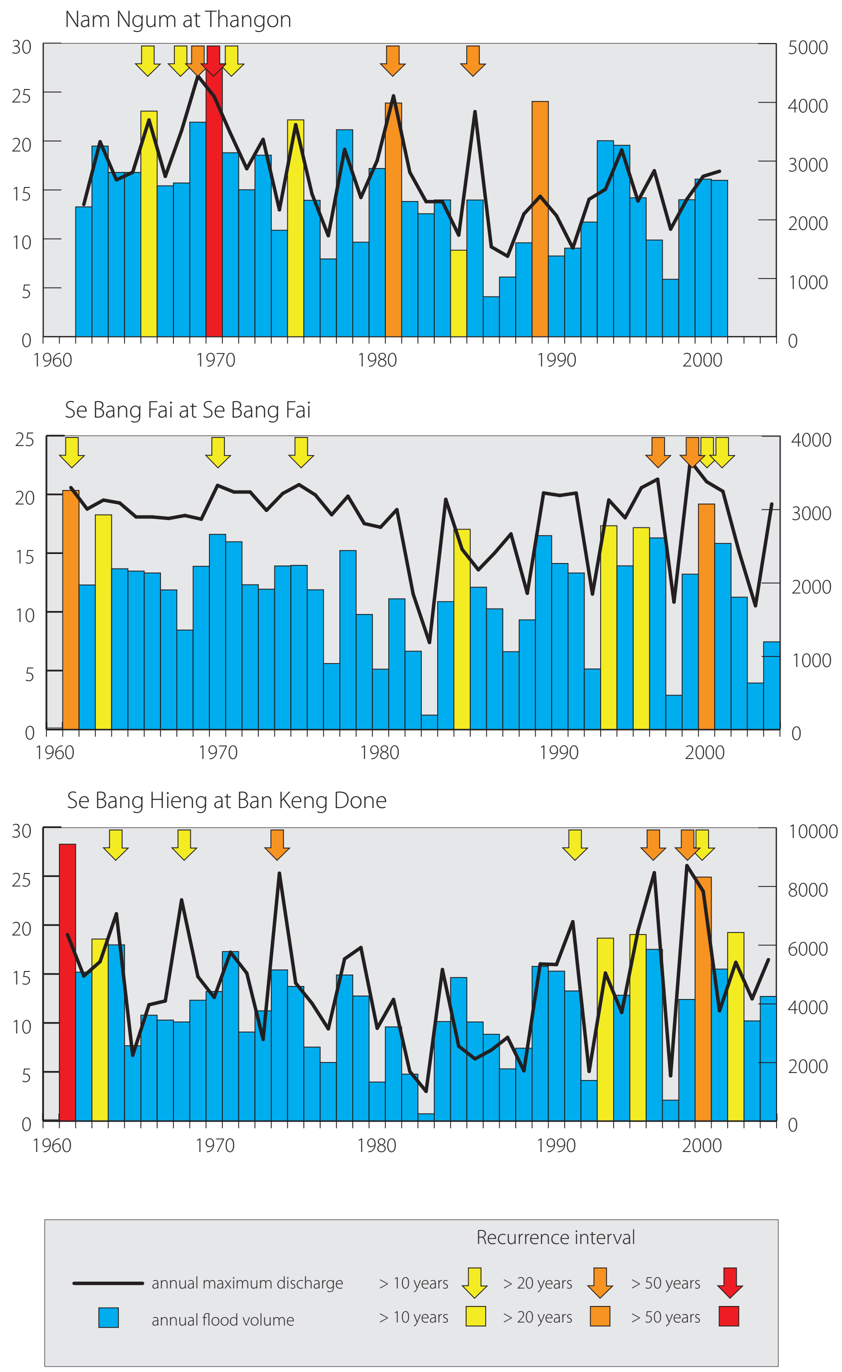


Figure 19. Time series of annual flood volume and peak discharge for selected right bank tributaries in Lao PDR.

Figure 19 shows the times series of annual flood peak and volume for three large left bank Mekong tributaries in Lao PDR:

- The data for the Nam Ngum at Tha Ngon clearly indicate the impact of the upstream reservoir on the flood regime. Since the dam was commissioned in 1971 only two significant flood events have occurred, while the most extreme regional flood events in recent regional hydrological history, those of 2000 and 2001 are not evident. Such impacts upon and scale of change to the downstream flood hydrology may be anticipated more widely as more reservoirs are developed regionally.

- Elsewhere, the evidence suggests that the tributary flood hydrology is broadly concordant with no significant events at during the 1980s and early 1990s followed by the events of 2000, 2001 and 2002, which dominate the regional picture.

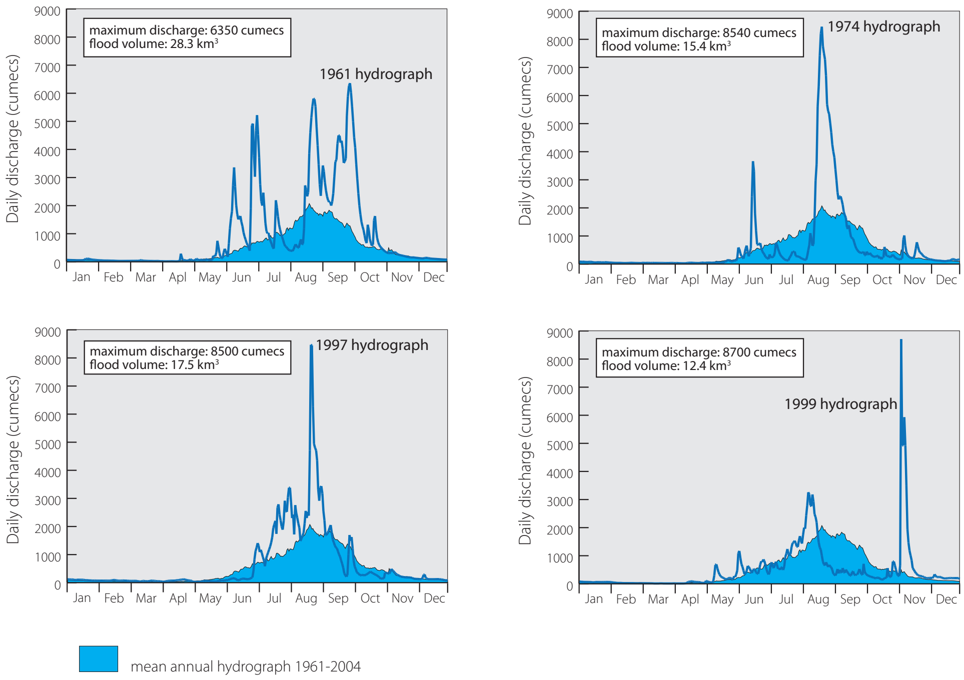


Figure 20. Se Bang Hieng at Ban Keng Done (catchment area: 19,400 km^2). Annual flood hydrographs of 1961, 1974, 1997 and 1999, indicating the highly variable nature of the annual flood regime and that between flood peak and volume.

- Other notable regional tributary events were those of 1961, 1974, 1997 and 1999. In comparing these four annual flood hydrographs, as in Figure 20 for the Se Bang Hieng, their highly variable nature from year to year becomes apparent, as does the often inconsistent relationship between flood peak and volume. The regularity of flash flood conditions, even within a very large catchments also emerges.

- The event of 1961 combined an exceptional 50 year flood volume with a series of peak flows, none of which exceeded a magnitude to be expected once in five years.

- On the Se Bang Hieng the flood season usually begins in mid June and extends to the end of October. During 1974 it got off to a false start during June but sustained flood flows did not begin until mid August. The flood season also ended a month early in the last week of September. It was therefore short and the volume of floodwater low. In the mean time the peak discharge reached almost 8500 cumecs, expected once on the average in 25 years.

- This type of flash flood hydrograph, from a catchment of almost 20,000 km^2 is even more evident during the flood of 1997, when discharges increased four fold over less than a week also to 8500 cumecs.

- The most remarkable seasonal hydrograph is that of 1999, when to all effect the flood season ended two months early at the end of August. Then during November, outside of the usual flood season, a severe tropical storm caused a massive increase in flows over two days from less than 500 cumecs to 8700 cumecs and the classic flash flood hydrograph.

This highly variable flood hydrology both within and between years is characteristic of the large left bank tributaries and there is, in effect, nothing that can be defined the ‘typical’ flood season hydrograph. Extremely rapid increases and decreases in flood discharge, generally associated with severe tropical storms can, even on very large catchments, cause flash flood conditions.

Due to the flat landscape, the lower rainfall and to some extent the presence of large reservoirs, flash floods are not a feature of the hydrology of the Mun-Chi Basin, except in the far upstream reaches. Historically, the events of 2000, 2001 and 2002 dominate, both in terms of flood peak and volume (Figure 21), as they do elsewhere in the LMB. On the Nam Mun the highest peak discharge occurred in 1978, corresponding with the year that the largest flood peak was observed on the Mekong mainstream at Kratie since records began in 1924.

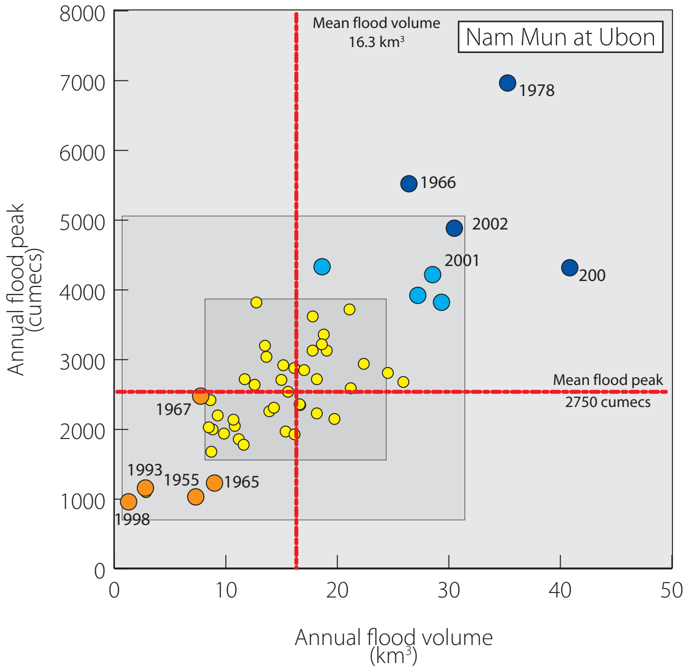
The evidence from the Nam Chi Basin suggests that below ‘normal’ flood years, when peak and volume are significantly less than average, tend to cluster. During the 13 years between 1967 and 1979, eight of the most extremely deficient annual floods were observed.

With a total basin area of 120,000 km^2 , equivalent to 22% of the Mekong drainage area at Pakse, the Mun-Chi contributes only 10% to the average flood volume at that point on the mainstream (Figure 22) and 6% to the total at the delta. It is never the less a key tributary system within the context of the flood hydrology of the Mekong, though overall the contributions of the left bank tributaries dominate:

Table 7. *Mean annual tributary contributions to the Mekong flood.*

China (Upper Mekong)	Lower Mekong	
	Left bank tributaries	Right bank tributaries
16%	60%	24%

	T (years)	Flood peak (cumecs)	Flood volume (km^3)
Below average annual floods	100	980	2.3
	50	1100	3.5
	20	1350	5.4
	10	1550	7.3
	5	1900	9.7
	2	2600	15.3
Above average annual floods	5	3600	22.4
	10	4250	26.8
	20	4850	30.8
	50	5650	35.7
	100	6250	39.2



	T (years)	Flood peak (cumecs)	Flood volume (km^3)
Below average annual floods	100	170	0
	50	250	0
	20	350	0.7
	10	470	1.6
	5	620	2.7
	2	900	5.3
Above average annual floods	5	1250	8.2
	10	1500	9.9
	20	1750	11.4
	50	2050	13.1
	100	2250	14.2

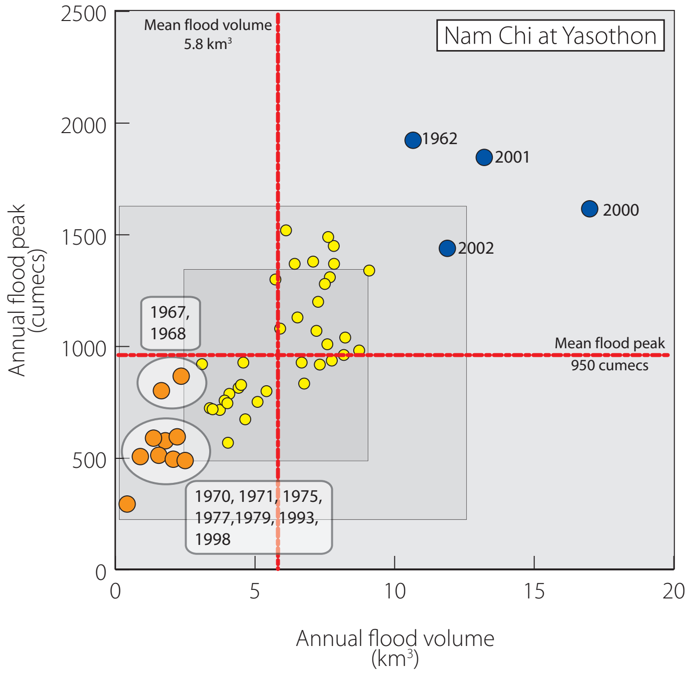


Figure 21. Mun-Chi—Scatter plots of the joint distribution of the annual maximum flood discharge (cumecs) and the volume of the annual flood hydrograph (km^3). The 'boxes' define 1 and 2 standard deviations about the mean of each of the two variables, outside of which the annual flood is described as significant and severe, respectively.

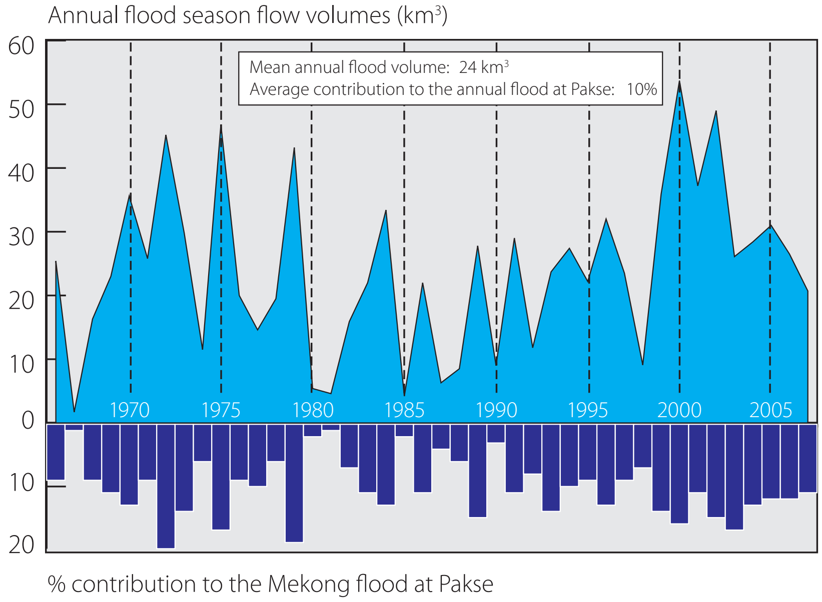


Figure 22. Mun-Chi Basin —Annual flood contributions to the Mekong (km3), also expressed as a percentage of the annual mainstream flood volume at Pakse (1966–2007).

The central role that these major tributaries play in the development of the annual flood becomes apparent from Figure 23 which indicates the cumulative volumetric accumulation of the 2000 flood along the Mekong mainstream downstream of Chiang Saen, expressed in percentage terms. The inputs of the largest tributaries, which include the Nam Ou upstream of Vientiane and the Se Kong, Se San and Sre Pok system downstream of Pakse, are evident as successive sharp increases in mainstream flow:

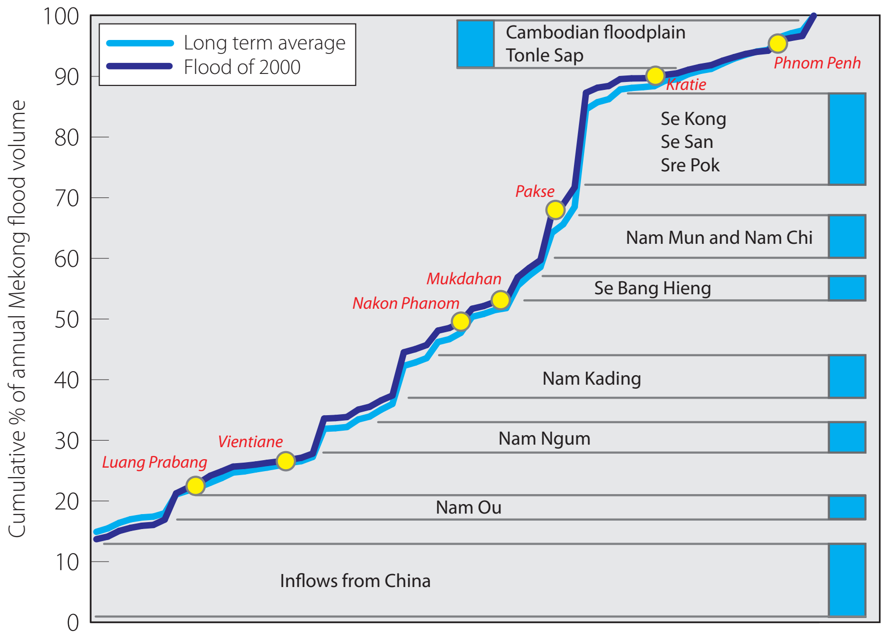


Figure 23. Mekong mainstream—the cumulative development of the 2000 flood event downstream of Chiang Saen, expressed in percentage terms.

- The Se Kong, Se San and Sre Pok system makes by far the largest contribution, amounting to 18%, exceeding that from the Upper Mekong in China. It is the pivotal element in determining the severity of flooding and inundation on the Cambodian floodplain and in the Mekong Delta, as indeed it was during the events of 2000.

- Tributary contributions during regional flood events such as this tend to replicate the average seasonal accretion of floodwater along the mainstream. Each of the major tributary systems tends to contribute a similar relative proportion of the overall flow from event to event.

- There are, however, periodic exceptions. The flood of 1966 provides the principal one when most of the floodwater originated in the Upper Mekong Basin and the northern Lao PDR and Thai tributaries.

- The tributary flood hydrographs during an extreme regional event such as that of 2000 can be quite dissimilar, as they reflect the hydrological consequences of catchment scale, the influence of landscape factors and the attenuating effect of large reservoirs.

- These dissimilarities are evident from Figure 24. Though they are very large tributary basins, the Nam Ou, Nam Kading and Se Bang Hieng still exhibit large but short term fluctuations in discharge. Flash floods conditions are not therefore confined to the smaller steeper river basins in the region.

- As catchment scale increases even further these relatively rapid variations in flow are smoothed out as the longer duration responses to each storm episode coalesce, resulting in the highly coherent and smoother hydrograph of the Se Kong, Se San and Sre Pok.

- Geographic scale is also a factor in the 'smoother' flood hydrograph for the Mun-Chi, though here the flat landscape is also an influence.

- In the case of the Nam Ngum, the large reservoir storage in the basin screens out any short term fluctuations in flow.

- The six hydrographs also differ in the timing and number of flood peaks reflecting the geographical variability of the seasonal storm rainfall and the various tracks and impacts of the tropical storms. The 2000 flood on the Mekong mainstream was therefore the result of an accumulation of very distinctive tributary hydrographs.

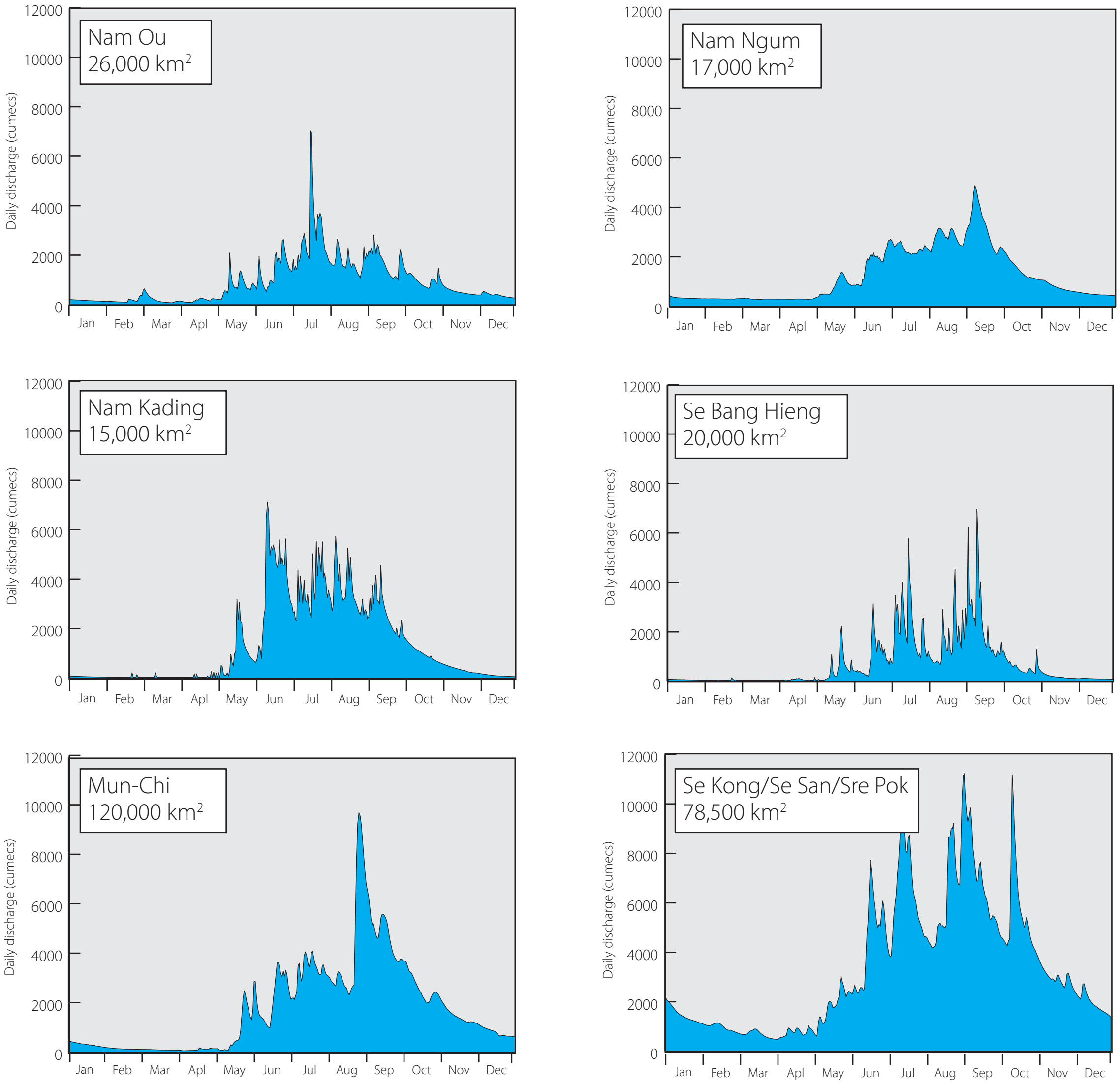


Figure 24. The distinctive hydrographs of the tributary flows of 2000, illustrating the various impacts on their pattern of catchment scale, landscape factors and the attenuation of reservoirs. The variability of the timing and number of peaks amongst them also points to the geographical variability of storm rainfall during 2000.

2.9 Vientiane to Pakse—the estimation of flood risk at un-gauged locations

The accelerating pace of hydropower development in the LMB means that there is a growing need for the development of a reliable procedures for the estimation of design flood risk at ungauged dam sites. Over recent years 'best practice' has involved the use of regional methods based upon the pooling of data in regions and sub-regions that might be considered to be homogenous with respect to their flood hydrology. The Mekong between Vientiane and Pakse can be considered to be one such, though the left and right bank tributaries require separate treatment.

Figure 25 shows a plot of the relationship between tributary catchment area and mean annual flood peak discharge which illustrates this hydrological distinction between the left and right bank rivers:

- for a given catchment area, the mean annual flood on the right bank is considerably less than that on the left, reflecting the lower rainfall and flatter landscape within the Mun-Chi Basin;
- the levels of correlation between the two variables is such that 80 to 90% of the variation in the mean annual flood from site to site is explained by basin area alone for each sub-sample.
- linear relationships with these levels of significance mean that the mean annual flood at an un-gauged site can be estimated with reasonable reliability;
- note that the data for the Nam Ngum at Tha Ngon was not included in the estimation of the right bank regression due to the presence of the large reservoir upstream.

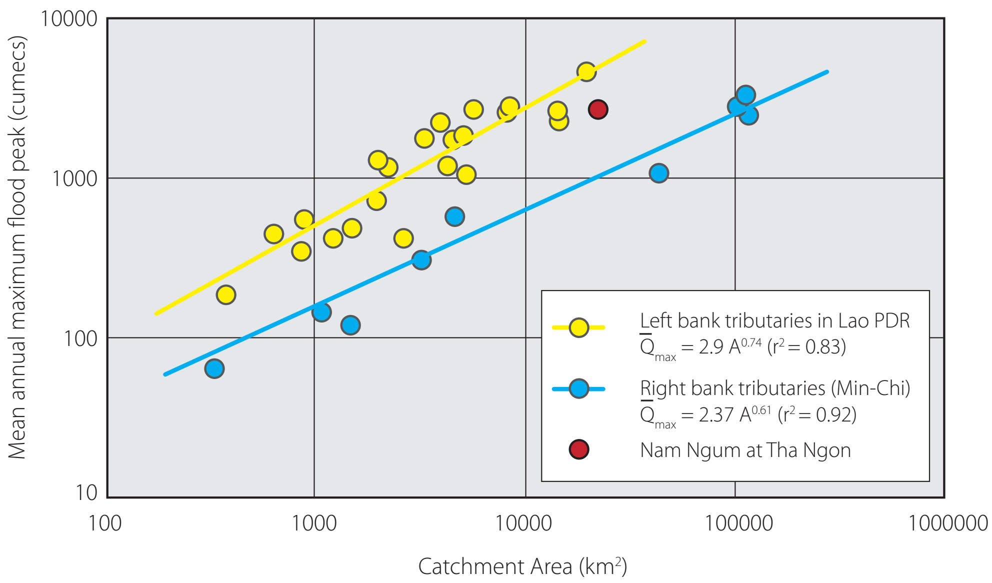


Figure 25. Vientiane to Pakse — relationship between catchment area and mean annual flood within the left bank tributaries in Lao PDR and the right bank tributaries in Thailand.

The next step in this regional methodology is to provide a means of scaling the mean annual event to obtain the T year flood. This is achieved by dividing out the data at each tributary site by the mean annual flood and then pooling the resultant modular data into a single regional sample. To these ratios the appropriate probability model is fitted to obtain the so called 'regional flood growth curve', the final results being illustrated in Figure 26. The statistical model selected in this case is the Two Component Extreme Value (TCEV) Distribution which acknowledges the fact that in tropical monsoon regions floods can often be separated into basic and outlier events, the former the result of 'normal' storm rainfall and the latter the consequence of severe tropical storms and typhoons. The latter are much larger for the data observed in the Mun–Chi Basin. That for the right bank tributaries in Lao PDR is more coherent and presents a probability distribution with only one component. This would tend to imply that here exceptional or outlier events are compatible in terms of magnitude and risk of occurrence with the main body of the sample and so no second component to the distribution of floods is identifiable.

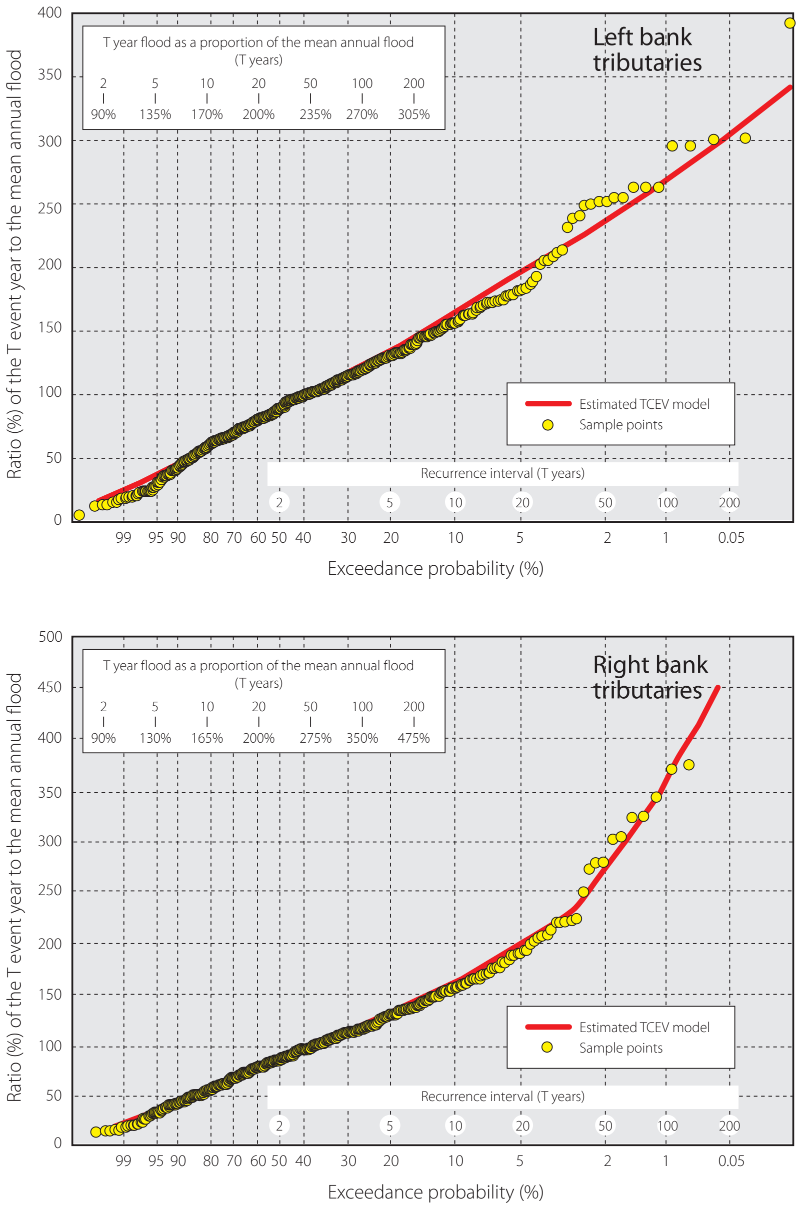
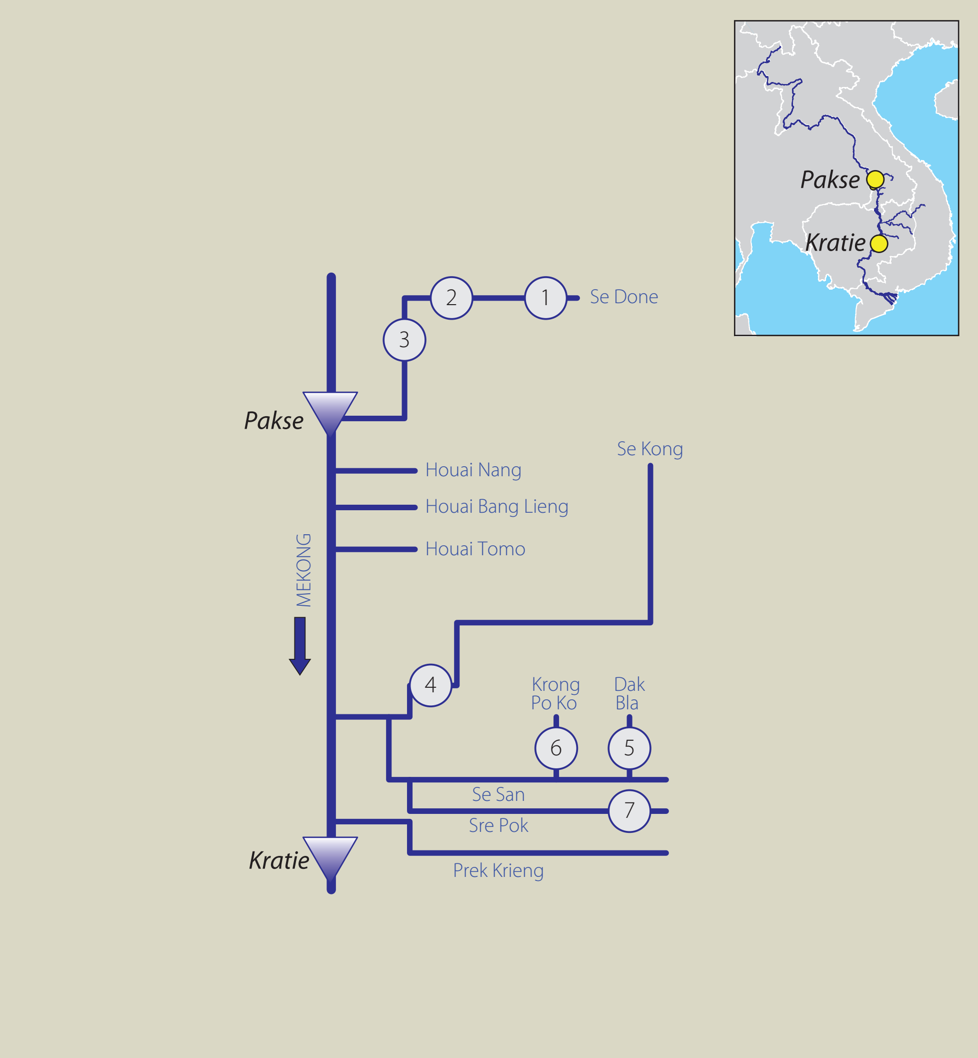


Figure 26. Vientiane to Pakse — ratio (%) of the T year event to the mean annual flood within the left bank tributaries in Lao PDR and the right bank tributaries in Thailand.

2.10 Pakse to Kratie - the regional tributary systems

This reach of the Mekong, which accounts for 18% of the total basin drainage area, the tributary contribution to the mean annual flood volume at the delta is about 20%. At Kratie 90% of floodwater has already entered the system and downstream of there most of the balance is made up by the contribution of the Tonle Sap Basin in Cambodia. Of this 20% around 18% is accounted for by the combined Se Kong, Se San and Sre Pok Basins, which makes the largest single contribution to the total Mekong flood in most years, a point already illustrated in Figure 23.



Total tributary catchment area	Percentage of LMB area	Total mean annual flow of all tributaries	Average annual sub-basin runoff
101,000 km^2	18%	110 km^3	1,050 mm

Figure 27. Pakse to Krate - schematic of the major Mekong tributary systems indicating the sites at which discharge data are available. (Numbers refer to the right hand column in Table 9.)

The major constraint to hydrological analysis in this sub-region is a lack of representative data, which are distributed amongst only seven sites, as shown in Figure 27. With the exception of the gauge on the Se Done at Kong Se Done, which records the flows from 65% of the basin and the gauge on the Se Kong at Attapeau, the others on the Se Kong and Sre Prok are far upstream and only provide information about the hydrology of the headwaters (Tables 8 and 9). Meaningful estimates of the flood hydrology of these key regional river systems is therefore dependent upon hydrological modelling.

Table 8. *Pakse to Kratie — major tributaries to the Mekong mainstream.*

Major Tributary (catchment > 1000 km²)	Catchment Area (km²)	Mainstream	Major Tributary (catchment > 1000 km²)	Catchment Area (km²)
		PAKSE		
Right bank tributaries are all small with catchments less than 1000 km²		↓	Se Done	7,00
			Se San/Se Kong/Sre Pok	78,500
			Prek Krieng	3200
		KRATIE		

Table 9. *Pakse to Kratie — tributary sites at which functional hydrometric data are available. (Sequence numbers refer to those in Figure 27.)*

Sketch	Station No.	River	Site	Catchment (km²)	Mean annual flow (cumecs)
1	390103	Se Done	Saravane	1172	40
2	390102	Se Done	Kong Se Done	5150	170
3	390104	Se Done	Souvanna Khili	5760	175
4	430105	Se Kong	Attopeu	10,500	430
5	440201	Dak Bla	Kontum	3060	100
6	440601	Krong Poko	Trung Ngia	?	130
7	451305	Sre Pok	Ban Don	10,600	280

2.11 Pakse to Kratie — the hydrological assessment of extreme regional tributary flood events

This lack of representative data means that only a limited assessment of the tributary flood hydrology is possible, which is unsatisfactory given the pivotal role of the Se Kong, Se San and Sre Pok in the generation of extreme flood conditions across the Cambodian floodplain and in the Mekong Delta. As has already been established their contribution to the extreme regional flood of 2000 was major (Figure 23). This event was characterised by a peak flow at Kratie on the Mekong mainstream that was only marginally above average. It was the total flood volume over the flood season that was extreme, the highest observed since 1924 (see Figure 29).

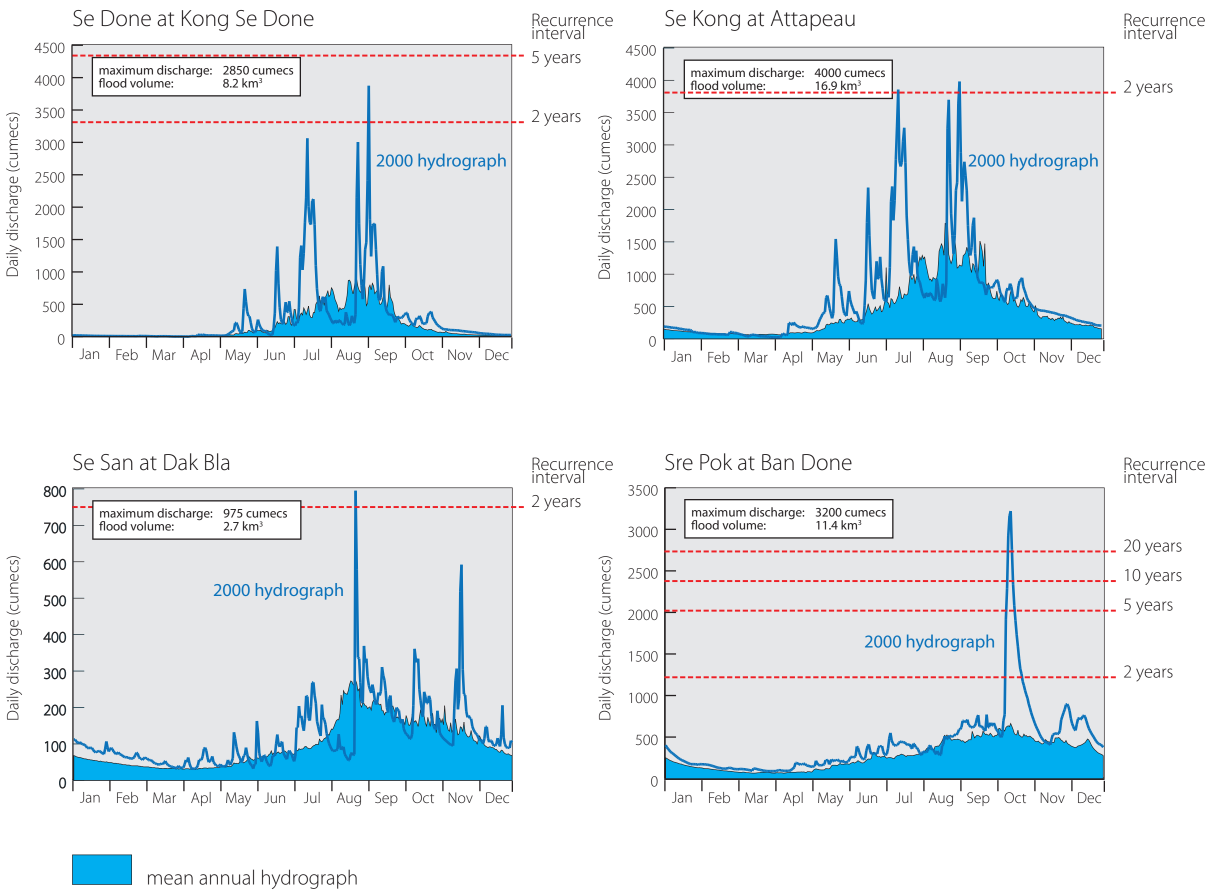


Figure 28. Annual hydrographs for the 2000 flood on the Se Done and in the Se San, Se Kong and Sre Pok.

These aspects of the 2000 event on the mainstream are reflected in the flows observed on the Se Done and Se Kong, indicated in Figure 28:

- The recurrence interval of the peak discharge in early September was only between two and five years. The seasonal flood volume, however, was up to twice the average figure and therefore exceptional.
- On the mainstream the flood season of 2000 began early and floodwater rapidly accumulated on the Cambodian floodplain. There is evidence that these tributaries contributed to this build up in May and June.
- The far upstream reaches of the Se San and Sre Pok at Dak Bla and Ban Don are distinctly different in terms of their flood hydrology, with evidence to suggest that they are affected by both the SE and NE Monsoons. Dry season flows are much higher than at Kong Se Done and Attopeu, with the occurrence of a significant number of spates. The peak event on the upper Sre Pok in October, with a recurrence interval in excess of 1:20 years is not evident elsewhere, which points to the local incursion of a severe tropical storm.

- There is also evidence to suggest that these Mekong left bank catchments have little natural storage. Throughout the LMB where the NE Monsoon has no effect, dry season flows are exceptionally small, as on the Se Done and Se Kong, indicating little carryover of water from the flood to the dry season.

- This lack of natural storage, the result of steep topography and geological conditions in the main, also explains the 'flashiness' of the flood hydrology, with a very rapid rise to flood peak, followed by an equally rapid recession.

3. The 2007 flood season

3.1 Hydrological aspects — the Mekong mainstream

In terms of peak discharges and seasonal flood volumes, conditions during the 2007 flood season along the Mekong mainstream were comparable to those that occurred during 2006 (Figure 29). As then, both variables fell below their long term average values, the degree to which they did so becoming more pronounced downstream, such that at Kratie both flood peak and volume were significantly below normal.

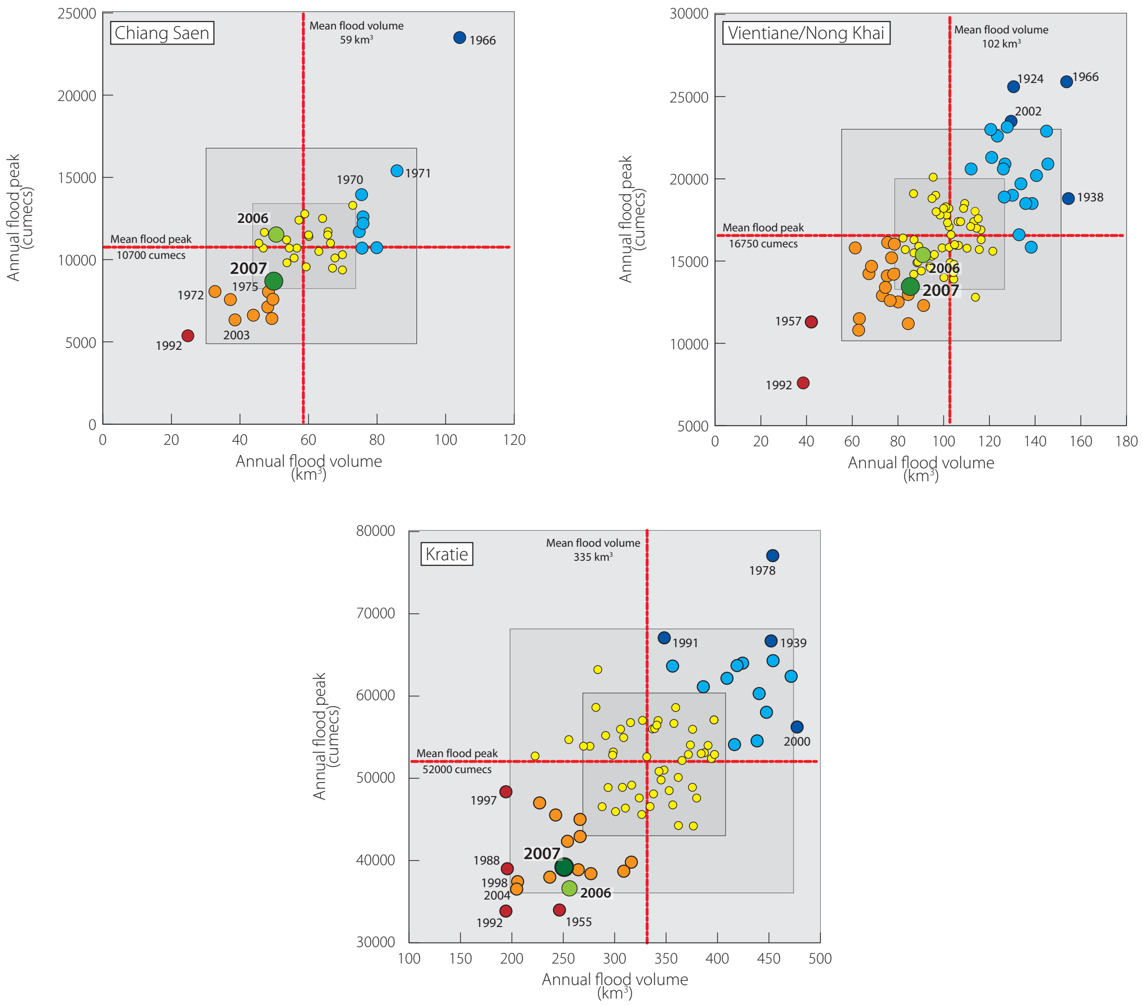


Figure 29. Scatter plots of the joint distribution of the annual maximum flood discharge (cumecs) and the volume of the annual flood hydrograph (km^3) at Chiang Saen (1960 – 2006), Vientiane/Nong Khai (1913 – 2006) and at Kratie (1924 – 2006). The 'boxes' indicate one (1δ) and two (2δ) standard deviations for each variable above and below their respective means. Events outside of the 1δ box might be defined as 'significant' flood years and those outside of the 2δ box as historically 'extreme' flood years.

In fact flood conditions at Kratie during 2006 and 2007 are amongst the eight lowest observed since 1924, seven of which have occurred during the last 20 years. This intensification of the shortfall in peak and volume downstream of Vientiane points to significantly reduced monsoonal rainfalls within the catchments of the large left bank tributaries that lie in Lao PDR over the last two seasons. Conditions in the mainstream reaches where the flood hydrology is dominated by flows from the upper Mekong River in China, that is those upstream of Vientiane, tended to be much less anomalous and closer to average. This observation underscores the fact that the flood regime of the Mekong and the climatological conditions that drive it from year to year are not geographically homogenous.

These below average flood conditions were not, however, the definitive hydrological feature of the 2007 season. This lies with the fact that throughout the mainstream the start of the flood season was generally the latest observed over the last 80 to 90 years. Typically, the season begins in the last week of June or the first week of July in those reaches above Kratie and a week or two later at Phnom Penh and in the Delta in Viet Nam. The onset is defined as the first sustained 'upcrossing' of the long term mean annual discharge or water level (see the 2006 Annual Flood Report for a detailed discussion) which characterises the arrival of significant volumes of monsoonal runoff. Defined in these terms this onset date has a remarkably narrow variability from year to year, typically of plus minus two weeks. Departures outside of this 'window' are relatively rare occurrences.

Events during 2007 are set out in Figure 30 and Table 10. In order to effectively illustrate just how atypical the flood season onset date was it is necessary to provide a picture of the flows on each day of the year over the complete period of record, since simply plotting the 2007 hydrograph against the long term average only provides the minimum degree of information and insight, as Figure 30 reveals.

- The scatter plots of historical daily flows across all years clearly reveal that conditions during 2007 were virtually unprecedented during July and early August.

- Compared to the mean historical daily flows during June and July, those over the same period in 2007 are clearly very low, particularly at Kratie. Here there was a 'false start' to the flood season during early July, but the higher flows were not sustained for more than a few days.

- The scatter plots reveal a much more detailed picture and the fact that throughout the mainstream within the Lower Mekong Basin flows by the end of July 2007 were amongst the lowest ever observed at this time of the year, indicating that the onset of flood conditions was very late. At Chiang Saen and Vientiane it was only during 1979 that the flood onset occurred later. At Kratie the 2007 flood onset was the latest observed over the 84 years since records began in 1924.

- These 2007 onset dates are summarised in Table 10 and compared with their historical average and standard deviation.

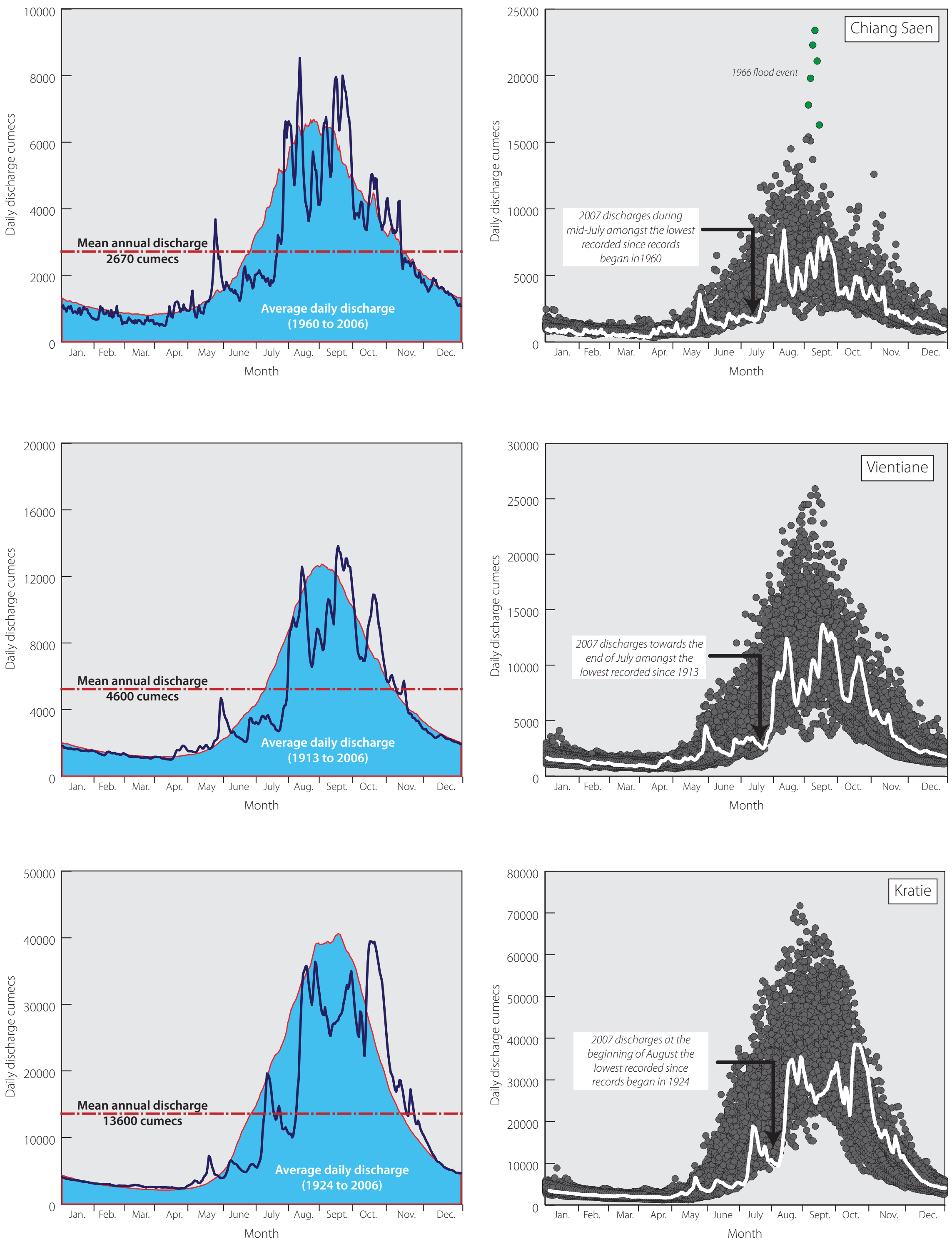


Figure 30. Mekong Mainstream—historical mean and range of the annual daily flow hydrograph at selected sites compared to that for 2007.

Table 10. *Onset and end dates of the 2007 flood season compared to their historical mean and standard deviation at selected mainstream locations.*

Site	Onset of flood season			End of flood season		
	Historical average	Standard deviation	2007	Historical average	Standard deviation	2007
Chiang Saen	28th June	14 days	17th July	14th November	14 days	7th November
Vientiane	3rd July	14 days	25th July	11th November	15 days	12th November
Kratie	1st July	16 days	3rd August	7th November	12 days	19th November

- At all three sites the 2007 onset lay well beyond the typical window, as measured by the standard deviation. The extreme case is Kratie, where the 3rd August represents a delay of over a month or two standard deviations, which may be regarded as extreme.

- The end of the flood season, defined by the last 'down-crossing' of the long term mean annual discharge, generally falls within the 'typical window', as defined by one standard deviation.

Table 11. *Duration of annual flood season at selected mainstream sites.*

Site	Average historical duration of flood season.	Duration of 2007 flood season.
Chiang Saen	139 days	114 days
Vientiane	132 days	111 days
Kratie	130 days	109 days

- The 2007 flood season was therefore an uncharacteristically short one (Table 11), which when combined with below average flood flows during August resulted in below normal flood volumes and maximum annual flood peak (Table 12) and a seasonal distribution of flows that was untypical, particularly downstream of Vientiane. (Figure 31).

Table 12. *The 2007 flood peaks and volumes compared to their historical averages at selected mainstream locations.*

Site	Period of record	Maximum annual flood peak (cumecs)		Annual flood volume. (km^3)	
		Historical average.	2007	Historical average	2007
Chiang Saen	1960 – 2007	10,550	8500	57.2	49.3
Vientiane	1913 – 2007	16,700	13,800	100.0	83.8
Kratie	1924 – 2007	51,500	39,450	329.1	255.0

These results emphasise the importance of employing a meaningful definition of the onset and end of the annual flood season. It is a random variable in time and not a fixed temporal event linked to some prescribed calendar date. Only by using the type of definition used here will the anomalous situation such as that which occurred during 2007 be uncovered and a means to quantify the anomaly in terms of timing be available. In this context it is worthy of note that during July 2007 there was a wider public appreciation that the flows in the

Mekong mainstream were uncharacteristically low for the time of year, thereby underscoring a general qualitative awareness of what is 'normal' and what is not. Being able to quantify such departures from so called 'normality' on a meaningful basis is a key function of such hydrological studies as the Annual Flood Report.

The distribution of flows during the 2007 flood season at all three sites was generally average in their lower range and below average in the higher ranges. This pattern became more pronounced in the lower reaches towards Kratie where the flood flows exceeded 50% of the time fell well below those that would be expected in a typical year. The pattern is largely explained by unseasonally lower than normal flows during August and September. Overall therefore the duration of discharges within the higher ranges was shorter than normal which would have resulted in a reduced period of inundation of the natural floodplain, particularly in Cambodia.

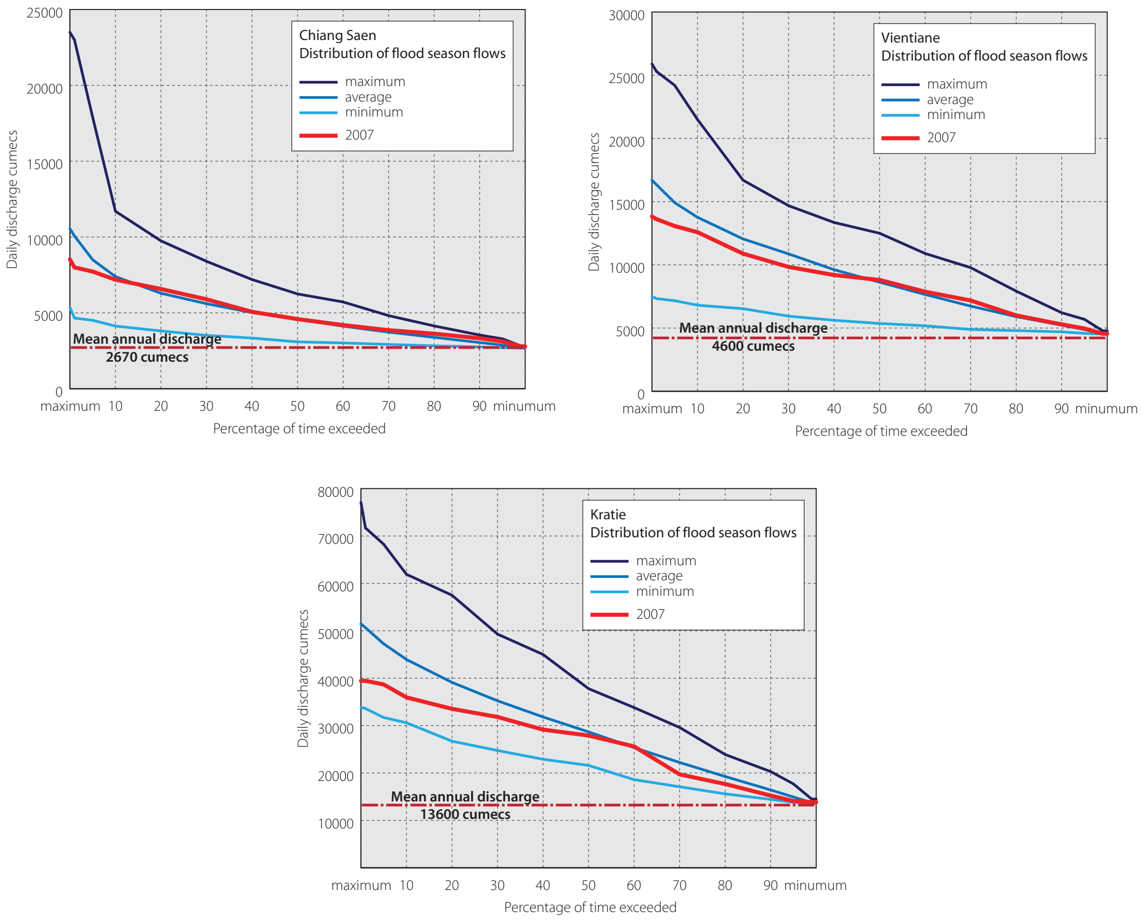


Figure 31. The distribution of flood season flows during 2007 at Chiang Saen, Vientiane and Kratie compared to their historical average and range.

3.2 Hydrological aspects — the Cambodian floodplain and Mekong Delta

Hydrological conditions over the Cambodian floodplain and within the Delta during the 2007 flood season (indicated in terms of water level rather than discharge) reflected those that prevailed upstream, as the results shown in Figure 32.

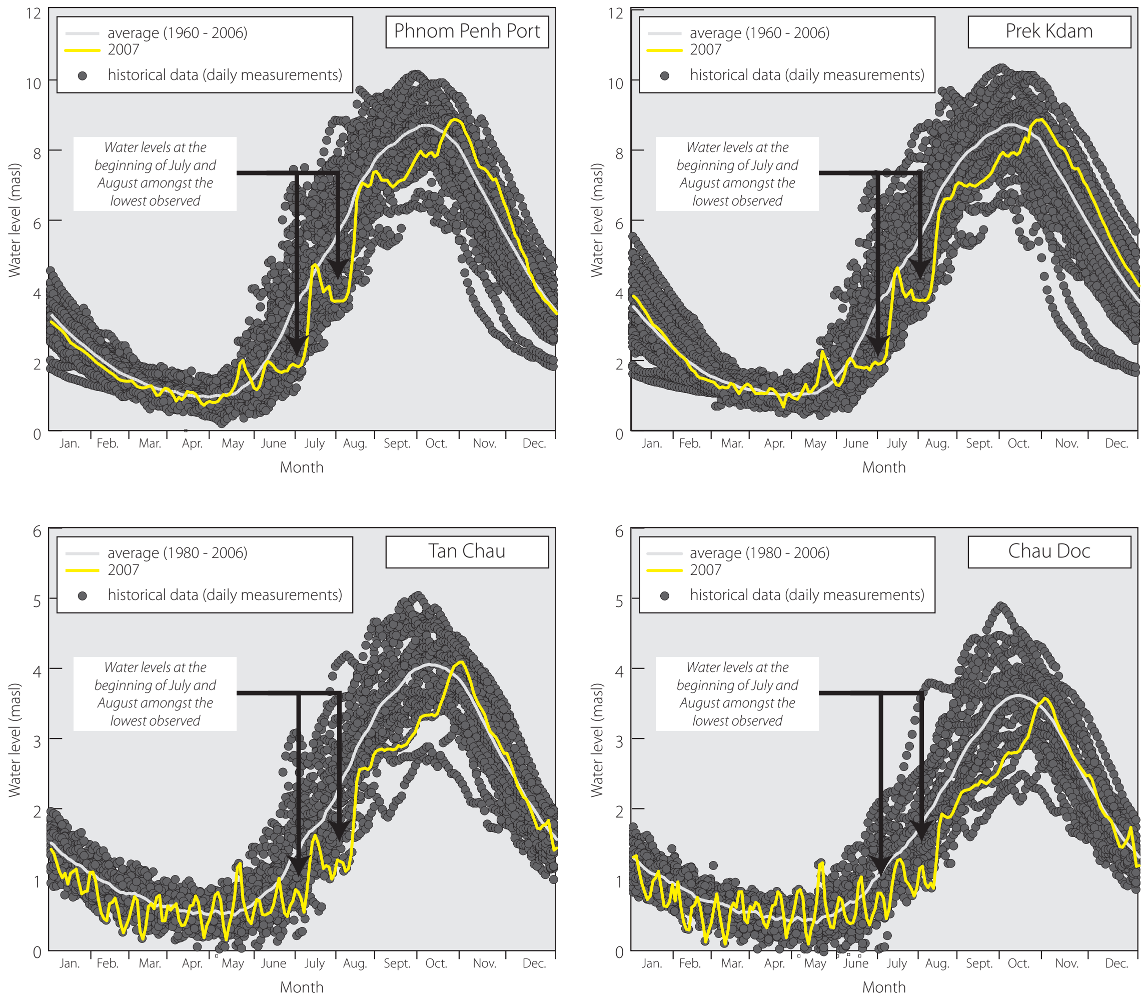


Figure 32. Cambodian Floodplain and Mekong Delta - Historical mean and range of the annual daily water level hydrograph at selected sites compared to that for 2007.

- Water levels at Phnom Penh Port, Prek Kdam, Tan Chau and Chau Doc in early and late July and on into the first week of August were the lowest observed over the last to 28 to 48 years (Figure 32) and continued to be consistently well below average until a response to late monsoonal storms upstream occurred in late October.

- This late arrival of significant flood waters generated higher water levels from this time onwards, though throughout November and December during the flood recession these were only marginally above average.

- The onset of the flood season, here defined as the first sustained 'up-crossing' of the long term mean annual water level, was up to three weeks late at Phnom Penh and Prek Dam and nearer two weeks in the Delta, though generally well outside of the characteristic 'window' defined by the standard deviation (Table 13).

Table 13. *Cambodian floodplain and Mekong Delta — onset and end dates of the 2007 flood season compared to their historical mean and standard deviation at selected locations.*

Site	Onset of flood season			End of flood season		
	Historical average	Standard deviation	2007	Historical average	Standard deviation	2007
Phnom Penh Port	10th July	14 days	4th August	14th November	14 days	15th December
Prek Kdam	11th July	16 days	5th August	20th December	17 days	29th December
Tan Chau	19th July	20 days	8th August	17th December	12 days	14th December
Chau Doc	23rd July	17 days	9th August	19th December	12 days	27th December

- The duration of the flood season was therefore curtailed (Table 14), with consequent implications for the period of time that natural riparian wetlands and the floodplain were inundated.

Table 14. *Duration of annual flood season on the Cambodian Floodplain and Mekong Delta.*

Site	Average historical duration of flood season	Duration of 2007 flood season
Phnom Penh Port	158 days	133 days
Prek Kdam	163 days	146 days
Tan Chau	151 days	128 days
Chau Doc	148 days	131 days

- The depth and therefore the areal extent of this foreshortened period of inundation was also below normal due to below average seasonal water levels (Table 15).

Table 15. *Cambodian Floodplain and Mekong Delta – 2007 annual maximum water levels at selected sites compared to their historical means and standard deviations.*

Site	Period of record	Annual maximum water level (masl)		
		Historical average	Standard deviation (m)	2007
Phnom Penh Port	1960 – 2007	9.02	0.67	8.85
Prek Kdam	1960 – 2007	9.08	0.73	8.86
Tan Chau	1980 – 2007	4.30	0.54	4.14
Chau Doc	1980 – 2007	3.82	0.58	3.62

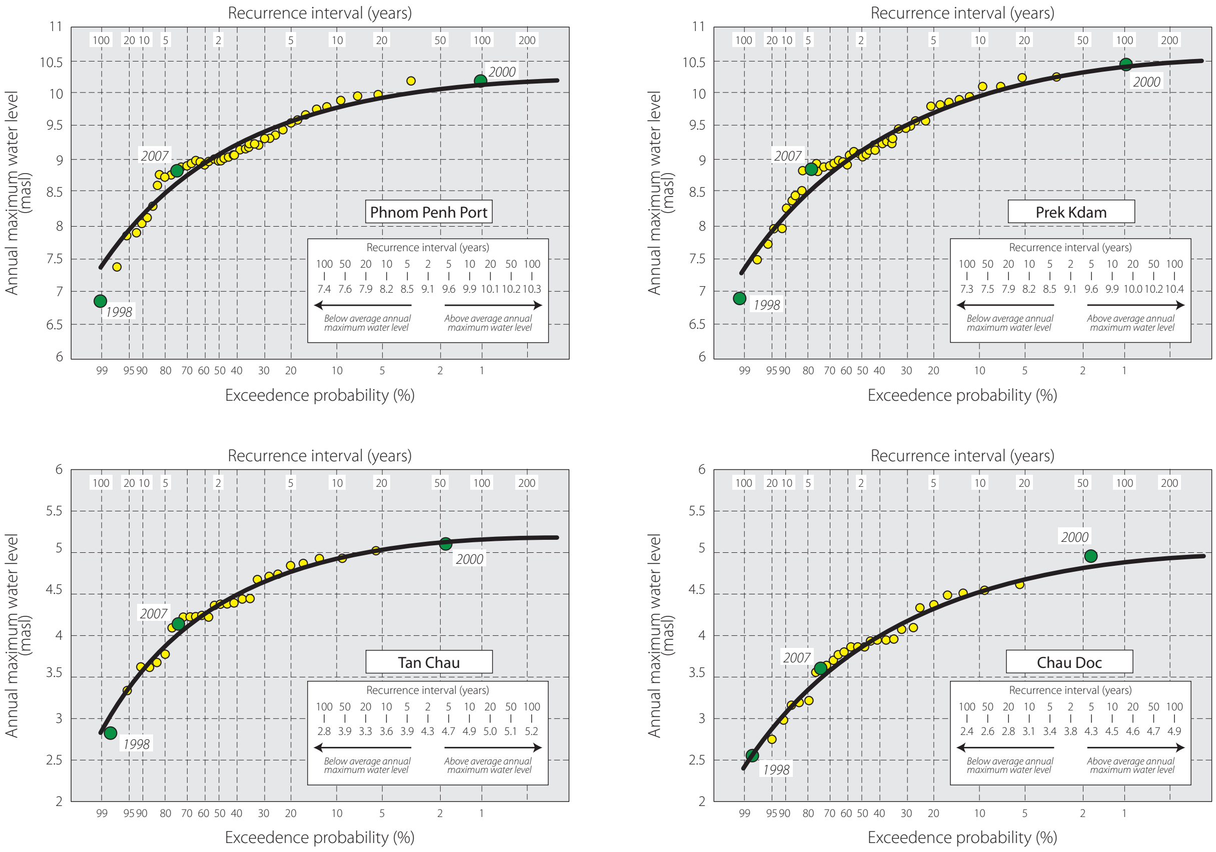


Figure 33. Cambodian Floodplain and Mekong Delta —historical sample distribution of annual maximum water levels and General Extreme Value Type III approximating distribution.

- The end of the flood season in this sub-region of the Lower Mekong Basin occurs several weeks later than in reaches further upstream, where the characteristic date is the second and third week of November (refer back to Table 10). On the Cambodian Floodplain natural flood storage comes into effect while downstream of the Tonle Sap confluence with the Mekong mainstream the natural regulation storage in the Tonle Sap and Great Lake system becomes evident. The flow reversal as the Great Lake drains into the mainstream results in a further delay to the characteristic end of the flood season to the later weeks of December, while in some years the season can last well into January of the following year.

- The effect of over-bank storage on the floodplain is also evident from a plot of the distribution of historical annual maximum water levels, as indicted in Figure 33. The plotted points asymptotically approach some undefined upper limit as floodwater spills out of the channels onto the floodplain. The higher the levels become therefore the incremental difference decreases as the area of inundation increases. The plots also indicate that the maximum water levels achieved during the 2007 flood season were marginally below average and would occur on average about once in four to five years.[1]

1 The water level quantiles quoted in Figure 33 for Phnom Penh Port have been revised downwards from those given in Appendix A1.3 of the 2006 Annual Flood Report. The other three remain the same.

3.3 The 2007 flood season — meteorological aspects.

With the exception of most of Cambodia and the Delta region, rainfall during the SW Monsoon of 2007 over the Mekong region was moderately below average. Figure 34[1] indicates the cumulative daily rainfall at selected sites during 2007:

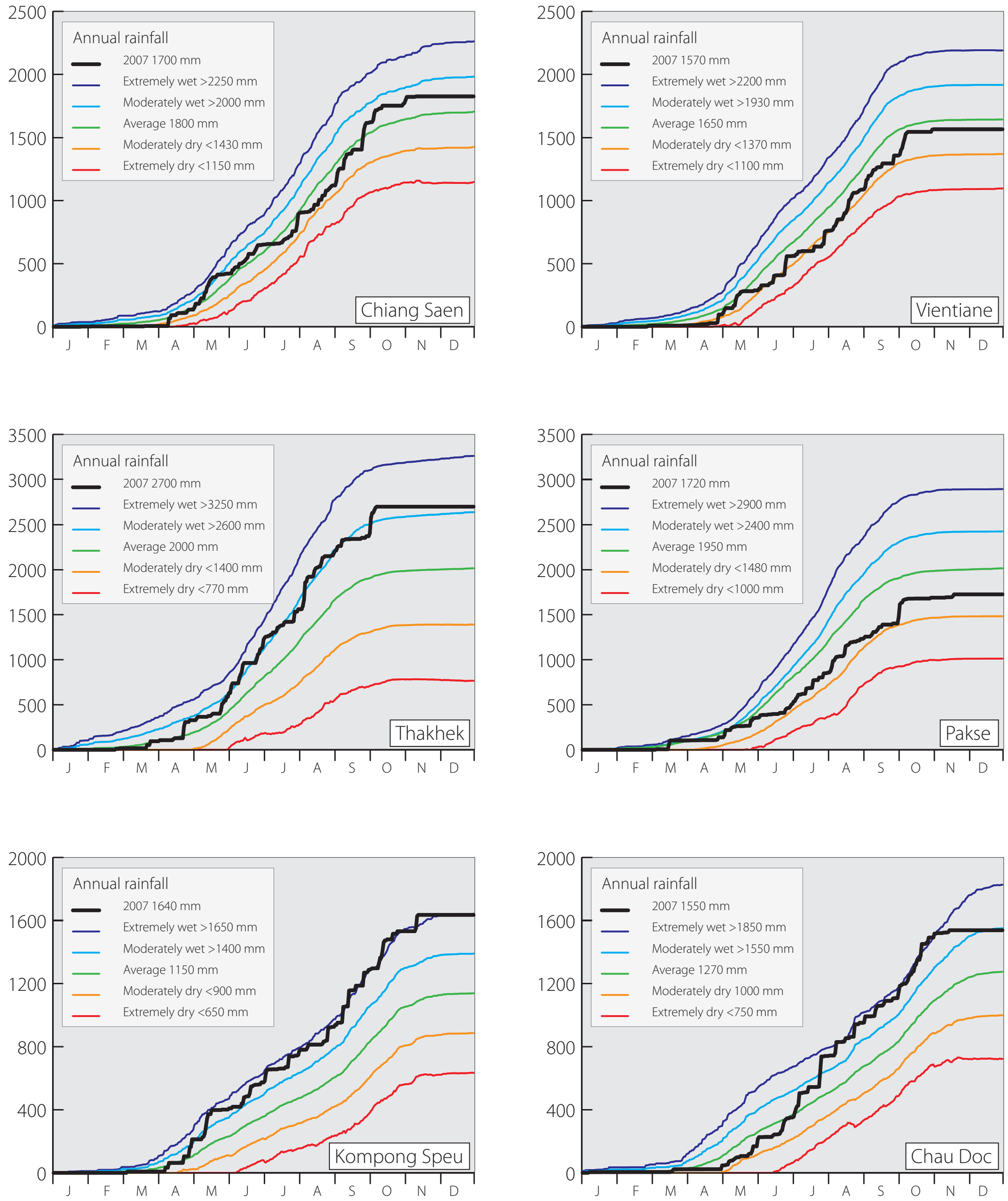


Figure 34. Cumulative daily rainfall at selected sites in the LMB, indicating average, moderate and extreme wet and dry conditions and those during 2007.

1 In this figure, moderately and extremely wet and dry are defined as plus/minus one and two standard deviations above and below the daily mean of the accumulated rainfall on day t, t=1,65.

- Reflecting the general regional situation, that at Chiang Saen, Vientiane and Pakse was average or below, though that at Thakhek, where it was considerably greater than average, reveals that there were local exceptions.

- In Cambodia and Vietnam the seasonal rainfall does not reflect meteorological conditions within the wider Basin and was very much above average. Locally, at Kompong Speu in Cambodia for example, the seasonal rainfall total was extremely high, though this appears to be largely explained by two significant storm periods during late April and early May.

- The rainfall generally accumulated steadily indicating that there were few periods of exceptional storm activity outside of the Delta and Cambodia. This lack of large accumulations of storm rainfall over a few days would be a major factor in explaining the regionally low stream flows and below average Mekong flood during the year.

- The only major regional storm event that had any large scale hydrological impact occurred during the first week of October. It resulted in the 2007 peak discharge at Kratie and the only time in the year that water levels in Cambodia and the Delta rose above average (see Figures 30 and 32).

- This was severe tropical storm Lekima, which tracked across the central areas of the LMB and resulted in heavy rainfall within the many of the large left bank tributaries, particularly the Se Bang Hieng, Se Bang Fai, Se Done, Se Kong and Se San (Figure 35). Three day rainfalls in excess of 250 mm were widespread.

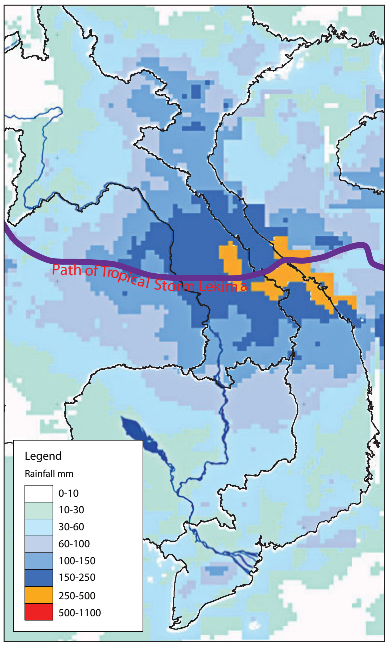


Figure 35. Track of severe topical storm 'Lekima' and associated rainfall within first week of October, 2007.

4. Cambodia 2007 country report

4.1 General situation

Events in Cambodia during 2007 centred around the flooding caused by Tropical Storm Pabuk in the northern and coastal areas of the country on the 4th and 5th of August. Otherwise, the fact that the annual flood on the Mekong mainstream was a month late in starting and that water levels, once it had, remained significantly below average until October following 'Lekima', meant that levels in the Great Lake were considerably less than average. This delay in the increase in lake levels until early August and the fact that inundation of the riparian forest covered a much smaller area than usual resulted in a large fall in the annual fish catch.

4.2 Tropical Storm Pabuk during August and flooding in Phnom Penh in July

'Pabuk' resulted in some exceptional daily rainfall totals, as the data in Table 16 indicate, which in turn produced widespread flash floods and extensive inundation.

Table 16. *Selected daily rainfalls (mm) associated with Tropical Storm Pabuk.*

Date	Koh Kong	Mondulkiri	Preah Vihear	Ratnakiri	Stung Treng
4th August	174	102	0	21	38
5th August	97	68	360	143	131

On the Sre Pok at Lumphat the maximum gauge height of 14 m was exceeded by the consequent flood peak (Figure 36 overpage). The most severe inundation occurred in Kampong Thom, Prah Vihear, Ratanakiri, Battambang and Sihanoukville. After a heavy rain for about an hour in the early morning of July 21 several places in Phnom Penh were inundated, principally due to the poor drainage infrastructure (Figure 36).

4.3 Damage and impacts

Reports from those provinces affected by 'Pabuk' during August indicate that more than 160,000 persons were affected, 5 people were killed, 37 km of rural roads were seriously eroded, along with some locally significant damage to public building, temples and residential areas. A number of dykes and irrigation canals filled with sediment or eroded. Over 8000 ha of rice and other crops were damaged or altogether lost due to prolonged submergence.

Flood peak water level of 15m

Figure 36. Sre Pok at Lumphat, maximum water level reached on the 7th August.

Figure 37. Flood inundation in Ratanakiri on 6th August.

Figure 38. Phnom Penh, flooding outside the National Assembly after intense storm rainfall with a duration of 1 hour on 21st July.

4.4 Lessons learnt

The lessons learnt during the 2007 flood season in Cambodia reflect the issues that have needed to be addressed for some time:

- There is a need to put in place a systematic flood preparedness and emergency planning process at the provincial, district and commune level.

- The coordination between institutions and agencies concerned with flood planning and mitigation is limited.

- Access to flood information is poor.

- There is a lack of funds for hydrological data collection and the operation and maintenance of outstations.

- Interventions initiated by externally funded projects should not cease upon the completion of the project. Practical strategies that ensure the long term continuation of flood management and mitigation activities need to be developed at the national level.

- This lack of continuity does not permit the required levels of technical expertise be developed and retained.

5. Lao PDR 2007 country report

5.1 General Situation

The central and southern parts of Lao PDR were the most affected by floods in 2007, which were mainly associated with impacts of tropical storm 'Lekima'. The resultant national damage and loss exceeded that for 2006, particularly with respect to the rice crop. Elsewhere in the country the only events of note in 2007 were heavy rainfall during mid September in Luangnamtha Province and a local storm that caused some damage in Vientiane during April.

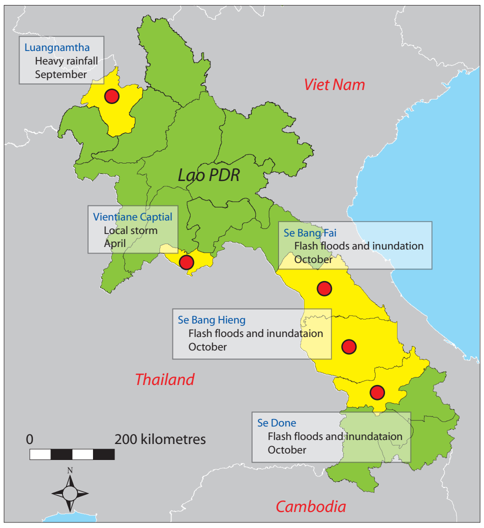


Figure 39. Lao PDR, local storms and flash flooding during 2007.

5.2 Tropical Storm 'Lekima'

Flash flooding and extensive flood inundation as a result of three days of heavy rainfall, locally in excess of 250 mm and widely above 150 mm, during the first week of October principally affected the catchments of the Se Bang Hieng, Se Bang Fai and Se Done. At the Mahaxi stream-gauge on the Se Bang Fai water levels rose almost 1 m above the danger level and the average depth of the consequent inundation was 1.5 m. Water levels on the Se Bang Hieng rose 7 m in less than 36 hours, causing very rapid inundation, typical of a flash flood situation. On the Se Done the river level increased by 13 m in the first five days of the month, while the Se Bang Fai rose by 10m. Figure 37 provides some photgraphs of the flooding.

Figure 40. Lao PDR, selected views of flood inundation in the Se Bang Hieng and Se Done river basin resulting from severe tropical storm 'Lekima' during the first week of October.

5.3 Heavy rainfall in Luangnamtha Province

Between the 10th and 13th September, sustained heavy rainfall of up to 75 mm caused local flooding in Luangnamtha Province, disrupting road communication. The intensity of the storms caused a number of landslides in steep terrain, a number of which blocked roads. Agricultural damage, however, was not significant.

5.4 Storm in Vientiane

On the 29th April a highly localised storm occurred over Vientiane, associated with very high winds, with gusts of between 130 and 140 kilometres per hour. The overnight rainfall was 63 mm. However, there was little ponding of the runoff and what damage there was to property resulted from the high winds.

5.5 Damage and impacts

In Khammuane, Savannakhet and Saravane provinces the consequences of tropical storm 'Lekima' were that two people were killed and over 600 villages were affected in some way by the floodwater. Almost 160,000 ha of rice crop was damaged to some extent by prolonged submergence along with 30% of the planted vegetable crop. Full details of the damage are listed in Appendix II.

5.6 Lessons learnt

- The ponding of flood water in urban areas, particularly Vientiane, would be minimised if urban development were planned accordingly and the drainage infrastructure improved and maintained — though these improvements are ongoing.

- Prior to the incursion of the 'Lekima' tropical storm the Department of Meteorology and Hydrology did provide warnings to Khammouan, Savanakhet and Saravanh provinces. However, some delays occurred in the dissemination of the warnings due to a lack of telecommunication equipment at the local level.

- As in other developing countries, Lao PDR lacks a reserve budget for emergency responses so the relief effort took time. However, the capacity of local communities in coping with flood conditions largely proved to be effective.

6. Thailand 2007 country report

6.1 General situation

Flood conditions in the northern Thai Mekong region in the Kam and Kok Rivers were less serious than those of 2006. As in Lao PDR the principal cause of flood damage and loss was Tropical Storm Lekima in October, which mainly affected the Mun-Chi River Basin. In Loei province a flash flood occurred on the 9th September, killing four people There was significant damage to property, including houses and schools, and 600 persons had to be evacuated. Locally floodwater was reported to be up to five metres deep.

6.2 Tropical Storm 'Lekima'

The southern parts of the Mun and Chi River Basins around Nakon Phanom, Kalasin Mukdahan, Roi Et Yasothon and Ubonrachatani were the most affected by the storm rainfall associated with 'Lekima'. Most rainfall occurred on the 4th and 5th of October, by which time the event had been downgraded to a tropical depression. Rainfall decreased from in excess of 250 mm in the east of the Mun-Chi Basin to less that 150 mm in the west during the first week of October as the intensity of the system decreased as it tracked westwards. In some areas the short duration storm bursts produced some of the highest rainfall ever recorded over a few hours. Flash flood conditions occurred in the Nam Pong, Lam Choen Rivers and upper Nam Mun, where the topography is steeper.

Figure 41. The remains of three houses destroyed by the 9th September flash flood in Loei. Three residents were lost.

6.3 Damage and impacts

Flooding in northeast and central Thailand during October 2007 was described by the *Bangkok Post* as the worst in 40 years, with troops and rescue workers dispatched to assist stranded residents. A number of people died as a result of being swept away and thousands of hectares of crop lands were inundated to a depth of 1 m and more. There was widespread disruption of road links and many communities were cut off. Other reports suggest that the total number of people killed was as high as 67 and that 17,000 people had to be evacuated.

6.4 Lessons learnt

The number of people killed by flash floods in Thailand each year underscores the ongoing difficulty of providing adequate warning. The need for flood risk mapping and land use zoning such that residential property is not constructed on land at risk needs higher priority. Such floods have the power to change the courses of rivers and streams and bury property in sediment and mud, which often arises from landslides into the river channel during the course of the event. While torrential rain on already saturated catchments is key to the onset of flash flooding, the drainage and topography of the surrounding area determines the scale and impact of the event. Losses from flash floods, including related hazards such as landslides and debris flows, appear to be increasing due to pressure on land resources. There is also widespread agreement that under global warming storm rainfall intensities will increase. The location, type and value of human activities that appear to be expanding into more hazardous areas needs to be reassessed on the basis of a better understanding of the flash flood phenomenon and the areas at risk. The approach should be based upon:

- risk identification, using flood mapping;
- vulnerability identification and building designs to reduce it;
- the implementation of mechanisms that ensure effective warnings and emergency response at the local scale.

7. Viet Nam 2007 country report

7.1 General situation

Seven typhoons and three tropical depressions, originating in the South China Sea, affected the Vietnamese regions of the LMB during 2007, of which those designated Numbers 2 (‘Pabuk’ in Cambodia) and 5 during August and November caused major flash floods in the Upper Se San and Sre Pok Basins. Flooding in the Delta was minimal, except during spring tides when areas of Can Tho City are inundated. Peak water levels occurred late on the 23rd October at Tan Chau (see Figure 32), though higher water levels late in the season has its advantages for the agricultural sector and the movement of irrigation water. Flood erosion, however, remains a significant issue in the Delta, even during years when discharges are modest, as they were throughout 2007.

7.2 Typhoon No.2

In August flash floods occurred within tributaries of the upper Se San and Sre Pok Rivers caused by exceptional storm rainfalls between the 2^{nd} and 5^{th} August associated with Typhoon No.2.

Table 17. *Cumulative rainfall in the Upper Sre Pok and Se San Basins over the three days between August 2nd and 5th.*

Station	River basin	Rainfall (mm)
Buon Ma Thuot	Sre Pok	323
Buon Ho	Sre Pok	575
Giang Son	Sre Pok	307
Duc Xuyen	Sre Pok	200
Cu Mgar	Sre Pok	571
Ban Don	Sre Pok	220
Krong Buk	Sre Pok	619
Krong Bong	Sre Pok	431
Ea Hleo	Sre Pok	446
Dak Lei	Se San	264
Kon Tum	Se San	171

Over wide areas total rainfall over the three days was between 300 and 400 mm resulting in local flash floods and water levels on the Sre Pok exceeding alarm level III (for definition see Appendix 8 of the Annual Mekong Flood Report 2006). The most serious loss and damage occurred in Dak Lak Province.

7.3 Typhoon No.5

Heavy rain of between 100 and 300mm over four consecutive days from the 7th – 11th November occurred over Kon Tum Province as a result of Typhoon No 5. Devastating deluges followed in the Upper Se San tributaries, particularly the Dak Bla and Krong Poko. Several floodplain villages were rapidly inundated to a flood depth one to one and a half metres with the Kon Plong District the worst affected.

7.4 Damage and impacts

Serious damage to infrastructure, agricultural production, and human settlements resulted from Typhoon No. 2 during early August. In Dak Lak province 23 people died and losses to the provincial economy estimated at US$5 million. Over 10,000 properties were inundated, more than 41,000 ha of agricultural lands flooded and 70 water control projects destroyed or damaged.

The flash floods, landslides and debris flows that took place in November as a result of Typhoon No. 5 caused extensive damage in the upper Se San. In Kon Plong one person died, four bridges were either damaged or completely destroyed and several villages flooded and cut off. The remoteness of many of the villages made rescue and repair operationally challenging.

Figure 42. Destroyed irrigation canal in Dak Lak as a result of Typhoon No. 2 and a flooded village in the Se San Basin following Typhoon No. 5.

7.5 Lessons learnt

The government's approval of the National Strategy for Natural Disaster Prevention, Response and Mitigation to 2020 during November 2007 will provide the political framework for the promotion of flood management and mitigation policy at the national and regional levels. In addition to the ongoing needs for training and investment in flood protection and mitigation measures, the specific lessons from the events in 2007 include:

- The need to recognise the flash flood problems in the more remote regions of the upper Se San and Sre Pok and to balance the investments made in flood protection in these areas with those made elsewhere. It is inevitable that most investment will be made in the more economically important regions such as the Delta, but upland flash floods are likely to become an increasing hazard that requires the development of management and mitigation strategies and investment in measures that reduce the number of people exposed to the risk.

- There is also a need to better understand the flash flood phenomenon so that forecasts and warnings can issued accurately and in time.

- Telecommunications with remoter villages at risk from flash floods could be improved.

8. Summary conclusions and recommendations

8.1 Summary conclusions

In many ways the flood season of 2007 mirrored that of 2006, with below average peak discharges, water levels and flood volumes, which at Kratie were significantly so. The definitive feature of the year was the exceptionally late start to the flood season throughout the Lower Mekong region. It generally starts during the early weeks of July but in 2007 the onset was as late as early August in Cambodia and Vietnam. This delay caused discharge and water levels towards the end of July to be some of the lowest observed since hydrological records began in the early 20th Century. The major impact of a shorter flood season, significantly low water levels over most of the season and the fact that maximum water levels were unseasonably late, not occurring as that did until October, was the reduction in the annual fish in the Great Lake by a reported 35%.

The only major regional storm event to cause widespread flooding over the Central Areas in Lao PDR and Thailand was Tropical Storm 'Lekima', which occurred in October and resulted in considerable damage and loss of life. This provided the only flood runoff during the year on a scale large enough to cause Mekong water levels to increase to anywhere near average.

Elsewhere, flash floods in Cambodia and Viet Nam during August and again in Viet Nam in November caused considerable damage and loss of life, particularly in the Upper Se San and Sre Pok Rivers.

8.2 Recommendations and lessons

Having contributed significantly to the understanding of Mekong mainstream floods and flooding in the 2006 Annual Flood Report, this document has made the logical progression and taken the hydrology of the flood regimes of the tributaries as its theme. These have been considered within three reaches of the mainstream, Chiang Saen to Vientiane, Vientiane to Pakse and Pakse to Kratie. The impacts of catchment scale, topography and reservoirs on the tributary flood regimes has emerged clearly as has the fact that extremely rapid rises and falls in water level and discharge, typical of flash floods, are not confined to small river basins. This hazard can occur on extremely large rivers in the region.

A major effort has been made to present the hydrological data available on the tributaries in a schematic way that shows where 'functional' data, that is those of sufficient length and reliability for meaningful analysis, are recorded. In the past the lack of such simple reference material has often confused. Unlike the mainstream data, those for the tributaries are not up to date so no analysis of conditions during 2007 is possible. Consideration should perhaps be given to the provision of current hydrological data for those rivers that contribute major volumes of flood water to the Mekong. These have been identified as part of this Report. Such data would add substantially to understanding current flood conditions, particularly in the event of an extreme flood year.

In 2007 the incidence of flash flooding and the death and damage that it causes has once again drawn particular comment, particularly through the National Flood Reports. There is general consensus that they are not well understood and that reducing the number of people and their property that is exposed to them is amongst the priorities for regional flood management and mitigation. It has also been observed in the national reports that investment in flood protection tends to take priority in the principal economic regions, which is inevitable, while far less is focussed upon the remoter areas where the flash flood hazard is significant. An improved balance has been suggested.

As far as hydro-meteorological data are concerned the Lower Mekong region has an excellent recording network by global standards. However, because storm rainfall is spatially very variable and the highest rainfall areas are in the remoter mountainous regions it is often not possible, as has been revealed here, to find any storm data from ground observations to link to many extreme flash floods that have occurred. This seriously limits efforts to understand them in terms of cause and effect. Satellite and weather radar are the obvious means of gaining this better understanding and efforts should be made to pursue such studies, perhaps under the remit of the FMMP.

Another data issue that drew comment is the lack of consistency between national water level datums and those held in the database at the MRCS. The latter should be audited in order to ensure that the water levels reported in documents such as this agree with the official national figures.

Finally, it has been recommended that consideration be given to the translation of the Annual Flood Report into the languages of the MRC member countries so that it can be more widely read and understood by the relevant stakeholders and line agencies and make a meaningful contribution to institutional strengthening and the available reference material.

8. References

FAO-CFOR (2005) 'Forests and Floods — Thriving on fiction or drowning on facts'. Centre for International Forestry Research. Food and Agriculture Organization of the United Nations. 340 pp.

Gruntfest, E. and J. Handmer (1999). 'Coping with flash floods'. Proceedings of the NATO Advanced Study Institute. Ravello. Italy. NATO Science Partnership Sub-Series: 2 Vol 77. Published by Springer. 340pp.

MRC (2007). 'Annual Mekong Flood Report, 2006'. Mekong River Comission. Vientiane. Lao PDR. March. 76 pp.

Appendix 1. Mekong mainstream: Summary hydrological statistics for the 2007 flood season

Location	Date of onset of flood season	Date of end of flood season	Maximum water level (masl)	Maximum discharge (cumecs)	Date of maximum	2006 Flood volume (km^3)
Chiang Saen	17th July	7th Nov		8500	6th Aug	49.3
Luang Prabang	23rd J uly	9th Nov		11,800	9th Sep	66.4
Chiang Khan	22nd July	11th Nov		13,000	10th Sep	80.1
Vientiane	25th July	12th Nov		13,800	10th Sep	83.8
Nong Khai	26th July	11th Nov		(3200)	10th Sep	(76.0)
Nakhon Phanom	29th June	15th Nov		25,250	12th Sep	192.4
Mukdahan	30th June	6th Nov		24,500	10th Oct	165.9
Khong Chiam	31st July	16th Nov		27,800	10th Oct	162.8
Pakse	1st Aug	16th Nov		37,600	10th Oct	190.1
Stung Treng	2nd Aug	23rd Nov		47,600	8th Oct	324.6
Kratie	3rd Aug	19th Nov		(39,500)	9th Oct	255.0
Phnom Penh Port	4th Aug	15th Dec	8.85		18th Oct	
Prek Kdam	5th Aug	29th Dec	8.86		22nd Oct	
Tan Chao	8th Aug	14th Dec	4.14		22nd Oct	
Chao Doc	9th Aug	27th Dec	3.62		23rd Oct	

Appendix 2. Cambodia: 2007 flood damage assessment

Description	Provinces						
	Mekong flood			Flash flood			
	Kampong Cham	Kratie	Stung Treng	Prash Vihear	Ratanakiri	Kampong Thom	Siem Reap
Households affected				3025	1876	11,207	
Houses damaged				11			
People affected					91,135	56,035	
People killed				3		2	
Roads affected		4 sites		34 km		3 km	
Schools and pagodas						6	
Public buildings						2	
Dykes and canals		600 m		8		9.5km	
Bridges		2 sites		7			
Animals				273	14		
Rice and crop (drought)	773ha						158 ha
Rice and crop (flood)		426 ha	813 ha	2545 ha		5700ha	

Appendix 3. Lao PDR. 2007 flood damage assessment caused by Tropical Storm Lekima

Description	Assessment methodology is based on data reporting from Provincial Agriculture and Forestry Office (PAFO), MAF, PDMC (NDMO), and damages data collection by representative of NDMO, DMH, LNMC and FMMP (MRCS) on the period from 2nd to 5th January, 2007
Population affected	
Provinces	4 provinces
Districts	27 districts
Villages	614 villages
House	25,292 households
People	118,074 persons of Khammuane, Savannakhet, and Saravane provinces
People	2 persons died (1 boy, 4 years old and 1 female, 39 years old)
Agriculture affected	
Hectares of rice field	256,778 damaged
Vegetable fields	490.62 ha damaged (planted areas is 1.384,03 ha)
Livestock	
Cattle	343 (buffalo, cows, goats, pigs)
Poultry	74,980
Fishpond	136 sites and about 1,000,000 fish damaged
Infrastructure affected	
Schools	11 primary schools were inundated
Health Centres	2 health centres affected
Temples	2 temples affected
Markets	Mahaxay district market affected
Boats	27 boats swept away by strong flow
Roads	60 – 70 meters of road length at 3 locations
Irrigation	29 sites affected (23 sites damaged)

Appendix 4. Viet Nam: 2007 flood damage assessment

Type of loss	Mekong Delta	Central Highlands
Human	30 people died	29 people died, 4 persons missing
Assets	1400 houses destroyed; 23,864 houses inundated; 164 education rooms damaged and 101 class rooms moved	166 houses destroyed, 12,447 houses inundated
Agriculture	33,700 ha of paddy 4,422 ha of upland crops damaged; 8328 ha of fruit trees damaged	20,344 ha of paddy damaged; 24,393 ha of short term crop inundated 252 tones food production lost
Fisheries	1100 ha fish & shrimp ponds damaged; 852 fish cases damaged and 29 tonnes of fishery lost	593 fish ponds damaged
Transportation	19 km national roads, 705 km rural roads, 140 bridges, 126 km long eroded and 49,000 m^3	59 bridges destroyed; 14 bridges damaged
Water control structures.	185 units damaged, 104 km embankment eroded	331,837 m^3 eroded; 13 water control structures drifted; 24 small structures damaged
Other	5 provinces	4 provinces
Total cost	US$1.5 million	US$5.08 million

Appendix 5. Thailand: 2007 flood damage assessment

	Description	Total	May	June	July	Aug	Sep	Oct	Nov	Dec
Areas	Provinces	46	12	3	6	11	8	34	2	4
	Districts	486	38	5	9	61	26	305	11	31
	Villages	20,479	876	-	85	2,681	366	15,331	343	797
Human	People	3,640,978	70,025	5,042	9,335	395,436	27,942	2,883,747	42,659	206,792
	Households	940,663	19,076	1,225	2,582	88,241	9,125	768,563	2,335	49,516
	Evacuees	3,455	-	-	390	NA	600	NA	-	2,465
	Casualties	62	-	-	-	2	23	27	-	10
Assets	Houses	7,369	59	-	35	71	209	6,931	-	64
	Fish ponds	34,767	113	-	15	666	645	30,971	88	2,269
	Livestock	38,079	1,548	-	-	NA	-	NA	16,700	19,831
	Agriculture fields (ha)	423,357	11,781	-	2,033	32,932	9,395	366,253	599	363
Infrastructure	Roads	8,330	153	15	97	657	-	6,690	432	286
	Bridges	309	50	5	10	14	5	192	3	30
	Hydraulic structures	591	82	6	2	50	2	448	1	-
	Institute buildings	271	29	-	-	4	-	198	-	40
	Drains	163	53	-	6	-	-	-	89	15
Cost (million baht)		1,697	60	10	12	277	13*	1,309	15	-

Source: Department of Disaster Prevention and Mitigation
* for one of three incidents that month