Mekong River Commission

Annual Mekong Flood Report 2009

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Editor: D. Kean
Graphic design editor: S. Cheap
Contribution author: P.T. Adamson, S. Hak, P. Phouliphanh, B. Buasuwan, M.T. Vu

Office of the Secretariat in Phnom Penh (OSP)
576 National Road # 2, Chak Angre Krom
P.O. Box 623, Phnom Penh, Cambodia
Telephone: (855-23) 425 353, Facsimile: (855-23) 425 363
E-mail: mrcs@mekong.org
Website: www.mrcmekong.org

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Summary

The annual flood pulse in response to the South West Monsoon during the months between July and October is the key hydrological characteristic of the Mekong River and drives the high ecosystem productivity in the Lower Mekong floodplains, both in the Cambodian lowlands and the Delta in Viet Nam. Climate change has the potential to modify the water balance of the river basin which, combined with higher sea levels, could have considerable physical and socio-economic implications. Changes in the frequency and amplitude of seasonal flooding driven by higher monsoon rainfall and stronger back-water effects will have significant implications for tropical wetlands and fisheries. The social implications are considerable. For example, some studies forecast that a one meter increase in mean sea level will see 15,000 km^2 to 20,000 km^2 of the Mekong Delta flooded and up to 14 million people exposed to annual flood inundation. Given that the delta is one of the world's most important regions for global rice production for export and is a key element in the economic wealth of Viet Nam, adaptation to climate change is clearly a developmental issue..

The theme of the 2009 Annual Flood Report is '*The Potential Impacts of Climate Change on the Flood Regime of the Mekong.'* The report begins with a review of the main regional studies that have been undertaken in recent years. There is broad agreement on the direction of the changes to the rainfall climate and the subsequent hydrological consequences that are likely to occur. There is less agreement with regard to the magnitude of the changes, which is not surprising. The two most common predicted findings are: an increase in the inter-annual variability of the SW monsoon; and an increase in the incidence of severe tropical weather systems such as typhoons. The latter have historically been associated with some of the most extreme and damaging flood episodes.

Most studies have referred to changes in climatic and hydrological variables in terms of their mean annual values. Few have considered in any detail modifications to their inter-annual variability or to temporal issues such as the timing of the onset and end of the monsoon, though these considerations are generally recognised as important.

The climate change impacts on the Plateau of Tibet are considered since snow melt plays a major role in defining the regional hydrological regime. The plateau has been identified by climatologists as a global 'tipping point' for the impacts of global warming. Such regions will, it is argued, show a sudden, dramatic and precipitous response to climate change. The plateau is the headwater of rivers that flow down to regions populated by half of humanity. Snowmelt studies at the MRCS indicate that the rate of melting will increase to 2050, which could increase the spring contribution of water from the Upper to the Lower Basin at Chaing Saen by as much as 10 percent.

The two major studies that have been recently completed are those published by the CSIRO (2008) and the WWF (2009). The former is the first to evaluate a number of global climate model (GCM) simulations. It attempts to quantify the uncertainty of future regional climate projections. Results reveal significant geographical variability, with increases to mean annual temperature greater in the northern / colder parts of the basin. Increases in precipitation and runoff are higher towards the Plateau of Tibet and over the central parts of the lower basin. The projected increases in runoff vary widely in terms of magnitude depending on the GCM scenario adopted.

The WWF (2009) study presents a brief review of the climate change impacts on the regional climate and hydrological regime, focusing upon the ecological, environmental and socio-economic consequences. The report takes the view that "*Many scientists are now concluding that these* [climate] *predictions are gross underestimates and that the region will likely experience the upper extremes of the climate scenarios forecast in the last IPCC assessment*".

Complementing these two major external studies are those recently completed at the MRCS. Here the findings are rather less dramatic that those presented in the CSIRO study. At Vientiane and Kratie an increase in mean annual discharge of the order of 10 percent is suggested. The inter-annual variance of the annual flows, as indicated by their standard deviation, increases by as much as 40 percent at Vientiane but just 13 percent at Kratie, again emphasising the geographical variability of the regional impacts.

Following this synthesis and review of the major studies focused on climate change impacts in the Mekong Basin as a whole, specific attention is given to the potentially severe consequences over the Cambodian floodplain and in the delta. Even by 2030, the sea level rise could expose around 45 per cent of the delta's land area to extreme salinisation and crop damage through flooding. UNDP and IPCC studies suggest that a 1m increase in mean sea level by 2099 were to come about, Viet Nam as a whole would lose about 12 percent of its land area and 23 percent of the national population would be affected.

There is convincing regional evidence of systematic increases in mean annual temperatures over the last 100 years but none with regards to any detectable changes in rainfall or stream flow. Statistical studies of the selected long term hydro-meteorological time series and the annual incidence of regional tropical storms and typhoons revealed that there were no significant shifts that could be attributed to global warming. What does emerge from these analyses is that there is high annual variability combined with quasi-periodic episodes of drier and wetter conditions which makes the statistical detection of long-term increasing or decreasing trends in line with those predicted as a result of climate change very difficult.

In socio-economic terms, agriculture is the most vulnerable sector to the expected increased variance in rainfall and the associated decrease in its reliability. Greater drought risk combined with the increased incidence of long-term flood inundation will potentially lead to greater crop losses and worsening food security. The regional capacity to mitigate drought through irrigation is limited outside of the delta. Increasing rainfall excess and deficit is not the only issue threatening regional agricultural production. Increasing temperature is also a factor. Research has indicated that rice yields decrease by 0.6 tons / hectare for every one degree increase in temperature. Present average yields vary from 4.5 tons / hectare in the delta, 3 tons / hectare in Lao PDR and just 2 tons / hectare in NE Thailand, due to water stress, and Cambodia, due to the use of less fertiliser. By the end of the century, the region is expected to warm another 2-4˚C so the potential impacts upon rice yields are potentially huge and underscore the need for the ongoing research to develop rice hybrids that are far more resistant to water stress.

Flood conditions in the Lower Mekong Basin during the 2009 monsoon season were significantly below average both in terms of peak discharge and with regard to the seasonal volume of runoff. The early end to the SW Monsoon determined that the flood season ended early with the onset of the flood recession beginning as early as September at Chiang Saen. The recession was also very rapid when compared to the average historical rate. By mid October flows were generally less than the long-term mean annual discharge which is adopted as the criterion to define the onset of the low flow season. As a consequence tributary and therefore mainstream flows and water levels had become critically low by late December and by January 2010 a severe regional drought had developed.

Five tropical storms made landfall in Viet Nam during the season. The most serious in terms of damage and loss was Ketsana which made landfall over central Viet Nam at the end of September causing high winds and three-day accumulated rainfall over large areas (between 600 mm locally and almost 1000 mm in the Central Highland and upper Se San and Sre Pok tributary basins.) Flash flooding occurred in these areas, as well as in northern Cambodia and southern Lao PDR. Damage and loss in Viet Nam was estimated to be US$ 800 million. The storm then passed into northern Cambodia and southern Lao PDR where accumulated rainfall continued to exceed extreme thresholds causing widespread flash flooding. Damage and loss in Cambodia alone amounted to US$ 132 million.

Although downgraded to a tropical depression when Ketsana passed into Thailand, the damage and loss figure, largely to irrigation infrastructure and property within the Mun / Chi Basin, still amounted to US$21 million. In Lao PDR the major impacts of Ketsana were felt in the Xe Kong and Xe Kaman catchments where water levels as much as 5m above danger levels were observed, following rainfall as high as 200mm in six hours. Direct damage is estimated to be US$58 million.

The 2009 season illustrates that even given a weak SW Monsoon and developing regional drought conditions, the independent impact of typhoons and tropical storms can be devastating. Events illustrated the continuing vulnerability of the region to tropical storm damage, particularly in the poorer rural areas. Ketsana struck when the rice crop was close to being harvested, causing maximum crop lossthat accounted for almost half of the total damage in Cambodia.

1. Introduction

Consistent with the Annual Flood Report format established in previous years, this 2009 document comprises the following major sections:

PART 2:	the annual theme, which this year considers climate change and the potential impacts on the annual Mekong flood regime.
PART 3:	a detailed review of the hydrological aspects of the flood season, which in 2009 was significantly below average in terms of peak discharges and overall flood volumes. In addition to the standard statistical and graphical analyses, two further aspects are considered. Firstly during 2009 the impacts on the flood hydrograph of the reservoirs in China is evident, most particularly the retention of flood water during the filling of Xiaowan dam during July, which has a reported active storage of 9.9 km^3, equivalent to 12 percent of the mean annual flow volume at Chiang Saen. Secondly, the fact that the flood season ended up to five weeks early in the northern parts of the basin meant that discharges decreased rapidly during October and November. The low levels of natural catchment storage to sustain runoff during the dry season meant that critical drought conditions began to develop from December onwards.
PARTS 4 to 7	a brief summary of each of the four annual country reports, and
PART 8:	summary conclusions and recommendations

Over the 100 year period between 1906 and 2005 average global temperature has risen by 0.74^0 C according to the Intergovernmental Panel on Climate Change (IPCC)[1], which isn't significant. However, it is not so much the magnitude of the rise as the reason for it. Previous changes in the world's climate have been precipitated by variations either in the angle of the earth's rotation or in its distance from the sun as the orbital dynamics of the solar system change. This time there is another factor: man-made greenhouse gases which effectively act as an atmospheric insulator, warming the planet.

Such warming would modify atmospheric dynamics globally and in Asia such systems as the tropical Indo-Pacific circulation, which determines the climate of the Mekong Basin, would be affected. The consensus is that the strength of the SW Monsoon would increase as would its inter-annual variability. There is broad agreement on the direction of the changes to the rainfall climate and the subsequent hydrological consequences. There is less agreement with regard to the magnitude of the changes, which is not surprising. A common finding is an increase in the incidence of severe tropical weather systems such as typhoons, the inevitable consequence of a rise in tropical sea surface temperature. With respect to the Mekong flood regime it could be argued that this change more than any other is potentially of the greatest consequence.

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[1] IPCC AR4 Synthesis Report. 2007. http://www.ipcc.ch/publications_and_data/ar4/syr/en/spms3.html

The projected climate change impacts vary from study to study. The more mainstream results, for example Vastila et al (2010), indicate an increase in annual rainfall of 4 percent by 2040 compared to the 1980's, with a similar increase in mean annual flows. Extreme flood events are forecast to increase in frequency. The MRCS climate change results are consistent with such projections

Other studies propose far greater change. The CSIRO (2008) results suggest an increase of 13 percent in mean basin rainfall by 2030, the projected increases being highest in the northern and central regions. Total annual runoff from the basin is forecast to increase by 21 percent. Currently, there is an annual probability of a severe flood of 5 percent . this is expected to rise to 80 percent.

There is general agreement that the threats posed by climate change in the Mekong Delta are severe. Sea level rise could be anywhere between 30cm and 1 metre by 2100, although the latter is the more likely figure (IPCC, 2007). If the sea level does increase by 1 metre, 90 per cent of the delta would be inundated annually. Even by 2030, the sea level rise could expose around 45 per cent of the delta's land area to extreme salinisation and crop damage through flooding.

The regional frequency and intensity of tropical storms is forecast to increase in response to global warming, though there is no evidence in the data to date that their annual rate has been greater in recent decades. There is, however, clear evidence of increasing temperatures in the region but none to suggest that so far this has affected the rainfall climate and in turn hydrological regimes.

The defining feature of the 2009 flood season was that Ketsana and the four other less severe tropical storms that affected the Lower Mekong Basin occurred during weak monsoonal conditions which caused critical hydrological drought conditions as early as December. By January mainstream flows in Yunnan and the northern parts of the Lower Basin were amongst the lowest observed. During the flood season flows and water levels throughout the basin were below average.

Extreme tributary flooding occurred as a result of Ketsana, principally in the Xe Kong, Xe Kaman, the upper Xe San, Sre Pok and Xe Kong basins. All four lower basin countries were affected, with damage and losses in Viet Nam amounting to US$ 800 million and US$132 million in Cambodia.

Ketsana is regarded as one of the most severe tropical storms to affect the region since typhoon Linda in 1997. Given the levels of damage and loss and the projected increasing risk of such events as a result of global warming both the Cambodian and Lao PDR governments, supported by the World Bank and the ADB, undertook comprehensive 'Post Disaster Needs Assessment' studies at a level of detail never before attempted. These are to act as the benchmark guideline for the future.

The developing world faces greater challenges than the developed world, both in terms of the impact of climate change and the capacity to respond to it. With much of their subsistence and economic wealth dependent on agriculture the potential impacts are much greater. Infrastructure is also less resilient to storms and floods than in developed countries. Regional governments recognize their national vulnerability to natural disasters and the intensification of the risk of such hazards posed by global warming and are acting to ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation.

2. Climate change and its impact on floods and flooding in the Mekong Basin

2.1 Introduction

The only way to project changes into the future and estimate the possible consequences of global warming is through global climate models. At the macro level modelling what is one of the most complex and chaotic global mechanisms is extremely difficult, not least with regard to the effect of the so called 'feedback loops', which may be positive, thus reinforcing warming, or negative, thus countering it. It is not surprising therefore that the projected increases in global temperature to the end of the 21st Century range from 1.1 to 6.4^{0}C (IPCC, 2007).

The Asian monsoons are particularly sensitive to changes in the heating and cooling of the Asian landmass relative to the Pacific and Indian Oceans. Rainfall is generally predicted to increase over mainland Southeast Asia, become more intense and more variable leading to an increase in the frequency of floods and droughts (Bhaskaran and Mitchell. 1998), particularly after 2030 (Hu et al. 2000). However, there are exceptions to this prognosis, for example Arora and Boer (2001) predict a decrease in rainfall and lower mean annual flows. Amongst the more extreme projections are an increase in rainfall in the Cambodian lowlands by as much as 35 percent by the end of this century (MoE. 2001) and an increase in the mean discharge of the Mekong of 25%–40% over the same timescale (Falloon and Betts. 2006).

The more mainstream projections are summarised in Table 2.1. A common finding is an increase in the incidence of severe tropical weather systems such as typhoons, the inevitable consequence of a rise in tropical sea surface temperature. With respect to the Mekong flood regime it could be argued that this change more than any other is potentially of the greatest consequence. Another significant aspect, though one not often referred to, is the impact of any systematic change to the onset and end dates of the SW Monsoon and therefore to the start and end of the Mekong flood season. These dates have a characteristic narrow range with a typical standard deviation of only two weeks. However, when they are atypically early or late the consequences can be severe. The early onset of the flood season in 2000 resulted in extreme seasonal volumes of floodwater and prolonged inundation which caused the worst damage and losses witnessed for decades in Cambodia and Viet Nam.

Source	Temperature	Rainfall	Hydrology
IPCC (2001)	Significant local variation in warming, which will be greater in the interior and less towards the coast	Increased monsoonal precipitation, particularly on the Tibetan plateau. Increase in the regional incidence of cyclones	Increase in the frequency of extreme flood events
Chinvanno (2003)	Locally variable increases of 1 to 3 ^{o}C between January and May, followed by a cooler late wet season in August and September.	Wet season will begin and end later in the year	Decrease in mean annual flood volumes but increased variability
Aerts et al (2006)	1 ^{o}C mean temperature increase	6 – 7% increase in annual rainfall	Increase in mean annual discharge.
AIACC. (2006)		Increases throughout the region, locally up to 25%. Greatest increases over Lao PDR with increased storm rainfall intensity	Increased magnitude and possibly frequency of flooding
IWMI (2006)	Increase by +1 ^{0}C in the period 2010-2039	Average rainfall will decrease by -20mm in 2010-2039	More drought and water shortage in dry season in lower Mekong sub-basins. Increased floods
Hoanh et al (2004)	Mean annual temperature in the whole MRB will increase from 24^{0}C in 1961-90 to 25. ^{0}C during 2010-2039 depending upon the climate change scenario modelled.	During 2010-2039, the change in mean precipitation in different sub-basins varies from about -6% to + 6% depending upon the climate change scenario modelled.	Tropical cyclone frequency and related floods may increase
SEA START (2006)	Depends on atmospheric CO_2 concentrations	Increases of 20 to 30% throughout the region	
IPCC Working Group 2 (2001)	Warming most rapid and significant over the Tibetan plateau, with glaciers projected to shrink from 500 000 km^2 in 1995 to 100 000 in 2030	Increase in winter precipitation over the Tibetan Plateau and summer rainfall elsewhere along with higher intensities and annual variability.	With a 1m increase in mean sea level 15 000 to 20 000 km^2 of the Mekong Delta will be flooded.
CSIRO (2006)	Regional temperatures projected to increase, the amount ranging from 0.5 to 2 ^{0}C.	Increased summer monsoon rainfall. Increased drought risk during El Nino events	Increased tropical cyclone induced floods.
ADPC (2005)	Increase of 0.5 to 2.5 ^{0}C by 2070	SW monsoon rainfall increased by up to 5%	Due to higher sea levels and backwater effects up to 14 million people will be exposed to frequent flooding in the Mekong Delta

Table 2.1: Selected climate change impacts reported for the Mekong Region

In 2009 the monsoon ended two months early causing drought and huge crop losses in NE Thailand and throughout Lao PDR. The current (2010) regional drought conditions are largely the result of the early withdrawal of the monsoon in 2009.

The rise in mean sea level associated with global warming will have a significant impact. It is clear that Holocene sea levels, which peaked at around 4.5 m above present mean sea level between 6000 and 5000 year ago, had a significant ecological effect on the Mekong Delta region which extended northward into central Cambodia (Penny, 2008). While a sea-level rise of a comparable magnitude to that which occurred during the middle Holocene is unlikely in the absence of the total collapse of the Greenland and West Antarctic ice sheets (Dasgupta et al, 2007), the social and ecological implications of higher-than-present sea levels are likely to be felt throughout the lower Mekong River Basin, either directly through changes in surface-water chemistry related to salt intrusion or indirectly as a result of more severe and prolonged back-water effects and more potent storm surges. Changes in the frequency and amplitude of seasonal flooding driven by higher monsoon rainfall and stronger back-water effects will have significant implications for tropical wetlands and fisheries. The social implications are considerable, with some studies forecasting that a 1 m increase in mean sea level will see 15 000 to 20 000 km^2 of the Mekong Delta flooded and up to 14 million people exposed to annual flood inundation.

2.2 The role of the Tibetan plateau

The Tibetan plateau, with a mean altitude of 4 000 m, accounts for almost a quarter of China's area and is one that climatologists have identified as a 'tipping point' for the impacts of global warming. Such regions will, it is argued, show a sudden, dramatic and precipitous response to climate change. The plateau is the headwater of rivers that flow down to regions populated by half of the world's population. (Figure 2.1)

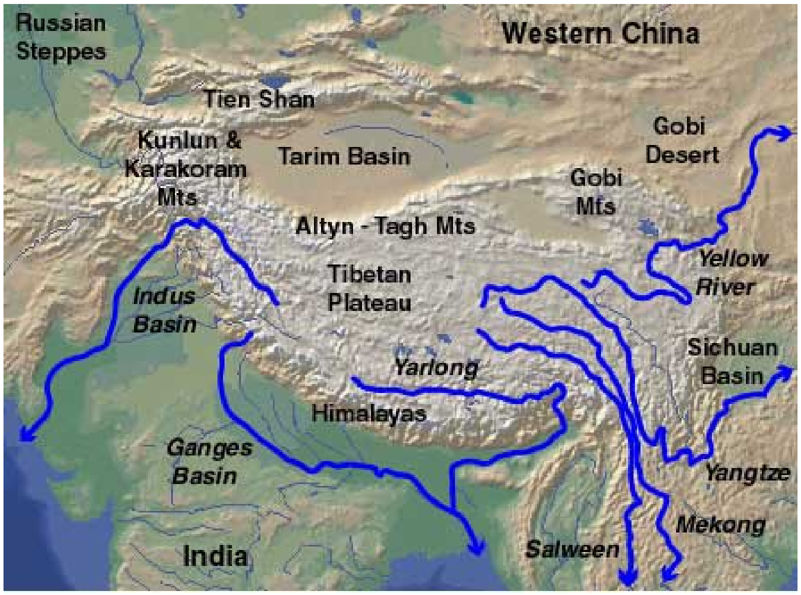

Figure 2.1: Plateau of Tibet. Major physical features and river systems

The sources of the Yellow River and the Yangtse are in north-eastern Tibet from where they flow eastwards across the greater part of China. The Mekong, Irrawaddy and Salween flow south through Burma, Lao PDR, Thailand, Cambodia and Viet Nam. The Tsang Po flows eastwards for nearly 2000 km before cutting through the Himalayas to become the Brahmaputra which discharges into the Bay of Bengal. Most of the major rivers in Nepal originate on the Tibetan plateau and come together to form the Ganges. Finally, there is the Indus and its tributaries such as the Chenab which flow westwards across Pakistan towards the Arabian Sea. In a warmer world, the reflective ice and snow of the Tibetan plateau will slowly turn to brown and grey as it melts and retreats to reveal the ground beneath. As the ground warms, melting will accelerate and Tibet will become a much warmer place. For these major global river systems with their sources on the plateau any sustained change in the hydrological response of the plateau is likely therefore to have significant, if not dramatic, long term impacts on their flow regimes.

According to the Tibet Meteorological Bureau the plateau is heating up by 0.3°C each decade, more than twice the worldwide average and much higher than the average figure over the rest of China of 0.05 -0.08 °C , a finding confirmed by Liu and Chen (2000). The latter authors also found that:

- compared with the Northern Hemisphere and the global average, the warming occurred early, with statistically significant increases in temperature starting in the 1950's, especially in winter.
- the linear rates of temperature increase are 0.16^0C for the annual mean and 0.3^0C for the winter mean.
- there is also a tendency for the rates of warming to increase with elevation.

This warming will have direct consequences for the hydrological regime of the Mekong, most particularly with regard to the dry season flows:

- in the upper part of the Lower Mekong system, at Vientiane, the so called 'Yunnan Component', that is; flows that originate in Tibet and Yunnan, not only provides most of the dry season flows but in addition most of the floodwater during the majority of years. Average seasonal contributions range from over 75 percent during the low flow months between April and May, to over 50 percent during the peak flow months of July, August and September. The year-to-year range of the contribution is, none the less, quite wide and indicates a complex and variable net contribution.
- further down stream, the large left bank tributaries in Lao PDR provide most of the flood season flow on the mainstream, such that the contribution of the 'Yunnan Component' at this time of the year is reduced to a modest 15- to 20 percent. However, its remains a significant source of dry season discharges, reaching a maximum long term average contribution that exceeds 40 percent during April, regionally usually the month of lowest flow.

The implication of this key aspect of the Mekong regime is that it is not the flood season hydrology that is potentially the most vulnerable to pivotal climate change impacts within the upper basin, but the low flow regime. This is particularly noteworthy within the regional context as it is arguably the low flow regime of the system that is most exposed to modification by resource development, by reservoir regulation for example. This will tend to increase the dry season hydrology, whereas in the longer term it is at risk of decreasing as the reliability and contribution of snow and glacial melt waters declines. Initially, global warming may enhance these melt water contributions but such increases may be relatively short lived as the glaciers and snowfields retreat to higher altitudes.

The evidence is accumulating of accelerating rates of glacial and snowfield recession (WWF, 2005). On the Qinghai-Tibetan Plateau during the past 40 years or more glacial extent has shrunk by some 6 600 km^2 out of a total of 110 000 km^2. Presently, 95 percent of glacial systems are in retreat, such that the long-term implications for the freshwater resources of much of Asia are immense. In a study of future water resources availability in the Sutlej River system, with is major sources in the Himalayan glacial snowfields, Singh and Bengtsson (2002) found that the impact of climate change to be more prominent on seasonal rather than annual water availability. Reduction of spring and summer melt water would have severe implications on future regional water resources at times of the year when hydropower and irrigation demand are at their peak.

Snowmelt modelling studies undertaken by the MRCS provide estimates of the potential future increases to annual melt rates in the Upper Mekong region. The 'baseline' (1986 to 2000) mean annual melt rate is estimated to be 23 mm, equivalent to 120 cumecs generated across the estimated area of the Upper Mekong snowfields. By 2050 the figures are projected to increase to 44mm, equivalent to 225 cumecs. The current mean discharge between February and April at Chiang Saen on the mainstream is 900 cumecs, which is (with the exception of minor contributions from Myanmar and the far north of Lao PDR) in effect the seasonal runoff contribution to the Lower Basin from China. The increased melt estimates therefore reveal the potential for a >10% increase in this contribution.

2.3 A review of the major regional climate change studies

Two major studies that have been recently completed are those published by CSIRO (2008) and by WWF (2009). The former is the first to evaluate a number of global climate model (GCM) simulations and thus attempts to quantify the uncertainty of future regional climate projections. The CSIRO study compares conditions during a baseline period from 1951 to 2000 to projections to 2030, the major findings being as follows:

- an increase in mean temperatures across the basin of 0.79°C, the uncertainty around this estimate being relatively small, ranging from 0.68 to 0.81 °C. Projected temperature increases tend to be greater towards the northern parts of the basin with their cooler / colder climates. (Figure 2.2)
- there is greater uncertainty around future (2030) precipitation projections. The most likely projected response in annual precipitation averaged across the basin is an increase of ~ 200 mm (13%), but the projections from different GCMs indicate increases ranging from ~300 mm to ~360 mm. The projected increases are highest in the northern and central regions (Figure 2.3)

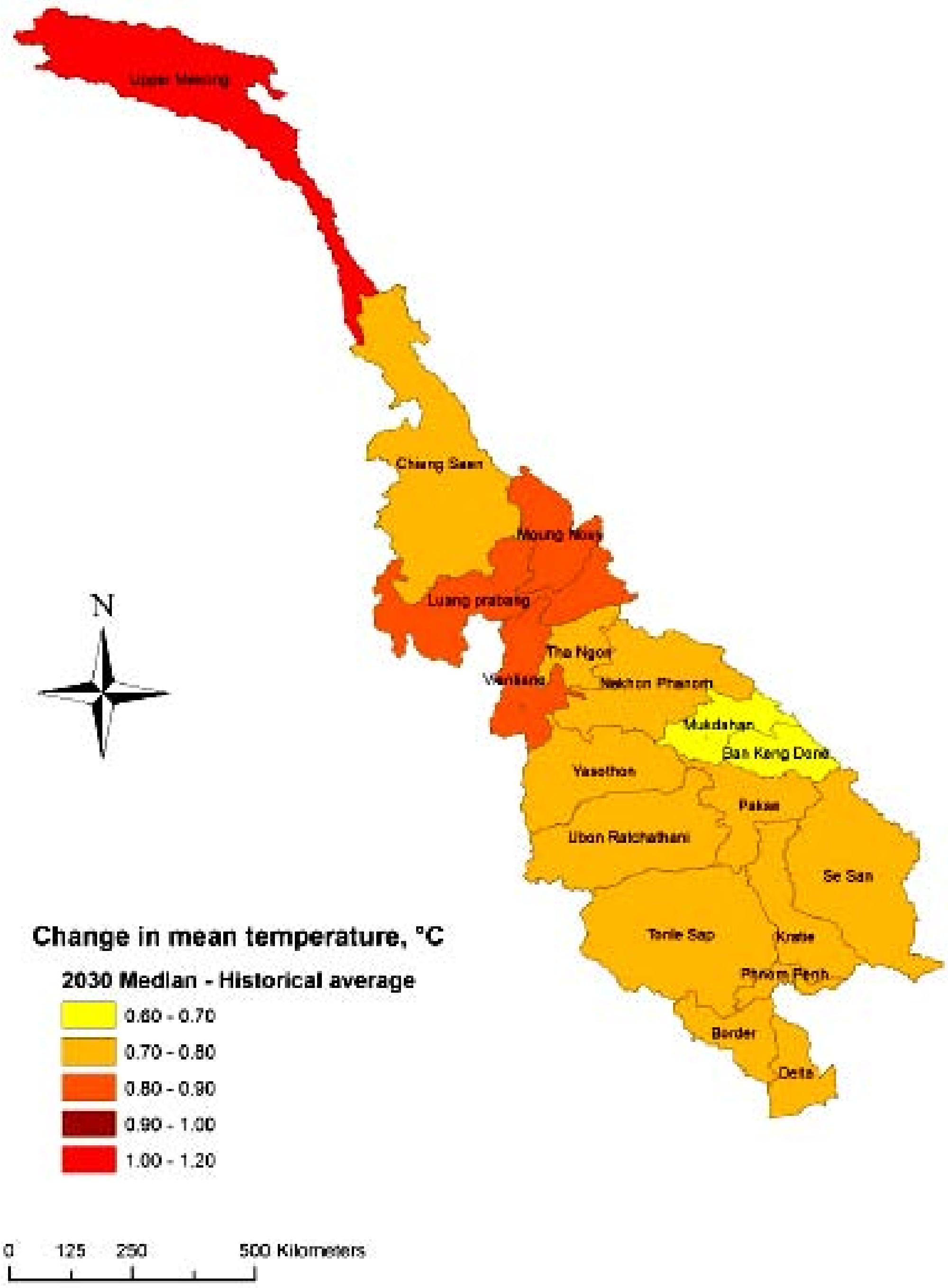

Figure 2.2: Geographical distribution of the projected change in mean annual temperature to 2030 compared with historical (1951-2000) figures. (Source; CSIRO, 2008)

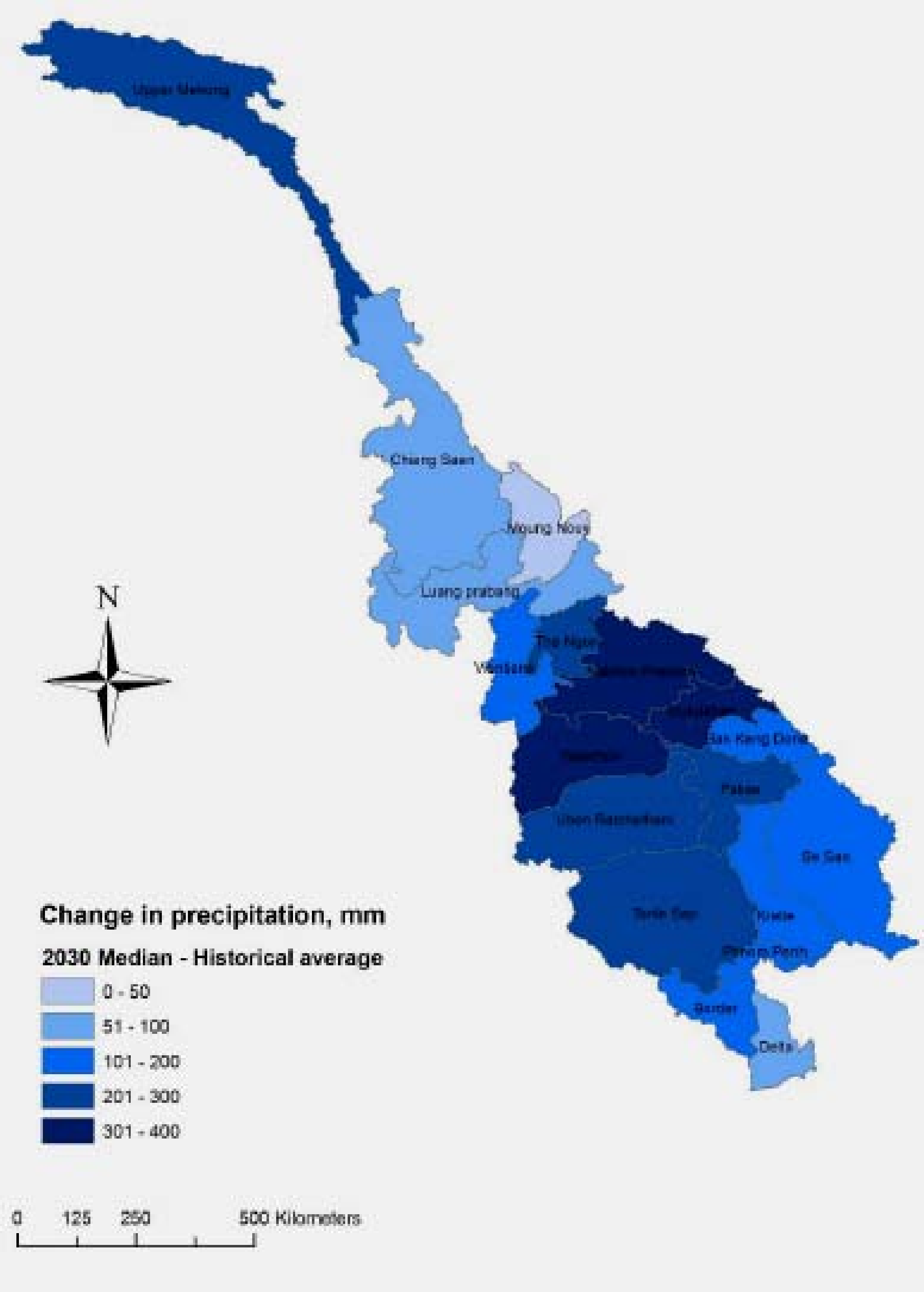

Figure 2.3: Geographical distribution of the projected change in mean annual precipitation to 2030 compared with historical (1951-2000) figures. (Source; CSIRO, 2008)

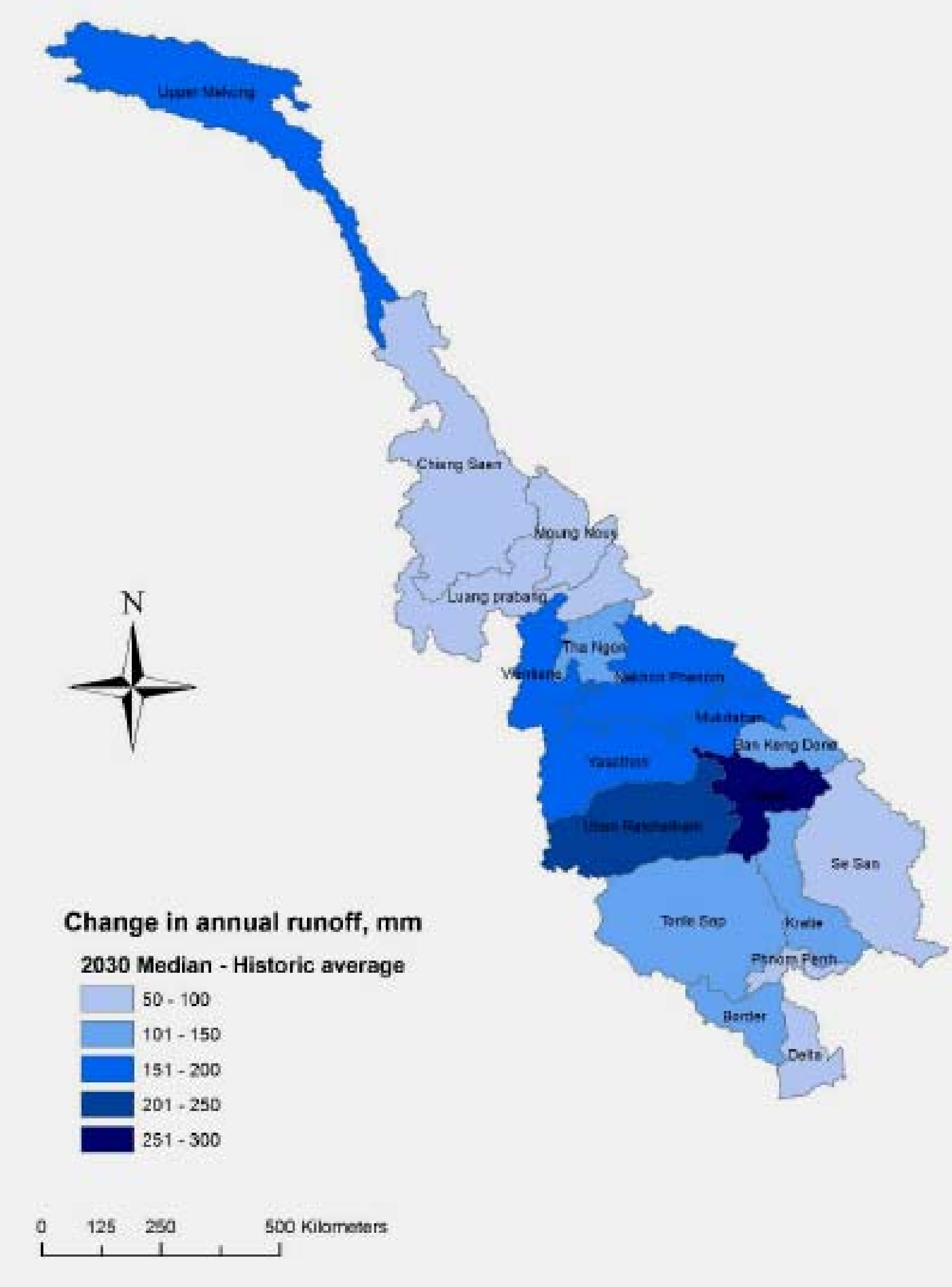

Figure 2.4: Geographical distribution of the projected change in mean annual runoff to 2030 compared with historical (1951-2000) figures. (Source; CSIRO, 2008)

- total annual runoff from the basin is forecast to increase by 21 percent, an increase of ~107 km^3 ,though there is significant uncertainty around this estimate associated with the climate projections from different GCMs, ranging from a decrease of ~41 km^3 (8%) to an increase of ~460 km^3 (90%). The median runoff projections for 2030 suggest that total basin runoff will increase in all months and not be limited to the flood season. (Figure 2.4)
- At Kratie, by 2030, it is projected that flood conditions currently defined as extreme (MRC, 2007), that is with a mean annual recurrence interval beyond 1:20 years, will be exceeded with an annual probability of 75 percent under the median of the future projections. In other words the present 1:20 year threshold conditions will be surpassed in four years out of five which then would have severe consequences for the depth and duration of inundation within the Cambodian flood plain and across the delta in Viet Nam. Intuitively, this appears to be an extreme and implausible assessment. The associated projected and baseline mean monthly hydrology at Kratie is shown in Figure 2.5.

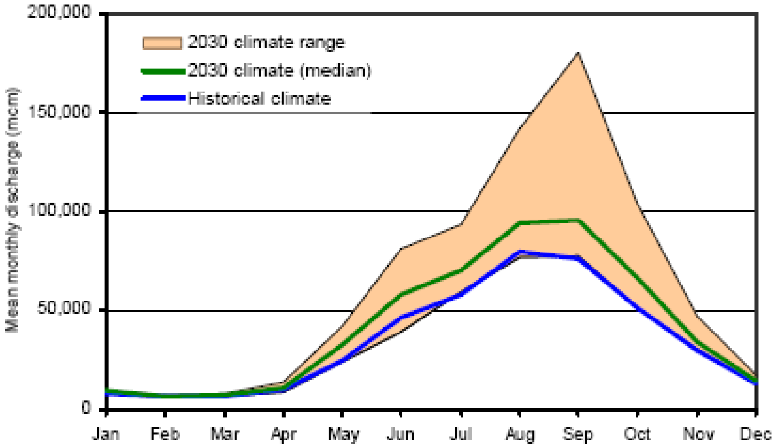

Figure 2.5 Kratie. Baseline (1951 – 2000) and projected climate change impacts upon mean monthly discharge (Source. CSIRO, 2008)

The WWF (2009) study only presents a brief review of the climate change impacts on the regional climate and hydrological regime, focusing as expected upon the ecological, environmental and socio-economic consequences. The view is taken that "*Many scientists are now concluding that these* (climate) *predictions are gross underestimates and that the region will likely experience the upper extremes of the climate scenarios forecast in the last IPCC assessment*". Other key observations are that:

- average daily temperatures across Southeast Asia have increased 0.5 to 1.5ºC between 1951 and 2000 (IPCC 2007). Thailand's temperatures have reportedly increased 1.0 to 1.8ºC in the past 50 years; average daytime temperatures in the month of April have been particularly high at 40ºC (ADB, 2009). Viet Nam's temperatures increased by 0.7˚C during this same period (ADB 2009). Daily maximum and minimum temperatures are also increasing.

- hot days and warm nights and fewer cool days and nights (Manton *et al* 2001). These changes in temperature extremes (and other extreme climatic events) are most strongly associated with climate change impacts (Griffiths *et al*. 2005). By the end of the century, the region is expected to warm another 2-4˚C (IPCC 2007, ADB 2009). In the next 20 years, mean temperatures across the Mekong River Basin will most likely increase by 0.79ºC with greater increases in the colder catchments in the north of the basin (Eastham 2008).

2.4 Climate change impact modelling at the MRCS

Climate change impact modelling at the MRCS has been undertaken using downscaled outputs from the ECHAM4 global climate model. (see Roekner, 2006, for details), while the SWAT model was used to simulate the climate and hydrology responses to the projected levels of climate change. The baseline period covers the 15 years from 1986 to 2000[2] and the 15 years between 2036 and 2050 are selected here to assess the potential future hydrological impacts. Rather than simply focus upon changes to average wet and dry season flows in the Mekong region, as most studies have previously considered;, here a wider assessment is made of aspects of the hydrological regime considered to be relevant, such as the onset and end of the flood season, the seasonal pattern of flow, the variance of the statistics and the distribution of annual maximum discharge. This broader statistical appraisal has revealed a number of potentially significant modifications to the regional hydrology beyond those usually reported.

Just two mainstream sites are selected for analysis, with the hydrology at Vientiane representing that for the northern region of the lower basin and that at Kratie describing that of the central and southern parts. Tables 2.2 and 2.3 summarise the basic results:

- at both sites there is an increase in mean annual discharge of the order of 10 percent. The inter-annual variance of the annual flows, as indicated by their standard deviation, increases by as much as 40 percent at Vientiane but just 13 percent at Kratie. Changes in the flood season flow volumes obviously follow this annual potential pattern of change. Increased variance of the annual flow volumes could have a significant potential impact upon the future reliability of water resources development.
- the most significant potential impact at both sites is the large increase in mean flow during the dry season[3], amounting to 40 percent at Vientiane and 30 percent further downstream at Kratie. This is a logical result of an increased snowmelt contribution from the upper basin which would result from increased temperatures. Flows from Yunnan make the dominant contribution to the low flow regime of the mainstream and such potential impacts during the dry season would be evident throughout the system.
- annual maximum flows at Vientiane look likely to be unaffected by climate change. At Kratie on the other hand, the mean increases by as much as 22 percent with a corresponding change in the inter-annual variance.

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[2] These baseline data are based on the calibrated SWAT model outputs, not the observed daily discharge time series.
[3] Annual dry season flow is efficiently defined as the 90 day minimum mean discharge during the year..

- as far as the timing of the onset and end of the flood season is concerned, the future mean onset date is estimated to be a few days later. However, the variance of the onset date from year-to-year increases dramatically. The mean end date is delayed by two to three weeks. These potential changes are significant since historically the start and end of the flood season on the mainstream has been highly predictable, with very low variance (see MRC, 2007). The early end to the flood season in 2009 has largely explained the current hydrological drought conditions. Any increase in the variance of flood season onset is likely to have far reaching consequences not only for the operation and productivity of water resources infrastructure but there would also be significant environmental, ecological and socio-economic repercussions.

Variable	1986 to 2000		2036 to 2050	
	Mean	Standard deviation	Mean	Standard deviation
Annual flow.	136 km^3	23 km^3	148 km^3	32 km^3
Flood season flow.	99 km^3	26 km^3	113 km^3	36 km^3
Dry season flow	1 350 cumecs	150 cumecs	1 750 cumecs	390 cumecs
Annual maximum flow	16 000 cumecs	3 500 cumecs	16 000 cumecs	4 000 cumecs
Onset of flood season	19th June	17 days	24th June	29 days
End of flood season	17th Nov	14 days	6th Dec	15 days

Table 2.2: Mekong at Vientiane. Comparative statistics of the hydrological regime during the ‘baseline’ years (1986 to 2000) and the projection under climate change (2036 to 2050)

Variable	**1986 to 2000**		**2036 to 2050**	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**
Annual flow.	406 km^3	77 km^3	423 km^3	87 km^3
Flood season flow.	316 km^3	85 km^3	330 km^3	100 km^3
Dry season flow	2 940 cumecs	420 cumecs	3 560 cumecs	620 cumecs
Annual maximum flow	46 750 cumecs	11 700 cumecs	57 500 cumecs	14 000 cumecs
Onset of flood season	18th June	15 days	13th June	50 days
End of flood season	12th Nov	9 days	22nd Nov	13 days

Table 2.3: Mekong at Kratie. Comparative statistics of the hydrological regime during the ‘baseline’ years (1986 to 2000) and the projection under climate change (2036 to 2050)

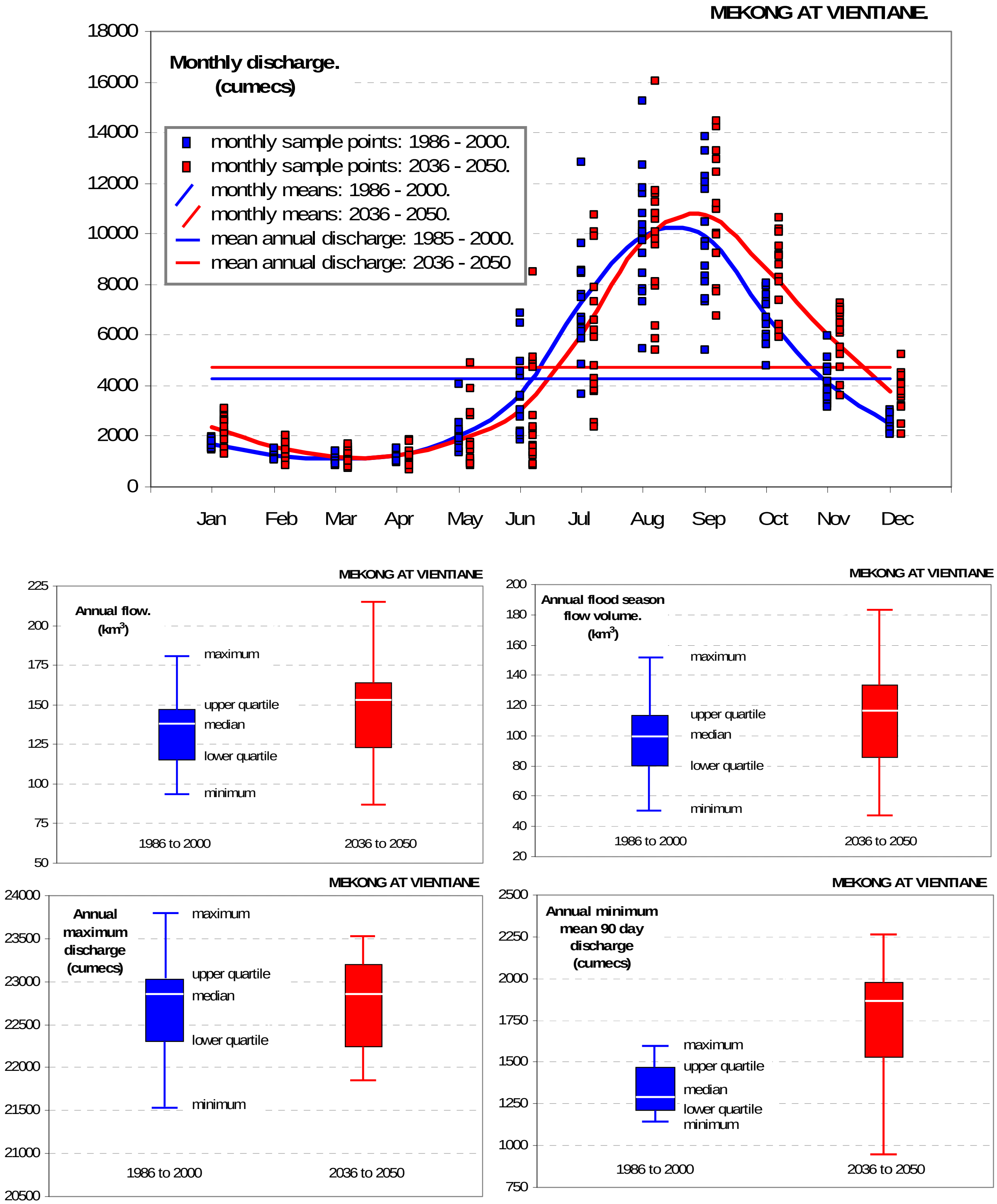

Figure 2.6: Mekong at Vientiane. Graphical summary of the potential impacts of climate change on selected hydrological statistics

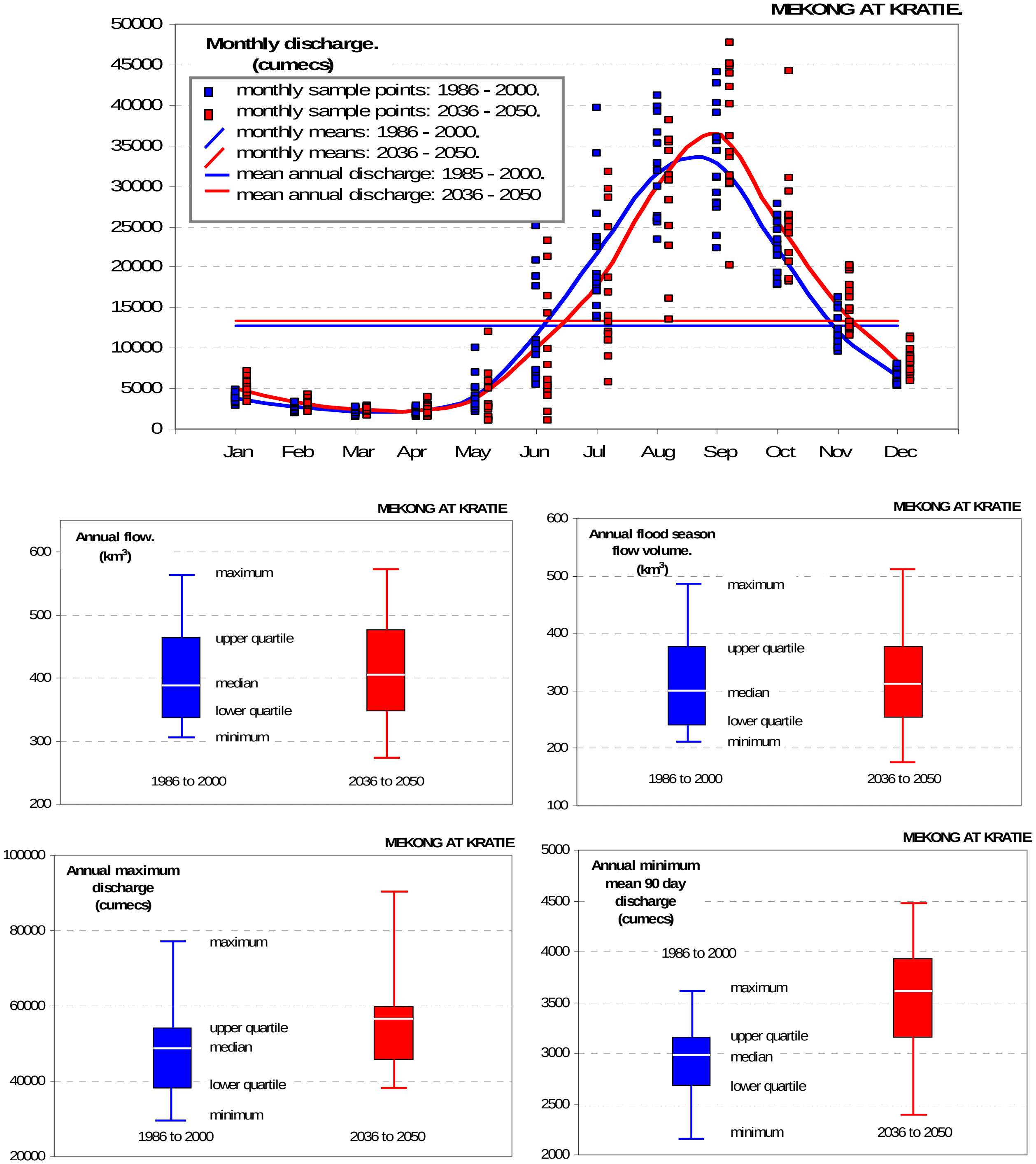

Figure 2.7: Mekong at Kratie. Graphical summary of the potential impacts of climate change on selected hydrological statistics

As these summary statistics illustrate there is a significant geographical diversity in the hydrology of the Mekong, already evident in any analysis of the historical data but also with respect to these potential responses to the impacts of global warming. The consequences for northern regions of the Lower Basin are largely driven by the climate change impacts on the Tibetan Plateau and in Yunnan, those further downstream by the impacts in Lao PDR and NE Thailand. Figures 2.6 and 2.7 reveal the results of a more detailed assessment of the modelling results:

- the sample distributions of monthly flows and their means indicates a displacement of flood season conditions to later in the year In a significant number of years flows between May and August are indicated to be much lower than at present, while those between September and February are estimated to be substantially higher one year in two. In other words the results indicate a significant shift in the seasonal flow pattern.
- annual maximum flows at Kratie are indicted to increase both in terms of their mean and inter-annual range.
- a major impact of global warming rests with the increase in the level and variance of flows during the dry season from year to year.
- This analysis emphasises that there is the prospect of a far more wide ranging modification of the Mekong flow regime than simply a change to mean discharge or the incidence and severity of floods and droughts. In general terms any increase in the year to year variability in the statistics points towards a far less certain hydrological environment, which has wide ranging implications for food security and the environment as well as for the economic returns from water resources investments, such as hydropower schemes.

2.5 Impacts on the Cambodian Floodplain and in the Delta

The threats posed by climate change in the Mekong Delta are severe. Sea level rise could be anywhere between 30cm and 1 metre by 2100, although the latter is the more likely figure. If it does reach 1 metre, 90 per cent of the Delta would be inundated annually. Even by 2030, the sea level rise could expose around 45 per cent of the Delta's land area to extreme salinisation and crop damage through flooding. Any climate change driven falls in dry season flows would add to the salinity problem, though the consequences of upstream hydropower development are almost certain to result in a net increase in the dry season discharge. Declining crop productivity would particularly affect the spring rice crop, which is expected to fall by 8 per cent by 2070. If sea level rise of 1 m were to come about, Viet Nam as a whole would lose about 12 percent of its land area and 23 percent of the national population would be affected. (all figures quoted here are drawn from UNDP (2007) and IPCC (2007)).

Most studies predict that flows during the dry season will increase largely as a result of a greater snowmelt contribution from the Upper Basin which in principle would mitigate the risk of more extensive saline intrusion. However, the projected rise in mean sea level is anticipated to far outweigh this benefit to the delta region and is likely to lead to potentially severe water quality problems. Assessing the impacts is important, since the productivity of both agriculture and aquaculture in the highly productive and populous delta area depend on salinity levels, their areal extent and their duration. The CSIRO study presents an estimate of the possible changes to the area of the delta flooded from year to year based on the historical relationship between the annual flow volume at Kratie and the inundated area. The result is shown in Figure 2.8 and indicates an increase from a mean annual figure of 34 000 to 37 000 km^2. It should be noted that this result is indicative only and that there is a need for detailed hydrodynamic modelling which combines the modified upstream hydrological conditions with the additional effects of a rise in sea level.

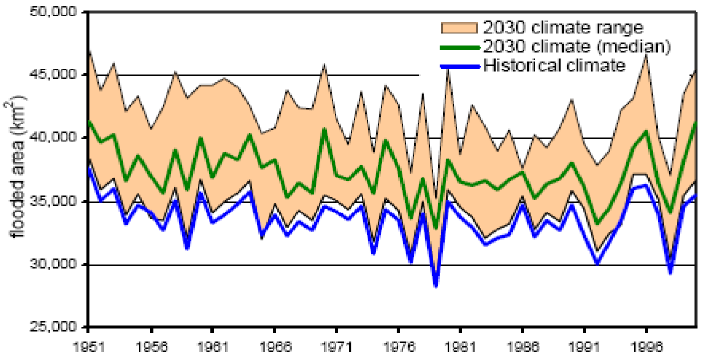

Figure 2.8: Historical (1951-2000) and future (2030) flooded area in the Mekong delta. (Source: CSIRO, 2008)

The CSIRO study also undertook an exploratory assessment of the potential impacts on the seasonal area of the Tonle Sap using a similar methodology, the results of which are shown in Figure 2.9. Both the annual minimum and maximum inundated areas are indicated to increase; the latter significantly even under the median climate change projection.

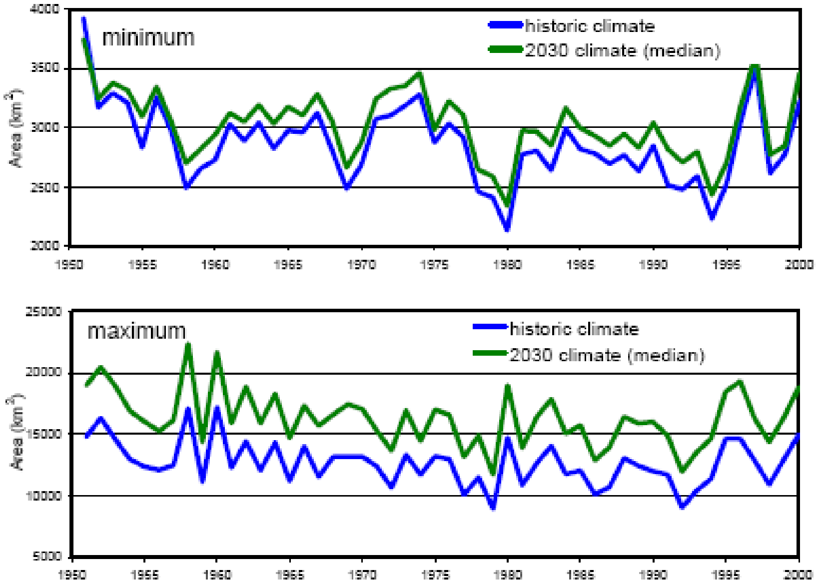

Figure 2.9: Historical (1951-2000) and projected (2030) annual maximum and minimum levels of the Tonle Sap lake. (Source: CSIRO, 2008)

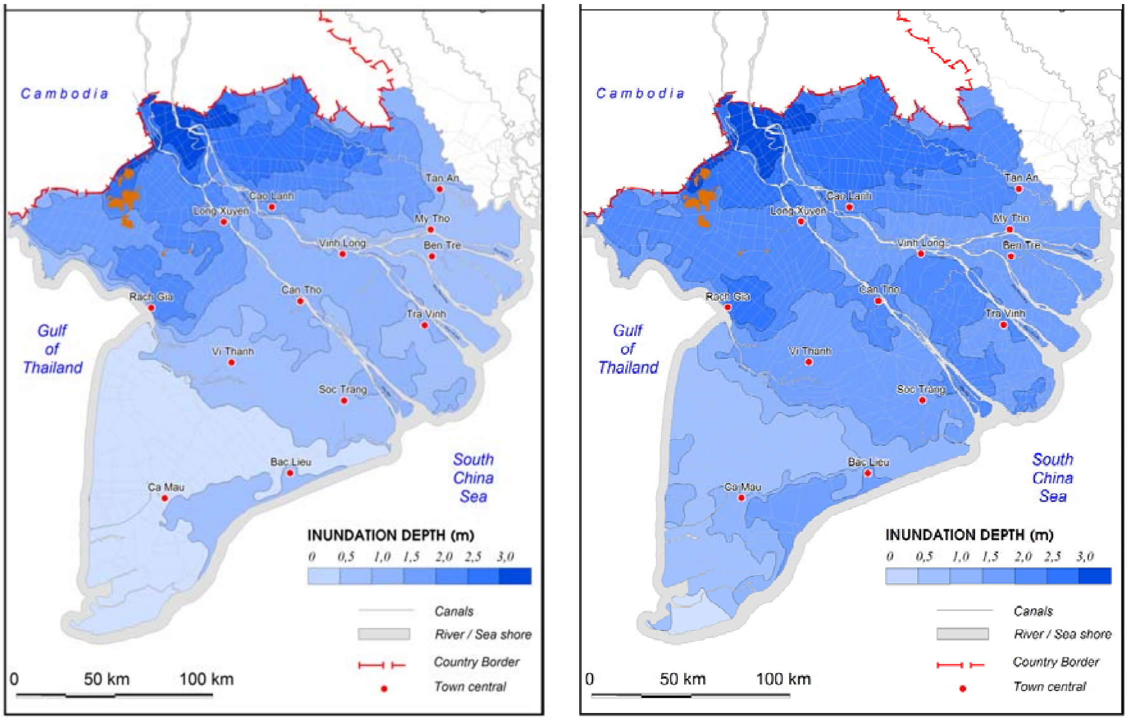

Figure 2.10: Mekong Delta in Viet Nam. The impact of a 1metre rise in mean sea level on flood depth. The map on the left shows the extent and depth of inundation at the peak of the extreme flood conditions during 2000. That on the right shows the impact on flood extent and depth given the same event but under conditions of a 1m higher mean sea level. The much larger area flooded to depths exceeding 1 m is caused not only by the fact of a higher sea level but also the much greater back water and tidal impacts. The result is based on a hydrodynamic modelling study undertaken by the Southern Region Water Resources Planning Institute, Ho Chi Minh City

Hydrodynamic modelling results (Figure 2.10) vividly illustrate the severe impacts of a 1m rise in sea level on flood inundation in the delta. Coastal storm surges, subsidence, erosion, salinisation of groundwater, rising water tables and impeded drainage all may seriously compromise the practicality of residence and agricultural production over most of the area (Oliver-Smith, 2009).

In a global screening study of the vulnerability of the world's large port cities to sea level rise and the increased risk of coastal flooding due to storm surge Nicholls et al (2007) ranked Ho Chi Minh City the fifth most vulnerable city in the world based on a ranking of the projected population exposed by 2070[4]. Exacerbating the exposure risk is the influence of human-induced subsidence due to shallow ground-water extraction and land drainage. The study urgently underscores the need to integrate the consideration of climate change into both national coastal flood risk management and urban development strategies.

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[4] The projected 2070 population of the city is given as 9 million, compared to the present figure of 2million.

2.6 Climate change – is there any regional evidence to date?

A number of regional studies have detected a systematic rise in temperature over the last 100 years, an example of which is shown below. The question arises therefore whether these increasing temperatures have had a detectable influence thus far upon the rainfall climate and the hydrological regime of the Mekong. Delgado et al (2009), for example, suggest that the variance of the annual Mekong flood is increasing, while admitting that the evidence is tentative and further research is required. What follows is a fairly empirical assessment along the lines of the type of exploratory data analysis that would precede the use of more refined statistical procedures.

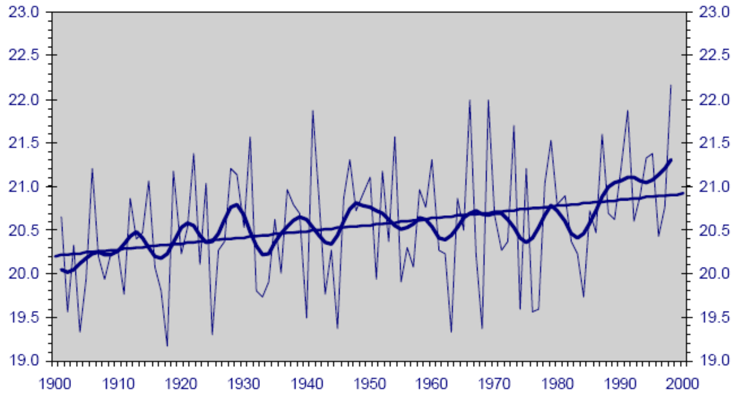

Figure 2.11: Viet Nam, winter mean temperature, 1901 to 1998. (Source: Schaefer. 2002)

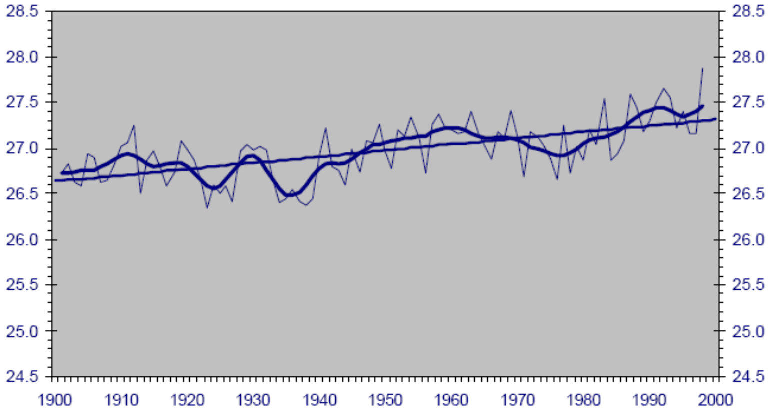

Figure 2.12: Viet Nam, summer mean temperature, 1901 to 1998. (Source: Schaefer, 2002)

Figure 2.13 shows the post 1950 annual rainfalls available at selected sites in the Basin[5]. No coherent trends are evident, except perhaps for increases since 1990 in NE Thailand (Khon Kaen and Surin), a result perhaps worthy of wider assessment. Mean annual rainfall is predicted to increase by 15 percent over the Lower Mekong region by 2050 (CSIRO, 2008), but Faures (2009) makes the interesting point that an increase in the inter annual

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[5] No such long term data were available for the basin areas in Cambodia and Viet Nam.

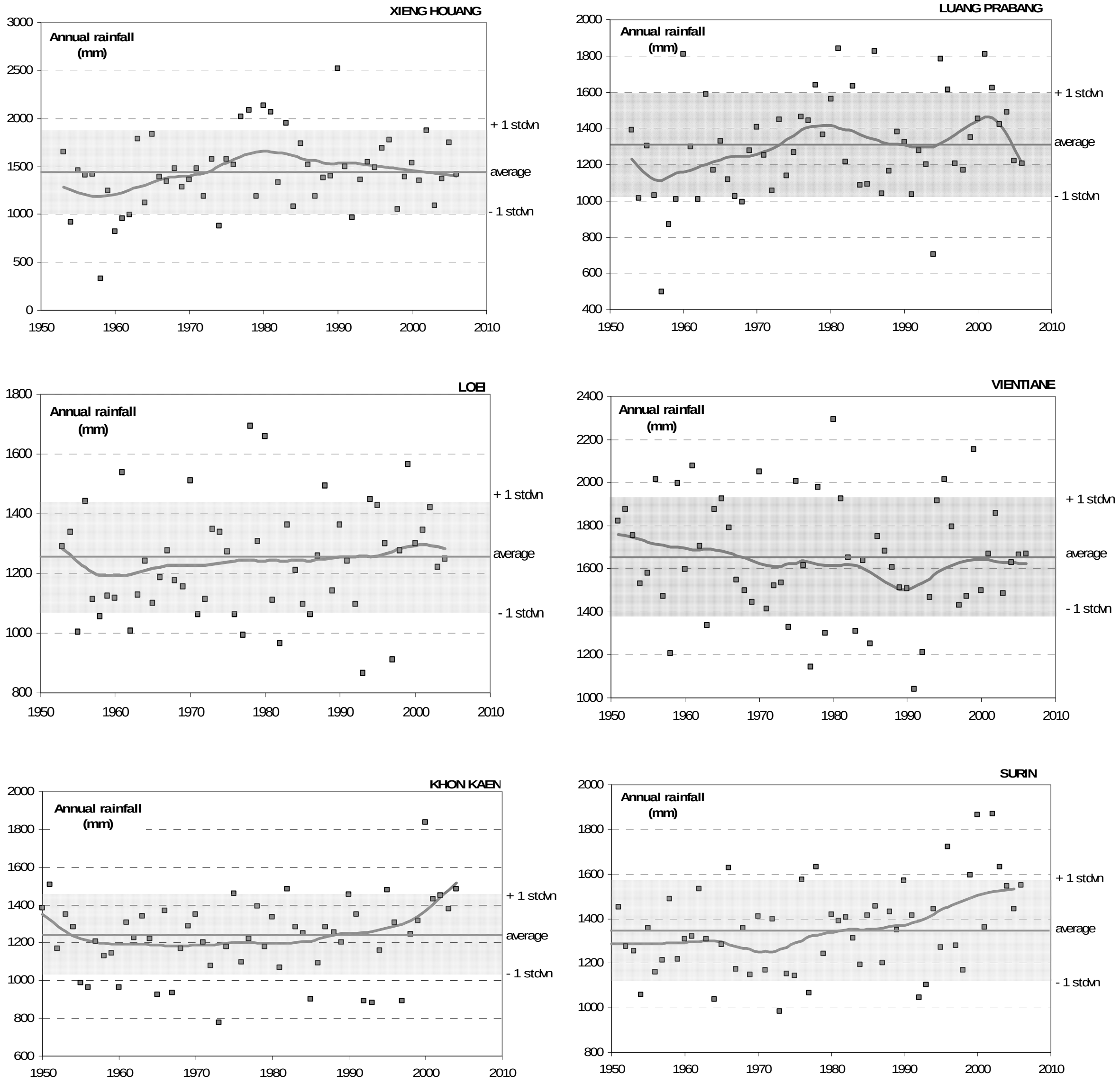

Figure 2.13: Annual rainfall at selected sites in the Lower Mekong Basin assessed for evidence of any non-linear trends that might indicate the effects of climate change[6]. As expected detecting systematic change in such time series with their high inter-annual variability and quasi-periodicity will be extremely difficult, give that the estimates of climate induced increases in regional mean annual rainfall, for example, are generally below 10%

variance of rainfall is much more likely to result in significant negative impacts, particularly in terms of agricultural production, than a modest change to the mean. Care needs to be exercised when assessing whether or not there is a trend in the mean level of a process. Many studies simply fit a time-based regression model, an example of which is shown below. In this case the suggested linear trend is arguably spurious and reflects the presence of a ‘change point’ in 1981 when rainfall entered a drier phase, which is a natural quasi periodic feature of the process. Prior to and after 1981 the time series is stationary.

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[6] The nonlinear smoothing function applied here to summarise the longer term trends in the data is based on the methodology in Friedman (1984).

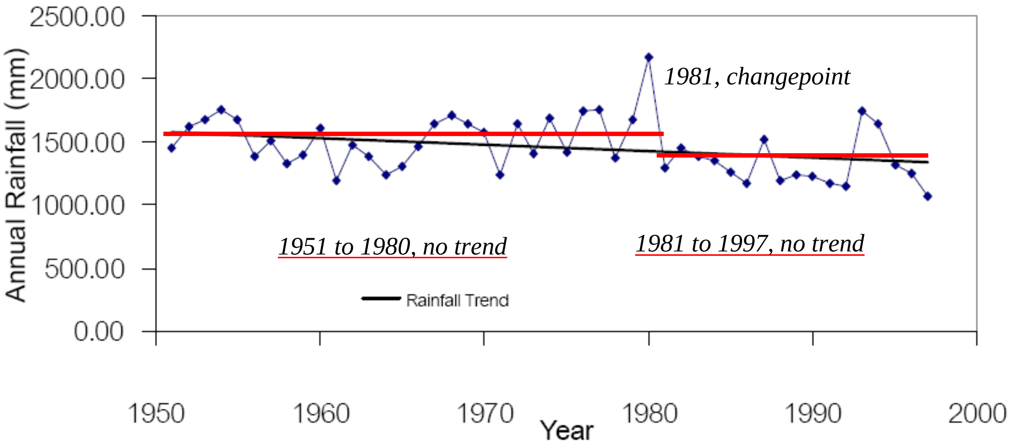


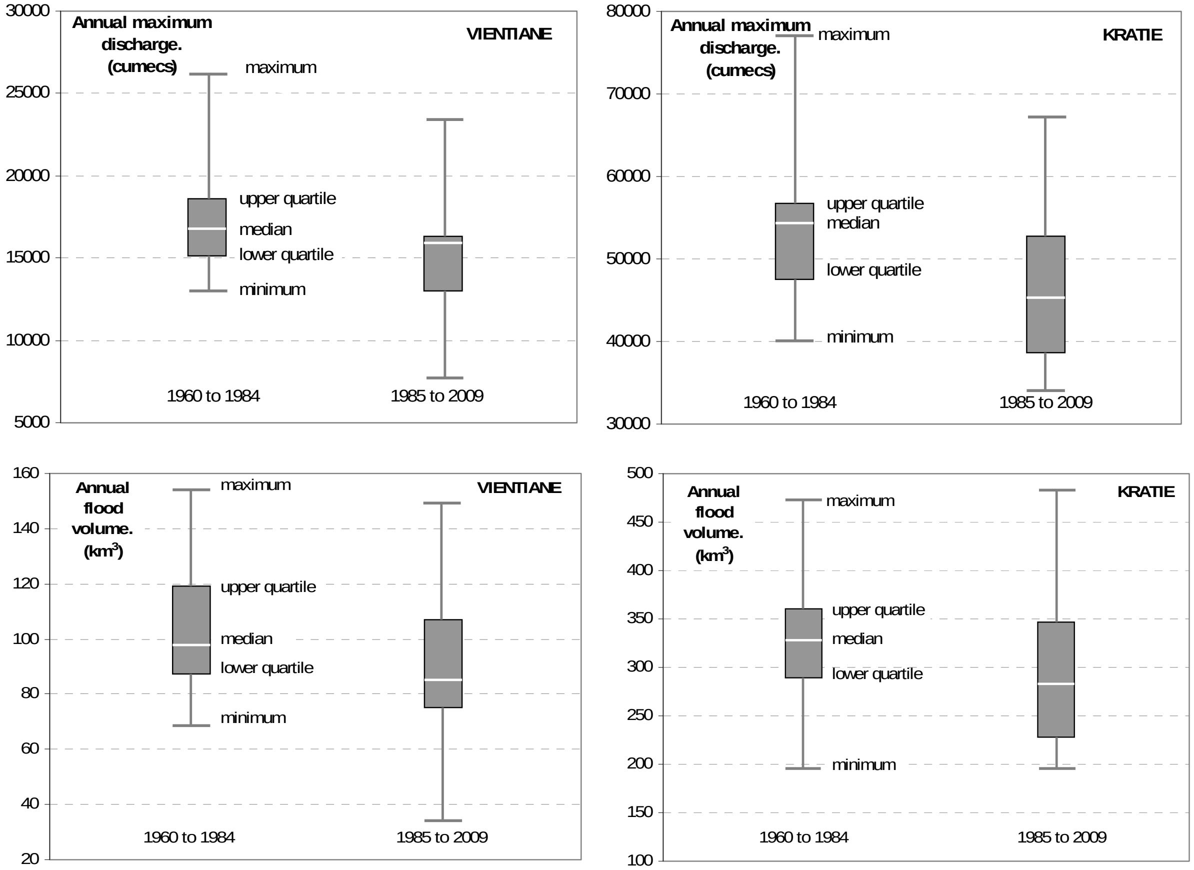
Figure 2.14: Kok River Basin, northern Thailand. Kwanyuen (2000) proposes that annual rainfall (1951 to 1997) over the basin has systematically decreased in response to global warming. However, in reality there is a change point in 1981 which is unlikely to be associated with climate change

The projected climate induced change to the Mekong flood regime is for there to be an increase in the mean annual flood and the inter annual variance. There is no convincing statistical evidence to suggest that such changes are already taking place.

- Figure 2.15 shows a simple split sample comparison of the peak and volume of the annual Mekong flood at Vientiane and Kratie between 1960 and 2009. Both variables indicate a decrease in range in the post 1984 sub sample, reflecting the much drier years between the mid 1980's and the late 1990's. This drier phase is consistent with the kinds of periodicity evident in the long-term data.

- This quasi-periodic feature of the data is evident in Figure 2.16 which shows the flood time series at the two sites over the last +85 years expressed as percentage deviations above and below the mean floods during the post 1980 years have generally been much lower in terms of both peak and volume but it would be unwise to define this as a trend. Such a period is also evident during the 1950's, though it was not so prolonged. A feature of the plot is that wetter and drier years tend to cluster in response to the medium term fluctuations in the Indo – Pacific climate which are in turn a response to the periodic fluctuations in global circulation. These periodicities can be linked to solar activity, for example.

- Figure 2.17 shows a similar plot of the long term deviations above and below the mean duration of the flood season, the purpose being to assess whether there has been any systematic change to the onset and or end dates. No long-term coherent trend is evident. An interesting feature that emerges is that the year to year variance of the length of the flood season is much higher at Vientiane than at Kratie. The reasons behind this are not clear, though the date for the withdrawal of the SW Monsoon in the northern regions of the Basin and in Yunnan has a much higher annual variance than in the southern regions.



Hydrological variable	Average			
	Vientiane		Kratie	
	1960 – 84	1985 - 2009	1960 – 84	1985 – 2009
Peak flood discharge.	17 200 cumecs	15 300 cumecs	54 200 cumecs	45 900 cumecs
Annual flood volume.	104 km^3	92 km^3	330 km^3	299 km^3

Figure 2.15: Split sample comparison (1960 to 1984 and 1985 to 2009) of the mean and range of annual flood peak and volume on the Mekong at Vientiane and Kratie

Tropical storms (hurricanes, cyclones, typhoons) have become the icon of climate change (Mendelsohn et al, 2009). As climate changes, the frequency and intensity of such storms are expected to increase, especially in the North Atlantic and the North West Pacific (Emanuel et al. 2008). Storms and typhoons affecting Viet Nam before moving eastwards into the Basin have been responsible in the past for some of the most extreme and damaging floods, recent examples include ‘Linda’ in 1997, ‘Xangsane’ in 2006 and ‘Ketsana’ in 2009. Any increase in their severity and frequency is a cause for major concern, bearing in mind that the worst 10 percent of storms currently cause 90 percent of the damage (Mendelsohn et al, 2009).

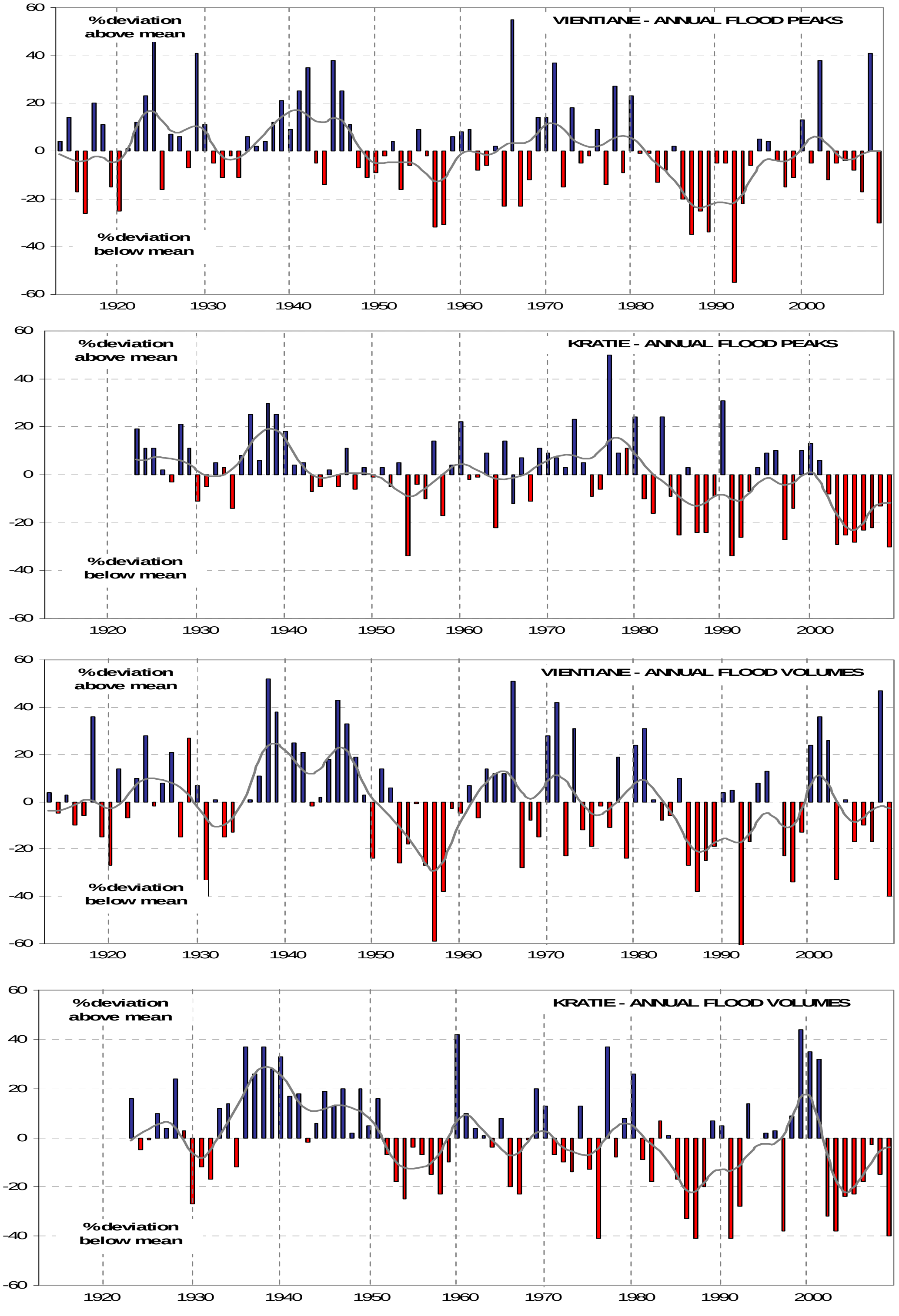


Figure 2.16: Percentage deviations of annual flood peak and volume above and below their historical mean values at Vientiane (1913 – 2009) and at Kratie (1924 – 2009)

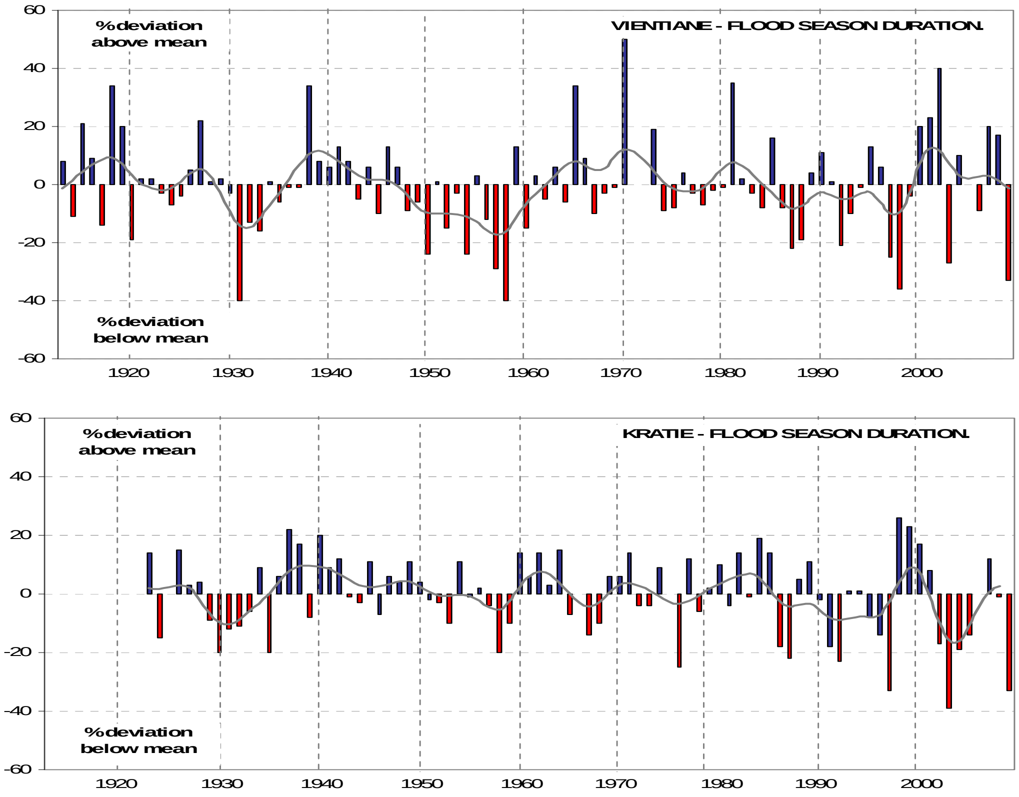


Figure 2.17: Percentage deviations of the duration of annual season above and below the historical mean value at Vientiane (1913 – 2009) and at Kratie (1924 – 2009)

There is no evidence to suggest that the frequency of typhoons and tropical storms is currently increasing. The data plotted in Figure 2.18 show the annual count of storms approaching Viet Nam from 1900 to date, with a mean rate of 6.9 events per year. There is no long-term systematic trend. Imamura and To (1997) reviewed the post 1950 data from a different source and also concluded that the expected increase due to climate change was not historically evident.

There is a widely acknowledged though complex relationship between ENSO events and the number of typhoons making landfall in Viet Nam and Guangdong province in China and then potentially passing into the Mekong Basin (see Elsner and Liu, 2003). Fewer but more intense storms occur during strong El Nino years but multiple occurrences have a higher probability in strong La Nina years. Because the number and intensity of storms is closely linked to sea surface temperatures any intensification of the ENSO cycle is expected to increase the annual risk of severe tropical storms entering the Mekong region.

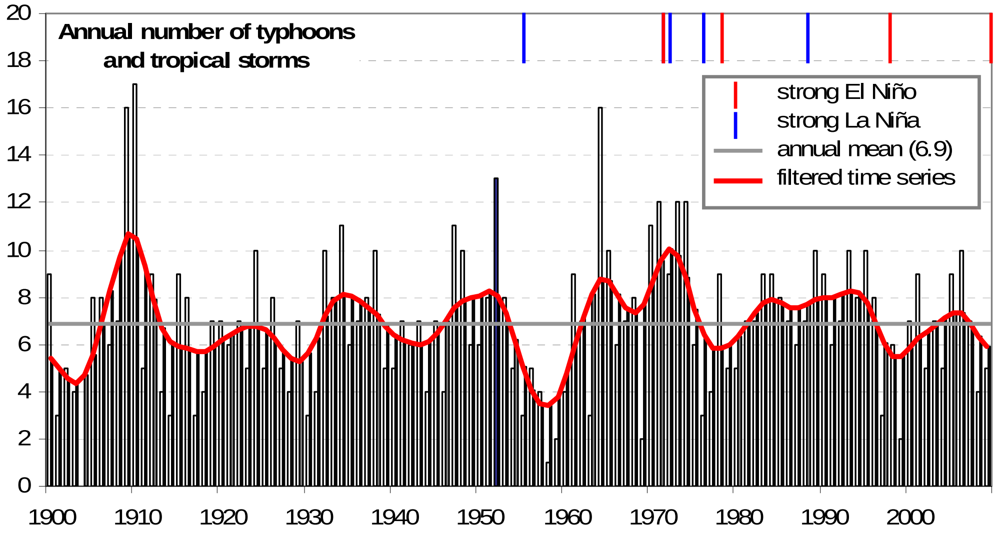


Figure 2.18: The number of tropical storms (wind speed > 16 m/sec) and typhoons (wind speed > 33 m/sec) approaching the coast of Viet Nam (specifically entering the latitude / longitude box 7.5 to 22.5^0 N and 105.0 to 115.0^0 E). The data from 1900 to 1995 are drawn from the CD-Rom Global Tropical and Extra-Tropical Cyclone Atlas, Version 2, US Navy, Department of Commerce, Washington DC. 1996. (see Adger et al, 2001). The post 1995 data to 2009 are drawn from Giang (2005) and the MRC Annual Flood Reports. The El Niño/La Niño information is taken from the 'consensus data' available from 1950 onwards at http://ggweather.com/enso/years.htm

2.7 Climate change – summary of the regional socio-economic issues

There is significant geographical variation is the anticipated impacts of global warming across the Mekong Basin. Rainfall, for example, is expected to increase more in the northern and central regions, where most of the flood runoff from year to year is generated. Agriculture is the most vulnerable economic sector to the expected increased variance in rainfall and the associated decrease in its reliability. Greater drought risk combined with the increased incidence of long term flood inundation will potentially lead to greater crop losses and lower food security. Agricultural output is vulnerable not only to less reliable rainfall amounts but also to any change in its seasonal distribution. In 2004, when the monsoon rains virtually ceased two months early, crop losses and national economic impacts, particularly in NE Thailand, were severe.

Clearly rice is by far the region's most important crop, being grown on 90 percent of the land used for cereal production in Thailand and Lao PDR (Chinvanno *et al.* 2008), most of it being rain fed. The regional capacity to mitigate drought through irrigation is limited outside of the delta. Increasing rainfall excess and deficit is not the only issue threatening regional agricultural production. Increasing temperature is also a factor. IRRI[7] research has indicated that rice yields decrease by 0.6 tons / hectare for every one degree increase in temperature. Present average yields vary from 4.5 tons / hectare in the Delta, 3 tons / hectare in Lao PDR and just 2 tons / hectare in NE Thailand, due to water stress, and in

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[7] International Rice Research Institute.

Cambodia, due to low use of fertiliser. (Kirby and Mainuddin, 2009). By the end of the century, the region is expected to warm another 2-4˚C (IPCC 2007, ADB 2009) so the potential impacts upon rice yields are huge and underscore the need for the ongoing research to develop rice hybrids that are far more resistant to water stress.

Global demand for food is forecast to double by 2050 (IWMI, 2010). Only 7 percent of global rice production is traded internationally, Thailand and Viet Nam being the main exporters. In the case of Viet Nam most of the rice grown for the international trade is produced in the delta. Consequently the threats posed by climate change and sea level rise have international implications.

Everywhere, temperature and rainfall affect agriculture directly. In the Lower Mekong Basin changes in the hydrological regime will also have a direct impact since the most productive agricultural land in the basin is prone to flood inundation, while traditional flood recession farming remains widespread, particularly in Cambodia. Increases in sea level have a clear direct impact on agriculture in the delta. In Lao PDR and Cambodia losses in the agricultural sector comprise the major proportion of total flood damage. In the delta and NE Thailand the proportional agricultural losses are less, with infrastructure damage accounting for the major proportion (MRC, 2009).

Most regional climate change impact studies have forecast an increase in extreme flood events. The key linkage is with the projected increase in the regional incidence of typhoons and severe tropical storms which have been responsible for the majority of the most damaging events. In an average year a broad estimate of the regional cost of the annual Mekong flood is US$76 million, rising to over US$800 million in an extreme year such as 2000 (MRC, 2009). The economic implications of an increase in extreme events are therefore considerable.

The need to adopt adaptive strategies to manage the impacts of global warming in the agricultural sector have inevitably focused on the potential increase in drought risk and the need to use water more productively. In the developing world though it is not always clear if there is in effect any distinction between policies aimed at the mitigation of climate induced impacts and overall poverty reduction strategies, such as increasing access to financial resources and the diversification of income sources as an effective means of reducing vulnerability by spreading risk. The prospect that the frequency of extreme floods may increase makes no difference to flood management and mitigation policies that effectively reduce impact, loss and damage. All climate change impacts are, with the exception of sea level rise, simply the intensification of underlying hazards such as drought, floods and storm surges that already exist. Therefore, actions to adapt to climate change invariably draw upon policies already developed to manage the risks that arise from natural climate variability.

Adaptation is a different concept since it involves a permanent adjustment to changed climatic and environmental circumstances in terms of, for example, relocating populations currently settled in areas that become uninhabitable due to sea level rise or where the risk of flooding becomes impractically high. Climate change adaptive policy is closely integrated with aspects of national development policy, not least because of the costs involved, which in turn leads to the need for detailed cost benefit analysis. Regionally, adaptive climate change strategies are being integrated into national development policy, with Viet Nam leading the way. There remains, however, a need to develop detailed policy at the regional and local level, recognising the specific issues at this scale, which in turn would inform national policy initiatives (MRC, 2009b). Recognising this, the MRC has instigated the '*Mekong Adaptation and Climate Change Initiative*' aimed at adaptation planning at a pilot site in each Member Country, followed by basin-wide demonstration and the development of improved national capacity to manage and respond to climate change.

3. The 2009 flood season

3.1 General observations

Flood conditions in the Lower Mekong Basin during the 2009 monsoon season were significantly below average both in terms of peak discharge and with regard to the seasonal volume of runoff. The early end to the SW Monsoon determined that the flood season ended early with the onset of the flood recession setting in as early as September at Chiang Saen. The recession was also very rapid when compared to the average historical rate such that by mid October flows were generally less than the long-term mean annual discharge which is adopted as the criterion to define the onset of the low flow season.

This early onset of the low flow season combined with flow volumes that were well below average during the flood season itself, reflecting the relative weakness of the SW Monsoon, meant that:

- natural catchment storage towards the end of the flood season , particularly in terms of groundwater levels and soil storage, was low;
- these reserves were drawn upon early and given that even under normal conditions natural subsurface water storage in the Lower Basin is not well developed in terms of large aquifers for example, these storages soon became depleted; and
- in consequence tributary and therefore mainstream flows and water levels had become critically low by late December such that by January 2010 a severe regional drought had developed.

As is now the well-established pattern, the geographical severity of these conditions typically varied from north to south in the basin. Conditions at Vientiane / Nong Khai and further upstream remain the most critical. Those further south at Pakse, Kratie, the Cambodian flood plain and the delta less so.

Five tropical storms made landfall in Viet Nam during the season. Tropical storm Ketsana made landfall over central Viet Nam at the end of September causing high winds and three-day accumlated rainfall over large areas as much as 600 mm and locally almost 1000 mm in the Central Highland and upper Se San and Sre Pok tributary basins. Flash flooding occurred in these areas and in northern Cambodia and southern Lao PDR.

During the first week of December tropical storm Mirinae tracked across the southern parts of Viet Nam and caused heavy rainfall of 200mm and more over two days, though the impacts were less widespread than those associated with Ketsana.

Finally, the 2009 flood season saw the first significant impact of the mainstream dams in China on the flood hydrograph within the Lower Basin. Notification was given to the MRC that the filling of Xiaowan would commence in July and the effects of this are clearly evident, particularly at Chiang Saen, Luang Prabang and Vientiane / Nong Khai. The operation of Manwan and Jinghong reservoirs is also becoming increasing evident during the flood season, an illustration of which is set out in the text to follow.

3.2 Meteorological conditions

From a meteorological perspective, conditions within the 2009 Mekong flood season are assessed with respect to two aspects:

- the intensity of the SW monsoon in terms of the seasonal rainfall compared to the expectation; and
- the incidence and severity of tropical storms and typhoons, which generally develop in the eastern Pacific and enter the basin from the east.

The timing of the regional onset and end of the SW Monsoon is remarkably consistent from year to year, with a typical standard deviation of only one to two weeks. The data for the locations indicated in Table 3.1 are based upon criteria applied in India by Khademul et al (2006). The annual onset of the SW Monsoon may be defined as the week during which more than 20mm of rainfall occurs within 1 or 2 consecutive days, provided that the probability of at least 10mm of rainfall occurring in the subsequent week is more than 70%. The latter component of the criterion screens out isolated storm events earlier in the year that do not fully indicate the start of 'true' monsoonal conditions. The date of monsoon withdrawal is defined as the day up to which at least 30mm of rainfall accumulates over a sequential seven day period, with no subsequent rainfall for at least 3 consecutive weeks.

Site	**Monsoon onset**			**Monsoon end**		
	Average Date	**Standard Deviation**	**2009**	**Average Date**	**Standard Deviation**	**2009**
Chiang Saen	7th May	9 days	30th April	7th Nov	25 days	18th Nov
Luang Prabang	7th May	9 days	6th May	24th Oct	33 days	9th Nov
Vientiane	4th May	8 days	4th May	10th Oct	16 days	26th Oct
Mukdahan	6th May	8 days	7th May	8th Oct	16 days	1st Nov
Pakse	5th May	11 days	26th May	15th Oct	17 days	4th Nov
Chau Doc	9th May	13 days	2nd Jun	21st Nov	17 days	5th Nov

Table 3.1: The onset and end of the 2009 SW Monsoon at selected sites in the Lower Mekong Basin

The onset of the Monsoon typically occurs within a remarkably narrow period of time in May. It withdraws usually during October in the more central areas of the Basin and in November in the north (Chiang Saen) and south. During 2009 the onset and end dates were within the characteristic range. From a temporal perspective therefore, monsoonal conditions during 2009 appear to have been typical across the region.

The key features of the 2009 flood season are that mainstream water levels and flows were considerably below average and that from October onwards a severe regional drought developed most particularly in the Upper Basin in China and in the northern parts of the Lower Basin.

3.2.1 Rainfall in the upper Mekong basin

The regional drought that has developed since the end of the 2009 flood season is largely explained by the general weakness of the 2009 SW Monsoon and its early withdrawal, most particularly in the Upper Mekong Basin. The early end to the wet season has historically been linked to the development of drought conditions, for example those of 2004 / 5 in Lao PDR and NE Thailand which caused severe agricultural losses.

The feature of conditions in 2009 / 10 is that the Mekong mainstream and the major tributaries have, between October 2009 and March 2010, fallen to levels that are widely historically unprecedented. In part this reflects the fact that groundwater and other zones of natural catchment water storage are not well developed in the Mekong Basin, particularly in the north. In turn this means that they are soon depleted. If this depletion begins early due to poor rainfall towards the end of the normal monsoon season and in combination with below average rainfall in earlier months leading to lower volumes of natural storage to begin with, then stream flows recede relatively quickly to critically low levels. Amplifying the wider post monsoon impact upon the dry season hydrology is the major contribution that flows from the Upper Mekong make to the low flow regime of the Lower Basin.

The current drought conditions in Yunnan have been widely reported by Chinese News Agencies as the worst in the last 50 to 60 years. Not only have the effects been agricultural but low levels of reservoir storage have led to much reduced hydropower outputs and projected power shortfalls against demand of 20 percent during the first half of 2010. That the 2009 Monsoon in Yunnan was weak and ended early is quite evident from an analysis of selected rainfall data available for downloading from the NOAA website for the network of gauging sites indicated in Figure 3.1.

Table 3.2 compares the 2009 rainfall with the long term average (1985 – 2008) and indicates that with two exceptions conditions fell well below normal:

- generally 2009 was one of the four driest years that have occurred over the last 25 years;
- conditions were generally the most severe in the north and central regions, with the annual total being less than 75% of normal;and
- here the annual rainfall at six of the ten sites lay below the average minus one standard deviation, which provides a useful benchmark to define a significant deficit compared to the 'typical' range.

The results in Figure 3.2 indicate the seasonal distribution of rainfall at six of the sites:

- rarely did monthly rainfall amount to anything above average and was throughout the region continuously and often significantly below average;and

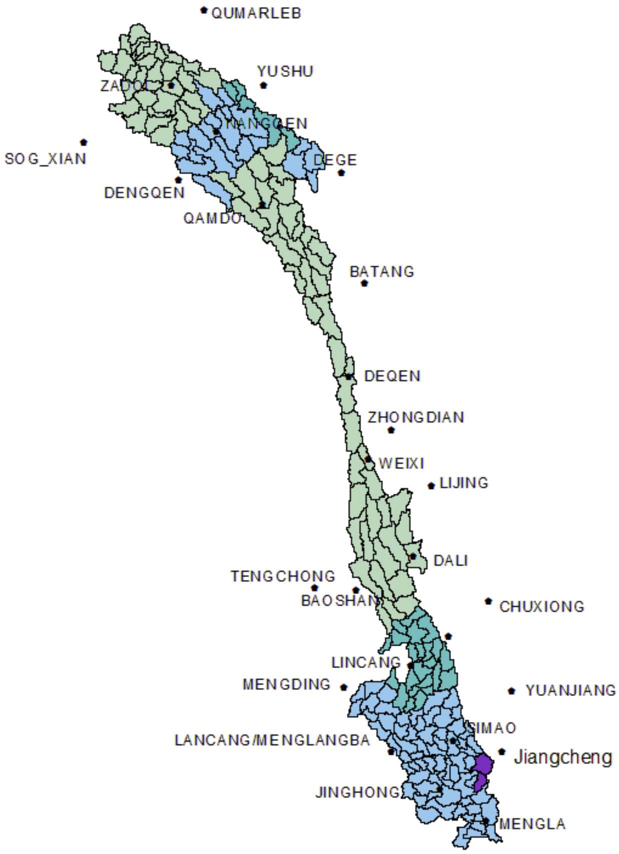
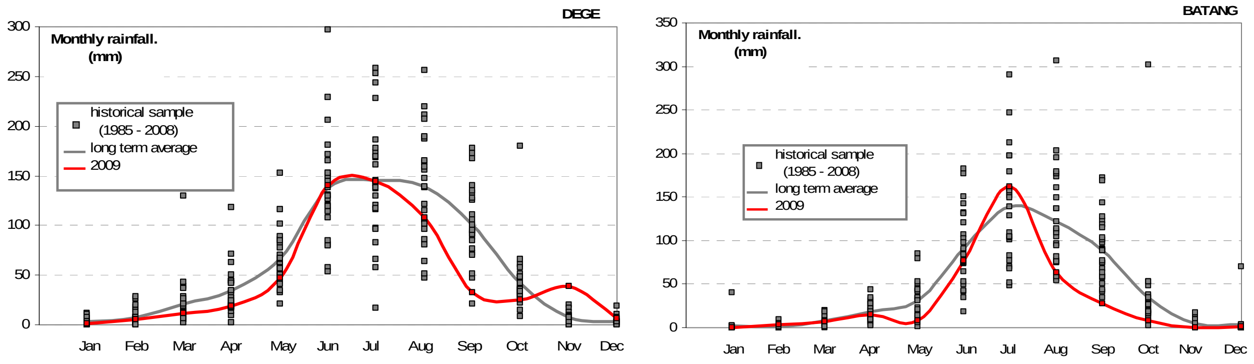


Figure 3.1: Upper Mekong Basin – network of daily rainfall observation stations for which data are available from 1985 to date from the WMO website (ftp://.ncdc.noaa.gov/pub/data/gsod) Highlighted sites are considered in Figure 5.2

Raingauge	Mean annual rainfall (mm)	2009 (mm)	2009 / average	
Dege	700	580	83%	NORTH
Dengqen	700	620	89%	
Qamdo	550	400	73%	
Batang	550	370	67%	
Leijing	1 000	840	84%	
Dali	1 150	1 150	100%	
Tengchong	1 500	1 150	77%	
Chuxiong	950	600	63%	
Baoshan	1 050	700	67%	
Lincang	1 200	870	73%	
Yuanjiang	880	760	86%	
Simao	1 500	1 500	100%	
Lancang Menglangba	1 600	1 500	94%	
Jiangcheng	2 300	2 000	87%	
Jinghong	1 200	1 100	92%	
Mengla	1 600	1 300	81%	SOUTH

Table 3.2: Upper Mekong Basin – 2009 rainfall compared to the mean (1985 – 2008). Shading indicates 2009 rainfall < the mean minus one standard deviation

NORTH



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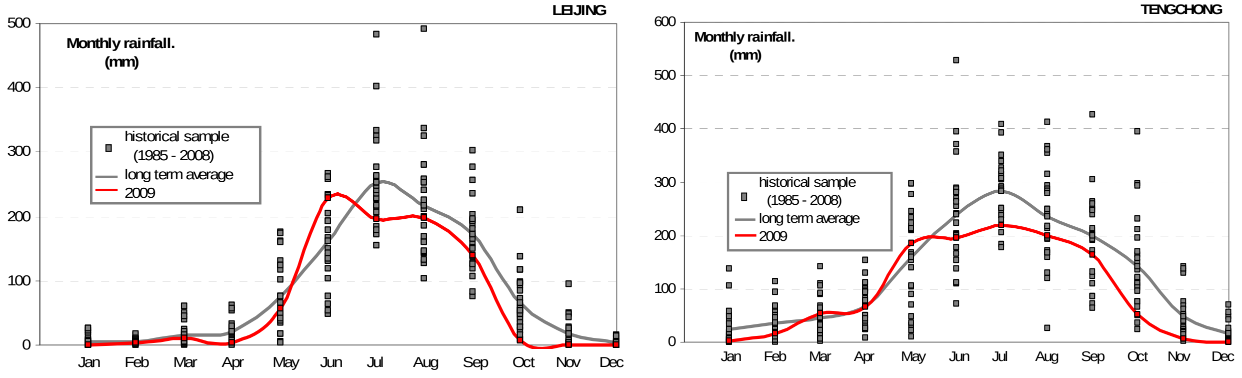

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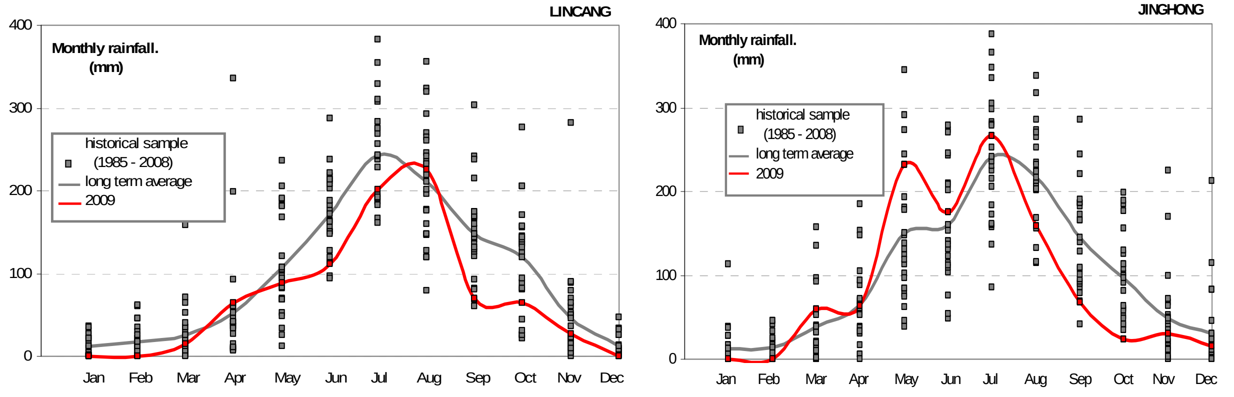


Figure 3.2: Upper Mekong Basin – historical range and average of monthly rainfalls compared to rainfall in 2009 at selected sites

- at the majority of sites no rainfall of any significance occurred after August (at Batang none after July) while during some of these later months of the monsoon season rainfalls were amongst the lowest observed.

This sudden and early end to the 'wet' season combined with generally below average rainfall in the earlier months precipitated the hydrological drought conditions that followed. Given the role that the flows from Yunnan play in determining the low flow regime in the Lower Basin (Figure 3.3) the critical hydrological drought conditions on the Mekong mainstream are set to continue well into 2010.

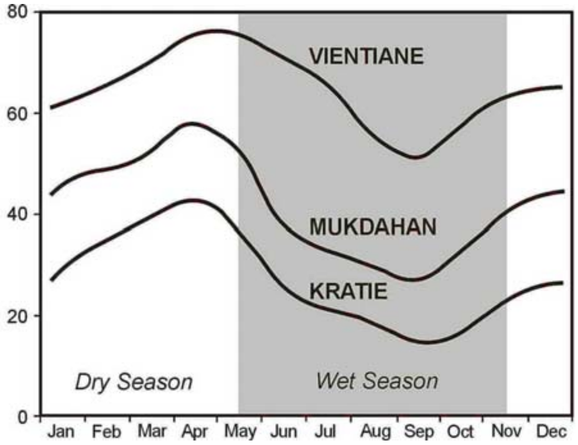


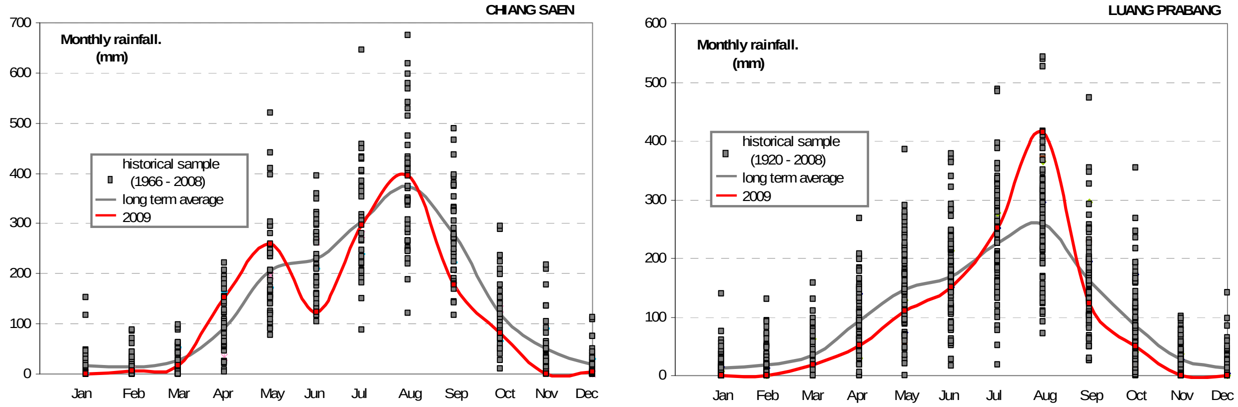
Figure 3.3: Lower Mekong Basin - Percentage contribution of the "Yunnan Component" to long-term mean monthly flows

3.2.2 Rainfall in the Lower Mekong Basin

The analysis of 2009 rainfall conditions is based on data recorded by the HYCOS automatic monitoring system. Monthly totals at selected sites are shown in Figure 3.4.

- the general pattern is one of considerably below average seasonal rainfall in most months.
- rainfall after August in the latter part of the monsoon season is below normal, following the pattern in the Upper Mekong.
- the significantly above average rainfalls at Luang Prabang in September and at Mukdahan in June are mainly the result of single day totals in excess of 150 mm.
- given the generally below average conditions over most of the season, natural catchment storage in groundwater reservoirs would have been below normal levels and the lack of rainfall during the later months meant that the flood recession began un-seasonally early. Dry season flows therefore became critically low by late December and early January.

NORTH



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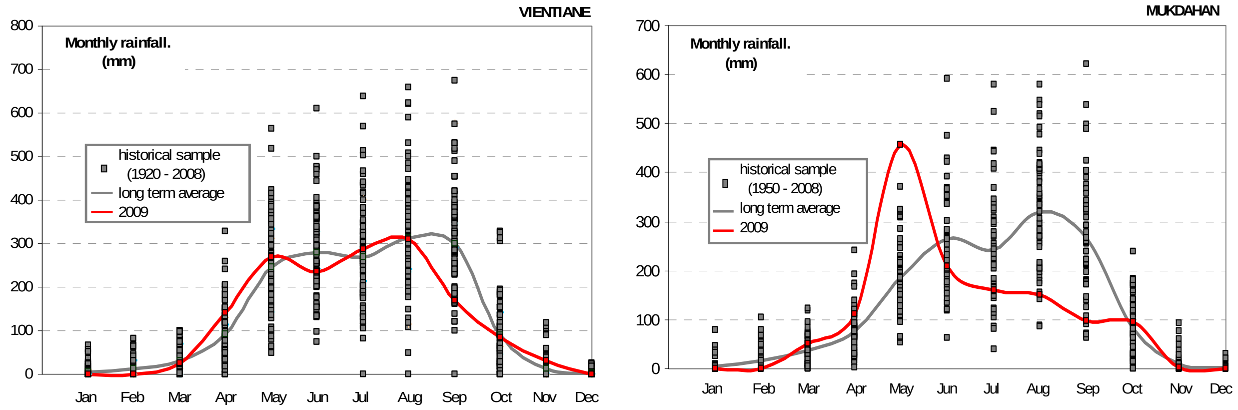

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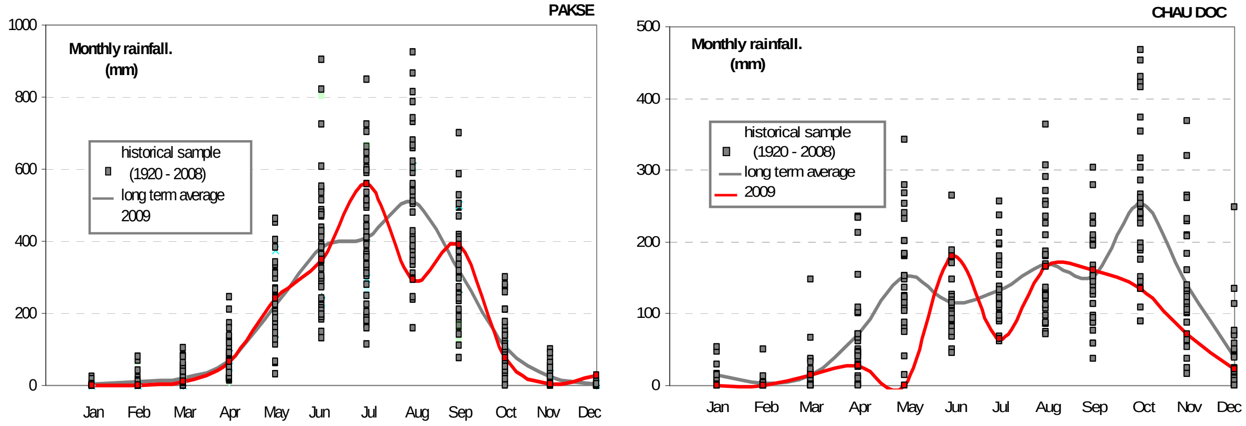


Figure 3.4: Lower Mekong Basin – historical range and average of monthly rainfalls compared to rainfall in 2009 at selected sites

- considering the 2009 monsoon season as a whole, total rainfall across the Lower Basin was only marginally below average (Table 3.3) and did not reflect the much more severe situation apparent in the Upper Mekong region (Table 3.2).

Raingauge	Mean annual rainfall (mm)	2009 (mm)	2009 / average
Chiang Saen	1 750	1 500	86%
Luang Prabang	1 250	1 200	96%
Vientiane	1 650	1 450	88%
Mukdahan	1 500	1 350	90%
Pakse	2 100	2 000	95%
Chau Doc	1 250	1 000	80%

Table 3.3: Lower Mekong Basin – 2009 rainfall compared to the mean (1985 – 2008). Shading indicates 2009 rainfall < the mean minus one standard deviation

3.3 Temporal aspects of the 2009 Mekong flood season

Defining as usual, the onset of the flood season as the first sustained ‘up-crossing’ of the mean annual discharge and its end as the last ‘down-crossing’ the figures in Table 3.4 below indicate that

- the onset of the 2009 flood season throughout the Lower Basin was well within the usual weeks of the year that is from mid June to early July.
- it is, however, the end of the 2009 season that is atypical. At Vientiane and further upstream at Luang Prabang and Chiang Saen the season came to a close five weeks early at the end of the first week of October. At Pakse flood conditions ceased more than two weeks early, though at Kratie the season end on the historically expected date. This early end to the season in the north, which in terms of maximum water levels and the total season volume of flow was well below average, is the major contributor to the severe drought conditions that began to develop in the basin from December onwards.

Site	Onset of flood season			End of flood season		
	Historical average	Standard deviation	2009	Historical average	Standard deviation	2009
Chiang Saen	28th June	13 days	4th July	14th Nov	14 days	8th Oct
Luang Prabang	18th June	25 days	5th July	12th Nov	16 days	5th Oct
Vientiane	3rd July	14 days	6th July	11th Nov	15 days	9th Oct
Pakse	29th June	16 days	22nd June	5th Nov	11 days	22nd Oct
Kratie	1st July	16 days	24th June	7th Nov	12 days	7th Nov

Table 3.4: Start and end dates of the 2009 flood season compared to their historical mean and standard deviation at selected mainstream locations

3.4 Water levels

Nowhere did water levels rise significantly above average during 2009 (Table 3.5), the major seasonal feature being that at Luang Prabang and Vientiane the maximum seasonal water levels occurred very early during the first week of July in response to what turned out to be the only intensive period of storm rainfall during the whole season in these northern regions of the basin.

Site	Maximum water level		Date of maximum water level	
	average	**2009**	**Average**	**2009**
Chiang Saen	6.9 m	6.9 m	18th Aug	8th Aug
Luang Prabang	13.7 m	13.8 m	6th Aug	6th July
Vientiane	9.5 m	9.2 m	22nd Aug	8th July
Kratie	20.4 m	21.4 m	10th Sep	6th Oct

Table 3.5: Average maximum water levels and their dates compared to those of 2009 at selected mainstream sites.

A more detailed view of the 2009 water levels is given in Figure 3.5 in which they are compared to their long term average over the year and to those of 1992 which were regionally the lowest ever previously recorded. The plot is also extended to late February 2010 to illustrate how the early end to the 2009 flood season precipitated water levels even lower than those of 1992 / 1993.

- the key feature is that water levels at Chiang Saen from November 2009 onwards were higher than those that occurred in 1992 / 3. At Luang Prabang and Vientiane, the opposite is true.
- this strongly suggests that the water levels at Chiang Saen were kept artificially high by upstream reservoir releases until late January when they receded significantly in response to reduced releases in response to the drought conditions and low levels of reservoir storage in the upper Mekong. The levels at Luang Prabang and Vientiane being lower than 1992/3 from October onwards more truly reflect the regional drought conditions and its severity from September 2009 onwards and the very low contributions to the mainstream by the large tributaries in northern Lao PDR.
- that these tributaries had fallen to extremely low levels by January 2010 is shown in Figure 3.6.

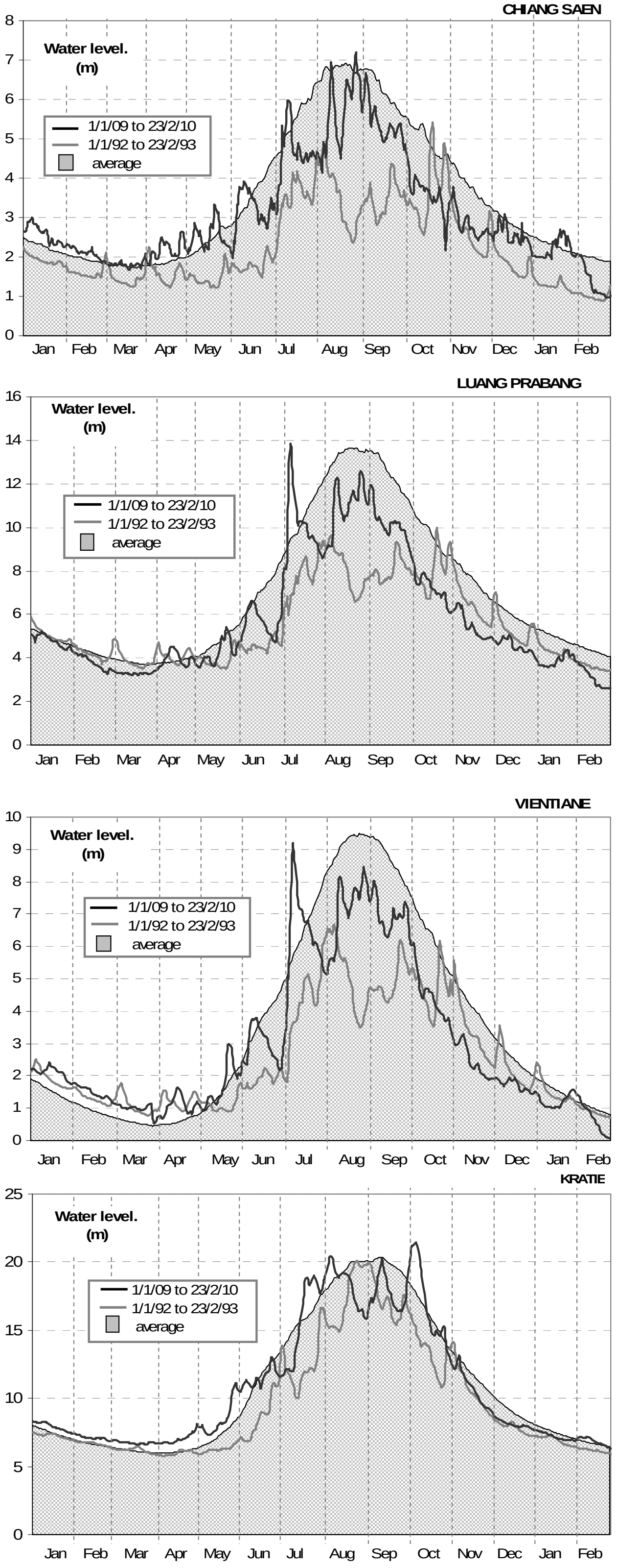


Figure 3.5: Comparison of water levels at selected sites on the Mekong mainstream for the periods 1/1/1992 to 23/2/1993 and 1/1/2009 to 23/2/2010

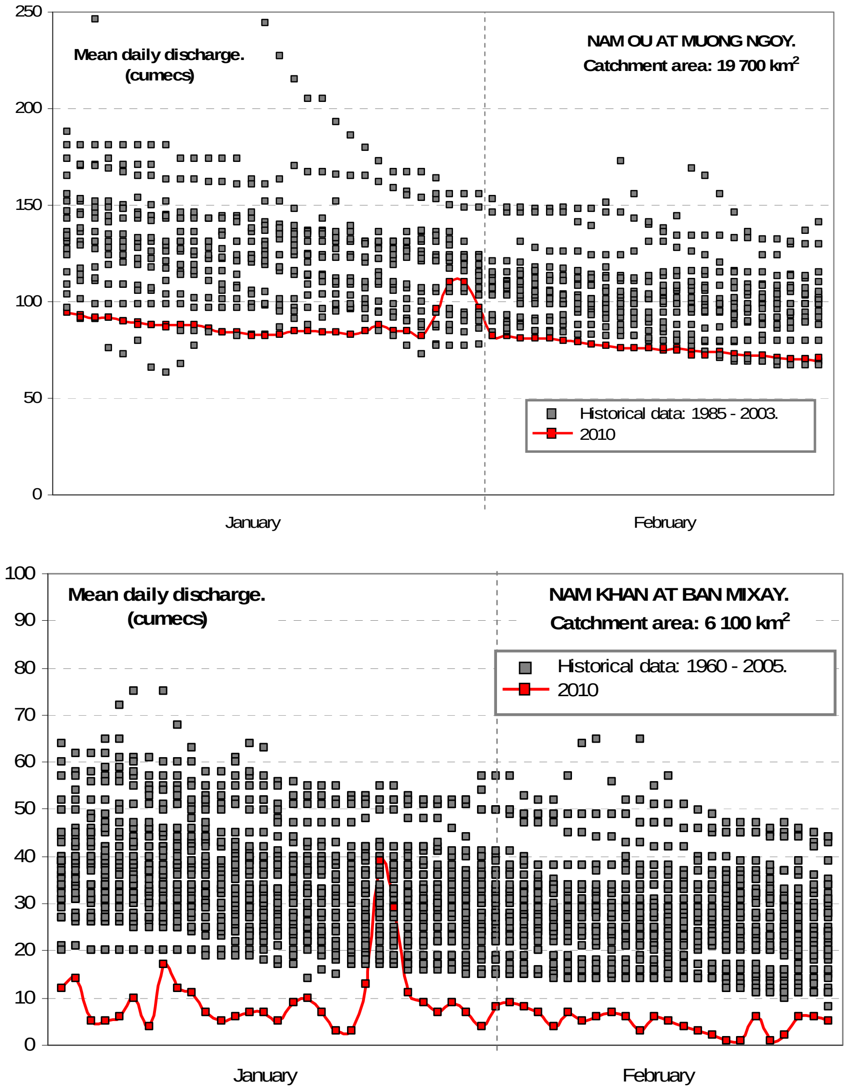


Figure 3.6: Nam Ou and Nam Khan in Northern Lao PDR: Daily discharges for the period 1st January to 23rd February, 2010 compared to their historical range

3.5 Flood discharges and flood volumes

The flood discharge hydrographs (Figure 3.7) merely serve to confirm the fact that conditions during the course of the 2009 flood season were considerably below average, particularly in the northern regions of the Lower Mekong Basin.

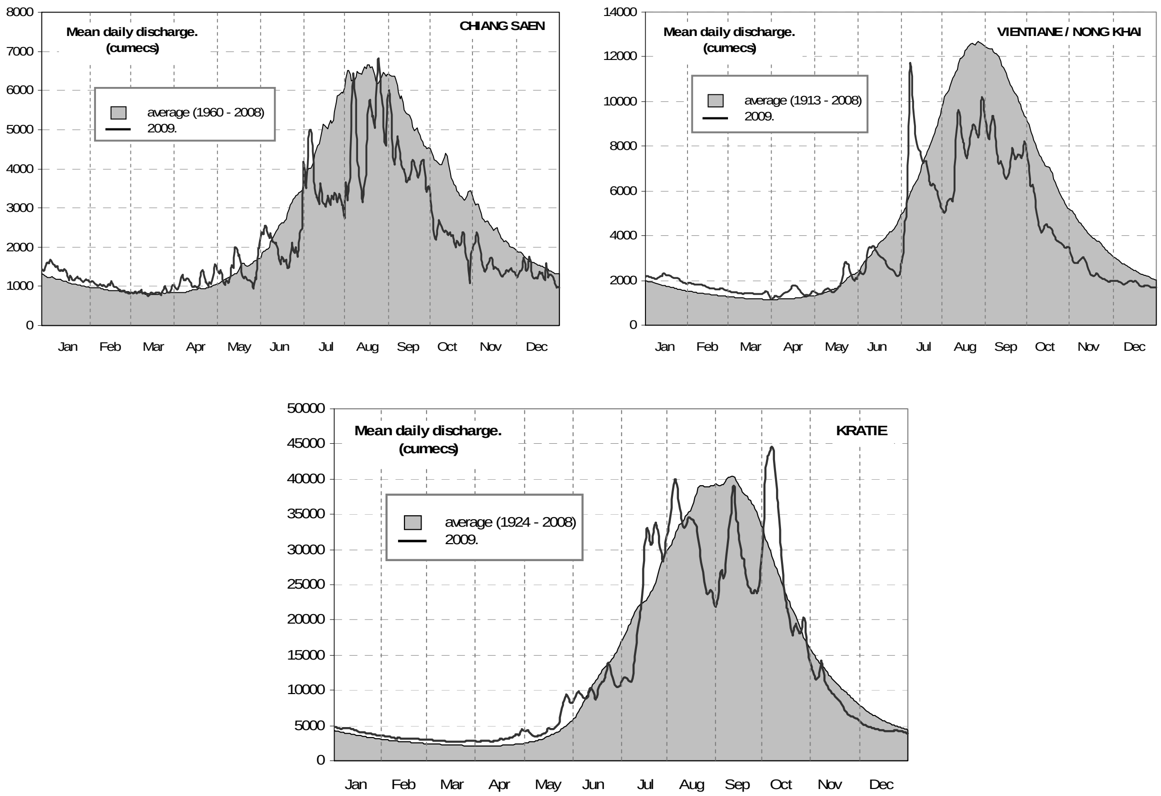


Figure 3.7: Chiang Saen, Vientiane and Kratie: The 2009 daily discharge hydrograph on the Mekong mainstream compared to the long term average. The peak discharge at Kratie during the first week of October is the response to Typhoon Ketsana

How these below normal conditions are set within the historical perspective is set out in Table 3.6 in which those of 2009 in terms of annual maximum discharge and seasonal flood volume are related to the rank order flood conditions, with the rank one year being the lowest peak or volume:

- the 1992 flood season was clearly regionally the most extreme recorded before or since, with a peak and volume far below any of those observed in the last 50 to (almost) 100 years, particularly in the northern parts of the Lower Basin.

- in these northern regions the 2009 event is amongst the smallest floods ever recorded, particularly in terms of its overall volume, largely a result of the early end to the season by as much as four weeks at Vientiane. Here the flood volume was the fourth lowest in almost 100 years.

Mainstream site	Sample years	Annual maximum flood peak			Annual flood volume		
		Rank	Year	cumecs	Rank	Year	km^3
Chiang Saen	50	1	1992	5 400	1	1992	24.8
		2	2003	6 000	2	1972	32.7
		3	1994	6 400	**3**	**2009**	**33.2**
		4	1988	6 600	4	2003	36.6
		5	**2009**	**6 800**	5	1975	37.2
Luang Prabang	71	1	1992	5 700	1	1992	20.5
		2	1987	8 800	2	1957	32.6
		3	2003	9 100	3	2003	49.3
		4	1989	9 500	**4**	**2009**	**49.6**
		5	1957	9 900	5	1958	51.3
		7	**2009**	**10 600**			
Vientiane	97	1	1992	7 500	1	1992	37.4
		2	1987	10 800	2	1957	42.1
		3	1989	11 100	3	1931	61.3
		4	1957	11 300	**4**	**2009**	**61.5**
		5	1958	11 500	5	1987	62.8
		6	**2009**	**11 700**			
Pakse	87	1	1992	24 600	1	1998	137.1
		2	1998	26 800	2	1992	143.1
		3	1955	27 000	3	1977	142.9
		4	1993	27 900	4	1988	144.0
		5	1965	28 100	5	1987	163.5
		9	**2009**	**29 000**	**12**	**2009**	**187.0**
Kratie	86	1	1992	33 900	1	1992	195.4
		2	1955	34 000	2	1977	196.6
		3	2004	36 500	3	1988	196.8
		4	2006	36 900	4	2004	204.7
		5	1998	37 400	5	1998	205.6
		17	**2009**	**44 600**	**20**	**2009**	**282.5**

Table 3.6: The 2009 flood season terms of maximum discharge and volume and its historical rank (smallest to largest) order

- further downstream at Pakse and Kratie conditions during 2009 were less of a historical precedent, though still well within the lowest quartile over the last 80 years and more.

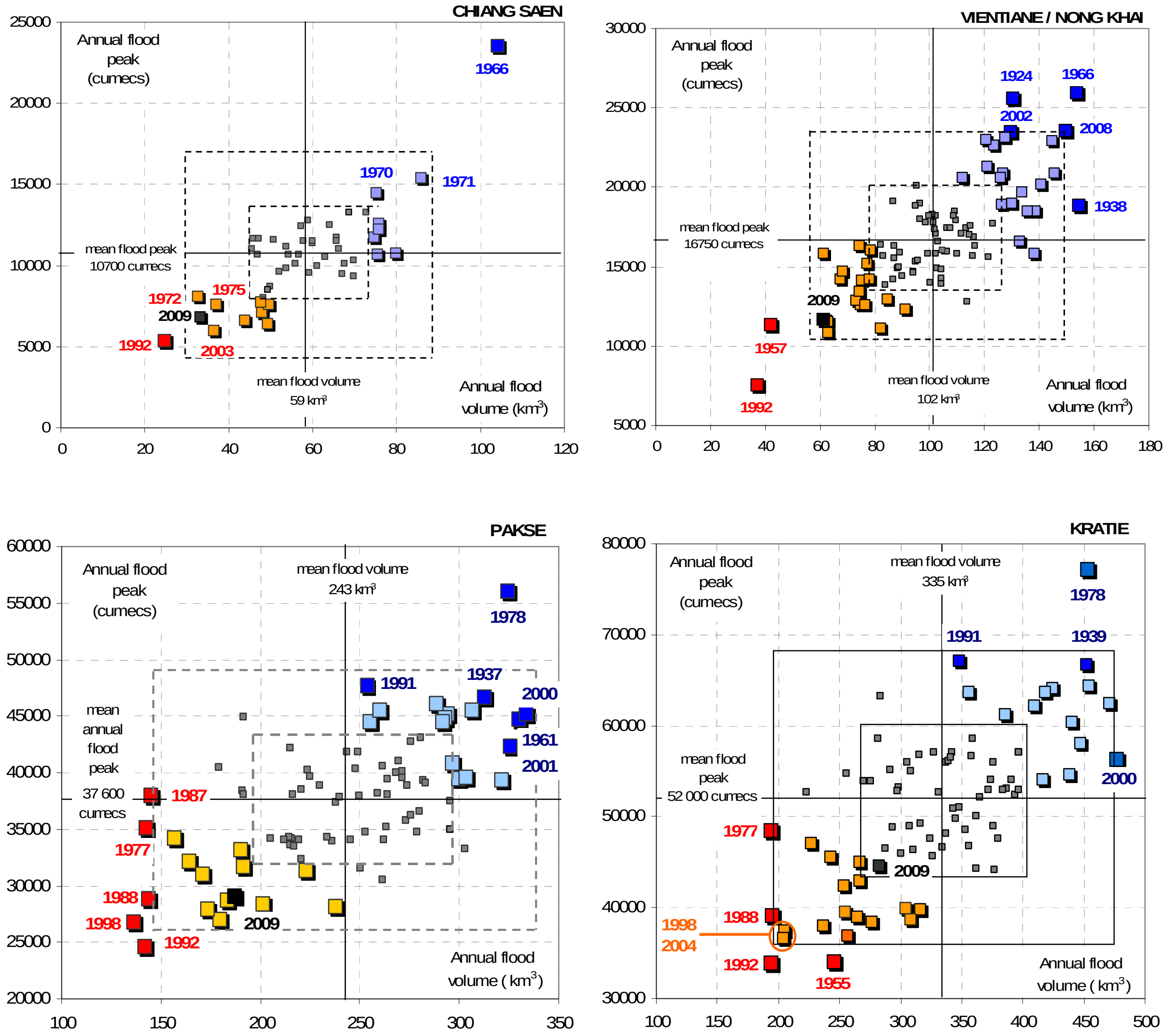


Figure 3.8: Scattered plots of the joint distribution of the annual maximum flood discharge (cumecs) and the volume of the annual flood hydrograph (km^3) at selected sites on the Mekong mainstream. The 'boxes' indicate one (1δ) and two (2δ) standard deviations for each variable above and below their respective means. Events outside of the 1δ box might be defined as '*significant'* flood years and those outside of the 2δ box as historically '*extreme*' flood years

Figure 3.8 provides a more comprehensive view in terms of the historical joint distribution of flood peak and volume. Conditions during 2009 were 'significantly' below average in terms of both variables at Chiang Saen, Vientiane and Pakse, while at Kratie they were not quite so exceptional though still below the historical 'norm'.

3.6 Aspects of probability and risk

Extreme events such as floods are generally considered, in the context of probability and risk, in terms of those that exceed critically high thresholds and cause losses and damage through inundation. However, on large rivers such as the Mekong where the annual flood has a positive ecological and socio-economic function there is also the case to be considered of years such as 2009 when conditions fall well short of the seasonal expectation. The incidence and severity of such episodes also needs to be assessed in terms of statistical risk. Tables 3.7 and 3.8 therefore indicate the estimated mean recurrence intervals of annual flood peaks and volumes that fall below the seasonal means by increasing degrees of severity.

Mainstream site	**Recurrence Interval. (years)**					
	100	**50**	**20**	**10**	**5**	**2**
Chiang Saen	5 200	5 600	6 300	6 900	7 700	9 500
Luang Prabang	7 800	8 400	9 300	10 200	11 400	13 800
Vientiane	10 000	10 500	11 400	12 200	13 200	15 500
Pakse	25 000	26 000	27 500	29 000	31 000	35 000
Kratie	33 000	34 500	37 000	39 000	42 000	48 000

Table 3.7: Estimated mean annual recurrence intervals of below average flood peaks

Mainstream site	Recurrence Interval. (years)					
	100	50	20	10	5	2
Chiang Saen	26.8	29.0	32.6	36.0	40.7	51.2
Luang Prabang	37.5	41.2	47.2	52.9	60.4	77.1
Vientiane	51.6	55.3	61.1	66.8	74.3	91.0
Pakse	138.6	146.6	159.5	171.8	188.3	225.2
Kratie	175.1	187.2	206.6	225.2	249.5	303.4

Table 3.8: Estimated mean annual recurrence intervals of below average seasonal flood volumes

Reference to the 2009 peak and volume figures quoted in Table 3.6 reveals that:

- between Chiang Saen and Vientiane peak discharges as low as those of 2009 would be expected to occur on average once every ten to twenty years**.** Further downstream at Pakse and Kratie the low annual peak was less exceptional and has a recurrence interval of between five and ten years.
- the statistical risk of the deficient flood volumes of 2009 is similar, being once in 20 years in the northern reaches of the mainstream and just once in five years towards Pakse and Kratie.

A more refined statistical assessment is obtained if the peak and volume of the event are considered jointly within the probabilistic context rather than separately. Adamson et al (1999) developed a method for obtaining a bivariate extreme value model of flood peak and volume which provides the type of result indicated in Figure 3.9. This may be perceived as adding the dimension of probability to the simple scatter plots shown in Figure 3.8.

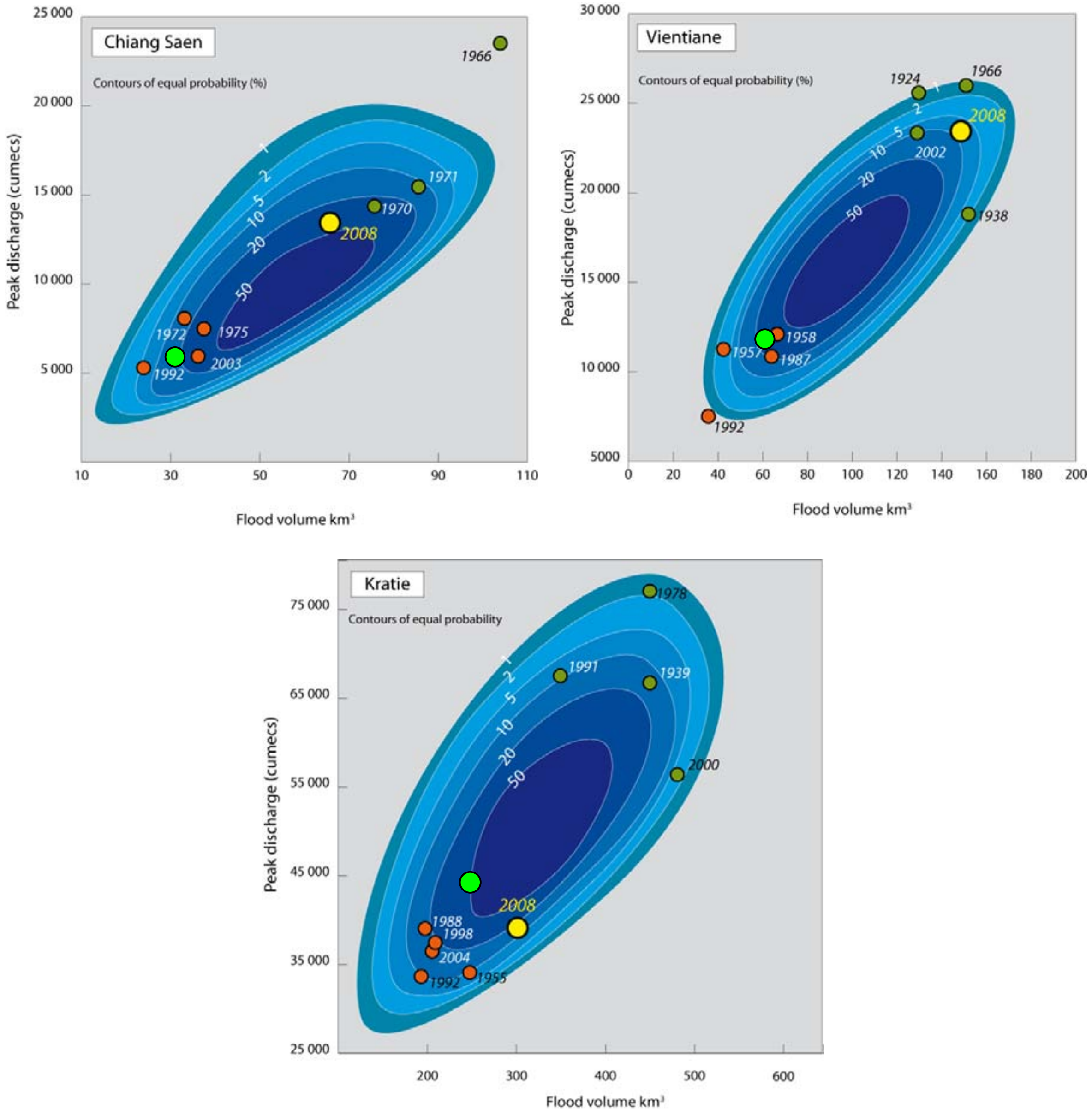


Figure 3.9: Bivariate probabilities of the joint distribution of flood peak and volume at selected mainstream sites. For example, points lying outside of the 1% isoline would have a recurrence interval in excess of 1:100 years; any outside of the 2% contour a recurrence interval in excess of 1:50 years, and so on. (● 2009)

- at Chiang Saen the 2009 flood conditions have a bivariate probability of occurrence of the order of once in ten years
- at Vientiane the bivariate risk is similar
- while at Kratie the bivariate conditions would be expected to occur on average once every 5 years or less.

3.7 Conditions on the Cambodian floodplain and in the Delta

Water levels on the Cambodian flood plain and in the Delta during 2009 were generally average throughout the year (Figure 3.10) as were the maximum water levels that occurred in October, a week to two weeks later than usual (Table 3.9). After the peaks the levels at Tan Chau and Chau Doc decreased rather more rapidly than usual in response to the conditions that prevailed upstream.

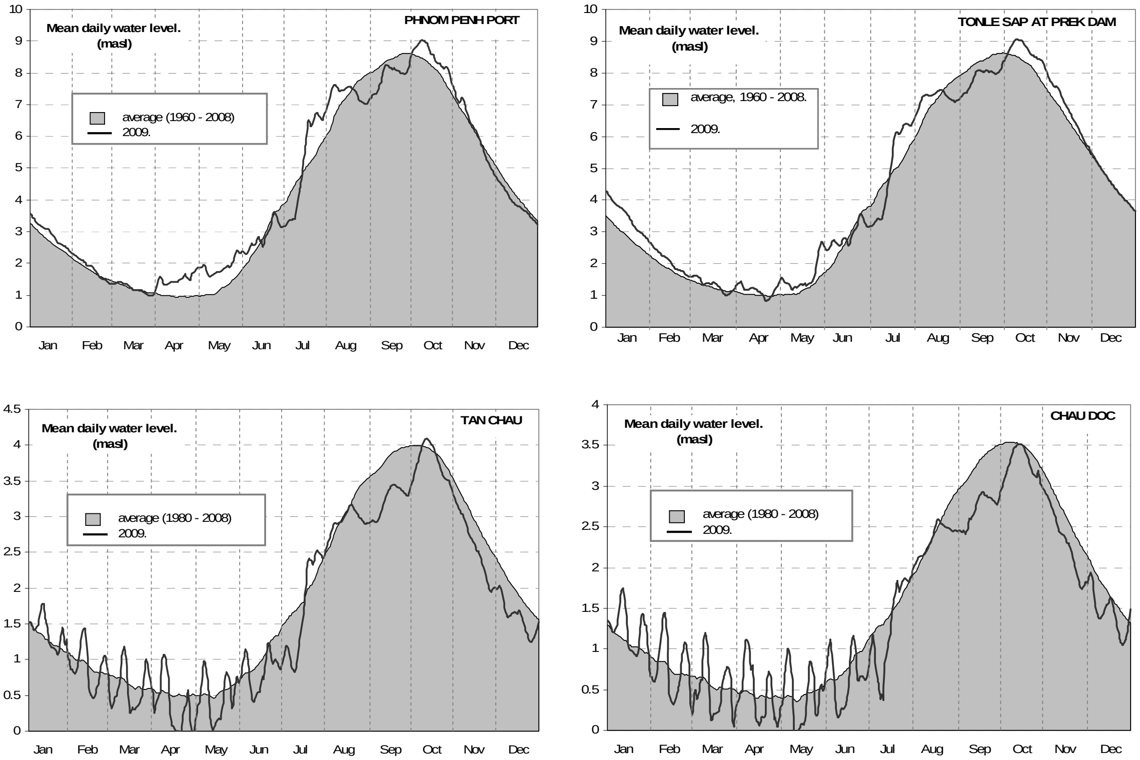


Figure 3.10: Mean daily water levels in Cambodia and the Mekong Delta for 2009 compared to their long term daily average

Site	Period of Record	Annual maximum water level. (masl)		
		Historical average	Standard deviation. (m)	200
Phnom Penh Port	1960 -2008	9.02	0.67	9,03
Prek Kdam	1960 – 2008	9.08	0.73	9.06
Tan Chau	1980 – 2008	4.30	0.54	4.09
Chao Doc	1980 - 2008	3.82	0.58	3.52

Table 3.9: Maximum water levels reached during 2008 in Cambodia and the Mekong Delta compared to their long term average.

In 2009 the start and end of the flood season in this part of the Lower Basin, defined as the period of the year when water levels exceed their long term average, were typical (Table 3.10)

Site	Onset of flood season			End of flood season		
	Historical average	Standard deviation	2009	Historical average	Standard deviation	2009
Phnom Penh	10th July	14 days	13th July	15th Dec	14 days	11th Dec
Prek Kdam	11th July	16 days	14th July	20th Dec	17 days	20th Dec
Tan Chau	19th July	20 days	18th July	17th Dec	12 days	6th Dec
Chau Doc	23rd July	17 days	20th July	19th Dec	12 days	19th Dec

Table 3.10: Cambodian floodplain and Mekong Delta – onset and end dates of the 2009 flood season compared to their historical mean and standard deviation

3.8 A note on the annual discharge hydrograph at Chiang Saen

Being significantly below the long term average, the 2009 daily discharge hydrograph at Chiang Saen reveals considerable 'noise' in the data both during the low flow and flood seasons. There are a great number of short-term fluctuations in discharge (Figure 3.11) with a frequency and pattern that appears to be inconsistent with the hydrological response to rainfall that might be expected over the upstream drainage area which amounts to almost 200 000 km^2. At this scale a much 'smoother' hydrograph would be the expectation. The oscillations also occur during the low flow season when, while most are quite small, there is little if any rainfall to explain them.

A simple definition of these fluctuations might be that they occur in the time series when the discharge on day 't-1' and 't+1' are both greater than (less than) that on day 't' (t=1,365), or when $q(t-1) < q(t) > q(t+1)$ or $q(t-1) > q(t) < q(t+1)$. These we might term '*discharge reversals*'. Figure 3.12 shows the annual count of these reversals over the 50 years between 1960 and 2009, the analysis being extended to include the Mekong daily discharge time series at Luang Prabang and Vientiane over the same time period.

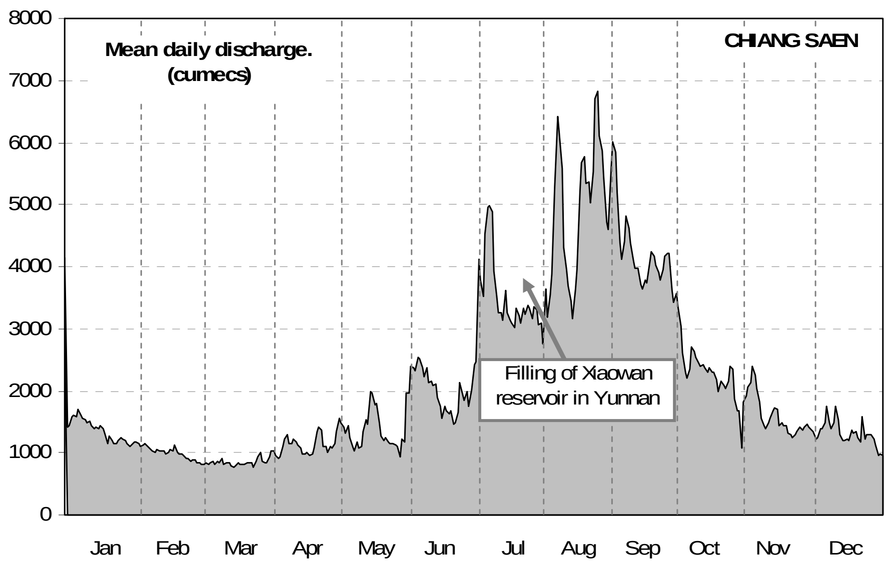


Figure 3.11: Chiang Saen: the 2009 daily discharge hydrograph

- there is a clear change point in their frequency around 1993 and the commissioning of Manwan dam.
- post 1993 the mean annual rate doubles at Chiang Saen.
- at Luang Prabang the increased rate remains significant, while at Vientiane the change is much more modest.
- clearly the short-term hydrological impacts of reservoir operation are modulated downstream as tributary inflows exert an effect and ‘damp’ them out, but the picture that emerges from this simple analysis is that the operational impacts of the dams in China on the flow regime of the Mekong are already manifest upstream of Vientiane.
- the impacts are not only be detectable during the low flow season, as expected, but also during flood seasons such as that of 2009 when discharges were considerably below average throughout.
- also revealed is the effect of basin scale on the short term variance of the annual flood hydrograph. Pre 1993 the hydrology may be considered to have been ‘natural’ and indicates that the mean annual frequency of discharge reversals decreases downstream as drainage area increases and the hydrograph become more coherent from day to day.

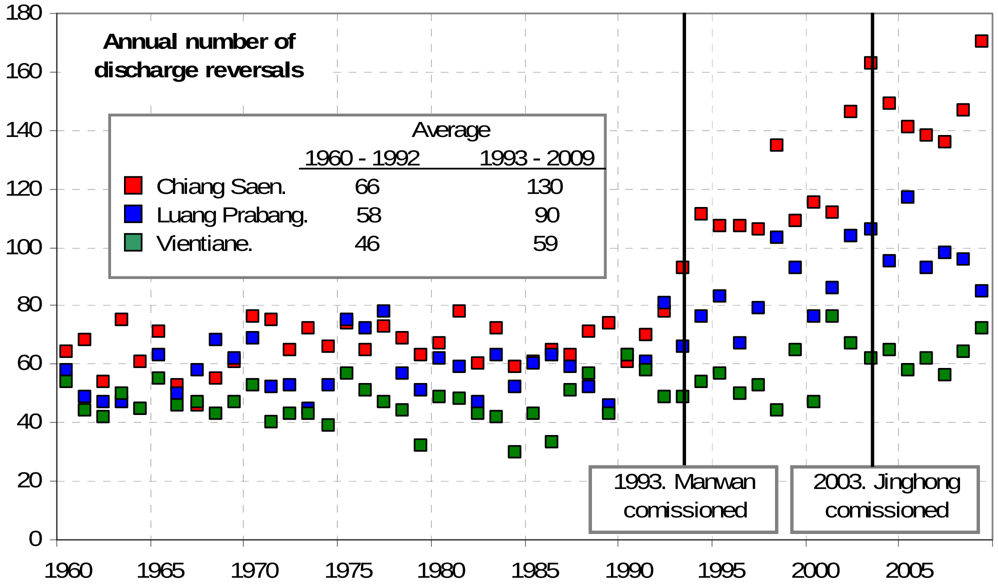


Figure 3.12: The annual number of discharge reversals at Chiang Saen, Luang Prabang and Vientiane, 1960 – 2009

During the course of 2009 notification was given by the Chinese to the MRCS that the large Xiaowan reservoir with 9.9 km^3 of active storage, equivalent to 12% of the mean annual flow volume at Chiang Saen, would start filling during July. Evidence of this seems to be apparent in the 2009 hydrograph at Chiang Saen (Figure 3.11) and the effects appear to have translated as far downstream as Kratie. The degree to which this retention of floodwater from the Upper Mekong Basin in Xiaowan contributed to the lower seasonal flood volume in the Lower Basin is not known, though by far the major cause lies with the weak seasonal monsoon and its early end in September.

3.9 Typhoons and tropical storms

Five tropical storms made landfall in Viet Nam during the season: Soudelor in July, Mujigae and Ketsana in September and Parma and Mirinae in October / November.

- Soudelor, Mujigae and Parma affected the northern provinces of the country with 2 day rainfall locally exceeding 200 mm. Both storms dissipated relatively quickly as they passed eastwards such that their impact in the north of Lao PDR and Thailand was not particularly significant.

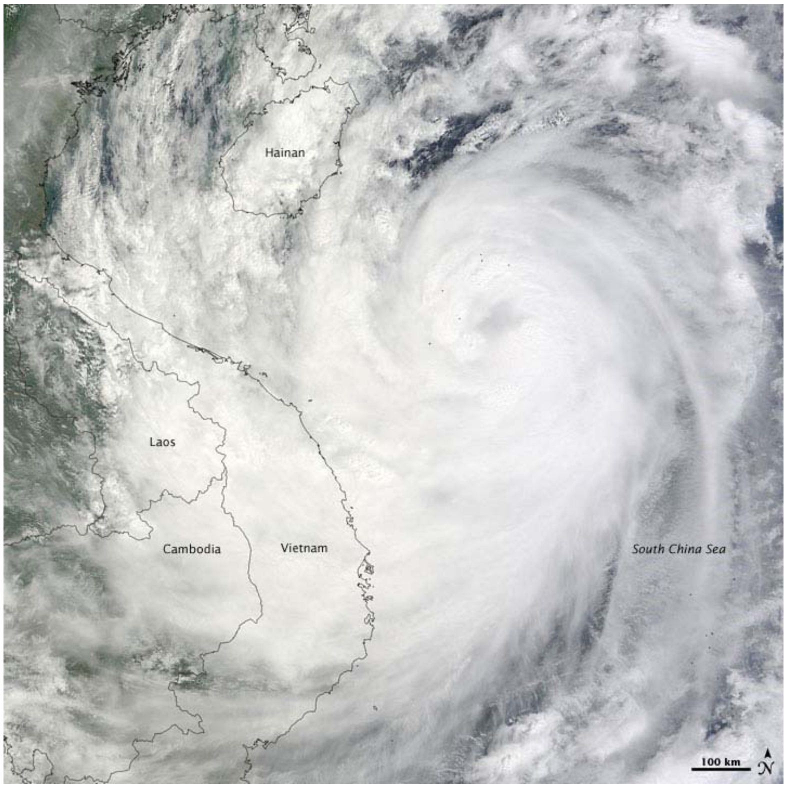
- Ketsana was by far the most damaging event and one of the most severe of recent years. The system made landfall over Central Viet Nam on the 29th September, causing three day rainfalls widely in excess of 600 mm and in some provinces as much as 800 to 900 mm was recorded. Damage and losses in Viet Nam were estimated to be US$ 800 million (National Committee for Flood and Storm Control). The storm then passed into northern Cambodia and southern Lao PDR where accumulated rainfalls continued to exceed extreme thresholds causing widespread flash flooding. Damage and losses in Cambodia alone amounted to US$ 132 million.

Figure 3.13: Typhoon Ketsana. Clockwise from top left. A: Satellite image as the system passed over the coast of Viet Nam, 29.9.2010. The system behind it to the east of the Philippines is Parma. B: Viet Nam: Bridge destroyed in Kon Tum Province. C: Cambodia: 1.3m of overbank flow at the Lumphat hydrometric station on the Sre Pok. D: Lao PDR: Flood inundation, Attapeu Province, Lao PDR

- Although downgraded to a tropical depression on passing into Thailand, the damage and loss figure, largely to irrigation infrastructure and property within the Mun / Chi Basin, still amounted to US$ 21 million. In Lao PDR the major impacts of Ketsana were felt in the Xe Kong and Xe Kaman catchments where water levels as much as 5m above danger levels were observed, following rainfalls as high as 200 mm in 6 hours. Direct damage is estimated to be US$ 58 million.

- Mirinae followed a similar track to Ketsana and entered south –central Viet Nam on the 2nd November causing 2 day rainfalls generally in excess of 200 mm and locally exceeding 600 mm. Over 80 deaths were reported.

Such was the damage caused by Ketsana in Cambodia that the government commissioned an economic assessment at a level of detail that was the first of its kind (Royal Government of Cambodia, 2010). The "Post Disaster Needs Assessment", as it is called, follows methodologies developed by the World Bank, the ADB and EU. A major



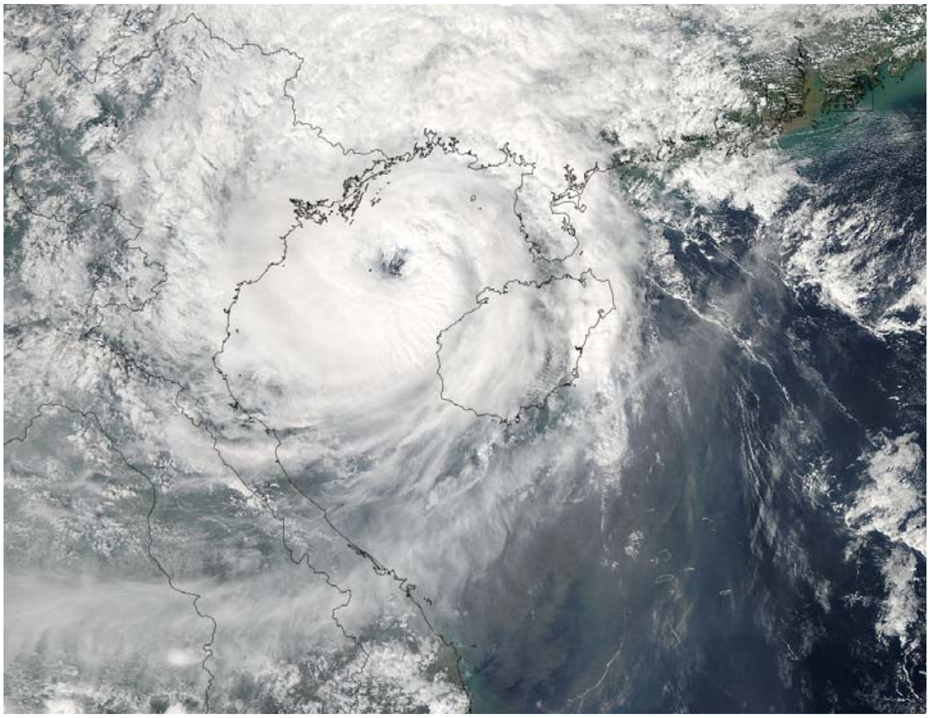


Figure 3.14: Ketsana (top) moving SW towards the coast of Viet Nam on the 28th September. This storm system was quickly followed by Parma (bottom) seen moving west towards the northern provinces of Viet Nam on the 13th October. (Source: NASA. http://earthobservatory.nasa.gov/NaturalHazards)

objective was to highlight the areas of reform needed in Cambodia's emergency response and disaster management systems, specifically data collection for damage assessment, the management of emergency response, warning systems, the identification of actions and policies required to reduce risk and the reconstruction needs with an emphasis upon '*disaster resilience*'. The Government of Lao PDR prepared a similar post disaster needs assessment, also supported by the World Bank, the ADB and EU (Government of Lao PDR, 2010).

The 2009 season illustrates that even given a weak SW Monsoon and developing regional drought conditions, the independent impact of typhoons and tropical storms can be devastating. Events illustrated the continuing vulnerability of the region to tropical storm damage, particularly in the poorer rural areas. Ketsana struck when the rice crop was close to the harvesting stage, such that crop losses were maximized and accounted for almost half of total damage in Cambodia. In both rural and urban areas poor water supply and sanitation infrastructure exacerbate the potential damage causing the development of public hygiene problems.

4. Cambodia 2009 country report

4.1 General situation

Until the incursion of Ketsana into the country at the end of September flood inundation was normal and damage minimal. At all mainstream stations along the Mekong, Bassac and Tonle Sap water levels nowhere reached alarm level, except briefly on the Bassac at Koh Khel, though even here the excedance was just 13 cm. Water levels on the Mekong mainstream peaked during the second week of October, just a week or two later than normal. They rose just 1 m in response to the flood runoff generated by Ketsana. Throughout the season levels were average to slightly less.

4.2 Ketsana losses and damage

Although the flood runoff from Ketsana had little impact on water levels in the Mekong, the levels of the Sre Pok, Se San and Se Kong rose very rapidly in response to extreme flash flood runoff. At the Veunsai gauge on the Se San levels rose by 4.5 m between the 29th and 30th September. This rapid rise combined with high local velocities and a lack of warning was instrumental in the severe loss and damage caused and the 43 deaths attributed directly to the flooding. A summary breakdown of the sectoral losses is shown below in Table 4.1:

- The production sector is the most affected accounting for 46% of the total monetary loss figure of US$ 132 million, followed by the social sector (33%) and infrastructure (19%).[8]
- The largest impact in the production sector was with regard to agriculture, livestock and fisheries. Agriculture alone provides 30% of Cambodia's GDP.
- Infrastructure direct loss and damage was principally to roads and bridges, which led to secondary impacts of increased operating costs due to detours and longer travel times.
- Damage to irrigation infrastructure generally arose from high water velocities, erosion and subsidence.
- At the macro-economic level Ketsana inflicted an estimated loss to GDP of US$ 17 million (Gov't Cambodia, 2010), essentially due to rice crop losses. This represents a reduction of economic growth for 2009 of 0.2%, thus reducing the expected growth rate for the year from 2.1 to 1.9%.
- The major macro-economic impact, however, will be on the expenditure required to finance the reconstruction needs. These are estimated to cost a total of US$ 191 million, of which 56% is required in the infrastructure sector and 31% in the

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[8] These figures correct an arithmetic error in Table 1 of the 'Post Disaster Needs Assessment Report'. Gov't Cambodia, 2010). Page 15.

productive sector (Gov’t Cambodia, 2010). An additional US$ 8.9 million is recommended for investment in improved national and local disaster management.

Sector and sub-sectors.	Damage and loss as proportion of total
Infrastructure	
Transport	19%
Water supply and sanitation	<1%
Water management and irrigation	1%
Energy	<1%
Sub-sector total	19%
Social Sectors.	
Housing	14%
Health	<1%
Education	18%
Sub-sector total	33%
Production sectors	
Agriculture, livestock and Fisheries	43%
Industry and Commerce.	3%
Sub-sector total	46%
Cross cutting sectors	
Environment	1%
Public administration	1%
Sub-sector total	2%
TOTAL	**US$ 132 million**

Table 4.1: Summary of the total losses and damage caused by Ketsana. (Gov’t Cambodia, 2010)

Figure 4.1: Scenes of flood inundation caused by Ketsana in NE. Cambodia. 30th September

4.3 Lessons learnt

Typhoon Ketsana highlights some of the fundamental areas for reform in Cambodia's emergency response and disaster management and mitigation systems and policies. The process of data collection for damage and loss assessment and tracking emergency assistance needs to be improved along with capacity building both in the Line Agencies and the National Committees for Disaster Relief in order to facilitate their effective and coordinated participation in the response and recovery process. The national early warning system is poor.

The Post Disaster Needs Assessment Study (Gov't Cambodia, 2010) suggests that it is imperative that for the disaster recovery process to be effective it is guided by three key principles:

1) transparency,
2) accountability and results based implementation, and
3) community based and equitable approaches towards the mitigation of future risks.

The recovery of the transport and agricultural sectors is crucial. There is a need to adopt a 'build it better' policy such that, for example, roads and irrigation infrastructure are far more resilient to the flood and storm hazard. The same goes for housing and public sector buildings such as schools and clinics.

In recent years disasters such as Ketsana have been evaluated in a socio-environmental context in the sense that the magnitude of damage and loss is a function of socially created risk. Vulnerability is intimately related to social pressures in areas at risk, environmental susceptibility and the lack of economic resilience. Land-use planning, for example, is a fundamental component of mitigating the potential losses. Population pressure makes this difficult to implement, while some of the most vulnerable land is also the most productive.

Ketsana vividly illustrated the vulnerability of Cambodian society and the economy as a whole to the flood hazard. The disasters of 2000 and 2001 were the result of extreme Mekong mainstream conditions that of 2009 to a tropical storm in an otherwise 'benign' flood year. The projected increase in the regional incidence and severity of tropical storms and typhoons under global warming underscores the need for the far more effective implementation and financing of national disaster management and response.

5. Lao PDR 2009 country report

5.1 General situation

During 2009 localised flash flooding occurred in Luang Namtha, Bolikhamxay, Khammuane Provinces during July and mid August caused by orographically induced monsoonal and tropical depression rainfall which produced >80 mm to 180 mm per day. Local inundation occurred but losses were minimal.

During the first half of August tropical storm Mutijae entered Lao PDR, though it had been downgraded to a tropical depression and passed over the central parts of the country. Locally heavy rainfall occurred with up to 220 mm recorded at Thakhek on the 8th and 9th. Flooding occurred but was local.

On the Mekong mainstream maximum water levels were reached during the first week of July at Luang Prabang and Vientiane, which is unusually early. After this mainstream water levels remained substantially below average for the rest of the season. At Vientiane water levels fell by 3 m during the first week of October, a rate historically unprecedented. As a result the flood season ended very early with the onset of the low flow regime in October and the subsequent development of hydrological drought conditions from late November.

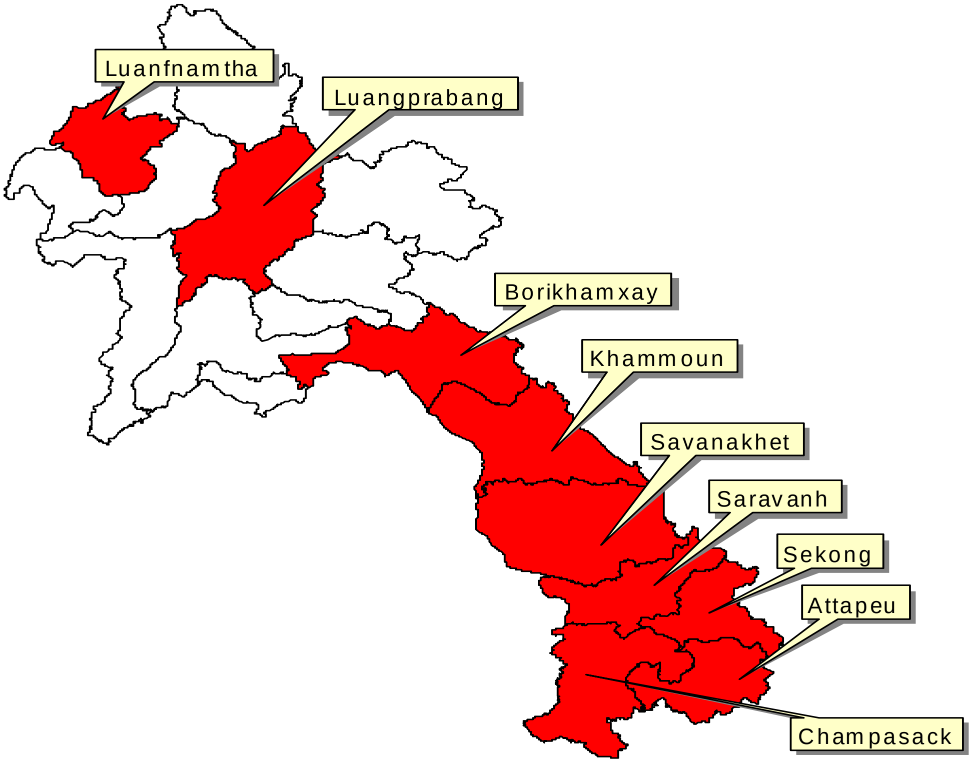

Figure 5.1: Lao PDR. Provinces affected by flooding in 2009

As elsewhere in the region the major event was Ketsana.. Rainfall in the Xe Kong and Xe Kaman catchments areas widely exceeded 200 mm in 12 hours. In response water levels rose by as much as 14 m in 24 hours on the Xe Kong causing widespread inundation of 1m and more. Water levels receded almost as rapidly as they had risen.

Figure 5.2: Post Ketsana flooding in Samakkhixay district, Attapeu province

Figure 5.3: Post Ketsana: Loss of a bridge in the south of Lao PDR

5.2 Ketsana – losses and damage

The Ketsana disaster struck the five southern provinces of Attapeu, Salavan, Xekong, Savannakhet, and Champasak, in which 26 districts were affected to various degrees, 18 of them very severely. More than 180 000 persons were directly affected and there were 28 storm-related deaths. Most of the 26 districts affected are among the poorest in the country, being food insecure. The disaster struck when household food stocks were at their lowest and farmers were preparing for the rice harvest, thus compounding the economic damage and the socio-economic impacts. Table 5.1 provides a summary of damage and loss by economic sector.

Sector and sub-sectors.	Damage and loss as proportion of total
Infrastructure	
Transport	30%
Communications	5%
Water management and irrigation	2%
Energy	6%
Sub-sector total	43%
Social Sectors.	
Housing	15%
Health	2%
Education	2%
Sub-sector total	19%
Production sectors	
Agriculture, livestock and Fisheries	31%
Industry and Commerce.	7%
Sub-sector total	38%
TOTAL	**US$ 58 million**

Table 5.1: Summary of the total losses and damage caused by Ketsana. (Gov't of Lao PDR, 2010)

- over 80 percent of the total loss and damage figure of US$ 58 million occurred in the infrastructure and production sectors.
- the largest single proportional loss (31%) was to agriculture, aggravating rice shortages, food security and household income generation and hindering progress toward poverty reduction targets. Most agricultural production within the affected provinces does not enter the commercial marketing system, being consumed instead primarily on-farm or traded within the community. Little agricultural income is therefore earned by most households.
- agricultural damage occurred in two forms. In the highland areas close to the Viet Nam border, most damage arose from flash flooding along mountain rivers, washing away crops close to the banks. However, the greatest damage was suffered in lowland areas where rice paddy is extensive.

- damage in the transport sector was to roads and bridges. Road infrastructure in the region is poor, almost all of it unsealed, and landslides and embankment collapse were a major factor.
- the loss of GDP is roughly estimated at 0.4 percent, or about US$ 20 million.
- recovery needs, that is the investment required for repair and reconstruction, are estimated to be US$ 52 million.

5.3 Lesson learnt

The Post-Disaster Needs Assessment undertaken in the wake of Ketsana was 'a first' for the Government and will provide the 'benchmark' for improving capacity to assess loss and damage and cost the needs for rehabilitation and reconstruction. Five priority 'actions' are identified to improve national policy:

1) Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation
2) Identify, assess and monitor disaster risks and enhance early warning, for example through flood risk mapping and improved lines of communication.
3) Use knowledge, innovation and education to build a culture of safety and resilience at all levels, including improved construction standards, safer water supply and education in hygiene and sanitation.
4) Reduce the underlying risk factors. A key issue in this respect is much improved land and catchment management towards erosion reduction and the risk of flash flooding in steep topography.
5) Strengthen disaster preparedness for effective response at all levels, including providing realistic emergency budgets and building capacity in disaster risk reduction from the national to the village level.

6. Thailand 2009 country report

6.1 General situation

As elsewhere in the region Ketsana proved to be the major event of the 2009 flood season in the Thai part of the Lower Mekong Basin. It moved into Thailand as a severe tropical storm but was soon downgraded to a tropical depression. Nevertheless there was widespread heavy rainfall and flash flooding between the 29th September and the 4th October resulting in damage and losses of US$ 21 million. Two deaths were reported. Water levels and discharge in the Mekong mainstream at Chiang Saen and Pakse, for example, were well blow average throughout the season.

Figure 6.1: Interviewing residents in the Mun river Basin.

6.2 Ketsana – losses and damage

No detailed breakdown of the financial costs for damage and loss due to Ketsana are available for Thailand. However, as the figures below indicate, losses during 2009 were well below those of previous years.

Year	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**
US$ millions.	21	74	50	208	176	25

Table 6. 1: Thailand. Damage and loss due to cyclone Ketsana in 2009 compared to national loss figures in recent years

Although the figure for 2009 is for Kesana only, the only other significant flooding in Thailand during the year was in the far south during November, which would not inflate the figure of US$ 21 million to any great extent.

6.3 Lessons learnt

Thailand has recognised the need for and advantages to be gained from advanced flood forecasting technology. The implementation of a national flood forecasting programme is ongoing based on hydrological and hydrodynamic modelling using the 'Infoworks' system developed by HR Wallingford, UK. It is designed to be linked to real-time hydrological and meteorological time-series to provide detailed and accurate real-time modelling in an operational environment. It will permit managers and scientists to carry out fast, accurate simulation of the key elements of system behaviour to support the effective mobilisation of emergency response and provision of public warnings. Inundation maps are produced as part of the forecast.

Issues still to be addressed in Thailand include:

- the fact that the process of implementing flood forecasting, management, mitigation and emergency response is performed by a number of agencies which potentially leads to a lack of coordination and duplication. In order to increase effectiveness, both practical and financial, a united and centralised body is required. Although this need is recognised in the Water Act of 2008, it has yet to be implemented.
- this central agency should be organized at the community, basin and national level.
- the considerable investment in flood forecasting technology would be more effective if the numerous national hydro-meteorological database systems were integrated.
- the legal aspects of the Water Act, for example with regard to water resources protection and watershed management practises, need to be promoted and implemented more effectively, particularly at the local level.

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7. Viet Nam 2009 country report

7.1 General situation

The meteorological conditions in Vietnam during 2009 were extreme with several significant flood events throughout the country. Five typhoons made landfall during the season (see Section 3.9), affecting the country from the far north to the delta and generating flash floods and extreme water levels (Figure 7.1). Of these Ketsana was the most severe.

Figure 7.1: Locations in Viet Nam in 2009 which observed water levels in excess of Alert Grade 3

The accumulated rainfall generated by Ketsana over the country between the 28th and 30th of September is mapped in Figure 7.2. Over large areas of the central regions and totals exceeded 400 mm and reached amounts in excess of 500 mm. It is likely that such figures occurred equally widely in the upper reaches of the Se San and Sre Pok tributaries in Viet Nam and Cambodia and locally in the Xe Kaman and Xe Kong in Lao PDR.

As a consequence water levels in the Central Highland rivers widely exceeded Alert Grade 3 (the most severe) thresholds. Most rivers exceeded this critical level by at least 1.5 m, many by as much as 3m and in the Upper Se San by as much as 7 m. Historical maximum levels were widely exceeded. Flash flood conditions followed and inundation to depths of 1.5 m and 2 m were widespread.

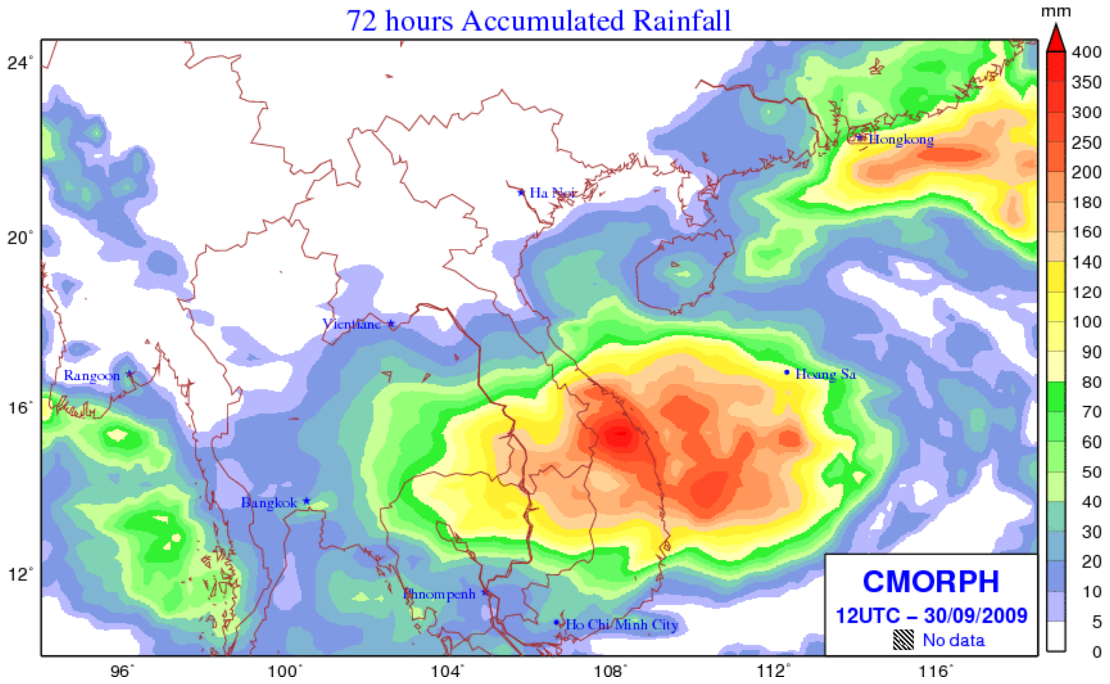

Figure 7.2: Ketsana. Accumulated rainfall (mm) - 28th to 30th September

7.2 Ketsana – losses and damage

According to the National Committee for Flood and Storm Control Ketsana was one of the most intense storm systems to affect Viet Nam in recent years. Typhoon Linda in November 1997 is generally regarded as the worst in the last 100 years. Typhoon Ketsana:

- killed 163 people, injuring 629 and left 11 others missing.
- over 21 600 houses collapsed completely, a further 258 000 suffered structural damage and almost 295 000 were flooded.
- rice paddy flooded and damaged amounted to almost 40 000 ha, secondary crops lost or damaged: 55 000 ha, corn and sugar cane crops flooded: 11 000 ha.

Total loss and damage is currently assessed at US$ 800 million (National Committee for Flood and Storm Control).

Although the Delta has generally provided the national focus for flood protection and mitigation investment in the Mekong region of Viet Nam, the incidence and severity of damage in areas such as the upper Se San and Sre Pok seems to be increasing as populations become more vulnerable and seek livelihoods on land prone to flash flooding.

Figure 7.3: Ketsana. Property damage Quang Ngai Province.

Figure 7. 4: Kontum Province, Central Highlands, 30th September 2009

7.3 Lessons learnt

In the Mekong region of Viet Nam, Ketsana emphasised the need to address the issue of typhoon induced flash flooding, in terms of :

- mapping the flash flood prone areas in the highland and mountainous areas and identify land management and settlement policies at the local scale.
- these policies should be integrated with rural development strategies with respect to agriculture, agro-forestry and irrigation, housing and infrastructure building standards.

- effective planning towards coping with flash floods needs to be developed, disseminated and rehearsed by the inhabitants of the flood prone areas.
- early and effective warning is essential, though recognized as difficult. The evacuation of people, properties and domestic animals, deploying relief measures in advance and providing relief materials as soon as possible is basic to reducing losses.

Most of these measures are already being undertaken in Viet Nam as part of the National Disaster Management Planning Process. The government recognizes the vulnerability of the country to natural disasters and the intensification of the risk of such hazards posed by global warming. Events such as Ketsana serve to emphasize the policy and planning needs.

8. Summary conclusions and recommendations

The defining feature of the 2009 flood season was that Ketsana and the other less severe tropical storms that affected the Lower Mekong Basin occurred during weak monsoonal conditions which determined that the region saw the development of critical hydrological drought conditions as early as December. By January mainstream flows in Yunnan and the northern parts of the Lower Basin were amongst the lowest observed.

Extreme flooding occurred as a result of Ketsana, principally in the Xe Kong, Xe Kaman, the upper Xe San, Sre Pok and Xe Kong basins. All four lower basin countries were affected, with damage and losses in Viet Nam amounting to US$ 800 million and US$ 132 million in Cambodia.

In the wake of Ketsana, the Governments of Cambodia and Lao PDR undertook 'Post Disaster Needs Assessments' at a level of detail previously unknown. These documents will provide the benchmark guidelines for similar future assessments. In both countries the vulnerability of the agricultural and infrastructure sectors clearly emerged. Agricultural damage was particularly severe since the storm occurred at the end of September just prior to the harvesting of the rice crop, thus maximising the economic losses in the sector.

The regional frequency and intensity of tropical storms is forecast to increase in response to global warming, though there is no evidence in the data to date that their annual rate has been greater in recent decades. There is, however, clear evidence of increasing temperatures in the region but non to suggest that so far this has affected the rainfall climate and in turn hydrological regimes. The projected climate change impacts vary from study to study. The more mainstream results, for example Vastila et al (2010), indicate an increase in annual rainfall of 4 percent by 2040 compared to the 1980's, with a similar increase in mean annual flows. Extreme flood events are forecast to increase in frequency.

Other studies propose far greater change. The CSIRO (2008) results suggest an increase of 13 percent in mean basin rainfall by 2030, the projected increases being highest in the northern and central regions. Total annual runoff from the basin is forecast to increase by 21 percent and floods currently considered as severe with an annual probability of 5 percent will occur with an annual probability of 80 percent.

There is general agreement that the threats posed by climate change in the Mekong Delta are severe. Sea level rise could be anywhere between 30 cm and 1 metre by 2100, although the latter is the more likely figure. If it does reach 1 metre, 90 per cent of the delta would be inundated annually. Even by 2030, the sea level rise could expose around 45 per cent of the delta's land area to extreme salinisation and crop damage through flooding.

The developing world faces greater challenges than the developed world, both in terms of the impact of climate change and the capacity to respond to it. With much of their subsistence and economic wealth dependent on agriculture the potential impacts are that much greater. Infrastructure is less resilient to storms and floods than in developed countries. All regional governments recognize the vulnerability of their countries to natural disasters and the intensification of the risk of such hazards posed by global warming. They are acting upon recommendations to ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation. The development of effective storm and flood forecasting is a seen as a priority area. Vulnerability is intimately related to social pressures in areas at risk, environmental susceptibility and the lack of economic resilience. Land-use planning and poverty alleviation through improved agricultural practices are therefore fundamental components of mitigation and adaptation policies. Above all it needs to be recognized that the response to climate change is a cross cutting issue that demands integration between government departments and economic sectors, both public and private.

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Appendix 1. Cambodia: Summary of flood damage, losses and recovery needs

SECTOR AND SUBSECTORS	DAMAGE	LOSSES	TOTAL
Infrastructure	**17.3**	**11.5**	**28.8**
Transport	14.4	11.1	25.5
Water supply and sanitation	0.064	0.39	0.46
Water management and irrigation	2.8	0.013	2.8
Energy	0.027	0.005	0.03
Social Sectors	**39.6**	**3.3**	**42.9**
Housing	15.3	3.3	18.6
Health	0.057	0.004	0.096
Education	24.2	-	24.2
Production sectors	**1.05**	**59.0**	**60**
Agriculture, livestock and fisheries	0.09	56.4	56.5
Industry and commerce	0.96	2.6	3.5
Cross cutting sectors	**0.2**	**0.1**	**0.3**
Environment	0.03	0. 1	0.13
Public administration	0.17	-	0.18
TOTAL	**58**	**74**	**132**

Table A1.1: Cambodia – flood damage and losses resulting from cyclone Ketsana. (Millions US$)
Source: Government of Cambodia, 2010

SECTOR AND SUBSECTORS	RECOVERY COSTS.		
	SHORT TERM	MEDIUM TERM	LONG TERM TOTAL
Infrastructure	**7.1**	**13.4**	**106.5**
Transport	5.1	9.3	90.7
Water supply and sanitation	-	0.5	4.8
Water management and irrigation	1.7	2.8	8
Energy	0.3	0.85	3
Social Sectors	**14.1**	**2.65**	**19.2**
Housing	12.1	2.01	14.2
Health	0.086	0.56	3.1
Education	1.9	-	1.9
Production sectors	**5.7**	**12.8**	**60**
Agriculture, livestock and fisheries	5	10	50
Industry and commerce	0.96	2.8	10
Cross cutting sectors	**0.196**	**2.4**	**5.4**
Environment	0.18	2.2	5.2
Public administration	0.015	0.16	0.18
TOTAL	**27.3**	**31.3**	**191**
DISASTER MANAGEMENT			**8.9**

Table A1.2: Cambodia – Estimated recovery costs from cyclone Ketsana. (Millions US$)
Source: Government of Cambodia, 2010

Appendix 2. Lao PDR: Summary of flood damage, losses and recovery needs

SECTOR AND SUBSECTORS	DAMAGE	LOSSES	TOTAL	RECOVERY COSTS
Infrastructure	**21.2**	**3.5**	**21.6**	**21.3**
Transport	14.1	3.3	17.4	14.1
Communications	3.0	0.1	3.1	2.96
Water supply and sanitation	0.52	0.02	0.54	2.9
Water management and irrigation	0.98	0.04	1.02	
Energy	3.1	0.07	3.17	1.4
Social Sectors	**10.1**	**0.74**	**10.8**	**13.6**
Housing	8.2	0.41	8.6	8.8
Health	1.01	0.23	1.2	1.1
Education	0.94	0.1	1.04	3.8
Production sectors	**19.7**	**2.3**	**22**	**16.5**
Agriculture, livestock and fisheries	15.5	1.98	17.5	14.9
Industry and commerce	3.6	0.13	3.7	1.6
Tourism	0.54	0.23	0.8	-
TOTAL	**51**	**6.5**	**57**	**52**

Table A2.1: Lao PDR – flood damage and losses resulting from cyclone Ketsana. (Millions US$)
Source: Government of Lao PDR, 2010

Mekong River Commission

Office of the Secretariat in Pnom Penh: P.O.Box 623, 576 National Road #2,
Chak Angre Krom, Phnom Penh, Cambodia

Telephone: (855 23) 425 353 Facsimile: (855 23) 425 363
E-mail: mrcs@mrcmekong.org Website: www.mrcmekong.org