ISSN: 1728-3248

Mekong River Commission

Annual Mekong Flood Report 2006

March 2007

ISSN Nº 1728 3248

Mekong River Commission

Annual Mekong Flood Report 2006

March 2007

Published in Vientiane, Lao PDR in March 2007 by the Mekong River Commission
Also available on the MRC website: www.mrcmekong.org

Cite this document as:

MRC (2007) Annual Mekong Flood Report 2006, Mekong River Commission, Vientiane. 76pp.

Editor: Dr. Tim 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 second Annual Mekong Flood Report, a major output from the Mekong River Commission's Flood Management and Mitigation Programme (FMMP) Regional Flood Management and Mitigation Centre.

The 2006 Annual Flood Report aims to fulfil two primary roles: a summary of the flood year 2006 and a collation of important data on the flood regime. These data will, in time, accumulate to provide a primary regional resource for flood research and the collation of historical reference material. The report is also considered a valuable contribution to the goals of the MRC Strategic Plan 2006-2010, in particular where it addresses issues such as basinwide impact assessment and enhancement of the MRC knowledge base.

In order to understand floods and their effects it is important to view them in an historical context, which is why this year we have designed the report to introduce more information on floods in the Mekong basin, by putting them into a global context and taking a look at the historical geography of floods on the Mekong mainstream. This report also examines the nature and analysis of floods on large rivers as well as temporal aspects of the Mekong flood regime.

Individual country reports present specific events of the 2006 Flood Season with reports of economic and social impact. The countries presented a broader picture during the 5th Annual Mekong Flood Forum, held in Ho Chi Minh City, Viet Nam in May 2007.

The 2006 report has been produced in a more condensed form with an emphasis on important data depicted in graphical form to make the information accessible and easily assimilated. The report has been divided into an area of main text with specific statistical data presented in detail in appendices for reference purposes. The appendices also provide the results of a statistical analysis of the discharge data at the major hydrometric stations on the mainstream and the water-level data in the Tonle Sap system, the floodplain regions and the Delta.

The 2006 flood season is also discussed in terms of its hydrological and meteorological aspects with particular emphasis on water levels in the Tonle Sap floodplain of Cambodia and the Viet Nam Delta region. It also looks at the hydrology of major tributaries.

This is the first 'theme' based Annual Mekong Flood Report. In this report the emphasis is on data analysis and the temporal and spatial nature of floods and flooding in the Mekong region. We feel this theme concept will, over coming years, enable MRC to build up a complete picture of all aspects of the Mekong flood regime and become a valuable source of data for the FMMP and a solid source of information for all those involved in flood management and mitigation in the basin. This report will be widely disseminated among stakeholders in the basin and welcome any comments from readers.

Dr Olivier Cogels
Chief Executive Officer
Mekong River Commission Secretariat

Table of Contents

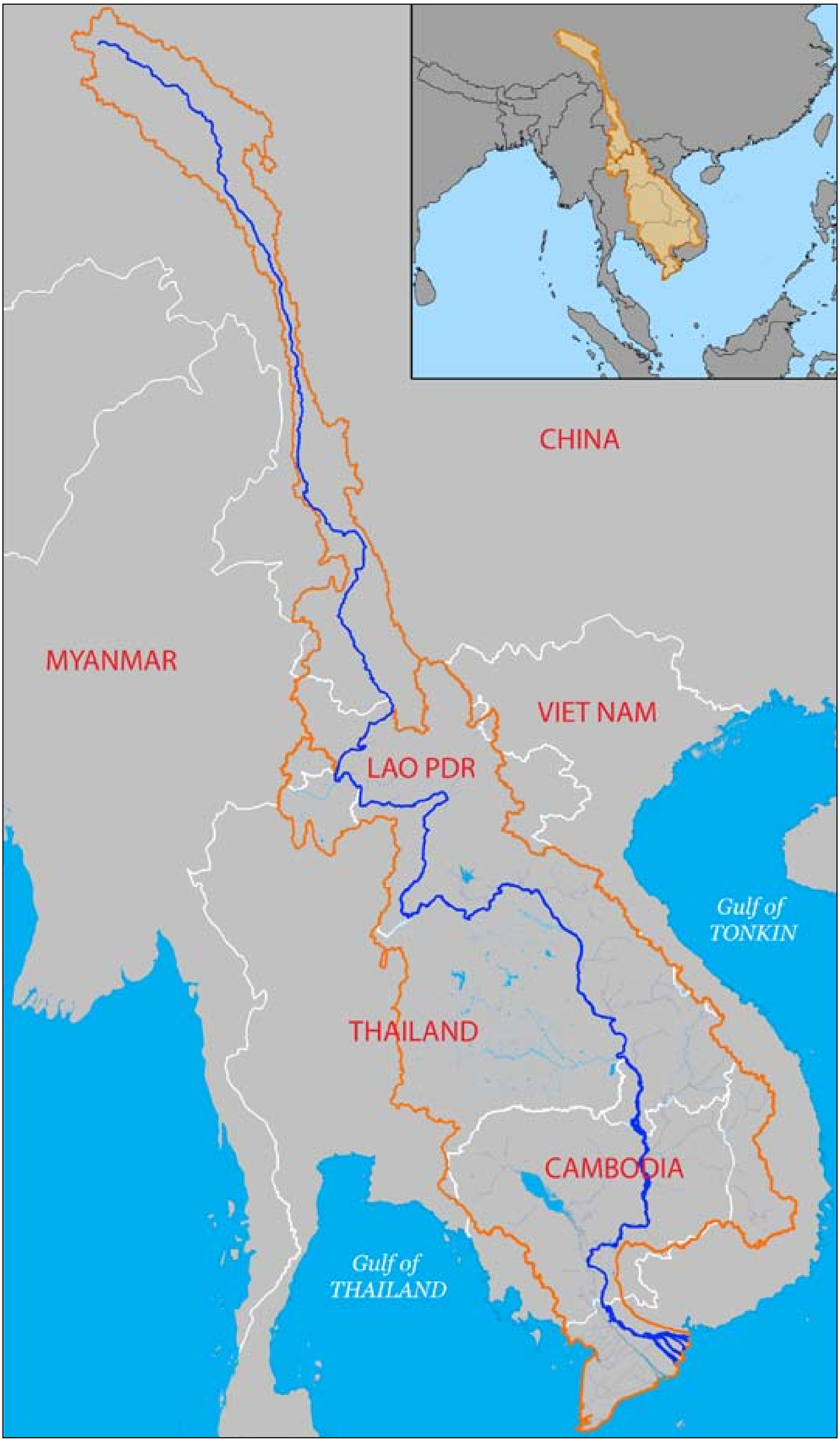
Acknowledgements

This report was prepared within the framework of the Flood Management and Mitigation Programme (FMMP) activities 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 this report. Dartmouth Flood Observatory, Dartmouth College, USA, the Canadian Space Agency, together with Hatfield Consultants Ltd, Canada, provided the satellite images used in support of the text.

Mr Eric Tilman compiled data gathered from the four member countries and supplied the basis for the country assessments of damages and losses as well as the information used to create some of the graphs.

Contributing authors: Dr Peter Adamson and Dr Chusit Apirumanekul

Graphic design: Dr Tim Burnhill



The Mekong River Basin

Summary

1. Introduction

The 2006 Annual Flood Report aims to fulfil two primary roles: it provides a summary of the flood year 2006 and it collates important data on the flood regime. These data will, in time, accumulate to provide a primary regional resource for flood research and the collation of historical reference material.

2. About floods in the Mekong Basin

2.1 The size of Mekong floods in their global context

Based on the data in the World Catalogue of Large Floods (IAHS. 2003), extreme floods on the Mekong are compared to those upon other global river systems with catchments in excess of 500,000 km^2, revealing that the river is amongst the world maxima classified upon the basis of peak discharge per unit area and very close to the global limit for rainfall generated flood runoff.

2.2 The historical geography of floods on the Mekong mainstream

An analysis is undertaken of the temporal and spatial nature of floods along the Mekong mainstream, revealing that the river basin is far from geographically homogenous with regard to the nature and severity of the flood season in any given year.

2.3 The nature and analysis of floods on large rivers

The quantitative definition of the magnitude of a flood exclusively in terms of its peak discharge is a useful and sufficient statistic in the case of small river basins where the duration of flood events is usually only a matter of several days. On large rivers the flood hydrograph has a much longer duration, which in the case of the Mekong is a matter of several months. The multivariate aspects of the hydrograph therefore need to be simultaneously taken into account in the assessment of flood risk and magnitude. In this report modern multivariate statistical technology is used; this brings together the peak flood discharge, the volume of the flood hydrograph and the duration of flows above critical thresholds.

2.4 Temporal aspects of the Mekong flood regime

The onset and duration of the flood season in the Lower Mekong Basin is clearly an important variable from year to year. In keeping with broader definitions of hydrological seasonality on the mainstream adopted by the Environment and Fisheries Programmes within the Mekong River Commission (MRC), four flow seasons are identified, namely the flood season, the dry season and two transition seasons. The hydrological indices adopted to define the onset and closure of each one are presented along with a historical assessment of how these dates have varied from year to year. It is demonstrated that these temporal variables have been remarkably consistent over the last 80 to 90 years and have a surprisingly small inter-annual variability. Studies of the palaeoclimate during the Holocene are quoted that suggest these temporal aspects of the Mekong flood regime have been unchanged over the last 5,000 to 6,000 years.

Throughout Part 1 the events of 2006 are set within this wider geographical, historical and temporal context and a number of graphical techniques are presented that could be adopted as standards for the comparative assessment of the Mekong flood for any year that is under consideration.

3 The 2006 flood season

3.1 Hydrological and meteorological aspects

The total volume of flows during the flood season of 2006, throughout the mainstream, was below average and in parts, significantly so. This deficit becomes more evident towards the downstream regions, particularly at Pakse and Kratie. The defining feature of the year's flood hydrology, however, is the second peak to the hydrograph during October, which brought about the only time of the year that discharges consistently approximated or exceeded their long term daily averages. This second peak was the response to Severe Tropical Storm Xangsane, which tracked over the Mekong Basin during the first week of October. Without this event, the flood volumes in the lower regions of the basin would have been amongst the lowest on record. Peak flows in response to Xangsane were not excessive.

3.2 Water levels in the Tonle Sap floodplain of Cambodia and the Delta in Viet Nam

Clearly these reflect the magnitude of discharges entering these lower regions of the Mekong system and were therefore generally below average. Once again, the conditions of 2006 are firmly set within their historical context. In this regard, the water levels for the Tonle Sap system as far back as 1924 are reviewed and some exploratory statistical analyses undertaken. The incidence and role of typhoon incursions into these regions of the Lower Basin are considered and some and their impacts upon the distribution of storm rainfall revealed.

3.3 Regional summary and tributary flood hydrology during 2006

Apart from the mainstream, arguably the major regional flooding took place in Northern Thailand where flash flooding occurred along the northern tributaries, such as the Nam Mae Kham, Nam Mae Kok and Nam Mae Ing, causing very considerable damage. The period between July and October saw a number of such events, which also caused excessive water levels in Northern Lao PDR, along the Luang Namtha, for example. These episodes are synthesized and summarised in terms of cause and effect.

4 Overview of annual flood reports

4.1 Lao PDR

During 2006 localised flash flooding in Luang Namtha and Attapeu Provinces were the only noteworthy flood incidents that occurred in Lao PDR. Events in Luang Namtha during the second week of August were in response to orographically induced monsoonal storms which produced 230 mm to 270 mm of rainfall over the first 10 days of the month. The flooding in Attapeu Province during the first week of October was attributable to the incursion of Severe Tropical Storm Xangsane. Elsewhere the only meteorological episodes of any significance were local storms over Vientiane which caused brief urban flooding in March, May and October and a highly localised 'whirlwind' which moved at high speed through the Chanthabouly district of the Capital at 7:25pm on the 5 May 2006, with wind speeds of over 100 km/h (30 m/sec) causing severe but very local structural damage.

4.2 Thailand

During 2006 Thailand was badly affected nationwide by floods from several storms, most particularly from Severe Tropical Storm Xangsane, which turned into a tropical depression in the country. Out of 75 provinces, 46 were locally inundated. By mid-October, Thailand's Department of Disaster Prevention and Mitigation (DDPM) reported that 47 people had been killed, two were missing and more than 2.4 million people had been affected to various degrees over the country as a whole. Approximate losses are estimated to be of the order of US$8 million.

4.3 Cambodia

In Cambodia conditions during the 2006 flood season were below average both in terms of peak and volume. The flood peak was in fact amongst the lowest recorded over the past 80 or more years. The maximum discharge for the year occurred in mid-August, after which water levels decreased considerably until early October and the passage across the region of Severe Tropical Storm Xangsane. This weather system generated a slightly lower second peak in mid-October, an uncommon feature of the annual hydrograph. As a result of these below normal seasonal flows no significant crop losses were reported, with the exception of the fact that the unseasonally late second peak led to the inundation of some low lying areas. Some early flood recession rice plantings were lost and a second replanting was required. No flood damage to infrastructure took place during the year.

4.4 Viet Nam

The moderate to below average 2006 flood regime in the Delta during the year meant that direct flood damage was not severe. However, the late appearance of flood peaks did bring about some unfavourable conditions for agriculture. What widespread inundation there was occurred when high tides combined with incoming flood flows from upstream, which occurred three times during August and September. The associated water levels at most stations were higher than Alert Level 3 (see Appendix 8) over a duration of one to three hours, though actual inundation was often longer due to poor drainage capacity (VNMC 2006 Annual Flood Report). By far the major damage during the year was associated with Tropical Storm Durian during the first week of December which generated extreme wind speeds and tidal surges. Immediate needs following this national disaster were estimated by the UN to be of the order of US$60 million.

5. Summary conclusions and recommendations

5.1 Summary conclusions

Regionally, the flood season of 2006 saw below average conditions both in terms of flow volumes and peak discharges, most particularly on the lower mainstream downstream of Vientiane. To the north, however, flash flooding in Thailand and Lao PDR resulted in significant damage and loss. Deep monsoonal depressions that were largely confined to these northern Provinces were generally responsible, though the wider regional impacts of Severe Tropical Storm Xangsane played a major role in early October, particularly in the south of Lao PDR. The major regional disaster in 2006 was the result of Tropical Storm Durian during December when extreme windspeeds and tidal surges caused immense damage in the Delta and southern coastal regions of Viet Nam.

5.2 Recommendations and lessons

The hydrological and water level data and information available for the mainstream are more than sufficient for a comprehensive assessment of the annual flood from year to year. Analyses of these historical data that have been reported here provide a framework for the objective and more perceptive evaluation of annual floods on the mainstream within their wider temporal and geographical context.

Tributary data analysis and information are far less complete at present, which amounts to a significant shortcoming, given the hazard of flash flooding in these river systems. The FMMP T2 Flood Risk Mapping Project on the Nam Mae Kok in northern Thailand is a recognition of this. Its modest extension to provide a regional flood risk analysis for the tributary systems upstream of Vientiane in both Thailand and Lao PDR would provide substantial ‘add on’ value. The HYCOS Project will also contribute much to the understanding of the flood hydrology of these tributary rivers.

In the longer term HYCOS will also add to the meteorological knowledge base and the nature of the linkages between regional storm rainfall and flood runoff. For the present purposes of the Annual Flood Report, however, daily satellite based rainfall estimates at the regional scale are sufficient and appropriate.

Finally, it is recommended that the Annual Flood Report be ‘theme’ based. Here the emphasis is on data analysis and the temporal and spatial nature of floods and flooding in the Mekong region. Such material provides an important supplement to the framework of knowledge within which the FMMP is being undertaken as well as contributing basic insight into the regime of the Mekong that are a necessary in many other contexts, for example the assessment of the environmental impacts of basin development. Other annual themes that should be considered are the socio-economic benefits, or otherwise, of the flood regime, meteorological aspects and the potential consequences of climate change, including links with El Nino Southern Oscillation (ENSO). The flood report should also provide a medium for reporting FMMP progress in the interests of dissemination to the wider audience and stakeholders.

1. Introduction

1.1 Introduction

This Annual Flood Report for 2006 represents the second such document produced within the framework of the MRC's Flood Management and Mitigation Programme (FMMP). The first Report for 2005 should be regarded as exploratory in that it uncovered the constraints and challenges that inevitably arise when seeking to produce a consistent and coherent account of each year's Mekong flood regime and its impacts. Through discussion and feedback, this earlier account has helped to sharpen awareness of precisely what the objectives are and the document content and structure required to achieve them.

It now seems clear that the Annual Flood Report should aim to fulfil two primary roles. It should at one and the same time:

- Provide a sound summary overview of the flood conditions over the year in question. This material should be presented in a way that strikes a balance between technical and quantitative detail and the needs of the wider target audience, a large part of which will be non-technical. The text should realise the first objective of providing a prompt retrospective of the foregoing flood season and setting it within its historical context.

- The second role of the report is a longer term one. It should act as a repository for the appropriate data, which would cover the geophysical (hydrology, meteorology), geo-spatial (maps, GIS material, satellite images) and socio-economic (flood inundation, agricultural, damage surveys) aspects of the flood regime and its impacts. These data will in time accumulate to provide a primary regional resource for flood research and the collation of historical reference material. Such data should be clearly set out in appendices and might also be stored digitally.

It is self evident that any appraisal of flood conditions in a given year must be considered within their historical context. This 2006 Report therefore gives this aspect very particular attention and presents a number of ways of setting out the data in the form of summary graphics that, it is suggested, are a far more effective means of gaining insight than simply tabulating the unprocessed data and information. If the structure and content of the Flood Report from year to year is to be consistent, it is also the case that a number of these graphics will need to be adopted as a standard.

A final theme needs to be emphasised at this point. Conventionally, floods and flooding are perceived as geophysical hazards within a common framework of natural disasters that also covers storms and hurricanes, earthquakes, volcanic eruptions, landslides and tsunami. In each case, socio-economic losses and damage increase exponentially with event magnitude and as a function of civil exposure and vulnerability. Such hazards are perceived as random events with entirely negative impacts, ignoring the fact that floods also have a positive ecological and socio-economic function and that great civilizations have developed within flood plains, where on the face of it, exposure and vulnerability have been high. Such societies have included Sumerian Mesopotamia along the Lower Tigris and Euphrates Rivers, the founding cultures of China in the Yellow River Valley and the Angkor civilization of the Lower Mekong Basin itself. Exploiting the benefits and avoiding the risks of the annual flood stimulated such societies to put greater efforts into social organisation and water management systems, which endorsed them as landmark civilisations.

Historical cultures that exploited the benefits of floodplains and contemporary societies that continue to do so, such as those in the Lower Mekong, therefore face a ‘two-tailed’ flood hazard. (see Webby *et al*, 2006). Either the annual flood is too small, leading to reduced agricultural output or too large, resulting in inundation, crop losses and general socio-economic damage. The dis-benefits arising from the ‘failure’ of the flood season must not therefore be ignored or even made light of. As will be seen, historically some of these deficiencies in the flood season hydrology of the Mekong have been quite spectacular.

1.2 Report Structure and Summary of Contents

The main text of the Report is laid out in such a way that there is a logical progression from the creation of an awareness of the nature and history of the flood regime of the Mekong towards a specific evaluation of events in 2006 and how they lie within this historical context. The causes and impacts of flood conditions during the 2006 season are evaluated, with the Country Reports, providing the major sources of information and data. The main text focuses on the interpretation and summary of this material, which is collectively presented in detail in the Appendices for reference purposes. An objective has been to keep the length of the main text modest and tabulate the minimum amount of data required, leaving it for presentation in the Appendices. The appendices also provide the results of a statistical analysis of the discharge data at the major hydrometric stations on the mainstream and the water level data in the Tonle Sap system, the flood plain regions and the delta. There is, in addition, a summary tabulation of the key quantitative features of the major historical flood events at each site, along with the current rating equations, specifying the relationship between water level and depth. The assembly of such material in the Appendices broadens the utility of this Annual Report to provide a basic source of reference.

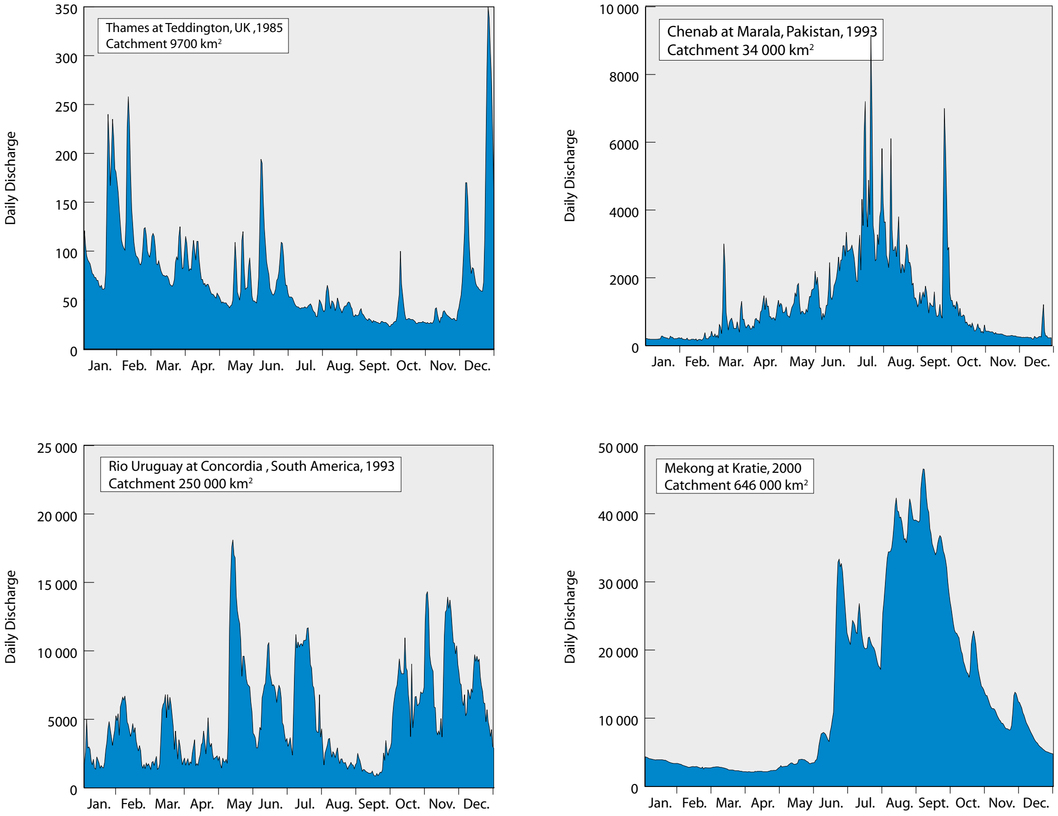


Figure 1. Comparative hydrological regimes of temperate (left) and monsoonal (right) river systems.

2. About Floods in the Mekong Basin

2.1 Flood magnitudes on the Mekong in their global context

The definitive feature of the hydrological regime of very large tropical monsoonal rivers, such as the Mekong, is that there is, in effect, just a single annual flood hydrograph in response to the SW Monsoon. On the mainstream and within its larger tributaries the vast geographic scale of the drainage systems means that the runoff responses to the individual storm events caused by monsoonal depressions tend to coalesce and therefore accumulate into a single seasonal flood hydrograph. It is therefore not generally possible to distinguish the runoff response to individual events unless the cyclonic storm system is very intense and regional in scale.

Tropical typhoon incursions into the basin from the South China Sea to the east and southeast across Viet Nam and southern China are the weather systems most responsible for generating distinct individual peaks to the monsoonal hydrograph. These generally occur during September and October when the seasonal discharge is already high and tend to generate a second significant peak to the annual hydrograph. Historically these events have been responsible for many of the most extreme flood discharges and water levels that have been observed within the Mekong system.

This highly seasonal and integrated nature of the flood hydrograph is revealed in Figure 1, where a comparison is made between the Mekong regime, that of two temperate catchments and the monsoonal flows of a much smaller river system in Pakistan. The flood hydrology of the temperate zone rivers is non-seasonal, with seemingly random flood pulses throughout the year. This is the case even for extremely large river basins such as the Rio Uruguay in South America. The Chenab is a large tributary of the Indus, where the monsoonal onset in June parallels that of the Mekong. Here, the additional earlier flood rise from March to May is a response to spring snowmelt runoff in Jammu and Kashmir. There is a clearly defined flood season, though the scale of the drainage basin is such that there is considerable ‘noise’ in the data, that is a great number of large but short term fluctuations in discharge. As catchment scale increases these relatively rapid variations in flow are smoothed out as the longer duration responses to each storm episode coalesce, resulting in the highly coherent hydrograph of the Mekong at Kratie in Cambodia, where the drainage area is almost twenty times greater than that of the Chenab at Marala.

This convergence and accumulation of monsoonal flood runoff into a single seasonal hydrograph places the Mekong amongst the global river systems within which the largest meteorological floods have been recorded. These lie within the tropics, especially where drainage basins, producing immense volumes of runoff. Such systems include the Brahmaputra, Ganges, Yangtze, Mekong, and Huang He (Yellow) River Basins. Accordingly, the flood hazard amongst these densely populated tropical river basins is extremely high. The worst flood disaster in recorded history occurred in August 1931, along the Yellow River and Yangtze Rivers in China, killing an estimated four million people as a result of the event itself and the ensuing famine (O’Connor and Costa, 2004).

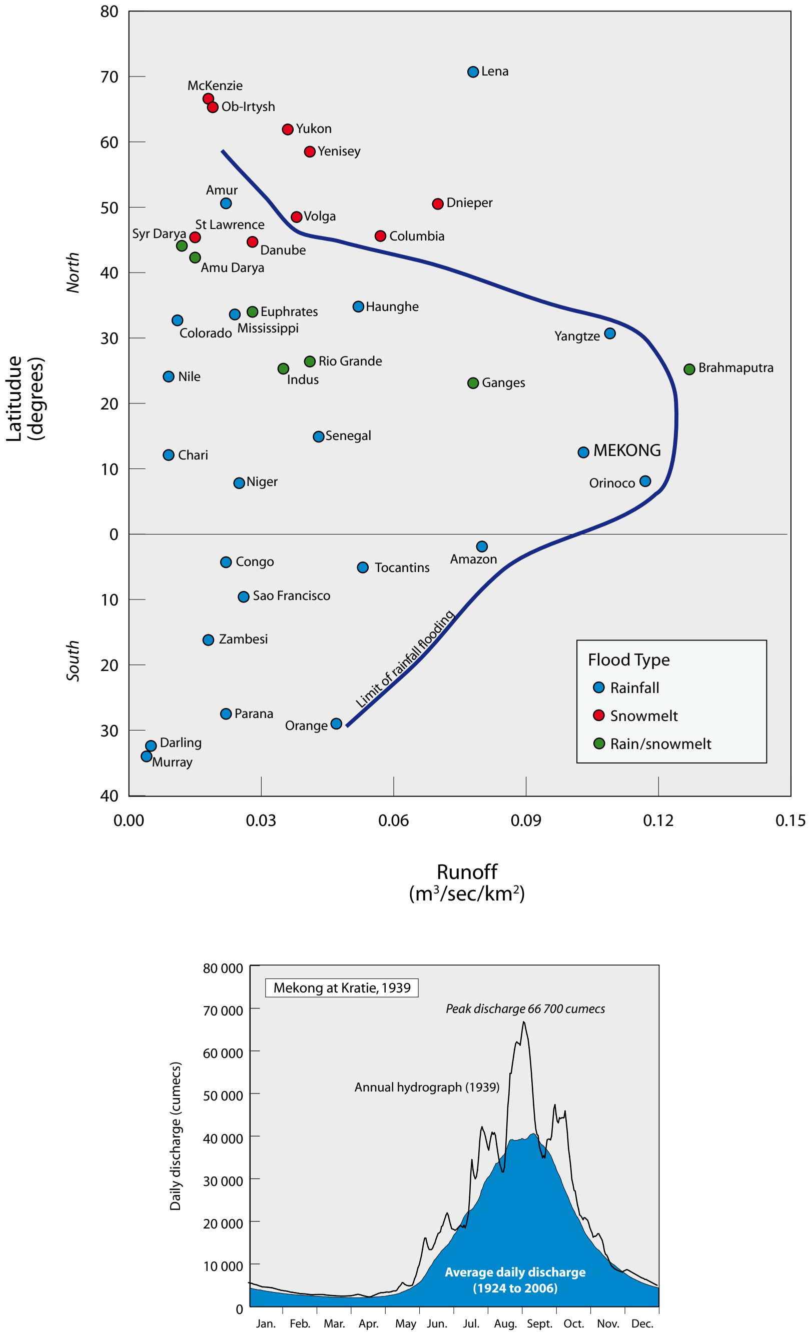


Figure 2. Above. The largest meteorological floods ‘reliably’ observed for global river basins exceeding 500,000 km^2 in area. The data are expressed as peak discharge per unit catchment area (cumecs/km^2). The plot is based on data and figures given in O’Connor and Costa (2004). See also IAHS (2003).
Below. The largest such event on the Mekong was observed during the 1939 flood season at Kratie, when the annual maximum discharge was 66,700 cumecs, though this figure was almost certainly exceeded in 1978 (see text).

Records of the world’s largest floods observed on the largest catchments, that is those exceeding 500,000 km^2, are shown plotted on Figure 2, where it can be seen that the Mekong is indeed amongst the global maxima[1]. The data are expressed as peak flood discharge per unit basin area or cumecs/km^2. The 'record' historical event observed for the Mekong on this basis occurred on 3rd September 1939 at Kratie in Cambodia, where the drainage area is 646,000 km^2 (see Figure 3 for a map of locations referred to in the text). This 1939 hydrograph is included in Figure 2, though it is almost certain that the peak discharge of 66,700 cumecs was exceeded in 1978 when the maximum historical peak flow between 1924 and 2006 was observed upstream at Pakse. At this time, only water level observations are available further downstream at Kratie, but based on a statistical analysis of the historical joint distribution of daily flows between these two mainstream locations, it is reliably estimated that the 1978 peak at Kratie was in excess of 77,000 cumecs, which places the Mekong even closer to the global limit for rainfall generated flood runoff.

There is a pronounced global pattern to the distribution of these extreme *meteorological* floods[2]. They are generally confined to areas of the tropics between 10 and 30 degrees north in Asia and between 10 degrees north and south of the equator in South America. The large rivers of tropical Africa, such as the Congo, have relatively modest flood regimes in terms of unit area discharge, which is attributable to a combination of low relief and less extreme tropical rainfall climates.

2.2 The historical geography of floods on the Mekong mainstream

The geographical distribution of significant flood hazard in the Lower Mekong Basin shows a close link to that of the regional population (Figure 4). Regions of high population density are generally those most exposed to flood inundation. This is consistent with the fact that in tropical regions floodplains provide the most fertile land areas and historically therefore they have witnessed the greatest levels of socio-economic development. A meaningful knowledge of the nature, history and geography of the regional flood regime is therefore basic to effective flood mitigation and management.

The annual flood regime of the Mekong is not geographically homogeneous in terms of its nature and magnitude from year to year. There is a significant discontinuity evident between the hydrological sub-regions upstream and downstream of Vientiane. The explanation is, however, quite straightforward. Upstream of Vientiane the nature of the flood hydrology in any year is dictated by outflows from Tibet and China—the so called 'Yunnan Component' of the overall Mekong regime. Downstream, the large left bank tributaries, particularly those that lie in Lao PDR (the Nam Ngum, Nam Theun, Se Bang Hieng and the Se Kong) and the Se San and Sre Pok, which enter the mainstream from Cambodia and Viet Nam, progressively mask the Yunnan Component. It is their contribution to the mainstream flow that becomes the foremost influence on the variability of flood season conditions from year to year. (See Figure 5, which maps this regional geography of the Mekong flood regime.) Because the incidence, severity and impact of the weather systems that determine the magnitude of the annual flood, such as monsoonal

---

[1] The data upon which this plot is based is given in Appendix 9.

[2] During the Quaternary Period, the largest known floods had a peak discharge of close to 20 million cumecs. These were, however, non-meteorological and were the result of the breaching of ice dams formed during glacial periods. Other cataclysmic floods result from the failure of other types of natural dams, such as blockages caused by landslides. For example, analysis of dam breaks reveals that the failure of a rock-slide dam on the upper Indus in Pakistan in 1841 triggered a peak discharge of 540,000 cumecs (see O'Connor and Costa, 2004 and Schroder *et al.*, 1991).

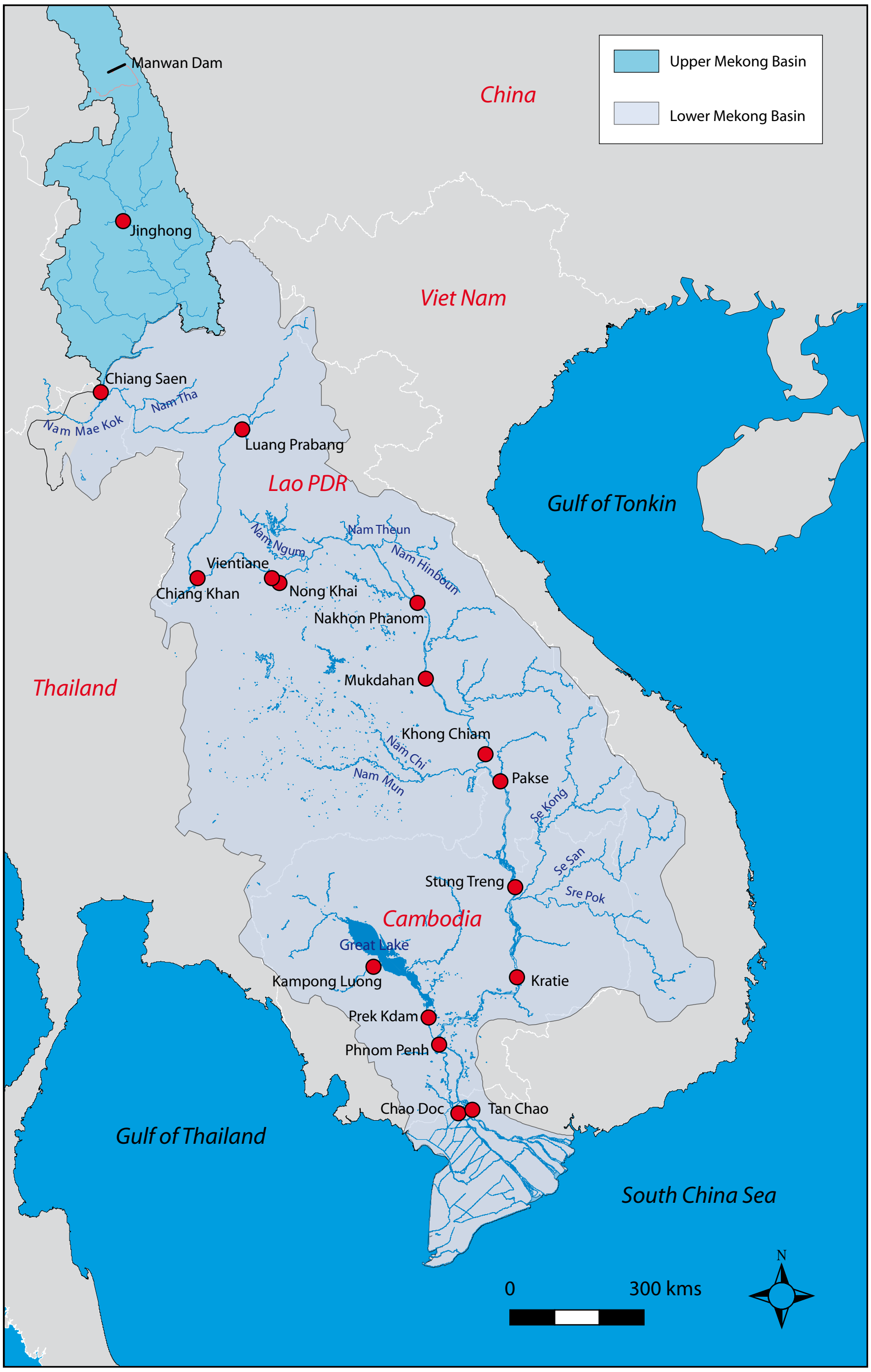


Figure 3. Locations referred to in the main text.

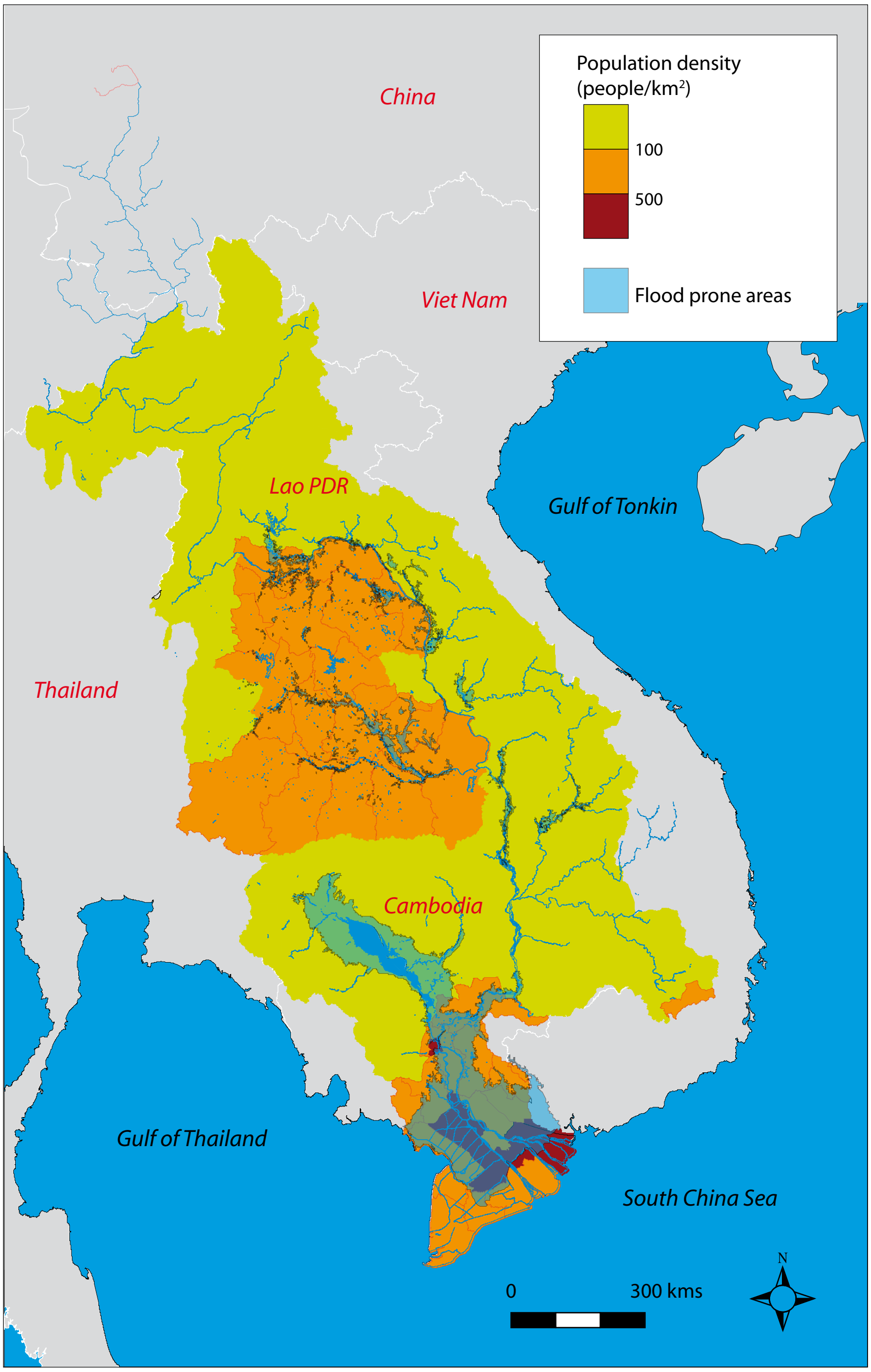


Figure 4. The geography of the flood prone areas in the Lower Mekong Basin compared to the distribution of population.

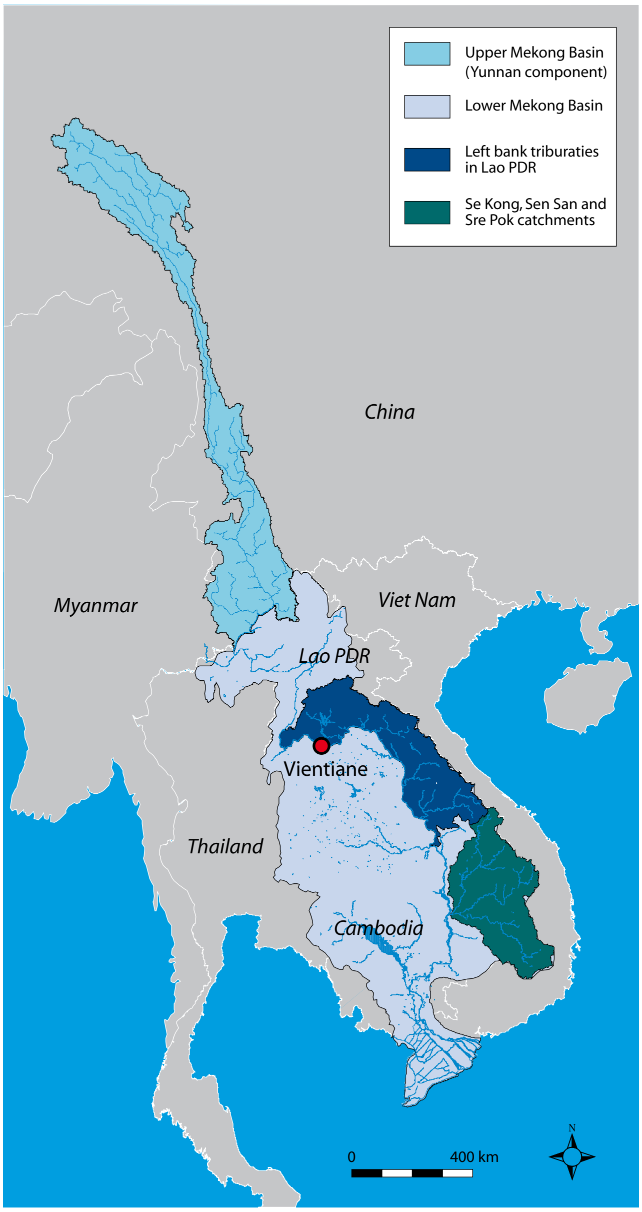


Figure 5. The ‘geography’ of the major hydrological sub-regions that contribute to the spatial non-homogeneity of the flood regime of the Mekong mainstream.

depressions and typhoons, is not necessarily common between these two hydrological sub-regions in any year, there can be significant geographical differences in the annual flood hydrograph.

In any year the annual Mekong flood may be above or below ‘normal’ and this departure outside of the ‘normal’ range may be significant or extreme. A basis for an analysis of the historical and geographical variability of the annual flood along these lines is presented in Figure 6. At Kratie, the mean annual flood volume between 1924 and 2006 is 333 km^3 and as the frequency histogram shows, there has been a considerable historical variability either side of this mean

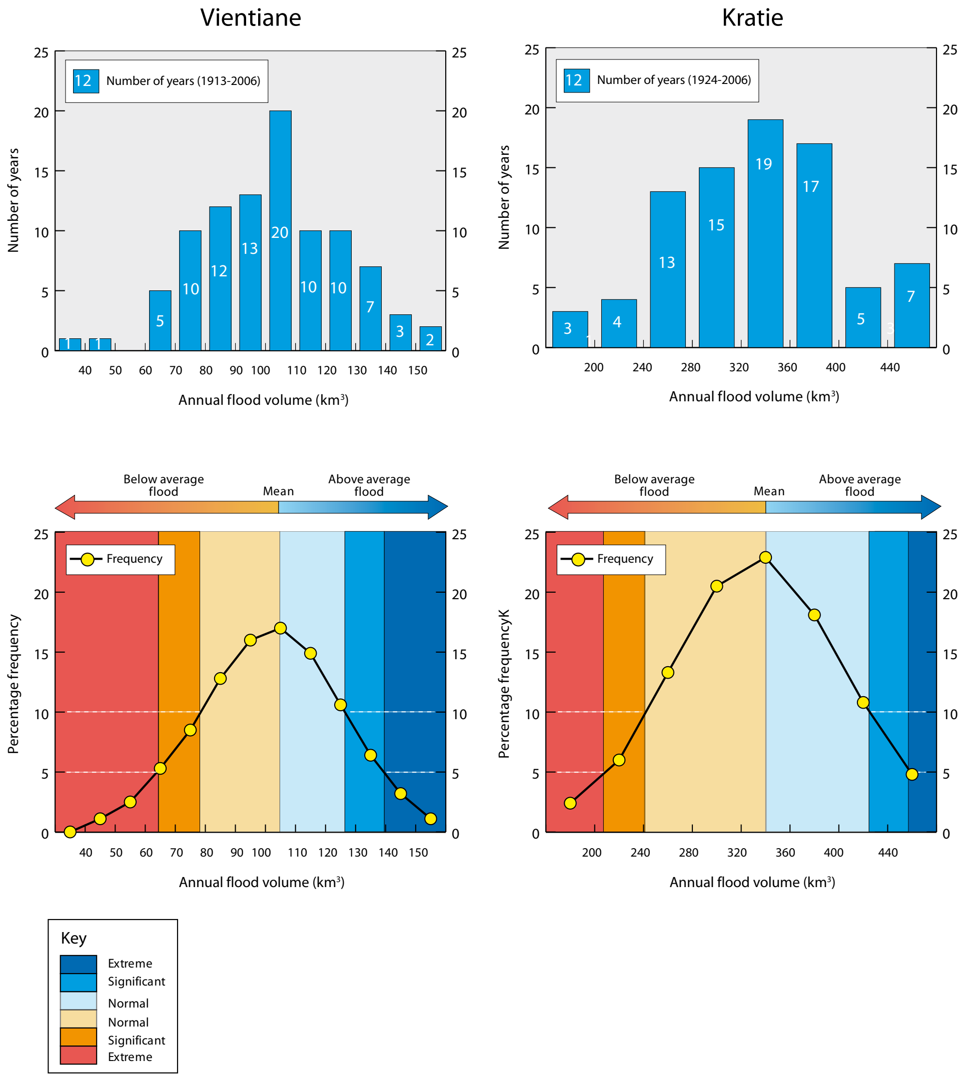


Figure 6. Frequency histograms of the historical distribution of the annual flood volumes on the Mekong mainstream at Vientiane (left) and Kratie (right). In each case these are Normally distributed, on the basis of which the annual flood volumes are classified as ‘significantly’ and ‘extremely’ above or below their normal range. A significant year corresponds to a flood with a recurrence interval exceeding 1:10 years (10% annual probability) and an extreme year to a flood with a recurrence interval exceeding 1:20 years (5% annual probability).

value. The distribution of these volumes can be approximated using a Normal Distribution, as shown in the lower plot, and this enables their risk and recurrence intervals to be estimated. ‘Normal’ flood years are defined as those when the flood volume lies within the 1:10 year range, equivalent to a 10% or less annual probability of occurrence. ‘Significant’ flood years are distinguished as those with an annual recurrence interval greater than 10 years and ‘extreme’ years those with an annual recurrence interval greater than 20 years, equivalent to an annual probability of occurrence of 5%. The annual flood volumes above and below the mean are indicated for both Vientiane and Kratie.

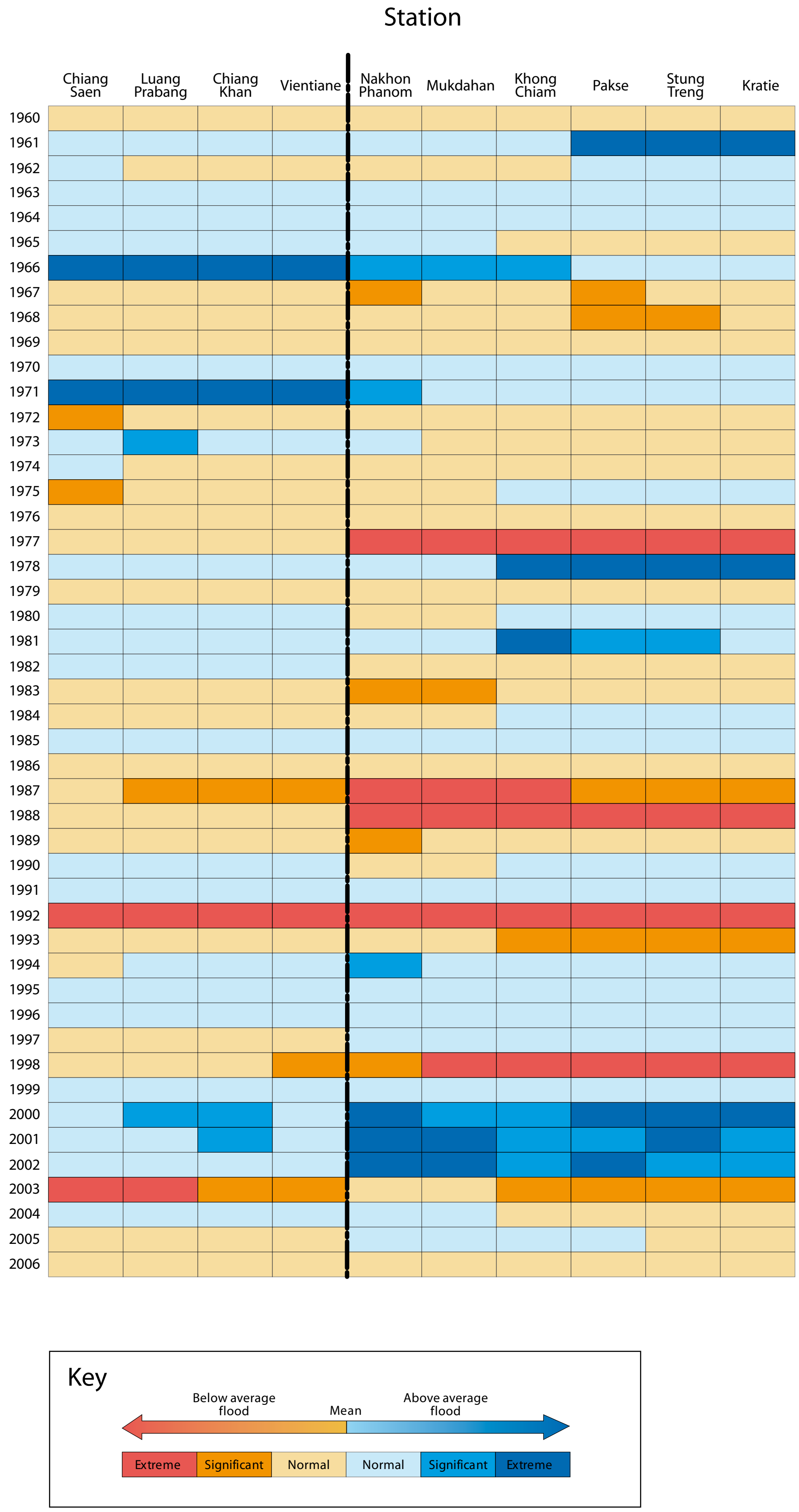


Figure 7. The historical geography of the annual flood regime of the Mekong mainstream (1960 – 2006). The matrix shows a simple classification of the annual flood volume and its inter-annual variability along the Mekong between Chiang Saen and Kratie (refer to text for discussion).

On the basis of this classification, Figure 7 portrays the historical geography of floods along the Mekong mainstream between Chiang Saen and Kratie for the 47 years from 1960 to 2006. The annual flood season flow volumes for each year at ten of the major river gauging locations have been classified as described into ‘significantly’ and ‘extremely’ above and below normal. The result is the flood ‘category matrix’, as shown in the figure:

- The discontinuity up and downstream of Vientiane is clearly distinguishable. For example, the largest flood event recorded at Chiang Saen, Luang Prabang, Chiang Khan and Vientiane, in 1966, diminishes in severity downstream. At Pakse and beyond conditions in 1966 fall into the ‘normal range’. This came about because this flood was the result of Typhoon Phyllis which tracked over northern Lao PDR and southern Yunnan, where extreme levels of runoff were generated in late September. Phyllis did not have any significant impacts further towards the south, where flood season volumes were unexceptional. Consequently there was an insufficient further accumulation of the annual flood volume for it to remain classified as severe or significant beyond Khong Chiam. A rather similar situation came about in 1971.

- Correspondingly, ‘significant’ and ‘severe’ large annual floods can be confined to the hydrological sub-region downstream of Vientiane, as is the case during 2000, 2001 and 2002. This occurs during years when monsoonal depressions and tropical storms generate exceptional volumes of flood runoff within the large left bank tributary catchments, while monsoonal rainfall upstream of Vientiane is less excessive.

- In some years, the occurrence of these exceptional flood volumes can be even more confined geographically, for example in 1961 and 1978. This is generally due to tropical storms and typhoons tracking over the far south of the Mekong system only. This was the case in 1978 when Typhoon Joe moved in over these downstream regions and was responsible for the highest annual flood peak recorded at Pakse (56,000 cumecs) and Kratie (77,000 cumecs) over the past 80 or more years (see Chapter 2 and Figure 2). Upstream, in contrast, the 1978 flood season was unremarkable both in terms of peak and volume.

- ‘Significantly’ and ‘extremely’ below average annual flood volumes can also exhibit this same type of geographical non-homogeneity. For example, during 1977, 1988 and 1998 such conditions were largely confined the regions downstream of Vientiane. An exception is 1992 (Figure 8), a year during which daily discharges during the flood season rarely came even close to their long term average and the seasonal flood volume fell to more than 40% below normal (see Figure 8). These unprecedented conditions existed throughout the basin.

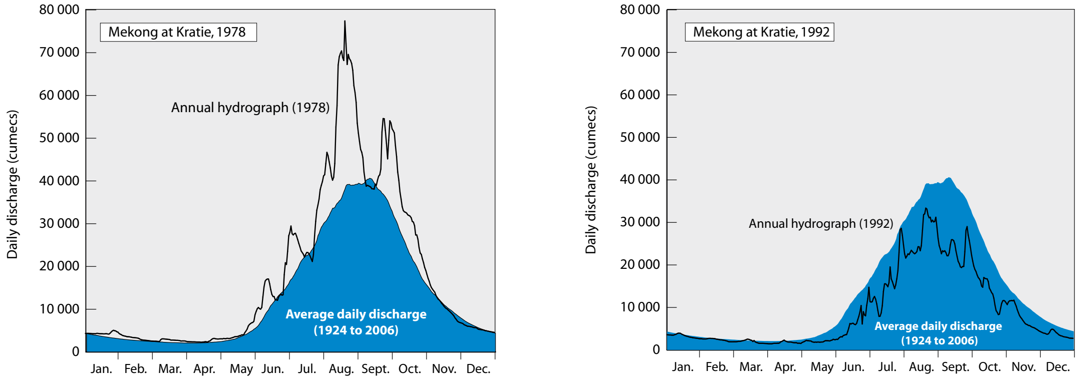


Figure 8. The largest (1978) and smallest (1992) seasonal flood volumes observed within the Mekong system at Kratie over the last 80 plus years. The peak of the 1978 hydrograph exceeds that quoted in the World Catalogue of Large Floods (IAHS. 2003) for 1939 (see Chapter 1).

2.3 The nature and analysis of floods on large rivers

This quantitative definition of the magnitude of a flood exclusively in terms of its peak discharge is useful for the purposes preparing a global catalogue of extrema, as above, and in the case of small river basins where the duration of flood events is usually a matter of several days and the peak is a *sufficient* (fully informative) statistic of magnitude. However, in common with most episodic hydrological phenomena, floods are intrinsically multivariate events, characterised not only by their peak flow but also by their volume and the durations of discharge and water levels above critical thresholds.

Peak flows and water levels are related to the fact of inundation, its maximum depth and therefore to the levels of *primary* economic damage that are sustained. *Secondary* damage is largely the result of event duration and relates to the time that economic activity is suspended and to the cumulative social, structural, agricultural and sanitary impacts of long term inundation. As river basin size increases, secondary damage becomes an increasing proportion of total damage (see Anderson *et al*., 1993).

A simple but effective way of drawing together these aspects of the annual Mekong flood is through a scatter plot of the joint distribution of annual flood peak and volume over the period of record, as illustrated in Figure 9. The value of such a presentation is much improved if a simple means can be devised to ‘sift out’ significant and extreme years. The proposed strategy is based on ‘boxes’ or envelopes defined by one and two standard deviations of each variable above and below their respective mean values.

At Kratie, the mean annual flood peak over the 83 years between 1924 and 2006 is 52,000 cumecs, and the mean annual flood volume 335 km^3, with standard deviations (δs) of 8,300 cumecs and 70 km^3 respectively. Adding and subtracting 1δ and 2δ to and from the mean value of each variable prescribes the boxes. One standard deviation (1δ) away from the mean in either

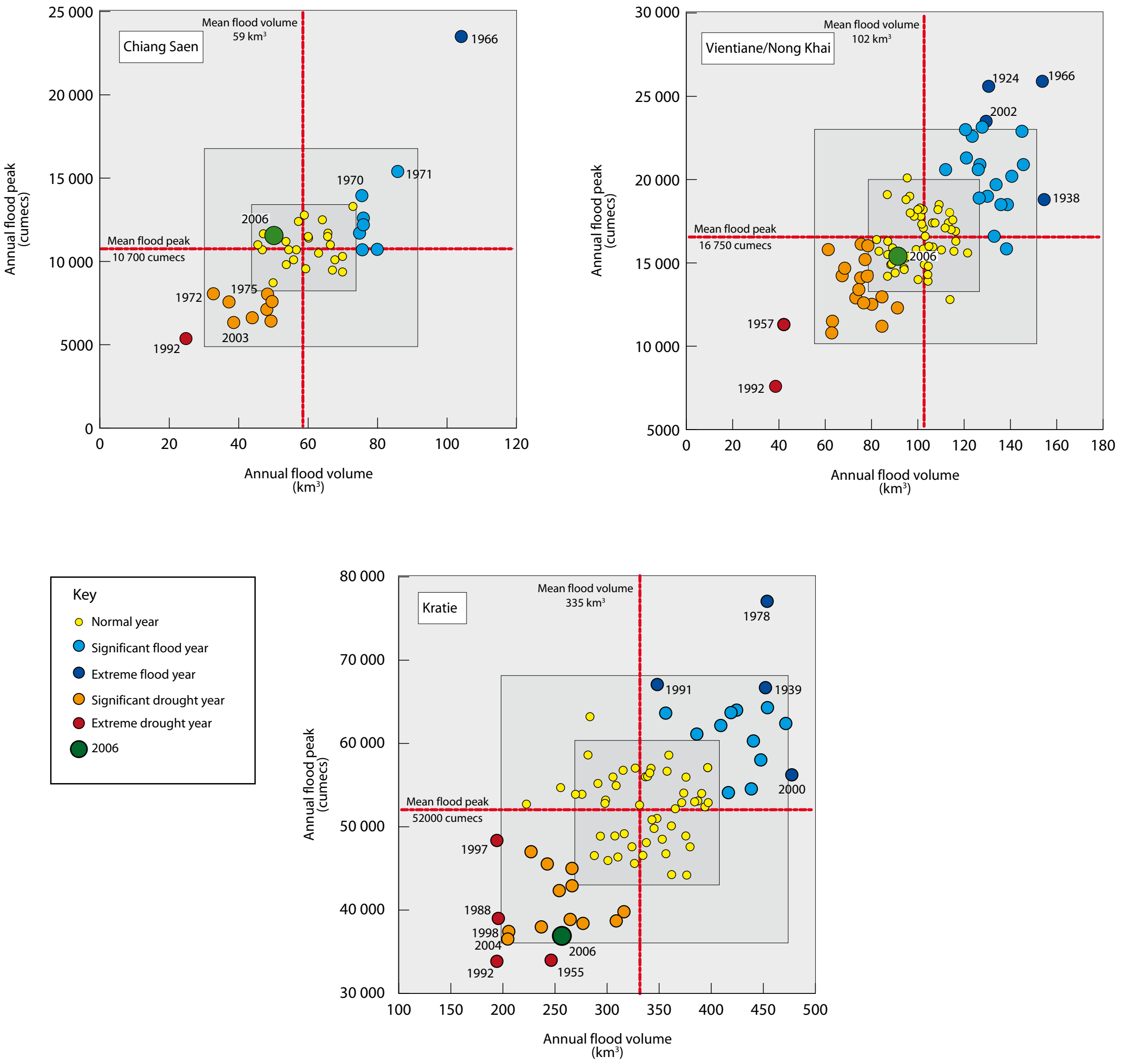


Figure 9. Scatter plots of the joint distribution of the annual maximum flood discharge (cumecs) and the volume of the annual flood hydrograph (km³) at Chiang Saen (1960 – 2006), Vientiane/Nong Khai (1913 – 2006) and at Kratie (1924 – 2006). The darker 'boxes' indicate one (1δ) and two (2δ) standard 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.

direction encompasses about 70% of the observations. Beyond two standard deviations (2δ) from the mean only 5% of the observations would be expected to lie and beyond three only 1%.

Such plots readily provide significant insights into the flood history of the Mekong and how events in 2006 fit into the picture:

- At Kratie, the world envelope event of 1939 (quoted amongst the global data in Figure 2) is surpassed by the 'reliable estimate' of 1978, when although the flood volume was similar, the peak discharge was much greater.

- The more recent extreme event of 2000 observed at Kratie killed more than 800 people and resulted in economic damage assessed at more than US$400 million (ADB figures). It was, however, entirely the result of an unprecedented flood volume of almost 480 km^3. The flood peak was only marginally above average, with an average recurrence interval of less than five years (Appendix 2). Such an observation underscores the point that flood maxima alone are not a satisfactory measure of flood magnitude and therefore of potential flood damage on large rivers such as the Mekong.

- The flood conditions of 2006 at Kratie were significantly below average and in terms of the peak flood discharge, especially low, in fact at an estimated 36,900 cumecs the forth lowest annual maximum since 1924. The 2006 flood season therefore joins the assembly of low peak and low volume flood hydrographs of 1955, 1988, 1992, 1993, 1998 and 2004. A point to note is that since 1924, six of the seven 'driest' flood seasons on record at Kratie have occurred during the last 20 years.

- Upstream, at Vientiane, 2006 flood mainstream conditions were conclusively average, both in terms of peak and volume. This difference in the conditions between here and Kratie and the fact that, other than the 'driest' season on record (1992), there is little commonality with respect to the classification of the flood seasons from year to year, is a significant aspect of the regional flood hydrology.

- As expected, given this geographical pattern of the mainstream flood regime, the 2006 flood peak and volume further upstream at Chiang Saen were both average and consistent with those at Vientiane in terms of their historical content.

A natural development of scatter plots such as these is the development of a bi-variate statistical theory for extreme values, within which the joint probability of combinations of flood peak and volume can be estimated. The development and application of such contemporary statistical methodology is reported in Adamson *et al.* (1999), using long term daily flow data for the Mekong to provide an example. The type of result that can be obtained is illustrated in Figure 10:

- The plots show the bivariate density of flood risk, taking the two key components of the flood hydrograph simultaneously into account and setting them within a common probabilistic framework. In so doing a more complete picture of flood risk emerges. The isolines are of equal percentage probability. Flood years that lie outside of the 1% isoline would have a return period exceeding 1:100 years in terms of the relationship between flood peak and volume, those beyond the 2% isoline a 1:50 year recurrence and so on. Years that lie within the 50% probability contour may generally be regarded as being typical in terms of both flood peak and volume.

- At Vientiane, conditions during 2006 were typical, while those that were experienced in 1966 are estimated to have a risk of occurrence of between 50 and 100 years. Correspondingly, the extremely low flood peak and volume of 1992 have a joint risk of occurrence in excess of 1:100 years.

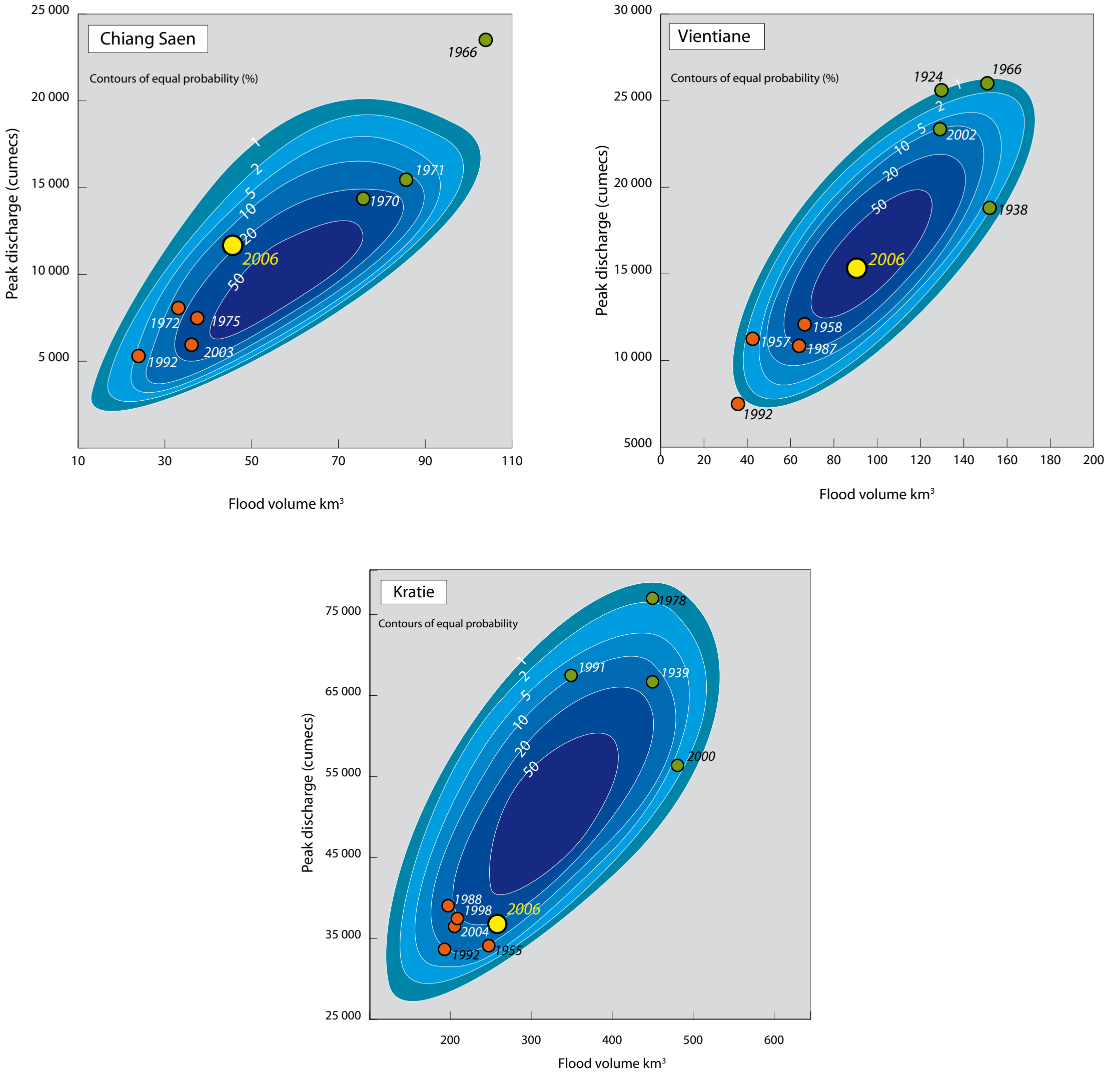


Figure 10. Bivariate probabilities of the joint distribution of annual flood peak and volume at Chiang Saen, Vientiane and Kratie. For example, points lying outside of the 1% isoline would have a recurrence interval in excess of 1:100 years, any outside of the 2% contour a recurrence interval great than 50 years, and so on.

- At Kratie, circumstances in 2006 were such that the much lower than normal combination of peak and volume would not be expected more frequently than 1:5 years on average over the long term. By virtue of the fact that the severe 2000 event had an unexceptional peak combined with an exceptionally high volume, the estimated recurrence interval lies somewhere between 20 and 50 years.

- At Chiang Saen, data are only available since 1960, providing a sample size only half that at Vientiane and Kratie. Conditions in 2006 were, as has been already observed, on average. The extreme conditions of 1966 define what is generally regarded as a complete ‘outlier’ within the historical record, combining an unprecedented peak discharge with an unprecedented flood volume (see Appendix 2).

2.4 Temporal aspects of the Mekong flood regime

An obvious omission from the material presented thus far is some definition of the 'flood season' over which the flood volume is accumulated. There are two ways to approach this. One is simply to set calendar dates, which is by and large arbitrary. Another is to provide a definition that extracts meaningful information with respect to the onset and termination of flood conditions, how this timing and duration of 'the flood season' varies from year to year and therefore whether the conditions under specific review are typical or otherwise. An intuitively attractive designation is that period of the year when discharge and water levels exceed their long term annual average.

In the case of Kratie, for example, the mean annual discharge is 13,600 cumecs, so in any year the flood season is that period when daily discharge is higher (Figure 11). A major advantage of this simple definition, other than the fact that it is logical in many ways, is that on the Mekong mainstream, during a typical year, there is usually only one up-crossing and a single down-crossing of this value. It is therefore quite precise. In years when there are more, and only in exceptionally dry years is this generally the case, then the latest up-crossing and down-crossing defines the season.

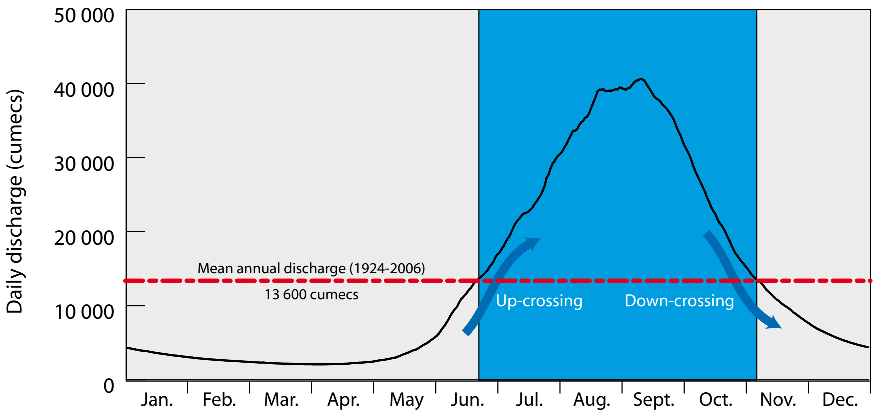


Figure 11. The definition of the flood season, with the mean annual hydrograph at Kratie as an example. The onset is the date of the up-crossing of the long term mean annual discharge and the termination, the down-crossing. In typical years there is only one such crossing in each case.

It would be irrational to define the rest of the year as 'the dry season', a point which is clear from the above figure. Work with the MRC's Environment Programme, supported by the Fisheries Programme, has in fact identified four flow seasons for the Mekong and 'The Annual Flood Report' should accord with this wider inter-disciplinary perspective. In so doing the Report supports active coordination between disciplines and programmes and becomes relevant to a much wider readership. The four seasons and the measures that define their onset and termination are as follows:

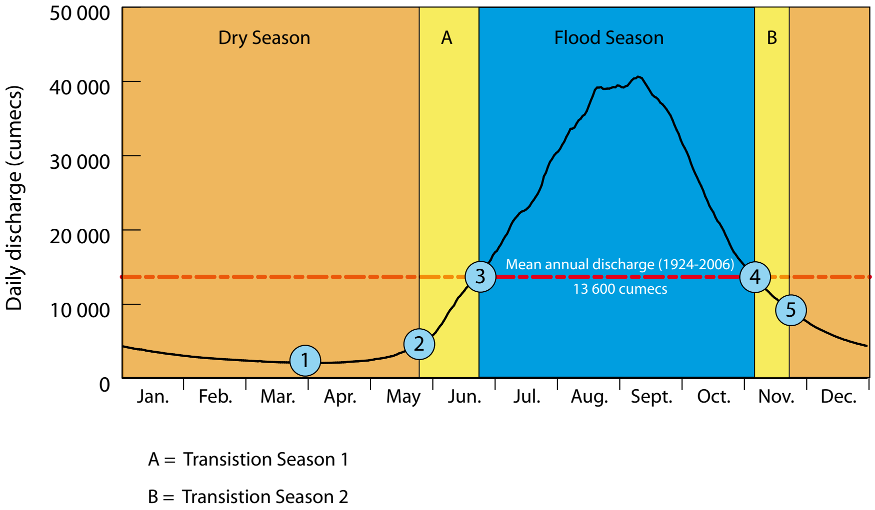


Figure 12. The definition of the onset and closure of the four flow seasons, based on the mean annual hydrograph at Kratie. The annual minimum daily discharge usually occurs in early April (1). The doubling of this discharge, generally in late May, defines the start of the first transition season (2). This ends when the flood season starts (3). The second transition season defines the period between the end of the flood season (4) and the start of the dry (5), which occurs when rates of daily flow decrease become typical of 'base-flow' recession. On average the dry season onset according to this definition is in late November.

1. Transition Season 1: This is a period of the year when the river is not strictly speaking 'in flood' but the dry season has clearly ended. Its onset is defined as the earliest date upon which the discharge rises to twice that of the minimum daily discharge observed in each year (see Figure 12). This occurrence confirms the fact that the hydrological response to monsoon rainfall is in progress. The arrival of this fresh seasonal runoff is extremely important biologically, most particularly as a 'cue' to fish migration.

2. Flood Season: This season begins when the flow exceeds the mean annual discharge.

3. Transition Season 2: This transitional period describes a short season between the end of the flood season and the start of the dry. The annual flood has plainly come to a close, but the day to day decreases in discharge are far more rapid than those that are characteristic of the dry season itself. The rate of flow recession at this time of the year has important environmental linkages, for example with the draining of wetlands and the floodplain as well as with the timing of the flow reversal in the Tonle Sap. It is helpful that usually this transition season never extends from one year to the next, historically the latest date for its termination being mid-December.

4. Dry Season: The second transition season comes to a close when the average day-to-day decrease in discharge becomes typical of so called baseflow conditions. The rates of flow recession or decrease that signal the start of the dry season were identified (on the basis of

some research) as the onset of a rate of decrease in daily flows of 1%, averaged over two weeks. This proved to be a consistent indicator along the mainstream.

The onset dates and duration of these four seasons has been remarkably consistent and unchanged over the last century, and almost certainly over the last 5,000 to 6,000 years[3]. Figure 13 shows a temporal plot of the historical variation of these dates over the last 80 to 90 years at Vientiane and Kratie. Figure 14 sets them within a probabilistic framework.

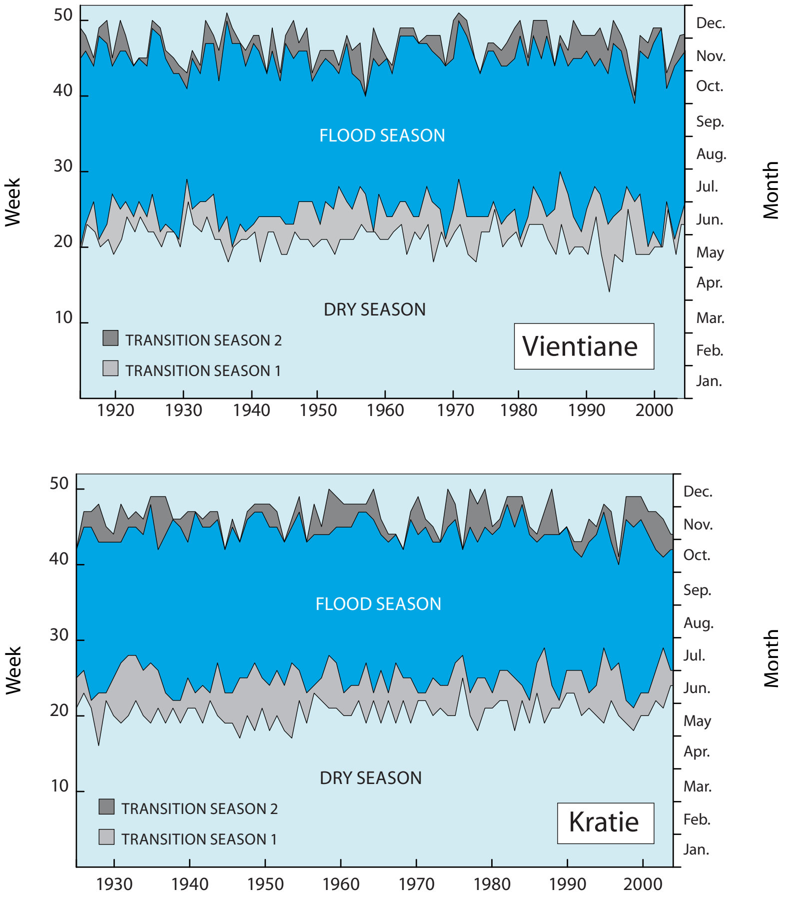


Figure 13. Historical onset and duration of the four flow seasons at Vientiane (1913–2005) and at Kratie (1924–2005).

- The timing of the onset and the duration of the seasons is virtually identical at Vientiane and Kratie, despite the fact that the hydrology of the former is dominated by the so called Yunnan component of the overall Mekong regime (see Chapter 5 of the Overview of the Hydrology of the Mekong Basin, MRCS, 2005), while at Kratie the flow regime is largely dictated by flows entering the mainstream from the large left bank tributaries in Lao PDR, downstream of Vientiane. The system is therefore entirely homogenous with regard to

---

[3] Results reported in Penny (2006), based on core samples recovered from the bed of the Great Lake in Cambodia, indicate a major change in the pollen assemblages found in the sediments at around 5,600 years before the present (BP). The change is from species characteristic of swamp environments to those characteristic of the seasonally flooded forests that prevail today. The transformation of the flora is a response to changing climatic patterns brought about by a reduction in the strength of the Southwest Monsoon and the development of the strongly seasonal weather patterns that typify the present regional climate.

these temporal aspects of its hydrology. However, it is not homogenous with respect to the incidence and severity of floods from year to year upstream and downstream of Vientiane (See Chapter 2.2).

- The data presented in Figure 14 (over-page) indicate the probability that a season will start and end before a particular week of the year. For example, at Kratie there is 50% probability in any year that the flood season will begin before week 25 (24th–30th June) and close before week 44 (4th–10th November). More generally, these figures reveal that there is a very narrow 'window' that defines the onset and closure of the seasons.

- The fact that there is no geographical variation with regard to long term average seasonal onset and conclusion along the mainstream is further emphasised in Table 1. The historical mean dates are virtually identical at the two sites. In addition, the very low values of the standard deviations about the means reveal just how predictable these dates are from year to year.

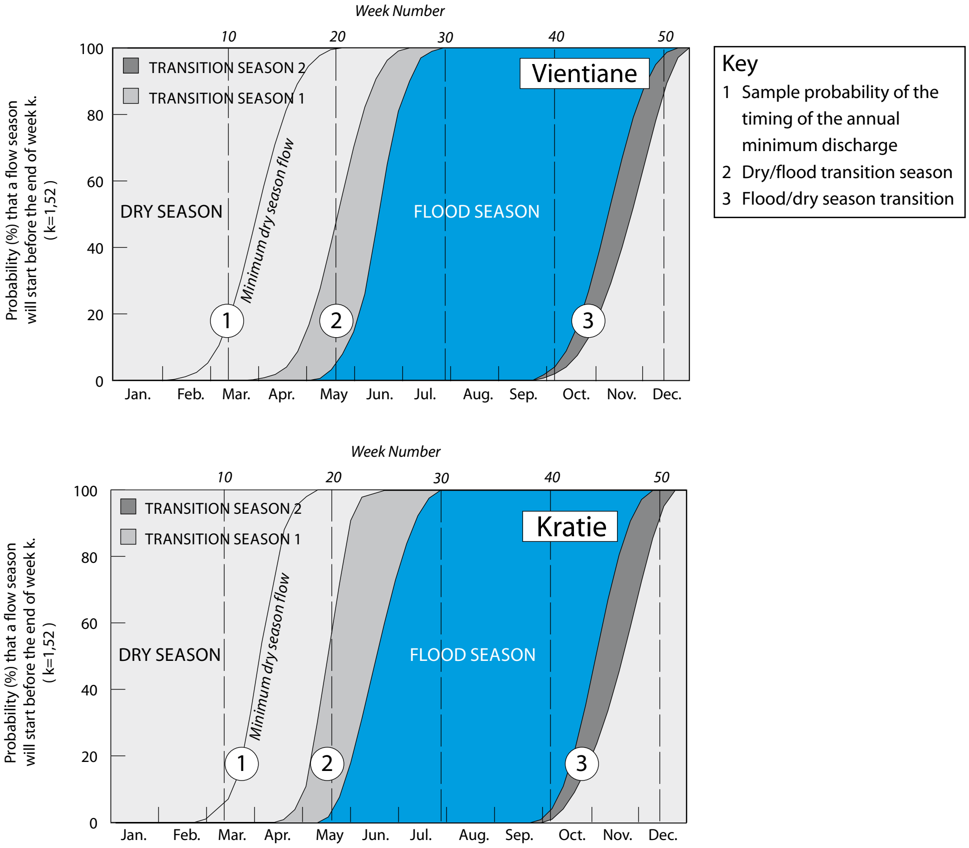
Table 1. *Average calendar week number of the onset and conclusion of the various hydrological seasons defined for the Mekong mainstream and their historical standard deviations. Average calendar day is given for the flood season dates.*

Annual calendar variable	Week of occurrence			
	Vientiane		Kratie	
	average	δ (weeks)	average	δ (weeks)
Minimum discharge	14	2.1	14	2.0
Dry season end	21	1.9	20	1.7
Flood season start	25 (23rd June)	2.2	25 (23rd June)	1.9
Flood season end	45 (11th Nov.)	2.1	44 (7th Nov)	1.7
Dry season start	47	2.4	47	2.3

- Table 2 presents the onset and end dates of the seasons for 2006. In the case of the flood season, no date departs more than a week either side of its long term historical average, with the exception of the start of the flood season at Kratie, which was more than two weeks early. Taken as a whole, however, 2006 was an unexceptional year as far as these temporal aspects of its seasonal hydrology are concerned.

Table 2. *Onset and closure of the hydrological seasons during 2006, with average calendar day given for the flood season dates.*

Annual calendar variable	Week of occurrence (2006)	
	Vientiane	Kratie
Minimum discharge	13	17
Dry season end	20	22
Flood season start	28 (29th June)	26 (6th June)
Flood season end	44 (5th Nov.)	44 (1st Nov)
Dry season start	46	48



P(K>k)	Week (k) in the year before which the flow season changes with probability P(K>k)									
	Annual minimum discharge		End of dry season		Start of flood season		End of flood season		Start of dry season	
	Vient'n	Kratie	Vient'n	Kratie	Vient'n	Kratie	Vient'n	Kratie	Vient'n	Kratie
10%	10	12	18	18	22	22	42	41	43	43
25%	12	13	19	19	23	23	44	43	45	45
50%	14	14	21	20	25	25	45	44	47	47
75%	16	16	23	22	26	26	47	46	49	49
90%	18	17	24	23	27	27	49	48	50	50

Figure 14. Mekong mainstream at Vientiane (1913–2005) and Kratie (1924–2005). Historical timing of the transitions between the flow seasons. The graph and summary table indicate the probability (P(K>k)%) that in any given year the minimum discharge and seasonal transitions will have occurred before week k (k=1,52). For example, at Kratie there is only a 10% chance in any year that the flood season will start before week 18 (late May) and a 90% chance that it will have already started before week 41 (end of June, early July).

3. The 2006 Flood Season

3.1 Hydrological and meteorological aspects

It has already been established that, from a hydrological perspective, flood conditions along the mainstream during 2006 were geographically quite variable.

- At Chiang Saen and Vientiane the flood peak of 16,800 cumecs on the 13th October was the second highest observed since 1960, while the flood volume was below average (Figure 9).
- At Kratie, the fourth lowest flood peak since 1924 was observed, while the flood volume was also significantly below normal (Figure 9).
- Throughout the mainstream, the onset and duration of the flood season was quite characteristic.

The daily discharge hydrographs for 2006 are illustrated in Figure 15, the key feature of which is the second peak and the fact that, without it, flood conditions would have been much very below average, particularly at Kratie.

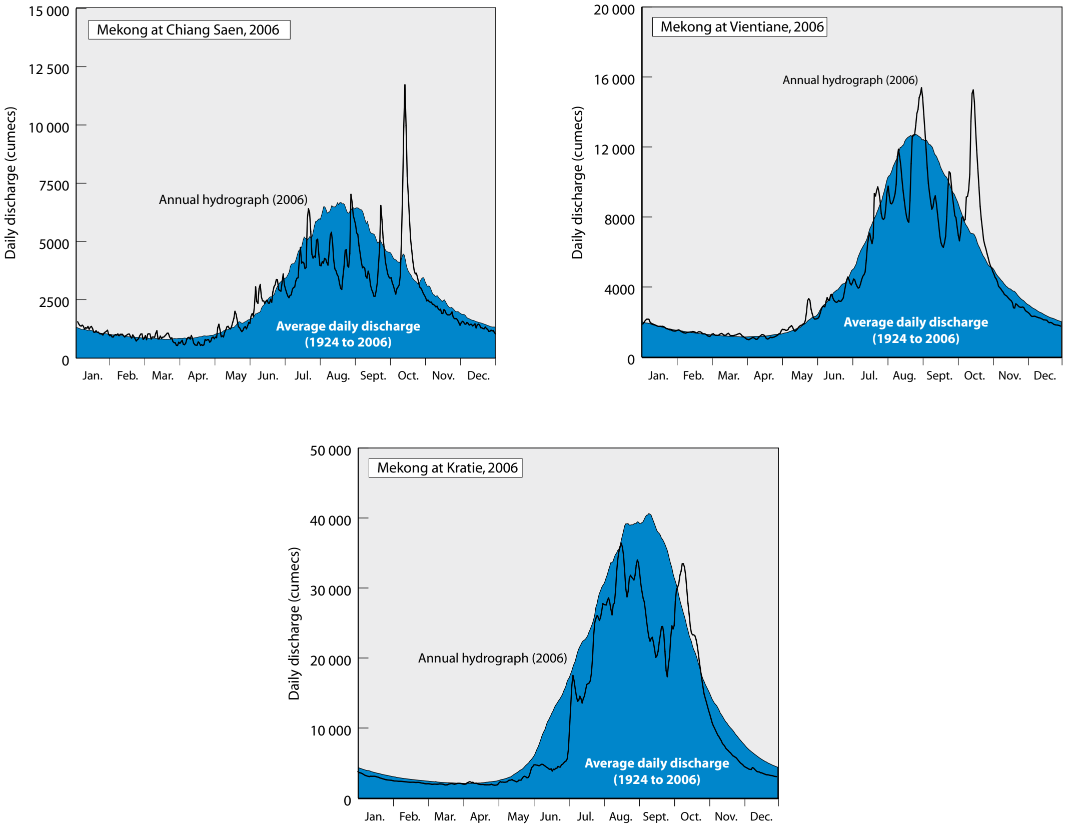


Figure 15. The 2006 daily discharges observed at Chiang Saen, Vientiane and Kratie, compared with the long term mean daily discharge hydrograph.

This picture of generally below average conditions, specifically from a volumetric viewpoint, is confirmed from an examination of the 2006 flood season flow duration curves (Figure 16), which show the percentage of time that a given discharge was exceeded.

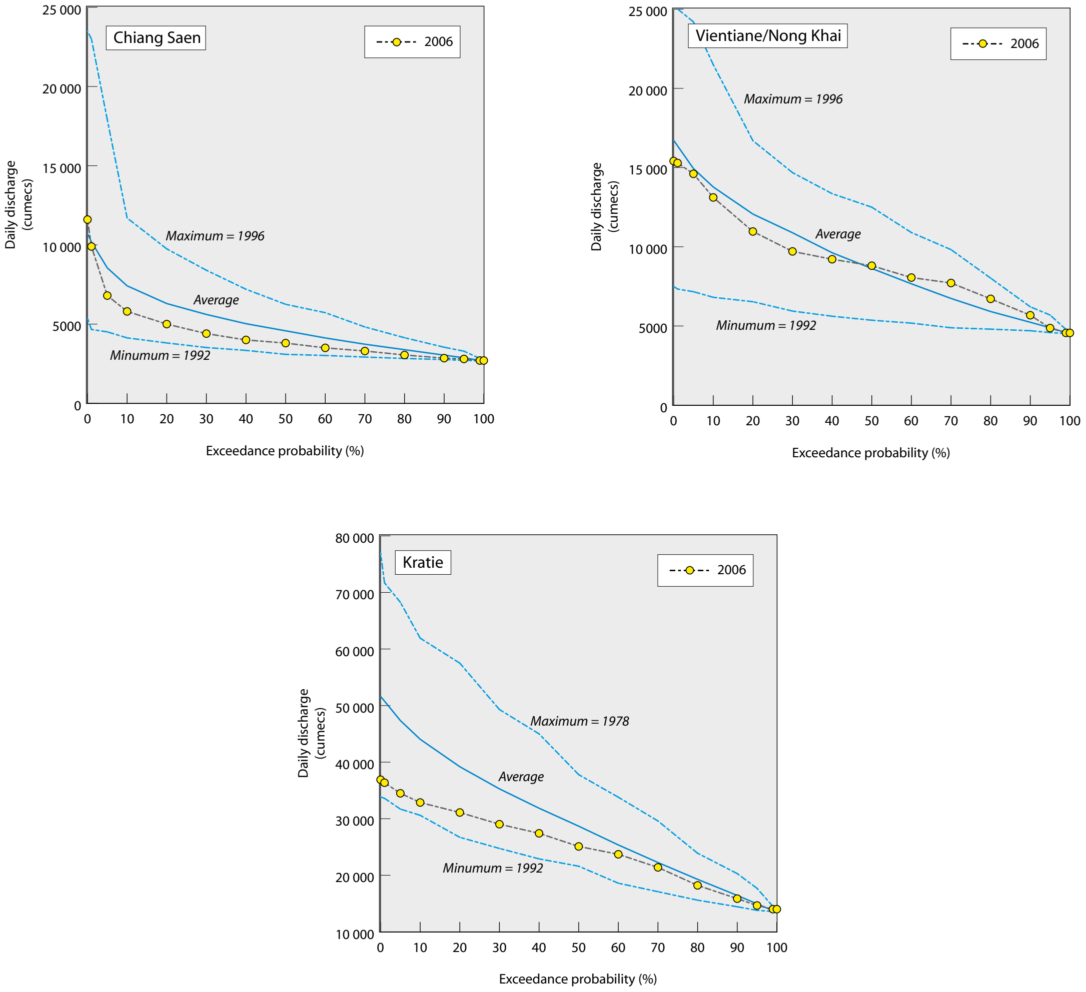


Figure 16. 2006 flood season daily discharges observed at Chiang Saen, Vientiane and Kratie, compared to their historical range and average.

- At Chiang Saen discharges were consistently below average until the arrival of the extreme flows associated with the October peak, which caused a sharp upturn at the high discharge/low exceedance probability end of the curve. The sharp rise in water levels upstream at Jinghong in Yunnan during early October which explains this very rapid but short lived peak at Chiang Saen is indicated in Figure 17.
- At Vientiane the distribution of the flood season discharges is entirely average.
- At Kratie the picture is of very much below average discharge magnitudes, resulting in a flood hydrograph volume 25% below normal. As can be appreciated from Figure 14, only during October were flows above average during the flood season, such that without the second peak overall volumes would have been extremely low.

Overall, these results indicate that during 2006 the peak discharge thresholds that were exceeded for any length of time were unexceptional. Only at Chiang Saen were severe flood discharges and water levels exceeded, though only briefly.

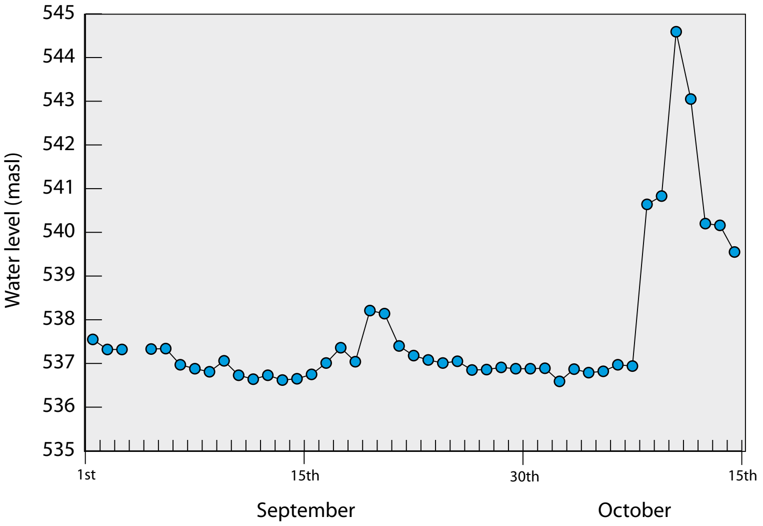


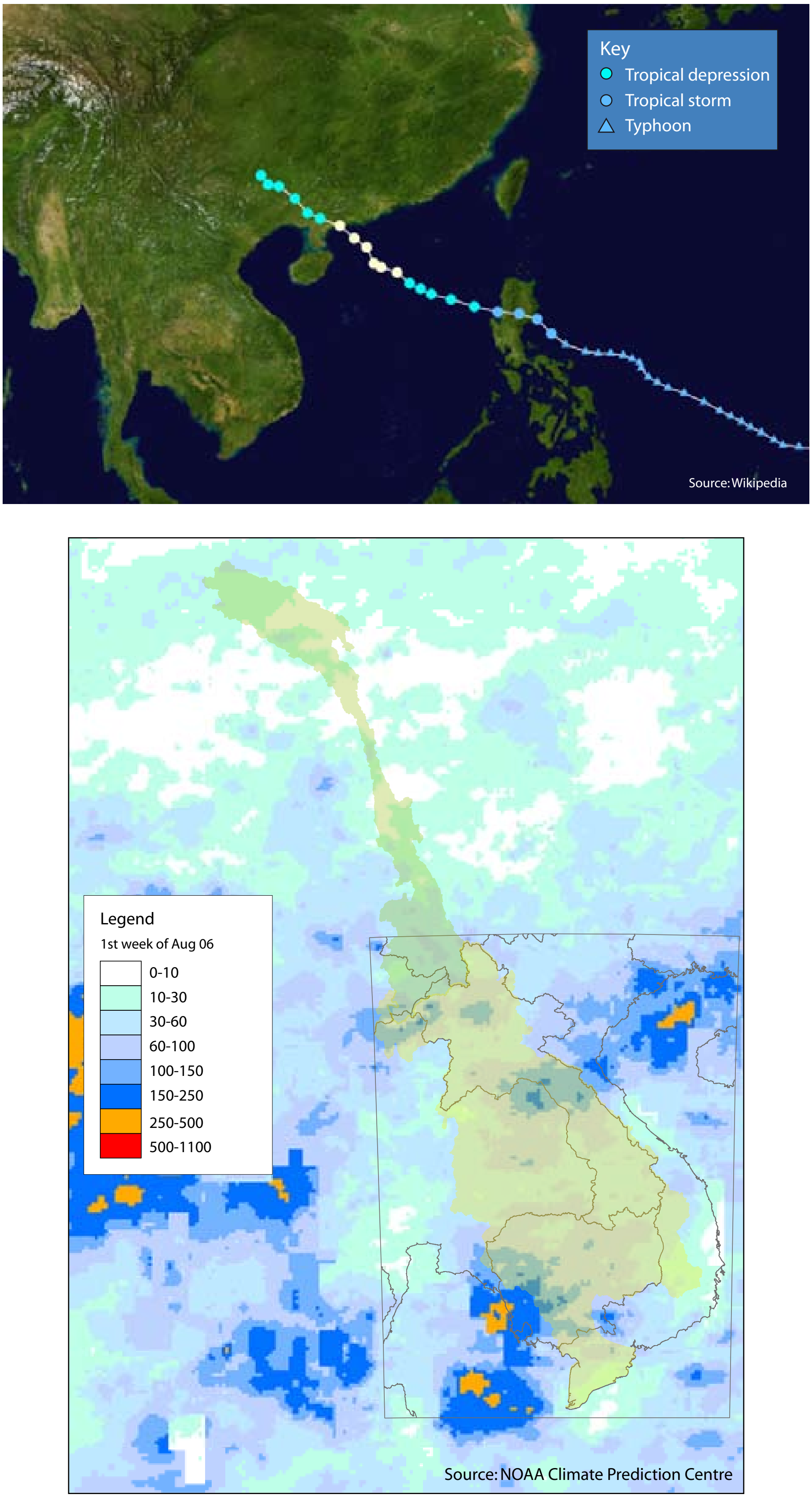
Figure 17. Water levels at the Mekong mainstream at Jinghong on Yunnan Province, China; 1stSeptember to 15th October 2006. The peak water level occurred on the 11th October.

The 2006 monsoon was generally rather weak overall, which is reflected in the hydrology of the flood season. Three major tropical storm systems tracked across the Mekong Basin during the year; their tracks and associated rainfall are presented in Figures 18 to 20:

- During the last week of August Tropical Storm Prapiroon entered the region as a tropical storm, but was quickly downgraded to an intense tropical depression as it weakened. Intense storm rainfall (150 to 200 mm) was confined to northern Thailand, northern Lao PDR and eastern Cambodia. This system was responsible for some severe tributary flash floods in northern Thailand, particularly on the Nam Mae Kok at Chiang Rai.

- Severe Tropical Storm Xangsane moved into the central and southern parts of the region during the first week of October. The rainfall and flood runoff associated with this system were responsible for the second peak to the annual flood hydrograph, already discussed in detail. Significant storm rainfall was widespread (Figure 19), particularly towards the south. To the north in Yunnan rainfall in the week exceeded 150 mm, which in part explains the extreme but brief October peak to the flow hydrograph at Chiang Saen and the very rapid rise in water levels at Jinghong (Figures 15 and 18).

- Tropical Storm Durian was not linked to widespread rainfall during its passage over the Viet Nam Delta during the first week of December (Figure 20), but principally with very high wind speeds and a storm surge which caused extreme sea levels and widespread inundation and damage as a result.



Source: Wikipedia

Source: NOAA Climate Prediction Centre

Figure 18. Tropical Storm Prapiroon, moved in over the Upper Mekong Basin during the last week of August, 2006, but rapidly weakened to become a tropical depression. Intense storm rainfall (150 to 200 mm) was confined to northern Thailand and eastern Cambodia.

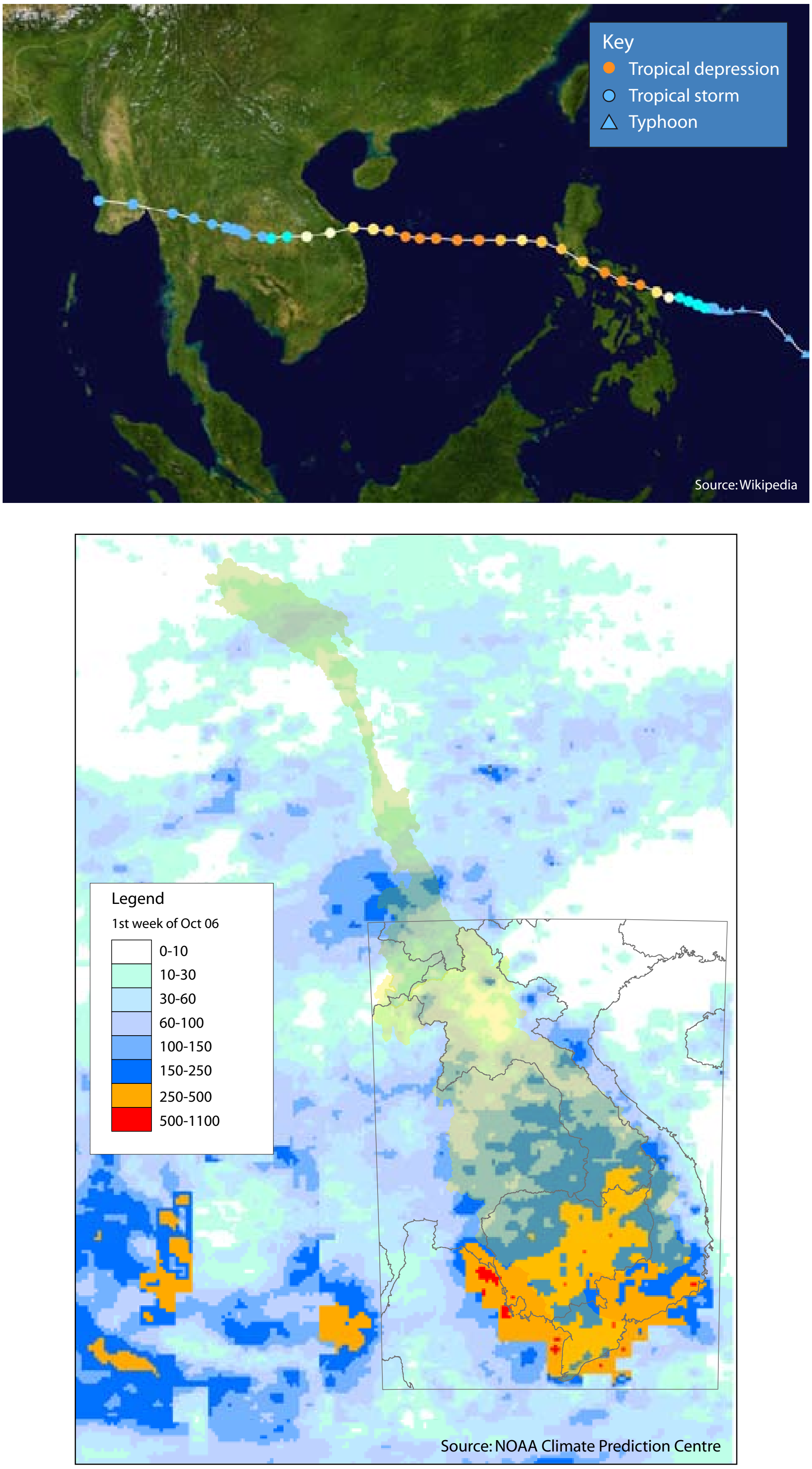
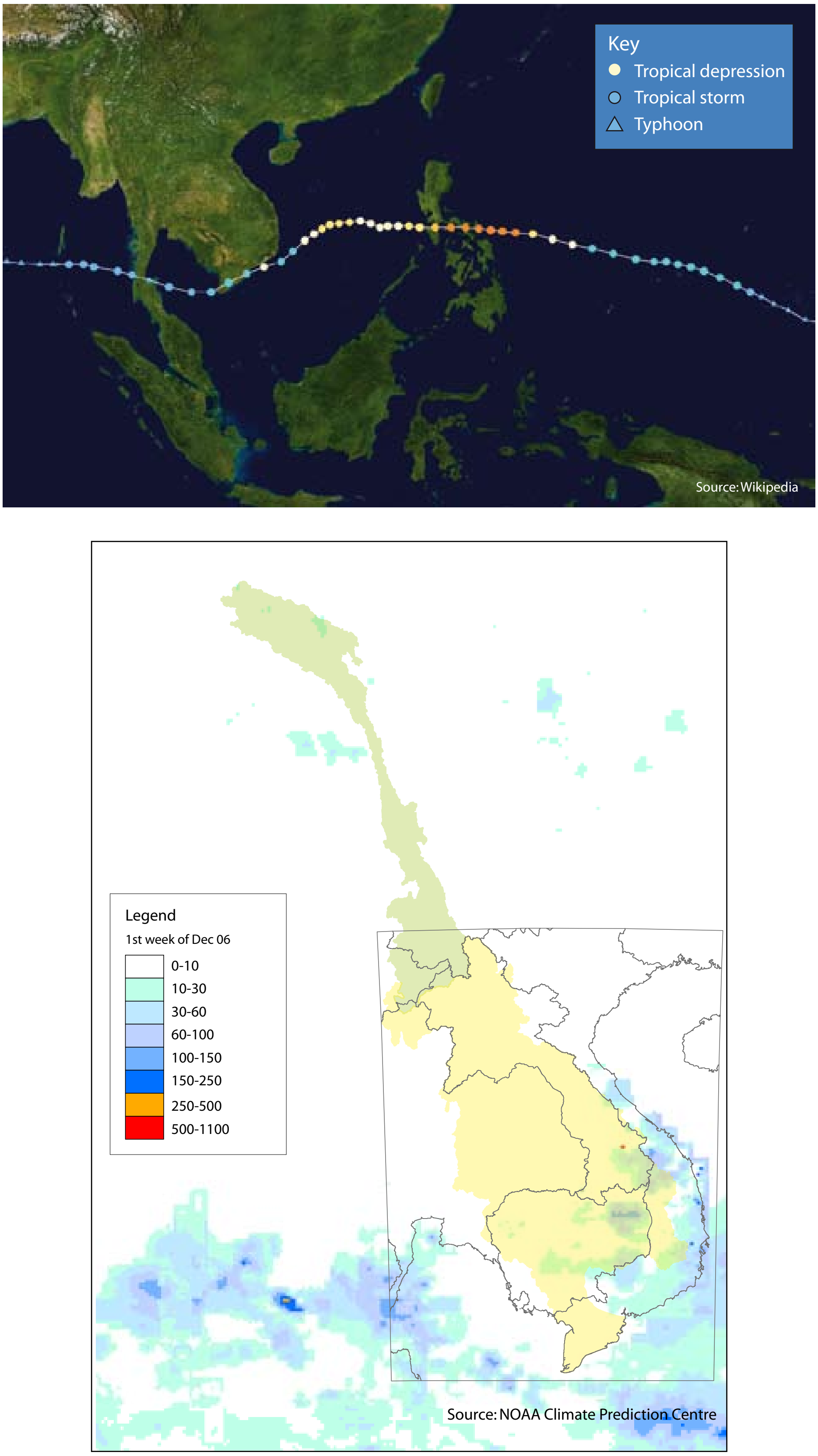


Figure 19. Severe Tropical Storm Xangsane, moved in over the Central Mekong Basin during the first week of October, 2006. Very intense storm rainfall (250 to over 500 mm) was widespread over southern Lao PDR, Cambodia and Viet Nam.



Source: Wikipedia

Source: NOAA Climate Prediction Centre

Figure 20. Tropical Storm Durian, moved in over the Mekong Delta in Viet Nam during the first week of December, 2006, but rapidly weakened to become a tropical depression. The associated rainfalls for the week were generally less than 100 mm.

3.2 The 2006 flood season: conditions over the Cambodian floodplain and in the Delta in Viet Nam

The generally below average magnitude of the mainstream seasonal flood hydrograph during 2006 carried over into the Cambodian floodplain and the Mekong Delta in Viet Nam, where seasonal maximum water levels were similarly below normal. This apparently did not apply to maximum water levels achieved in the Tonle Sap/Great Lake system, however, where as Figure 21 illustrates the 2006 maximum water level was only a few centimetres less than that achieved in 2000, an extreme flood year which led to the largest regional loss of life and socio-economic damage witnessed in recent decades.

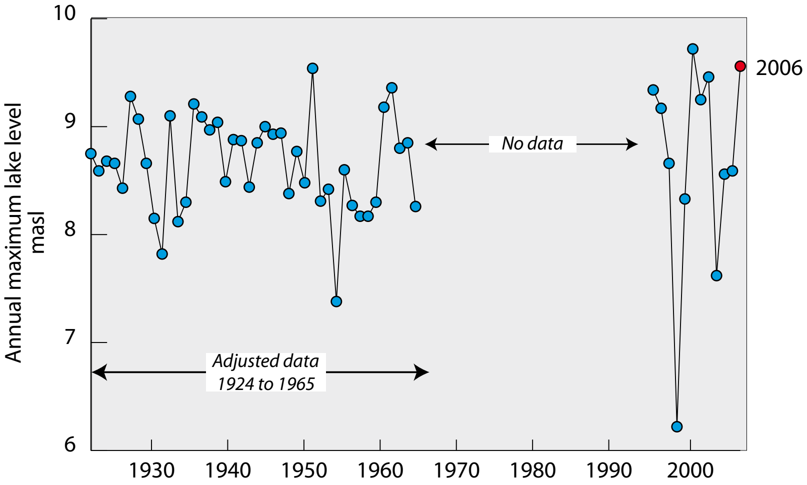


Figure 21. Cambodian Great Lake. Annual maximum water levels observed at Kampong Luong.

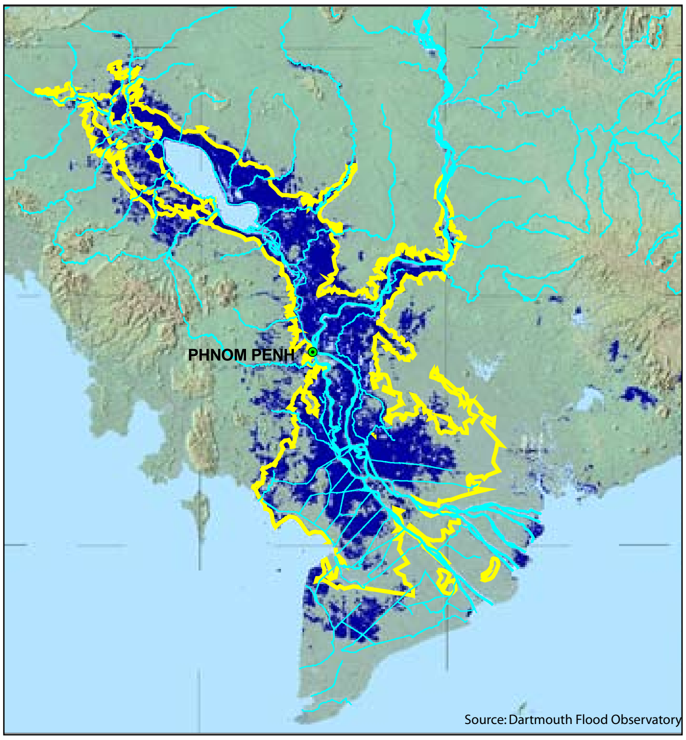
The 2006 maximum was observed on the 14th October and was a clear response to the storm rainfall and second peak to the regional flood hydrograph associated with Severe Tropical Storm Xangsane. As Figure 19 clearly shows most of the excessive rainfall generated by this system was confined to eastern Cambodia and the Great Lake's own system of tributaries, which would have caused significant volumes of local runoff, given that during the first week of October these areas received 400 to 500 mm of rainfall. Three other factors contribute to the fact that the 2006 maximum lake level almost matched that of 2000:

- The second peak on the Mekong mainstream in early October occurred when the Lake was close to its highest seasonal level and would have caused increased inflow to the Tonle Sap. Water levels therefore rose above what otherwise would have been their highest levels for the year.

- The 2000 flood and its impacts are largely explained in terms of exceptionally high volumes and the duration of the regional inundation. The peak was average (refer to Figure 9) such that the annual maximum level of the Great Lake level that year was not as extreme as the flood impacts might imply.

- Maximum annual levels in the Great Lake are largely bounded, in so far as the landscape is extremely flat, so water spills out over the floodplain and moves transversely. Physically therefore, water levels are limited vertically as excess water moves out over the landscape.

In the face of these factors therefore, the extent of flood inundation over the Cambodian floodplain in 2000 and 2006 were quite similar, as Figure 22 confirms.



Source: Dartmouth Flood Observatory

Figure 22. Comparison of the spatial extent of floodplain inundation over the Cambodian. Floodplain and the Mekong Delta for the years 2000 (delimited in yellow) and 2006 (area shaded blue).

Downstream from the Great Lake itself, at Prek Kdam on the Tonle Sap river and at Phnom Penh Port on the Mekong mainstream, the maximum water levels for 2006 were much closer to average, though only three to four centimetres lower than the maximum observed on the Great Lake. They were, however, much less than those observed during the 2000 flood at each of these sites (Figure 23). Quite why this should be so, when the level of the Great Lake in 2000 and 2006 were so similar, is not entirely clear, but the fact that the rainfall over the Great Lake basin and its tributaries was so extreme due to Severe Tropical Storm Xangsane, may go some way towards an explanation.

Over the Delta in Viet Nam the total area inundated in 2000 was much greater than during 2006, as can be seen from Figure 22. Maximum water levels for the year were marginally below average, as the data for Tan Chao and Chao Doc confirm in Figure 24. As regards the timing of

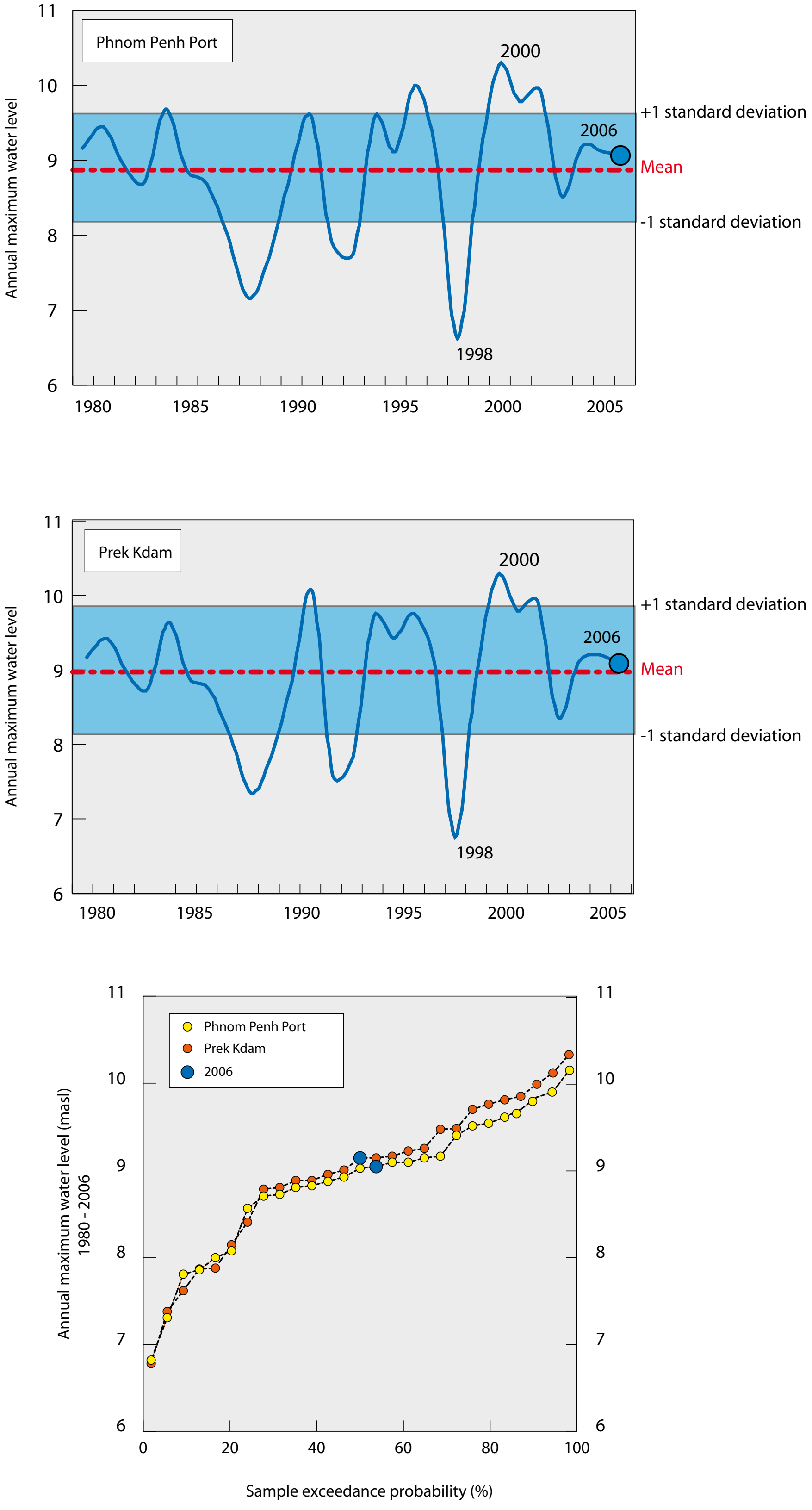


Figure 23. Annual maximum water levels for 2006 at Phnom Penh Port and Prek Kdam in their historical context. They were average and in 50% of years they would have been exceeded.

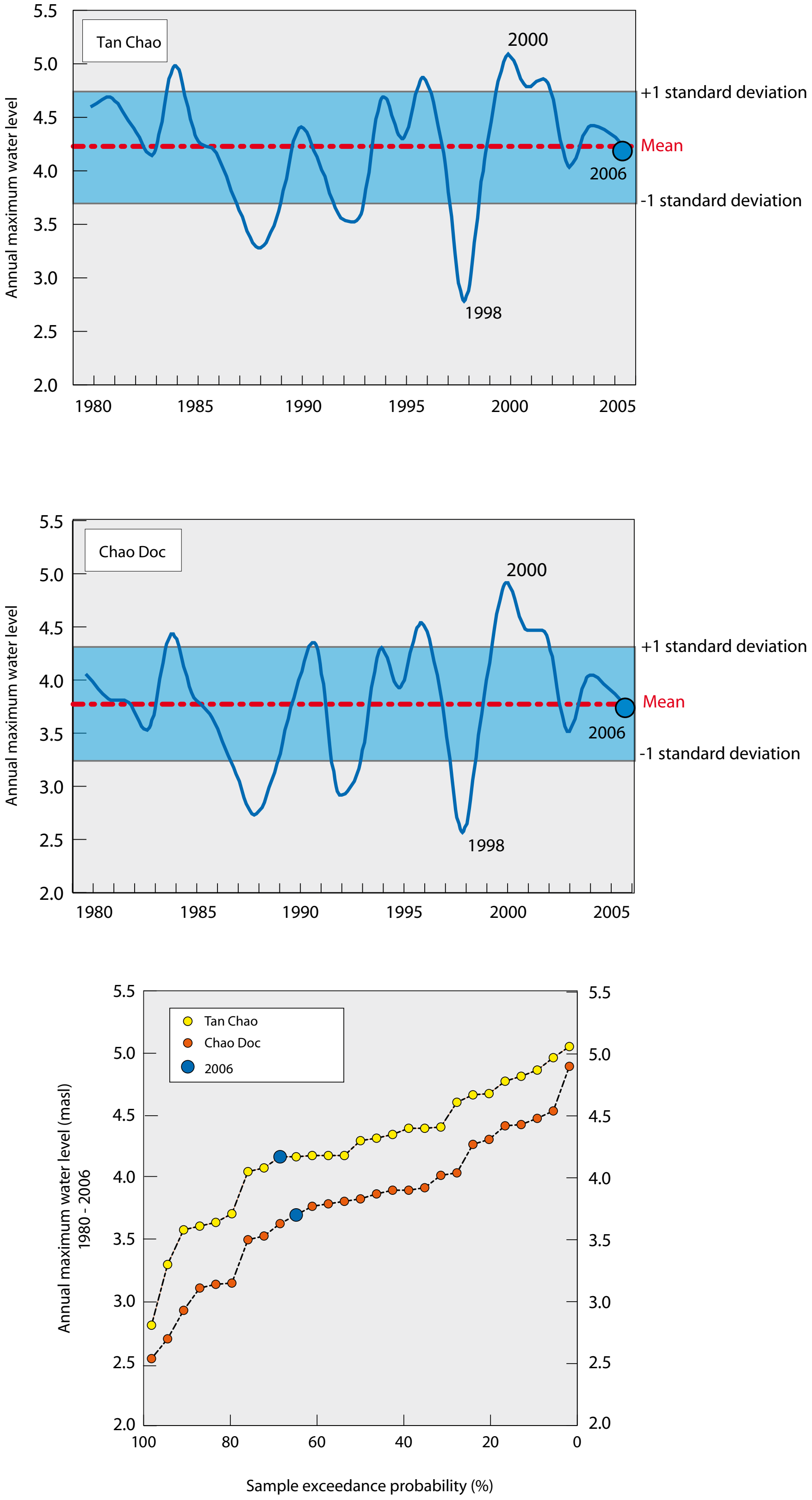
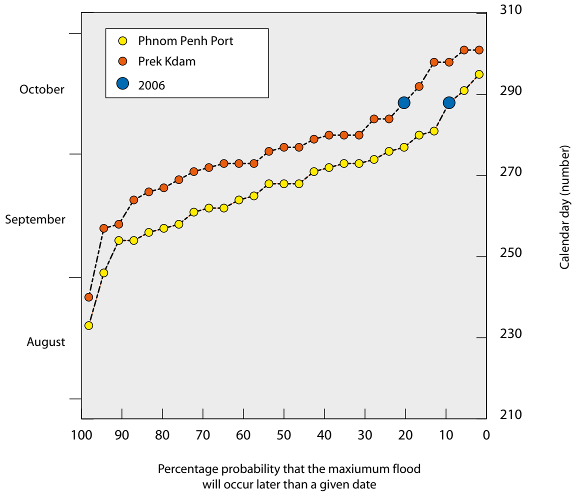


Figure 24. Annual maximum water levels for 2006 at Tan Chao and Chao Doc in their historical context. They were average and in 65% of years they would have been exceeded.



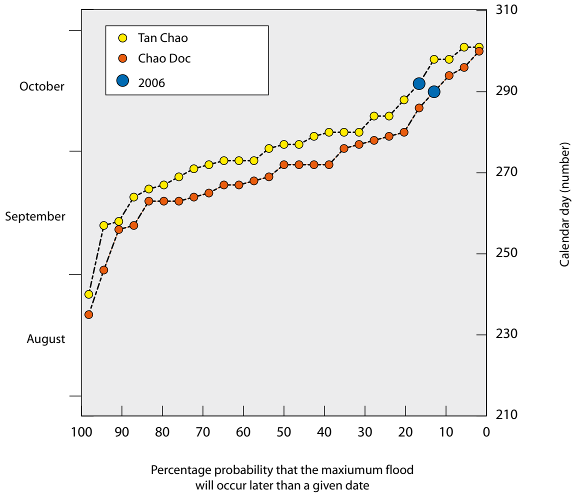


Figure 25. Historical (1980 –2006) probability distribution of the date of occurrence of annual maximum water level at Prek Kdam, Tan Chao and Chao Doc, which 50% of the time would be expected to occur not later than the beginning of October. During 2006, it's occurrence was atypically late, since maximum water levels were not observed until the latter half of October.

these annual maximum water levels, they were two weeks later than normal at all sites in these floodplain and delta regions, as illustrated in Figure 25.

Figure 26 summarises these downstream water levels for 2006. The maxima for the year were above the average for the day on which they occurred, but only marginally so. The fact that they occurred two weeks later than average is confirmed.

This moderate to below average flood regime in the Delta during the year meant that direct flood damage was not severe. However, the late appearance of flood peaks did bring about some unfavourable conditions for agriculture. What widespread inundation there was occurred when high tides combined with incoming flood flows from upstream, which occurred three times during August and September. The associated water levels at most stations were higher than alert level 3 over a duration of one to three hours, though actual inundation was often longer due to poor drainage capacity (VNMC 2006 Annual Flood Report).

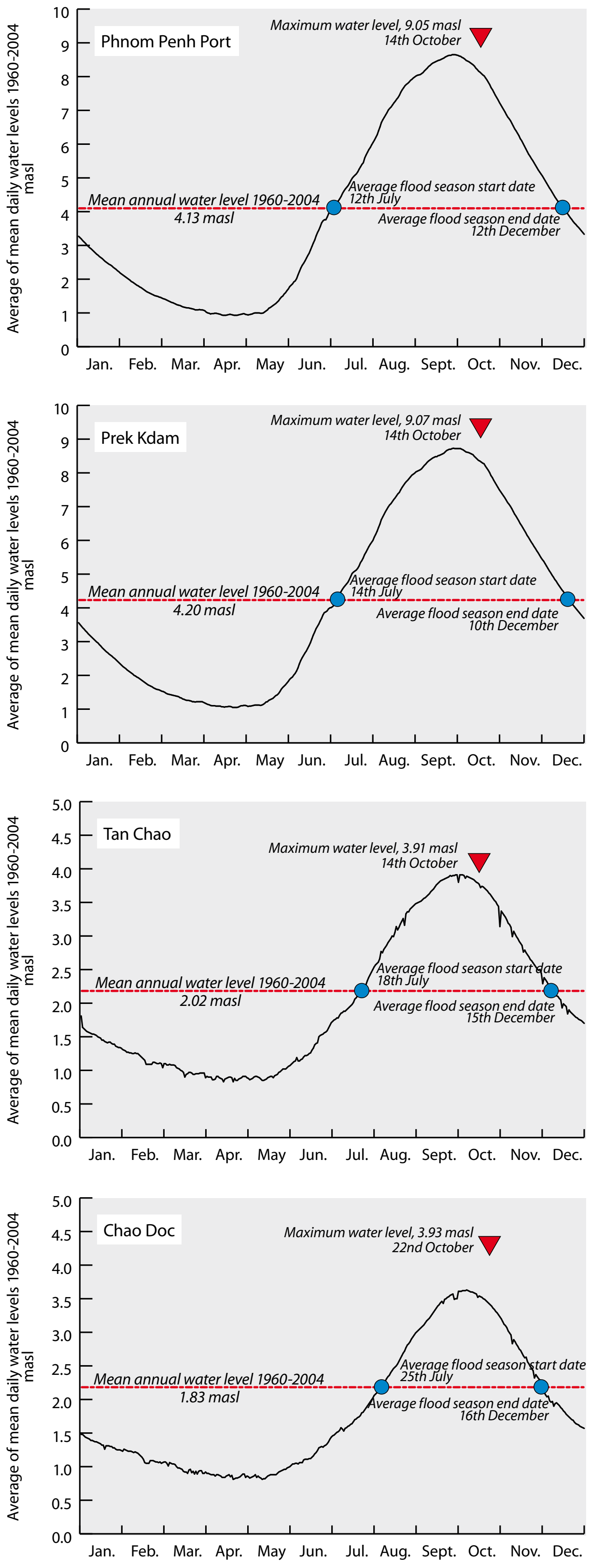


Figure 26. Long term distribution of daily water levels at Phnom Penh Port, Prek Kdam, Tan Chao and Chao Doc, the historical average onset and end dates of the 'flood season' and the comparative magnitude of the maximum water levels reached in 2006.

4. Cambodia 2006 Country Report

4.1 General situation

In Cambodia conditions during the 2006 flood season were below average both in terms of peak and volume. The flood peak was, in fact, amongst the lowest recorded over the last 80 or more years. The maximum discharge for the year occurred in mid August, after which water levels decreased considerably until early October and the passage across the region of Severe Tropical Storm Xangsane. This weather system generated a slightly lower second peak in mid October, an uncommon feature of the annual hydrograph. As a result of these below normal seasonal flows no significant crop losses were reported, with the exception of the fact that the unseasonally late second peak led to the inundation of some low lying areas. Some early flood recession rice plantings were lost and a second replanting was required.

No flood damage to infrastructure was recorded for the year.

4.2 Lessons learnt from a field trip to Kampong Cham, Kratie and Stung Treng—24th to 26th October 2006

- Kampong Cham: The major flood related issues here are river bank erosion, the regular loss of crops and damage to property, domestic and commercial disruption, low levels of social awareness of the flood hazard, inadequate institutional capacity to receive and disseminate flood warnings and inadequate investment in flood mitigation and rehabilitation measures.

- Kampong Cham: The present warning flood stage of the Mekong at Kampong Cham needs urgent review since in the recent past, during 2000, 2001, 2002, parts of the city were flooded despite the fact that the flood stage of 16.20 masl had not been reached. Frequency analyses of long term annual maximum water levels between 1930 and 2006 indicate that the flood warning stage of 15.20 masl has a return period of less than 4 years.

- Kratie: The western part of the town was flooded at a Mekong River level of 22.05 masl, noting that the flood level at the hydrometric gauge is 21.9 masl. (Appendix 2). The 2006 maximum flood did not reach the warning level at any of the villages equipped with flood referencing facilities. It would be useful to establish the flood marks from the most recent 2000–2002 floods at each village as reference levels for issuing flood warning.

- Kratie: The province has identified a total of 97 safe areas. Some provide emergency living accommodation during floods while others provide refuge for farm stock, which is generally the major family asset. Accessibility can be difficult during the dry season since access roads can be very poor. During the flood season, however, they are easily accessible by boat. One pilot site with an area of 55 ha has been identified and will be equipped with facilities such as water supply, sanitation and proper access roads.

- Stung Treng: The town has no protection from flood inundation, which is mainly caused by high water levels in the Mekong mainstream and backwater in three major local tributaries.
- Stung Treng:The strategic location of the Stung Treng hydrometric station at the head of the major part of the Cambodian floodplain downstream is a key element within the regional flood forecasting network. The reliability of the station is not, however, what it should be under these circumstances. Forecasting accuracy could be improved in conjunction with data observed at Siem Pang and Chant Ngoy on the Sekong, at Andaung Meas, Veun Sai and Ban Kamphun on the Se San and at the Lumphat on the Sre Pok. Some of these stations, however, have ceased to operate and transmit data due to poor maintenance schedules and a lack of investment
- Stung Treng. The reference levels used by the Regional Flood Management and Mitigation Centre at the Stung Treng are 10.7 masl for the alarm stage and 12.0 masl for the flood stage. These correspond to annual return periods of two and slightly less than fifteen years, which appears to be inconsistent and illogical.
- Stung Treng: Provincially, 116 flood refuges have been identified, though only a few are equipped with even basic facilities such as water supply and toilets. Effective evacuation to them during a flood emergency is a village responsibility, though the capacity to organise and coordinate the process is not well developed. Nor are the means in place to transmit prompt flood warnings to vulnerable villages.

5. Lao PDR 2006 Country Report

5.1 General situation

During 2006 localised flash flooding in Luang Namtha and Attapeu provinces were the only noteworthy flood incidents that occurred in Lao PDR (Figure 27). Events in Luang Namtha during the second week of August were in response to orographically induced monsoonal storms which produced 230 mm to 270 mm of rainfall over the first 10 days of the month. The flooding in Attapeu province during the first week of October was attributable to the incursion of Severe Tropical Storm Xangsane. Elsewhere the only meteorological episodes of any significance were local storms over Vientiane which caused brief urban flooding in March, May and October and a highly localised 'whirlwind' which moved at high speed through the Chanthabouly district of the capital at 7:25 pm on the 5th May, with wind speeds of over 100 kph (30 m/sec) causing severe structural damage to numerous buildings.

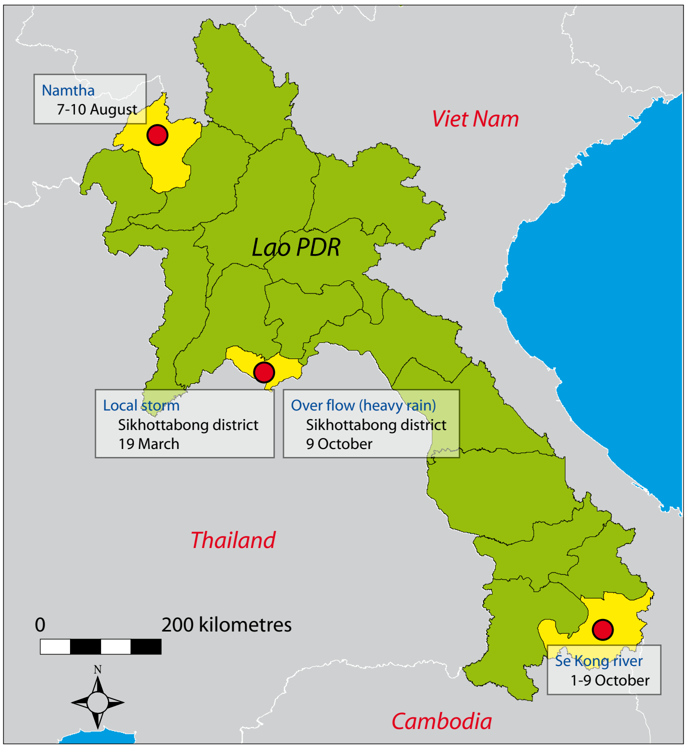


Figure 27. Lao PDR—provinces affected by flash floods and local storms during 2006.

5.2 Flash flooding in Luang Namtha province

The rainfall from the local monsoonal storms during early August reached maximum intensities on the 6th and 7th of the month, with totals in excess of 100 mm widely observed for the two days. In response the Luang Namtha River rose over 5 metres in 12 hours and inundated its natural floodplain to a depth of 1.2 metres and more. At Hongleuai hydrometric station the maximum water level of 13.25 m was more than 3 metres higher than the danger level. The resulting flash flood inundated 132 villages, and affected 1,916 households in the NamTha, Long, Sing, Viengphoukha and Nale districts. (Plates 1 and 2)

Plates 1 and 2. Army and police supervise the evacuation of residents of Dounamphanh village and locals begin to clear rubbish trapped in the Luang Namtha weir (August 2006).

5.3 Flash flooding in Attapeu province

Rainfall intensities in the upper Nam Xekong and Xekhaman catchments associated with incursion of Severe Tropical Storm Xansane during the first week of October over the south of Lao PDR are estimated from satellite imagery to have exceeded 100 mm in 12 hours. Water levels in the Xekong River at the Ban Veunkhen hydrometric gauge rose 9 metres in 48 hours and as a consequence inundation of the natural floodplain was rapid. The five provincial districts of Samakkhixay, Sanamxai, Phouvong, Xaisetha and Sanxai were affected by the flash flooding, with river water levels almost 1.5 metres above their critical levels. In all over 270 villages in Attapeu, Champassak and Saravan provinces were inundated to a greater or lesser degree (Plates and 4).

Plates 3 and 4. Samakkhixai district, Attapeu province—flash flooding during the first week of October associated with Severe Tropical Storm Xangsane.

5.4 Damage and impacts

This local flash flooding in the far north and far south of Lao PDR during May and October affected over 400 villages and 13,500 households, according to Ministry of Agriculture and Forestry and National Disaster and Management Organisation figures. Five people were killed and almost seven million hectares of rice and other crops were damaged (Appendix 6). There were some livestock losses and some damage to national infrastructure was recorded. Direct economic losses are estimated to have been US$3 million, which is a comparatively small figure and less than 20% of the economic losses incurred in 2005, which was not in itself a year of particularly severe or extensive flooding.

5.5 Lessons learnt

- The Department of Meteorology and Hydrology operational staff concerned with extreme weather events, typhoons, floods, flood monitoring and forecasting successfully consolidated their experience and expertise during the events of 2006.

- A meeting one month before the start of the monsoon season of the National Disaster Management Committee, with representatives drawn from 13 ministries, and with the aim of clarifying responsibilities and coordination was found to be most useful. A second annual post flood season meeting to assess the performance of the relevant agencies and ministries would have significant additional benefit.

- Effective medium and long-term flood forecasts are required to prepare the agricultural sector, the national flood management programme and the relevant national agencies for the management and mitigation of flood impacts.

- The weather, typhoon and flood forecasting skills as well as the procedures for issuing and disseminating flood warnings from the Department of Meteorology and Hydrology must continue to be improved from year to year. Official procedures to ensure even closer coordination between the Department, the mass media, relevant ministries and line agencies should be prepared.

- Knowledge and experience of flash floods and the ability to forecast them needs to be improved and the facility to communicate and disseminate warnings to high risk areas requires more consideration. A start lies in identifying, zoning and mapping these high risk areas.

- Close coordination with the Regional Flood Management and Mitigation Centre in Phnom Penh is essential and should be further reinforced.

6. Thailand 2006 Country Report

6.1 General situation

During 2006 Thailand was badly affected nationwide by floods from several storms, most particularly from Severe Tropical Storm Xangsane (which turned into a tropical depression in the country) and Tropical Storm Prapiroon. Out of 75 provinces, 46 were locally inundated. According to the Ministry of Public Health, the most affected provinces were Phra Nakhon Si Ayuttaya (South Central Region), Nakkon Sawan (Eastern Thailand and within the Mekong Basin) and Sukkothai. (Northern Region). Storms and local urban flooding in particular were a constant news feature from May onwards.

By mid-October, Thailand's Department of Disaster Prevention and Mitigation (DDPM) reported that 47 people had been killed, two were missing and more than 2.4 million people were affected to various degrees over the country as a whole (see Appendix 7). According to the Ministry of Education, a total of 378 schools in 21 provinces were affected, of which 310 were closed for significant periods of time. Approximate losses are estimated to be of the order of US$8 million (United Nations Office for the Coordination of Humanitarian Affairs, UNOCHA).

6.2 Specific events

In 2006 the rainfall intensity in May and October was the highest for 30 years.

At the beginning of August Tropical Storm Prapiroon passed over the South China Sea to the northern part of Thailand and created heavy rainfalls in the north, northern central region, the north east and the east coast of Thailand.

From 19th to 21th August the strong low pressure that passed over the northern and northeastern part of Thailand produced intense rainfall, this measured a maximum of 259 mm in Nan province and caused flash flooding of the Nan river. Water levels rose very quickly and created floods of 2–3 m at Amphoe Tha Wang Pha on the morning of 20th August, followed by 1–1.5 m floods at Amphoe Muang and Amphoe Phu Piang.

Between 27th August and 4th September a strong low pressure passed over the northern part of the country and brought heavy rainfall that caused water-levels in rivers in the Ping, Kuang, Tha, Yom and Wang river basins to rise very rapidly.

Shortly after this (from 9th to 12th September and from 18th to 23th September) another strong low pressure cell passed over the northern and north eastern part of the country. This combined with the southwestern monsoon and low pressure in the Southern China to become Severe Tropical Storm Xangsane. This depression generated very heavy rainfall in the southern area of the northern provinces and the central part of the country, bringing with it fast rising water levels and floods in many areas.

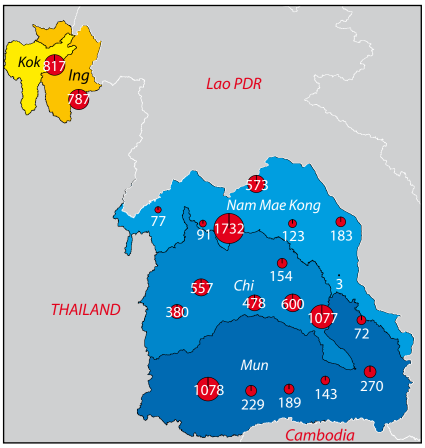


Figure 29. Flood affected areas (km^2).

Serious floods were experienced in the following sub basins of the Mekong River in Thailand in the year 2006:

1. Kok river basin: There were major floods in Chiang Rai province and Pa-yaw Province. In Chiang Rai about 159,617 rai or 255 km^2 was inundated, most of which was flat land located in Amphoe Muang, Maesai, Mae Chan, Pha Yam Eng Rai, Thueng and Padad. In Pa-yaw about 174,584 rai or 279 km^2 was inundated in Amphoe Chun, Chieng Kam, Dok Kam Tai and Phu Kam Yao.

2. Nam Mae Kong basin: One major flood occurred in Nong Khai and Udon Thani provinces with about 393,639 rai or 630 km^2 inundated.

3. Chi river basin: Major floods occurred in Chaiyaphum, Koonkaen, Masarakam, Roi-et and Yaso Thon provinces inundating about 1,271,814 rai or 2,026 km^2.

4. Mun river basin: Major flooding occurred in Nakhonrachasima, Buriram, Surin Srisakes and Ubon Rachathani provinces inundating about 2,101,470 rai or 3,362 km^2.

6.3 Flash flooding in the Thai Mekong region and bordering provinces

Incessant monsoonal storm rainfall, particularly during August and September, caused flash floods in Chiang Rai and Nan provinces, with three people killed or missing. The flooding in Nan was reported to be worst in more than 40 years (Bangkok Post, 13/9/2006), with general depths of inundation of between 1.20 –1.80 metres. In Chiang Rai four schools were closed for indefinite periods and more than 5,000 villagers were badly affected.

Flash floods in mid August caused the flooding of 500 houses and the inundation of 5,000 rai of farmland in Chiang Rai province alone. The loss of crops and therefore income reportedly caused the temporary migration of many rural family members to Bangkok to find work (Bangkok Post. 13/9/2006). Provincial public health authorities reported that stagnant floodwaters were a constant threat to public health and leading to significant outbreaks of conjunctivitis and leptospirosis (The Nation, 15/9/06).

An additional hazard associated with flash floods, particularly in the steeper landscapes of Chiang Rai province for example, are mud slides which annually threaten many villages. These not only threaten to cut rural communities off during times of flood emergency, such that relief aid cannot get through, but in many cases they threaten rural life and property directly. The prevalence of land and rock slides under saturated conditions during storm rainfall should be perceived as an integral part of the flash flood hazard, as they often temporarily block rivers and streams, are then over-topped, collapse and can release an extremely destructive flood wave.

Plate 5. Mid–August floods in Nan Province caused many families to retreat to the upper floors of their houses.

6.4 Damages and costs

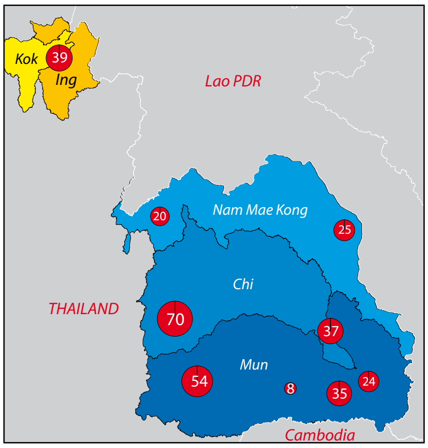


Figure 30. Cost of serious damage from flooding during 2006 (million baht).

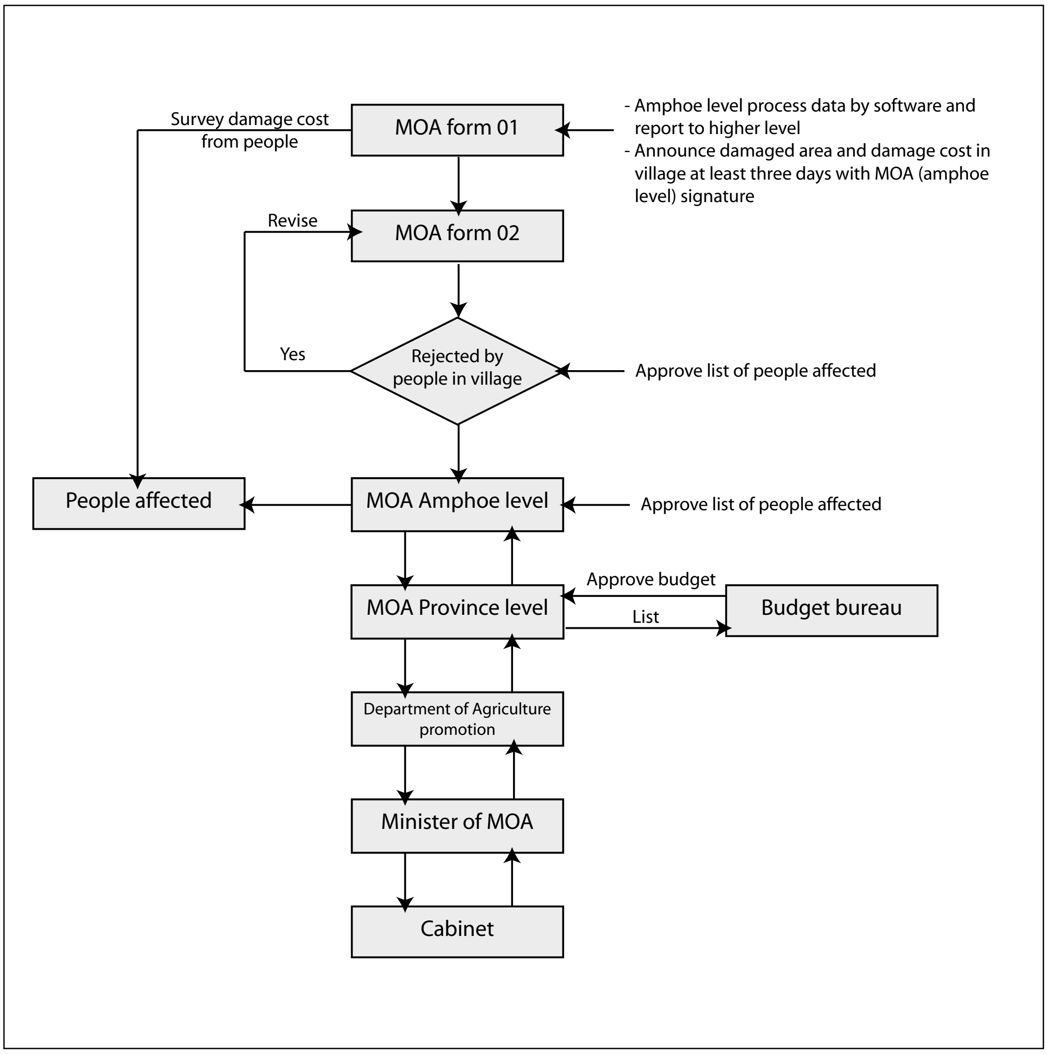


Figure 31. Example (draft) of the mitigation process in an agricultural area.

Table 3. *Government compensation for flooded agricultural land*

Type	Baht/rai	Per person
Agriculture		
Rice	243	
Crop	289	
Other plants	369	
Fisheries		
Farm ponds and paddy fields	1,400	Not more than 5 rai
Shrimp and shell fish	3,800	Not more than 5 rai
Freshwater fish	150	Not more than 80 m^2
Livestock (poultry)		
Traditional cock and hen rearing	22.50	Not more than 300
Commercial cock and hen rearing	15	Not more than 1000
Ducks	15	Not more than 1000

7. Viet Nam 2006 Country Report

7.1 Conditions over the Se San and Sre Pok River basins

Within these river basins the onset of significant monsoonal rainfall was later than normal and resulted in some un-seasonally low water levels. Few tributary floods were observed, there being only two of moderate magnitude:

- The mid August event (8th – 17th) followed widespread heavy and very heavy rains over most of the Sre Pok river basin, with accumulated storm depths during the 10 day period of 150 to 200 mm generally and as much as 250 mm to over 400 mm locally. The corresponding flood discharges in the Sre Pok and its tributaries exceeded alert level 2.
- The event of early October event (5th – 9th) which was in response to storms over the Central Highlands associated with Severe Tropical Storm Xangsane, with cumulative five day rainfall depths locally in excess of 180 mm. However, only low levels of flood alert were broadcast.

7.2 Flooding in the Mekong Delta

Plate 6. Tidally induced flooding during August and September 2006 in the lower Delta (Dong Thap province).

At the start of the 2006 flood season, during the last few days of June, the rise in water levels in the Delta regions was extremely rapid, a fact which can be appreciated by referring to the 2006 Kratie discharge hydrograph in Figure 15. Initial peak water levels were reached in early September, with water levels of 3.9 masl and 3.4 masl at Tan Chao and Chao Doc respectively, though these were only of the order of the seasonal average (Figure 24). This initial peak was followed by 20 days of declining water levels, followed by an increase in response to the effects of Severe Tropical Storm Xangsane. This second peak marked the highest water levels attained for the year, these being 4.2 m on 17th October at Tan Chao and 3.7 m at Chao Doc a few days later on the 21st October, annual maxima which were no more than average (Figures 24 and 26). These annual peaks were two weeks later than usual, as has already been noted, such that late October and early November water levels remained higher than normal. At Tan Chao the flood alert level was exceeded for a period of 20 days and the flood level reached (see Appendix 5), which resulted in the widespread inundation of agricultural lands. Flooding in the Lower Delta regions during August and September was generally tidally induced and short lived, except in areas where drainage capacities were poor (Plate 6).

7.3 Flood damage

Due to the fact that flood magnitudes during 2006 were average, damage was not widespread, but it was locally significant. In the Sre Pok and Se San river basins, in Dak Nong and Dak Lak provinces, almost 1,400 properties were inundated, including one school, and 800 households had to move temporarily. Crops were damaged over a total area of almost 5,800 hectares, almost all of which were planted to rice paddy and coffee. Total (write-off) crop losses were not significant, however. Farm stock losses were small. Damage to infrastructure such as roads, bridges, dykes and irrigation channels was relatively widespread but not untypical of that for an average year. Considerable damage and loss was associated with Severe Tropical Storm Xangsane during the first two weeks of October, though much of this was the result of very strong winds which brought about structural damage, cash crop losses and disruption to transport and communication.

In the Delta regions there were 55 deaths recorded that were linked to flooding and storms. Of these 50 were children. Total damage was estimated to be US$15 million, a significant factor in which was property losses due to bank erosion during the flood season (Plate 7).

Plate 7. Severe to total structural damage caused by riverbank erosion and soil saturation during flood conditions (Dong Thap province).

Major regional damage was brought about by Tropical Storm Durian during the first week of December, though most of this was the result of high winds and coastal storm surges and was not attributable to hydrological flooding or intense storm rainfall (see Durian rainfall map in Figure 20 and Plate 8). Over 6,000 households were urgently evacuated and more than 68,000 people moved to safe refuges.

Plate 8. Damage caused by Tropical Storm Durian in the Mekong Delta during the first week of December.

7.4 Lessons learnt

During the course of Tropical Storm Durian, most local authorities were found capable of implementing official mitigation directives and successfully carried out the necessary measures such as household evacuation and the recall of vessels at sea. Less experienced authorities were identified and institutional strengthening will be undertaken. A particular measure that was recognised as requiring attention was the need to encourage the strengthening of the roofs of domestic properties in order to reduce wind induced damage, which was the most significant factor associated with the storm losses.

- On the whole the cooperation of the local people with the authorities was commendable, though there were exceptions in some districts. These were often the result of complacency brought about by a third consecutive year of average flood and storm conditions.
- Local budgetary limitations meant that deteriorated and damaged flood protection infrastructure has not been systematically maintained and promptly repaired. Priority new schemes are often delayed due to difficulties in ground clearance and the relocation of households.
- The permanent relocation of highly vulnerable households from high risk areas and those undergoing active flood erosion continues to be difficult. Residents in such localities generally have poor living conditions and are unconvinced that their livelihoods can be sustained or bettered unless the new infrastructure and facilities provided for them are clearly far superior to their current situation.
- Local Steering Board for Flood and Storm Control staff may hold several positions and have a wide range of responsibilities, making timely data collection and processing less effective in an emergency.

- Wave and wind protection for local infrastructure lags behind that for hydrological flooding, which as the damage from Durian illustrated, requires attention in order to reduce the losses to national assets from tropical storms.

8. Summary Conclusions and Recommendations

8.1 Summary conclusions

Regionally, the flood season of 2006 saw below average conditions both in terms of flow volumes and peak discharges, most particularly on the lower mainstream downstream of Vientiane. To the north, however, flash flooding in Thailand and Lao PDR resulted in significant damage and loss. Deep monsoonal depressions that were largely confined to these northern provinces were generally responsible, though the wider regional impacts of Severe Tropical Storm Xangsane played a major role in early October, particularly in the south of Lao PDR. The major regional disaster in 2006 was the result of Tropical Storm Durian during December when extreme windspeeds and tidal surges caused immense damage in the Delta and southern coastal regions of Viet Nam.

8.2 Recommendations and lessons

The hydrological and water level data and information available for the mainstream are more than sufficient for a comprehensive assessment of the annual flood from year to year. Analyses of these historical data that have been reported here provide a framework for the objective and more perceptive evaluation of annual floods on the mainstream within their wider temporal and geographical context.

Tributary data analysis and information are far less complete at present, which amounts to a significant shortcoming, given the hazard of flash flooding in these river systems. The FMMP T2 Flood Risk Mapping Project on the Nam Mae Kok in northern Thailand is a recognition of this. Its modest extension to provide a regional flood risk analysis for the tributary systems upstream of Vientiane in both Thailand and Lao PDR would provide substantial 'add on' value. The HYCOS Project will also contribute much to the understanding of the flood hydrology of these tributary rivers.

In the longer term HYCOS will also add to the meteorological knowledge base and the nature of the linkages between regional storm rainfall and flood runoff. For the present purposes of the Annual Flood Report, however, daily satellite based rainfall estimates at the regional scale are sufficient and appropriate.

Finally, it is recommended that the Annual Flood Report be 'theme' based. Here the emphasis is on data analysis and the temporal and spatial nature of floods and flooding in the Mekong region. Such material provides an important supplement to the framework of knowledge within which the FMMP is being undertaken as well as contributing basic insight into the regime of the Mekong that are a necessary in many other contexts, for example the assessment of the environmental impacts of basin development. Other annual themes that should be considered are the socio-economic benefits and dis-benefits of the flood regime, meteorological aspects and the potential consequences of climate change, including links with ENSO. The report should also provide a medium for reporting FMMP progress in the interests of dissemination to the wider audience and stakeholders.

9. References

Adamson, P.T., Metcalfe, A.V. and B. Parmentier (1999) Bivariate extreme value distributions: An application of the Gibbs Sampler to the analysis of floods. *Water Resources Research* **35** (9). pp 2825 – 2832.

Anderson, R.J., dos Santos, N. and H.F. Diaz. (1993). An analysis of flooding in the Parana/Paraguay River Basin. Laten Dissemination Note 5. Latin America and Caribbean Technical Dept. Environment Division. World Bank. Washington DC.

IAHS (2003) World Catalogue of Maximum Observed Floods (ed: R. Herschy). IAHS Publ. 284. IAHS Press, Wallingford, UK. (see also the introduction by John Rodda at http://www.cig.ensmp.fr/~iahs/redbooks/a284/28400e.htm and the review by Zbyszek Kundzewicz in IAHS newsletter 79, January 2004 at http://www.cig.ensmp.fr/~iahs/newsletters/news79/NL79.pdf).

Fumihiko, I. and Dang Van To (1997) Flood and Typhoon Disasters in Viet Nam in the Half Century Since 1950. *Natural Hazards* **15(1).**

O'Connor, J.E. and J.E. Costa (2004) The world's largest floods, past and present—Their causes and magnitudes. *U.S. Geological Survey Circular 1254*, 13 pp.

Linhart, H. and W. Zucchini (1984) *Model Selection*. John Wiley Series in Applied Probability and Mathematical Statistics. New York.

Penny, D. (2006) The Holocene history and development of the Tonle Sap, Cambodia. *Quaternary Science Reviews* **25**, 310-322.

Shroder, J.F. Jr., Cornwell, K., and M.S. Khan, (1991) Catastrophic breakout floods in the western Himalaya, Pakistan. *Geological Society of America Abstracts* **23(5)**, p. 87.

Webby, B., Adamson, P.T., Boland, J., Howlett, P. and A.V. Metcalfe (2006) Conditional Value at Risk (CVaR) analysis of flooding in the Lower Mekong Basin. In: *Proceedings of the 3rd IAHS International Symposium on Integrated Water Resources Management.* Ruhr University, Bochum. Germany.

Appendix 1. Statistical Analysis of Annual Flood Risk on the Mainstream Mekong

This appendix contains the results of a statistical analysis of the distribution of annual flood risk along the Mekong mainstream. Both flood volumes and annual maximum flood peaks are considered. The flood volumes with a given annual risk of occurrence are provided both in terms of above and below normal values with an annual recurrence interval, as described in Part 2.2 and specifically in Figure 6. The flood peaks are given only as the distribution of extremes in excess of the annual mean value.

The results of an indicative statistical analysis of the annual maximum water levels at Phnom Penh Port, Prek Dam, Tan Chau and Chao Doc are also presented.

For the estimation of the quantiles of all variables, a General Extreme Value Distribution was employed, estimated using Probability Weighted Moments and using the univariate model selection criteria described in Linhart and Zucchini (1984).

A1.1 Mekong mainstream: recurrence intervals of annual flood volumes

Chiang Saen (1923–2006)[1]

	Recurrence Interval (years)										
	100	50	20	10	5	2	5	10	20	50	100
Annual flood volume (km^3)	29.8	32.7	37.1	41.3	46.7	56.0	69.2	78.5	86.1	97.0	105.9

Luang Prabang (1939–2006)

	Recurrence Interval (years)										
	100	50	20	10	5	2	5	10	20	50	100
Annual flood volume (km^3)	35.2	41.1	50.1	58.2	68.1	83.1	106.4	114.7	121.6	128.7	133.4

Chiang Khan

	Recurrence Interval (years)										
	100	50	20	10	5	2	5	10	20	50	100
Annual flood volume (km^3)	49.6	55.6	64.4	72.2	82.0	91.2	111.1	125.2	135.1	154.6	160.0

---

[1] The 1966 flood at Chiang Saen combined a 100 year return period flood volume of 104.1 km^3 with a historically unprecedented flood peak discharge of 23,500 cumecs.

Vientiane/Nong Khai (1913–2006)

	Recurrence Interval (years)										
	100	50	20	10	5	2	5	10	20	50	100
Annual flood volume (km^3)	50.3	55.8	64.4	72.2	82.0	100.1	121.7	132.8	140.3	165.0	178.3

Nakhon Phanom (1923–2006)

	Recurrence Interval (years)										
	100	50	20	10	5	2	5	10	20	50	100
Annual flood volume (km^3)	79.6	91.2	108.8	124.5	143.7	180.4	214.8	230.7	242.3	253.9	260.3

Mukdahan (1923–2006)

	Recurrence Interval (years)										
	100	50	20	10	5	2	5	10	20	50	100
Annual flood volume (km^3)	91.3	103.8	122.5	139.0	158.7	193.6	226.8	241.2	251.5	260.2	269.0

Khong Chiam (1966–2006)

	Recurrence Interval (years)										
	100	50	20	10	5	2	5	10	20	50	100
Annual flood volume (km^3)	96.7	109.9	130.0	148.1	170.4	212.7	254.3	274.6	289.0	304.4	313.8

Pakse (1923–2006)

	Recurrence Interval (years)										
	100	50	20	10	5	2	5	10	20	50	100
Annual flood volume (km^3)	123.7	138.9	161.5	181.5	205.4	240.2	287.5	305.7	318.4	330.4	338.2

Stung Treng (1950–2006)

	Recurrence Interval (years)										
	100	50	20	10	5	2	5	10	20	50	100
Annual flood volume (km^3)	168.3	184.8	210.3	233.6	262.5	320.0	377.7	407.8	431.2	454.0	468.4

Kratie

	Recurrence Interval (years)										
	100	50	20	10	5	2	5	10	20	50	100
Annual flood volume (km^3)	172.5	190.4	217.7	242.6	273.4	333.7	394.2	424.6	447.5	470.6	483.4

A1.2 Mekong mainstream: recurrence intervals of annual flood peak discharge.

Chiang Saen (1960–2006)[2]

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual flood peak (cumecs)	10 000	13 000	14 500	16 000	18 000	20 000

Luang Prabang (1939–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual flood peak (cumecs)	15 000	17 500	19 500	20 500	22 000	23 500

Chiang Khan (1976–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual flood peak (cumecs)	16 000	18 500	20 000	21 500	23 000	24 500

Vientiane/Nong Khai (1913–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual flood peak (cumecs)	16 500	19 000	21 000	22 500	24 000	26 000

---

[2] The 1966 flood at Chiang Saen combined a 100 year return period flood volume of 104.1 km3 with a historically unprecedented flood peak discharge of 23,500 cumecs. This would be regarded as an 'outlier' event, that is one outside of the main body of the historical data observed over the last 47 years.

Nakhon Phanom (1924–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual flood peak (cumecs)	26 000	30 000	32 000	33 000	34 500	36 000

Mukdahan (1923–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual flood peak (cumecs)	29 000	32 500	34 500	36 000	38 000	39 500

Khong Chiam (1966–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual flood peak (cumecs)	34 000	40 000	43 000	45 000	48 000	50 000

Pakse (1923–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual flood peak (cumecs)	37 000	42 000	45 000	49 000	53 000	56 000

Stung Treng. (1950–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual flood peak (cumecs)	50 000	55 500	60 000	64 000	69 500	74 000

Kratie (1924–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual flood peak (cumecs)	52 000	58 000	63 000	68 000	74 000	78 500

A1.3 Cambodian floodplain and Mekong delta: indicative analysis of the recurrence intervals of annual maximum water level (masl)

Phnom Penh (1960–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual maximum water level (masl)	8.9	9.4	9.8	10.2	10.7	11.1

Prek Kdam (1960–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual maximum water level (masl)	9.1	9.6	9.9	10.0	10.2	10.4

Tan Chao (1980–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual maximum water level (masl)	4.3	4.7	4.8	5.0	5.1	5.2

Chao Doc (1980–2006)

	Recurrence Interval (years)					
	2	5	10	20	50	100
Annual maximum water level (masl)	3.8	4.3	4.5	4.6	4.7	4.9

Appendix 2. Rating Equations and Flood Alarm Levels

Data in this appendix may be used to convert discharge to water level and vice versa. For example, the annual maximum discharges with a given recurrence interval tabulated in Appendix 1 can be converted to a maximum annual water level with the same annual risk of occurrence. This figure can then be compared with the flood alarm levels reported in A2.2, for example:

A 2.1 *Current rating equations for the hydrometric stations on the Mekong mainstream*

Mainstream Site	Coefficient			Gauge Zero m.msl	Equations	
	a	b	c		Q →→ H	H →→ Q
Chiang Saen	0.838	1.892	132.7	357.1	H = (Q/c)**(1./b)-a	Q = c*(H+a)**b
Luang Prabang	1.38	2.16	29.83	267.2	≈	≈
Chiang Khan	6.805	3.545	0.347	194.1	≈	≈
Vientiane	5.99	2.72	7.14	158.0	≈	≈
Nong Khai	6.29	3.02	2.53	153.6	≈	≈
Nakhon Phanom	1.526	1.533	562.0	131.0	≈	≈
Thakhek	1.09	1.83	273.8	129.6	≈	≈
Savannakhet	2.97	1.91	217.66	125.4	≈	≈
Mukdahan	1.7 3	1.81	271.0	124.2	≈	≈
Khong Chiam	0.67	1.51	527.3	89.0	≈	≈
Pakse	1.60	1.70	454.7	86.5	≈	≈
Stung Treng*	-0.94	1.49	1839.0	36.8	≈	≈
Kratie**	Rising Stage			-1.08	H = (Q**(1./2.1)+10.16) / 8.16	Q = (8.16*H-10.16) ** 2.1
	Falling Stage				H = (Q**(1/2.5) – 1.26) / 3.3	Q = (3.3*H +1.26) ** 2.5

* Old rating

** Mekong at Kratie (WUP-JICA, 2004), Draft Final Report, Main Report Volume-I, p.II-36

A 2.2 *Flood alarm levels for the hydrometric stations on the Mekong mainstream*

Mainstream location	Flood Alarm Level		Flood Level	
	Water level (masl)	Discharge. (cumecs)	Water level (masl)	Discharge. (cumecs)
Chiang Saen	368.6	15 400	368.9	16 000
Luang Prabang	284.7	17 000	285.2	18 000
Chiang Khan	211.4	23 200	211.5	23 500
Vientiane	169.5	17 100	170.5	19 900
Nong Khai	165.0	14 800	165.8	16 900
Nakhon Phanom	145.3	38 500	145.4	38 800
Mukdahan	136.7	33 000	136.8	33 500
Khong Chiam	105.0	36 900	105.2	37 600
Pakse	97.5	34 700	98.5	38 500
Stung Treng	48.5	63 400	48.8	66 000
Kratie	20.9	47 300	21.9	52 400
Phnom Penh Port	9.5	-	11.0	-
Prek Kdam	9.6	-	10.1	-
Tan Chao	3.0	-	4.2	-
Chao Doc	2.5	-	3.5	-

Appendix 3. Mekong Mainstream: Summary Hydrological Statistics for the 2006 Flood Season

A3.1 *Mekong mainstream: summary hydrological statistics for the 2006 flood season*

Location	Date of onset of flood season	Date of end of flood season	Maximum water level. (masl)	Maximum discharge. (cumecs)	Date of maxima	2006 Flood volume (km^3)
Chiang Saen	*5th June*	30th Oct	366.9	11 600	14th Oct	45.9
Luang Prabang	12th July	1st Nov	282.6	13 200	14th Oct	68.2
Chiang Khan	27th June	7th Nov	207.6	15 000	15th Oct	88.0
Vientiane	29th June	5th Nov	168.8	15 400	1st Sep	91.4
Nong Khai	*15th July*	31st Oct	164.5	*13 500*	31st Aug	-
Nakhon Phanom	1st July	7th Nov	141.6	25 700	31st Aug	175.2
Mukdahan	3rd July	1st Nov	134.7	25 300	31st Aug	188.6
Khong Chiam	4th July	5th Nov	101.5	25 800	31st Aug	193.2
Pakse	4th July	4th Nov	97.0	31 300	31st Aug	223.0
Stung Treng	3rd July	8th Nov	47.0	-	18th Aug	-
Kratie	6th July	1st Nov	20.1	36 900	18th Aug	256.6
Phnom Penh Port	-	-	9.05	-	3rd Sep	-
Prek Kdam	-	-	9.07	-	14th Oct	-
Tan Chao	-	-	4.2	-	17th Oct	-
Chao Doc	-	-	3.7	-	21st Oct	-

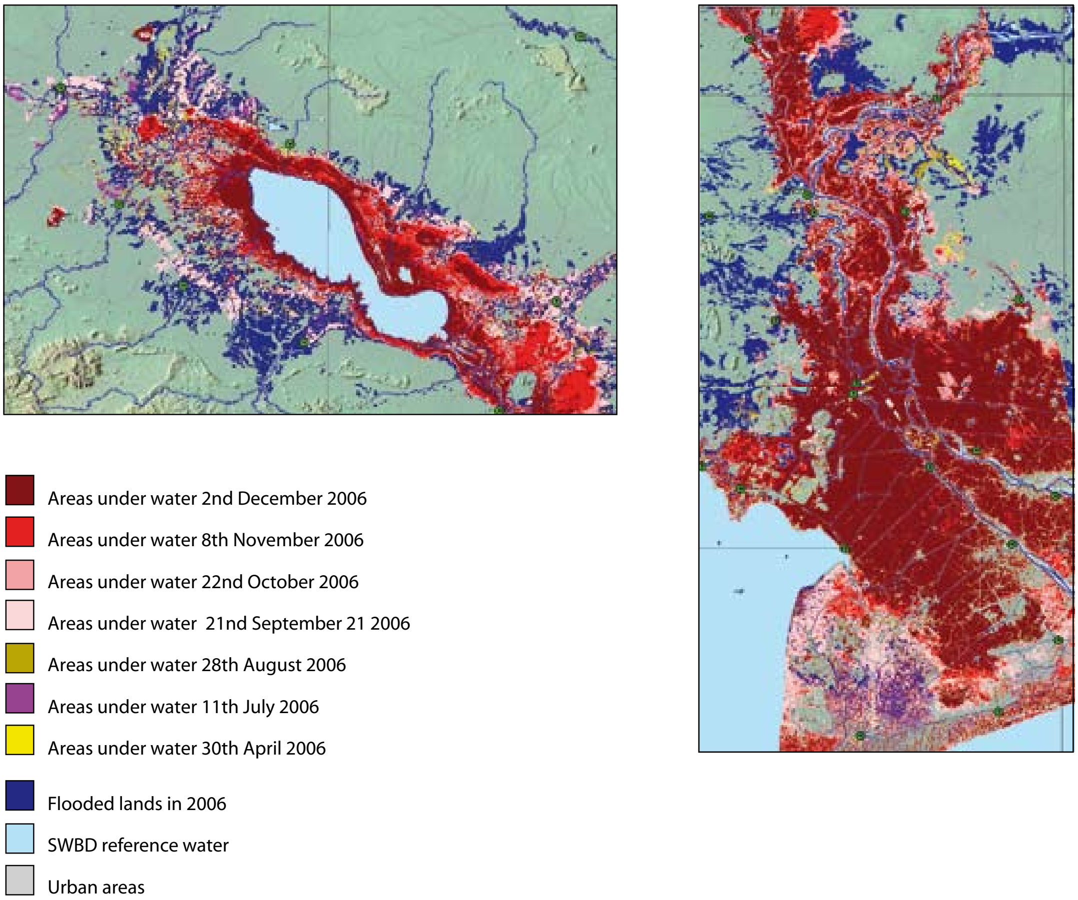
Note: Anomalous figures in italics

Appendix 4. Cambodia: 2006 Flood Loss and Damage Data

A4.1 *Cambodia: assessed flood damage—2006*

Total affected area (ha)		Crop damage (ha)				Total damage (ha)		Recovered (ha)
		Insect/disease		Flood				
seedling	trspl/frcast	seedling	trspl/frcast	seedling	trspl/frcast	seedling	trspl/frcast	trspl/frcast
	9,249				7		7	
379	2,487				1,549		1,549	
	827		5		15		20	
130	3,573		9		190		199	97
591	14,525			217	2,183	217	2,183	
	27,363				662		662	
917	4,910		10	50	1,217	50	1,227	524
	3,749				1,412		1,412	
	2,277				366		366	190
	1,609				169		169	
	1,742				743		743	
					400		400	
	8,616							
	5,307			24	1,075	24	1,075	
	2,653		106		1,198		1,304	1,190
	786		30		214		244	
3,026	235	5				5		
3,174	15,381							
	1,165				41		41	41
8,217	106,569	5	160	291	11,441	296	11,601	2,042

Appendix 5. Extent of the 2006 Flood in the Great Lake/ Tonle Sap System and in the Mekong Delta



Data processing : Hatfield Consultants, Feb 2007 – based on satellite imagery provided by the Canadian Space Agency, 2006

Background image copyright 2006 -
Dartmouth Flood Observatory, Dartmouth College Hanover, NH 03755 USA
Elaine K. Anderson and G.R. Brankenridge

Figure A5 1. Extent of the 2006 Flood in the GreatLake/Tonle Sap System (left) and Mekong Delta (right) of Cambodia and Viet Nam.

Appendix 6. Lao PDR: 2006 Flood Loss and Damage Data

A6.1 *Lao PDR: assessed flash flood damage—2006*

Description	Assessment methodology is based on data reporting from Provincial Agriculture and Forestry Offices, Ministry of Agriculture and Forestry and the National Disaster Management Organisation.
Provinces affected	Luangnamtha, Attapeu, Xekong Saravan and Champassak
Districts affected	20
Villages affected	404
Houses affected	13.549
Houses damaged	21 houses and 17 farmer’s rice stock swept away
People affected	89.849 persons
Home ware	1.352 units
People killed	5
Agriculture	
Hectares of rice and other crops damaged	6.913, 22
Livestock	
Cattle	298 head (buffalos, cows, pigs) lost
Poultry	5.912 head lost
Fishponds and aquaculture	168 sites and 98.2 ha damaged
Infrastructure	
Schools	13 sites affected - 1 primary school was closed, 5 classrooms damaged and 175 students affected (Luangnamtha province). - 1 elementary school affected (Saravan Province) - 10 primary and 1 elementary schools affected: 75 desks, 75 chairs, 481 steel roofs damaged (Attapeu province)
Health centres	3 sites affected
Markets	Namtha market inundated to a depth of 0.6 metres
Boats damaged or lost	21
Bridges damaged	2 in Xekong and Attapeu Provinces.
Road damage	12 sites in Luangnamtha and numerous lengths of road in Xekong and Attapeu Provinces. In Saravan Province 3.8 km badly eroded.
Irrigation	259 sites. Damage to reinforced concrete, masonry weirs, gabion and traditional earth weirs.
Headworks damaged	20
Canal systems damaged	8 km

Appendix 7. Thailand: 2006 Flooded Districts and Estimated National Loss and Damage

A7.1 *Thailand: flooded districts—2006*

Province	No. of flooded districts	Maximum flood depth (m)	Date of provincial flooding
Chiang Rai	18	1.2-1.5	1 Jul – 29 Jul
Loei	7	1.5	
Nong Khai	10	2	7 Aug – 26 Sep
Nakhon Phanom	13	2	15 Aug – 3 Oct
Mukdahan	5 (149 villages)	2	
Amnat Charoen	5	1.5	15 Aug – 17 Sep
Ubon Ratchathani	20	2	15 Aug – 29 Sep

A7.2: *Thailand: national flood damage and losses—October 2006*

Description	Assessed losses and damage (October. 2006)
Areas affected (number of districts/villages)	32 provinces (217 districts; 1,302 sub-districts; 7,372 villages)
Total population affected	2,212,413 persons of 605,401 households
No. of flood-related deaths	164 deaths (149 drowned; 10 electrocuted; 2 snake bite; 3 other)
No. of people suffering from flood-related diseases	591,968 persons (261,790 fungal infection to foot; 84,401 rash/itch; 65,562 cold; 38,463 stress; 12,225 poisonous animal bite; 10,597 diarrhoea; 98,882 others)
Estimated number of houses and property damaged	54 houses totally damaged 9,137 houses partially damaged 5,241 roads and 326 bridges destroyed 3,007,431 rai or 481,189 hectares of farmland destroyed (6.25 rai = 1 hectare) 35,152 fish ponds and 1,132 schools/ temples destroyed Cost of damages to government structures such as roads and bridges from initial surveys estimated at US$9.94 million. This figure does not include damages to farmland, houses and personal belongings.
Public health interventions (surveillance, immunisation, sanitation, etc.)	Rapid Surveillance and Response Team at regional, provincial and district levels for communicable diseases. Public toilets both on land and floating provided to the victims.

Source: WHO SE Asia Regional Office Website

Appendix 8. Viet Nam: National Flood Warning and Alarm Levels and 2006 Flood Loss and Damage Data

A8.1 Viet Nam: National flood warning levels

Warning (Alarm) Level I: Flood stage reaches flood protection dike footing. Potential inundation of low lying unprotected areas. Initial warnings issued to local authorities.

Warning (Alarm) Level II: Flood stage reaches dike body or inundation risk to unprotected populated areas with associated risk of property damage

Warning (Alarm) Level III: Flood stage close to dike crest elevation threatening serious inundation and threat to life, property and economic activity

Emergency Warning Level: Flood stage exceeds dike crest elevation.

A8.2 *2006 Total monthly seasonal rainfall in the Se San and Se Kong region and the Mekong Delta*

Month	Year	Stations															
		Kon Tum	SakTo	Pleicu	BM Thuot	Buon Ho	Suc Xuyen	Cau 14	Ban Son	Chau Soc	Moc Hoa	Rach Gia	Cao Lanh	My Tho	Can Tho	Soc Trang	Cang Long
		Monthly Rainfall (mm)															
May	2006	368	182	152	262	169	319	239	178	102	45	386	145	116	208	82	149
	Mean	236	233	249	245	185	251	26	208	159	171	211	135	167	176	224	161
Jun	2006	175	96	202	226	156	240	168	176	113	239	381	190	223	139	388	247
	Mean	257	301	346	220	267	290	252	227	108	146	288	172	198	220	283	187
Jul	2006	669	487	649	217	398	180	190	168	96	215	416	201	94	176	243	198
	Mean	288	309	388	284	186	280	220	224	139	204	376	207	202	241	307	242
Aug	2006	499	470	526	406	372	360	334	283	235	181	279	199	284	148	369	171
	Mean	315	425	471	311	217	308	218	247	172	166	347	181	162	252	296	241
Sep	2006	421	353	338	365	348	273	280	255	145	372	526	359	355	307	249	180
	Mean	295	287	360	283	248	313	272	261	148	219	266	208	245	243	273	220
Oct	2006	115	112	202	157	250	136	148	195	239	218	232	274	191	295	130	231
	Mean	166	163	182	125	215	247	246	201	255	372	285	312	270	291	319	332
		Seasonal Total (May – October)															
	2006	2247	1699	2068	1634	1692	1509	1359	1255	930	1268	2220	1368	1263	1273	1463	1176
	Mean	1556	1719	1997	1469	1318	1690	1234	1368	981	1277	1774	1215	1244	1422	1701	1383

A8.3 *Provincial flood damage for 2006.*

Flood Damage	Kon Tum	Gia Lai	Dak Lak	Dak Nong	Long An	An Giang	Dong Thap	Vinh Long	Can Tho	Hau Giang	Total
Loss of Human Life											
Total drownings					6	21	11		6	11	55
Children					5	19	10		5	11	50
Adult					1		1		1		3
Other						1					2
Domestic											-
Inundated house					450	4					454
Collapsed house						2					2
Uninhabitable house	5	67	1,160	204		26		1814			3,276
Evacuated people	10			16	160						186
Inundated school	139			18	7						164
Agriculture											-
Inundated	1			1		200		30			232 ha
Irrigation											-
Canal embankment erosion	16				49	4.5	45	4			119 km
Eroded soil	20						62				82 10^3 m^3
Canal siltation	126	23,3	5,059	347,7	18			486			5,689 km
Traffic											-
Inundated road			0,012		119	56.0	17	87			279 m
Road erosion					86	348.0					434 m
Eroded soil				1,218			9				1,227 10^3 m^3
Bridges damaged					7						7
River Bank erosion											-
Embankment erosion		30		3,150			165				3,345 km
Eroded area		32,28	6	453		76.5	32				567 ha
Dangerous house	7,100						4,735				11,835
Evacuated house	1		1	16		619.0					637
Collapsed house						4.0					4
Total Damage Estimate					2		12.67		0.42		US$ 15 million

A8.4 *Provincial damage caused by Tropical Storm Durian during the first week of December*

Damage	Tien Giang	Ben Tre	Tra Vinh	Vinh Long	Can Tho	Dong Thap	Long An	An Giang	Total
Human									
Killed	0	15		4					19 persons
Missing	4								4 persons
Injured	24	492		68	4	1	2	2	593 persons
Evacuated persons	1123	720	257					2381	4481 persons
Evacuated households	16933	3588	694					7841	29056
Domestic, commercial and industrial									
Collapsed houses	5702	29048	830	5294	55	96	66	4	41095
Severely damaged houses	8137	92600	2352	16031	1125	437	176	208	121066
Commercial roof damage		250	11	25		4			290
Collapse of commercial premises	17		5	10					32
Public heath centre roof damage		39		21	2				62
Collapsed public health centres				4					4
Collapsed industrial premises			3	232				1	236
Industrial roof damage		457	8	160					625
Public market roof damage	1	27	1						29
Education									
Collapsed class rooms		96	3	7					106
Roof damage and unusable classrooms	221	1416	32	204	12	26	3	6	1920
Other school premises damaged						625			625
Affected students						332000	108257		440257
Electrical Services									
Collapsed or damaged transmission poles	235	4017	139	225	27	4	88	4	4739
Collapsed sub-stations			6		7				13
Agriculture									
Inundated paddy field	2103	17267	3033	500			3000		25903 ha
Damage crop	1140	998	128	73		0.2			2339.2 ha
Damage orchard	63607	15515	524	2552		4.5			82203 ha
Damage industrial crop (sugar-cane, rubber tree, pepper tree)	493	6160	6160	135					12948 ha
Felled verdure	294		235		131				660 ha
Felled coconut-tree		12295	23						12318 ha
Damaged sylviculture crop area		80							80 ha
Irrigation									
Eroded systems		4							4
Telecommunications									
Damaged telephone poles				715					715
Fishery									
Fishing vessels lost	51	50	1	1			1	1	105
Small boats lost			4	23	2		9		38
Fishing rafts lost	37			24	3				64
Total estimate of damage									Not available

Appendix 9. Largest meteorological floods for global river basins larger than half a million square kilometres

A9.1 *Largest meteorological floods for global river basins larger than half a million square kilometres (R: rainfall, S: snow melt, RS: combination).*

River basin	Country	Hydrometric station	Latitude	Area. 10^3 km^2	Peak discharge. Cumecs	Specific discharge. Cumecs/km^2	Flood type
Amazon	Brazil	Obidos	1.9S	4640	370 000	0.08	R
Nile	Egypt	Aswan	24.1N	1500	13 200	0.009	R
Congo	Zaire	Brazzaville	4.3S	3475	76 900	0.022	R
Mississippi	USA	Arkansas Ciry	33.6N	2928	70 000	0.024	R
Amur	Russia	Komsomolsk	50.6N	1730	38 900	0.022	R
Parana	Argentina	Corrientes	27.5S	1950	43 070	0.022	R
Yenisey	Russia	Yeniseysk	58.5N	1400	57 400	0.041	S
Ob	Russia	Salekhard	66.6N	2430	44 800	0.018	S
Lena	Russia	Kasur	70.7N	2430	189 000	0.078	S
Niger	Niger	Lokoja	7.8N	1080	27 140	0.025	R
Zambesi	Mozambique	Tete	16.2S	940	17 000	0.018	R
Yangtze	China	Yichang	30.7N	1010	110 000	0.109	R
Mackenzie	Canada	Norman Wells	65.3N	1570	30 300	0.019	S
Chari	Chad	N'Djamena	12.1N	600	5160	0.009	R
Volga	Russia	Volvograd	48.5N	1350	51 900	0.038	S
St Lawrence	Canada	La Salle	45.4N	960	14 870	0.015	S
Indus	Pakistan	Kotri	25.3N	945	33 280	0.035	RS
Syr darya	Kazakhstan	Tyumen-Aryk	44.1N	219	2730	0.012	RS
Orinoco	Venezuela	Pte Angostura	8.1N	836	98 120	0.117	R
Murray	Australia	Morgan	34.0S	1000	3940	0.004	R
Ganges	Bangladesh	Hardings Br	23.1N	950	74 060	0.078	RS
Euphrates	Iraq	Hit	34.0N	264	7366	0.028	RS
Orange	South Africa	Buchuberg	29.0S	343	16 230	0.047	R
Huang he	China	Shanxian	34.8N	688	36 000	0.052	R
Yukon	USA	Pilot Station	61.9N	831	30 300	0.036	S
Senegal	Senegal	Bakel	14.9N	218	9340	0.043	R
Colorado	USA	Yuma	32.7N	629	7080	0.011	R
Rio grande	USA	Roma	26.4N	431	17 850	0.041	RS
Danube	Romania	Orsova	44.7N	575	15 900	0.028	S
Mekong	Cambodia	Kratie	12.5N	646	66 700	0.103	R
Tocantins	Brazil	Itupiranga	5.1S	728	38 780	0.053	R
Columbia	USA	The Dalles	45.6N	614	35 100	0.057	S
Darling	Australia	Menindee	32.4S	570	2840	0.005	R
Brahmaputra	Bangladesh	Bahadurabad	25.2N	636	81 000	0.127	RS
San Francisco	Brazil	Traipu	9.6S	623	15 890	0.026	R
Amu darya	Kazakhstan	Chatly	42.3N	450	6900	0.015	RS
Dneiper	Ukraine	Kiev	50.5N	328	23 100	0.070	S

Source: O'Connor and Costa (2004)

Mekong River Commission

P.O.Box 6101, 184 Fa Ngoum Road, Unit 18, Ban Sithane Neua,
Sikhottabong District, Vientiane Lao PDR

Telephone: (856) 21 263 263 **Facsimile:** (856) 21 263 264
E-mail: mrcs@mrcmekong.org **Website:** www.mrcmekong.org