Annual Mekong Flood Report 2013

MEKONG RIVER COMMISSION
MRC
FOR SUSTAINABLE DEVELOPMENT

Flood Management and Mitigation Programme

Mekong River Commission

Cambodia · Lao PDR · Thailand · Viet nam
For sustainable development

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Annual Mekong Flood Report 2013

Theme:
Regional Impact of Tropical Storms

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The opinions and interpretation expressed within are those of the authors and do not necessarily reflect the views of the Mekong River Commission.

Acknowledgements

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1.   SYNOPSIS

As is now the established format the Annual Flood Report is made up of three major sections:

- The annual theme, which for 2103 is the regional incidence of typhoons and tropical storms and their role in the flood hydrology of the Lower Mekong Basin.
- A review of the flood season over the year, and
- A summary overview of the four National Flood Reports

In an average year 4 to 6 typhoons or severe tropical storms make landfall in Viet Nam, a number of which will track across the Lower Mekong Basin and cause significant to extreme flooding. There are many years when far more systems make landfall, for example 1964 (18), 1973 (12), 1978 (12), 1989 (10) and 1996 (10). The incursion of these storm systems into the Mekong region has historically been associated with most of the largest flood peak discharges on the mainstream. This said, it has to be acknowledged that the annual Mekong flood is in its greater part a response to the SW Monsoon and is a multivariate event defined by not only the seasonal maximum discharge but also by the volume of floodwater and the duration of flows above critical thresholds. The events of 2000 illustrated quite clearly that extreme floods cannot be defined exclusively in terms of the annual maximum discharge. On that occasion the flood peak was no more than average but the volume of floodwater over a prolonged flood season was critical and had a devastating impact across the Cambodian floodplain and within the Mekong Delta.

The role of typhoons and tropical depressions in the flood hydrology of the Mekong is well established. However, there has never been a detailed systematic study nor an inventory of their annual incidence and impacts. The challenge lies with the fact that in meteorological terms the severity of tropical low pressure systems is indicated according to wind speed, while in a hydrological context the focus of interest lies with the consequent storm rainfall and resulting flood runoff. Prior to the introduction of the Annual Flood Reports by the FMMP in 2006/7, supported by the four National Reports, assembling the relevant historical data is a considerable task since ideally storm rainfall maps are required for each of the key events. The further back in time one goes the more difficult it is to put together sufficient rainfall data to accurately depict the geography and intensity of the storm rainfall. This arises because the observation network becomes increasingly sparse.

 The exercise undertaken here has proved to be useful and informative, with the linkage between tropical low pressure systems and regional flooding examined back to the early 1950's. In a sense though, it should be seen as "exploratory" and setting

the framework for a more detailed research assessment. The importance of undertaking the latter lies within the context of potential climate change impacts upon regional floods and flooding. Due to warming sea temperatures the incidence and severity of tropical low pressure systems is forecast to intensify with secondary consequences with regard to the frequency of intense storms and flooding. As is made evident in Section 2, there is no evidence to suggest that the regional annual count of storm systems has increased in recent years, although it may be the case that their scale and severity has intensified, or at least the occurrence of super typhoons such as HAIYAN in 2013, has become more frequent. This though could be difficult to establish to any degree of statistical satisfaction. Super typhoons and extreme tropical storms are hardly a contemporary development. Chinese historical annals and Vietnamese records chronicle a long history of tropical storm impacts. Amongst these is the Haiphong super typhoon of 1881 which killed a reported 300 000 people and is regarded as the third most deadly tropical storm in recorded world history.

If the intensity of tropical storms has increased in recent years, the evidence would lie in part with systematically higher short duration (one to three days) storm rainfall over modern decades. As shown in Section 2 there is no regional evidence to suggest that this is the case.

The WMO data examined in Section 2.1 quite clearly indicates an increase in Asian storm and flood related disasters in each decade since 1970. The question that arises in this context is, however, is whether the increase in the rate of disasters and the associated fatalities and economic damage is a consequence of more frequent extreme events brought on by climate change or whether it is simply a case that more people and infrastructure are exposed. The latter argument is compelling. In Asia over the last 50 and more years population increase has been historically unprecedented and the subsequent pressure on land and agricultural resources has forced the settlement of exposed and vulnerable sub regions, particularly in river deltas and to a lesser extent in marginal upland areas. In effect the susceptibility of the regional populations to meteorological and hydrological disasters has grown relentlessly.

An issue with the WMO study, which is acknowledged, is that the results are determined in large part by just a few decisive events. These include the Bangladesh cyclones of 1970 and 1991 which killed almost 450 000 people between them, cyclone NARGIS in Myanmar in 2008 which caused over 136 000 deaths, floods in Thailand in 2011 which caused US$ 41 billion in damage and a tropical cyclone in Japan in 1991 which caused US 17 billion in damage and was the costliest on record. Despite the influence of these prominent events on the statistics, the WMO findings describe a disturbing trend. Whether this is climate driven in some measure or far more the consequence of socio economic pressure on resources is arguable.

The climate change debate, in terms of systematic quantitative evidence, revolves around increasing maximum air temperatures, sea temperature, sea levels and polar ice coverage. These indicators can be monitored on a year by year basis as a sequence of continuous random variables. Historic trends are widely accepted as established. Much more challenging is the statistical evaluation of discrete variables, that is events such tropical storms and floods, which occur in discrete or disconnected points in time. Statistically, they are defined as a "point process". The components of interest are the annual "count" and their intensity above a pre-described threshold level. The statistical analysis of such data is complex compared to that of continuous time series. Within the field of the earth sciences very little research has been carried out in order to establish whether significant changes to the incidence and severity of tropical storms, for example, is evident.

Consequently, the case for potential future change is based upon the physical effect of increasing sea surface temperatures and climate modeling. The possible impacts upon the storm / flood linkage is then assessed on the basis of "what if" scenario analysis, again using numerical models. A major issue though, as has already been indicated, is the increasing vulnerability of riparian societies to flood induced fatalities, loss and damage, especially those living on the margins of economic development. What clearly emerges is that yesterday's norms will not be the same as tomorrow's.

However, historical, geo-referenced information about deaths and damages can be used to estimate risks before the next disaster occurs. It can support practical measures to reduce potential impacts, such as investing in early warning systems, retrofitting critical infrastructure or enforcing new building codes. Information about past impacts can also be used to assess the resilience of a society.

2. A REGIONAL HISTORY OF TROPICAL STORMS AND FLOODS

2.1 Meteorological hazards in Asia – 1970 to 2012

In a global study of meteorological disasters over the 43 years to 2012 the WMO (WMO, 2014) assessed the full damage and loss data arising from floods, storms, droughts and other hazards such as landslides and mud lows. A challenge for users of such risk information is concerned with the changing characteristics (frequency, location, severity) of weather-, climate- and water-related hazards. Natural climate variability is now exacerbated by long term, human-induced climate change, so that yesterday's norms will not be the same as tomorrow's.

The disasters included in the report are classified as meteorological (storms), climatological (droughts, extreme temperatures and wildfires) and hydrological (floods and mass movement wet, which includes subsidence, rock falls, avalanches and landslides). There are six WMO global regions. Of these the Asian region covers India, Indochina, China, Japan and Korea. Over the period of assessment a total of 2 680 disasters were observed regionally:

- Of these, 45% were due to floods and 35% the result of storms (Figure 2-1).
- Of the more than 915 000 deaths, 76% were linked to storms, principally tropical cyclones and intense low pressure systems (Figure 2-2). Of this fatalities total, more than 500 000 were the result of events in Bangladesh and Myanmar.
- Total economic damage is estimated to have been US$ 790 billion, 90% of which arose from the impacts of floods and storms (Figure 2-3). These economic losses were dominated by events in China such as the devastating floods of 1998.
- The number of disasters, the number of fatalities and the economic damage has risen several fold, decade by decade, with floods and storms dominant (Figure 2-4 to Figure 2-6).

The key implications of these figures are firstly, that floods and storms dominate the hazard landscape in Asia, which by and large reflects the global patterns, with the exception of Africa where drought is the principal hazard, Secondly, the seemingly relentless increase in the incidence of disasters over recent decades along with their consequent impacts points towards a clear confirmation of the influence of climate change.

The major regional hazards are of course inter-related. Storms, most notably typhoons and tropical storms, generate floods and landslides and it is potentially

difficult to accord the impacts directly to one or the other given the cause / effect relationship. Never the less the linkage between tropical storm systems and the consequent flooding is the key hazard causative factor within the Asian region. By country, within Indochina, the disaster count is dominated by Viet Nam, factored in the main by typhoon landfalls and the associated floods and storm surges. (Table 2-1).

Table 2-1   The disaster count 1970 to 2012 in the four Mekong countries. (WMO, 2014).

Number of disasters	Cambodia	Lao PDR	Thailand	Viet Nam
	24	27	107	165
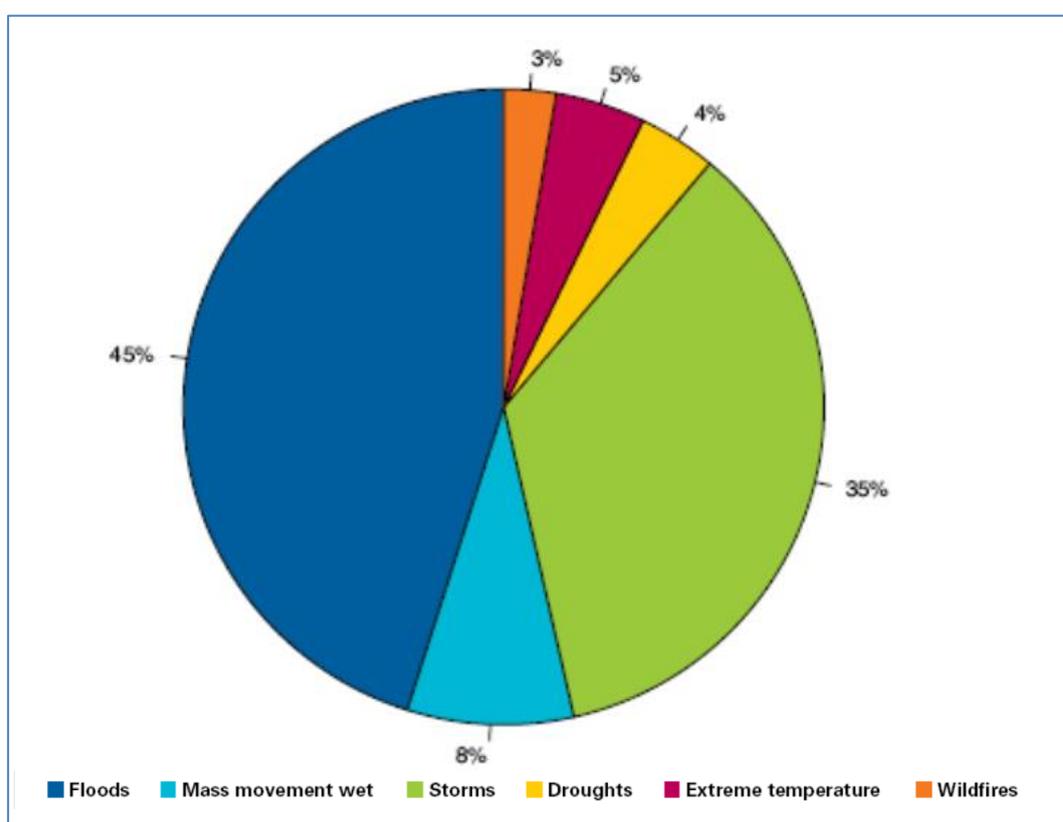
Figure 2-1   The distribution of the total number of disasters in WMO Region II – Asia, 1970 to 2012. (WMO, 2014).
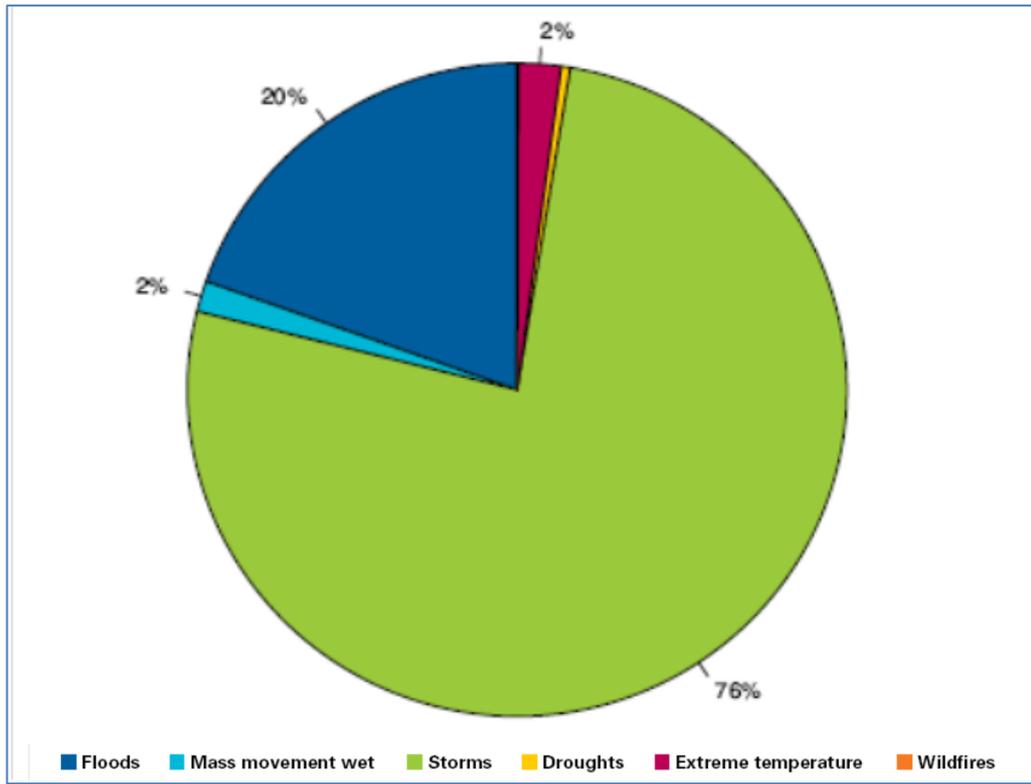
Figure 2-2   The distribution of the total number of disaster related deaths in WMO Region II – Asia, 1970 to 2012. (WMO, 2014).
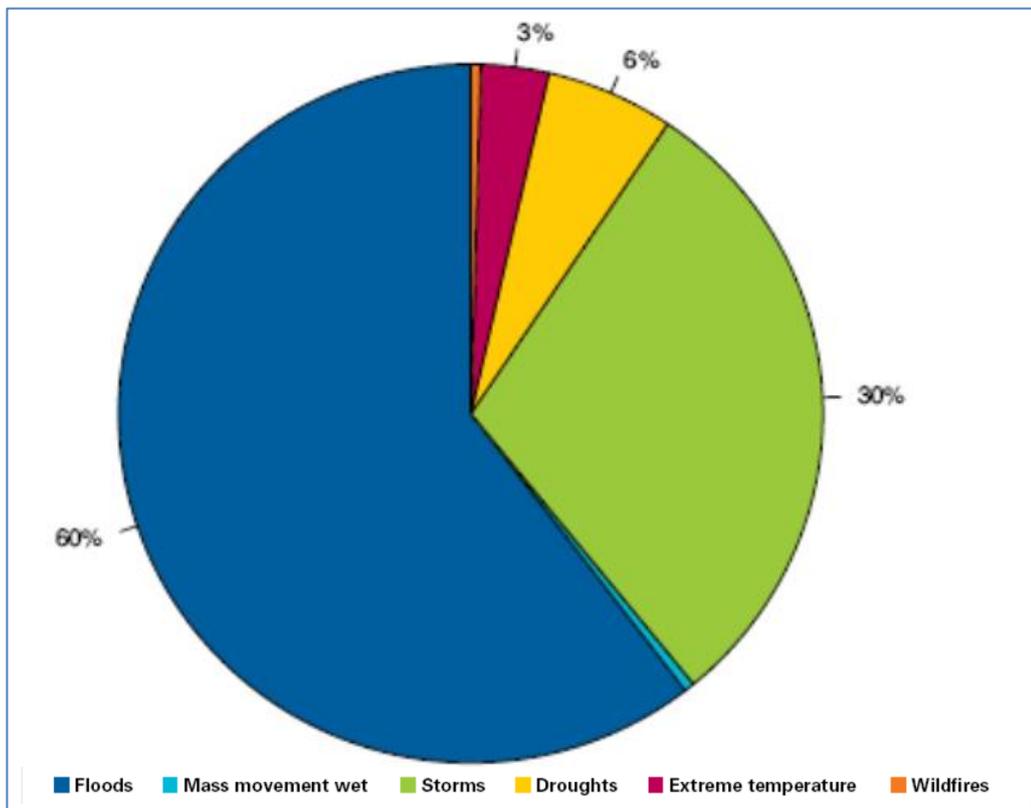
Figure 2-3   The distribution of the total number of disaster related economic loss and damage in WMO Region II – Asia, 1970 to 2012. (WMO, 2014).
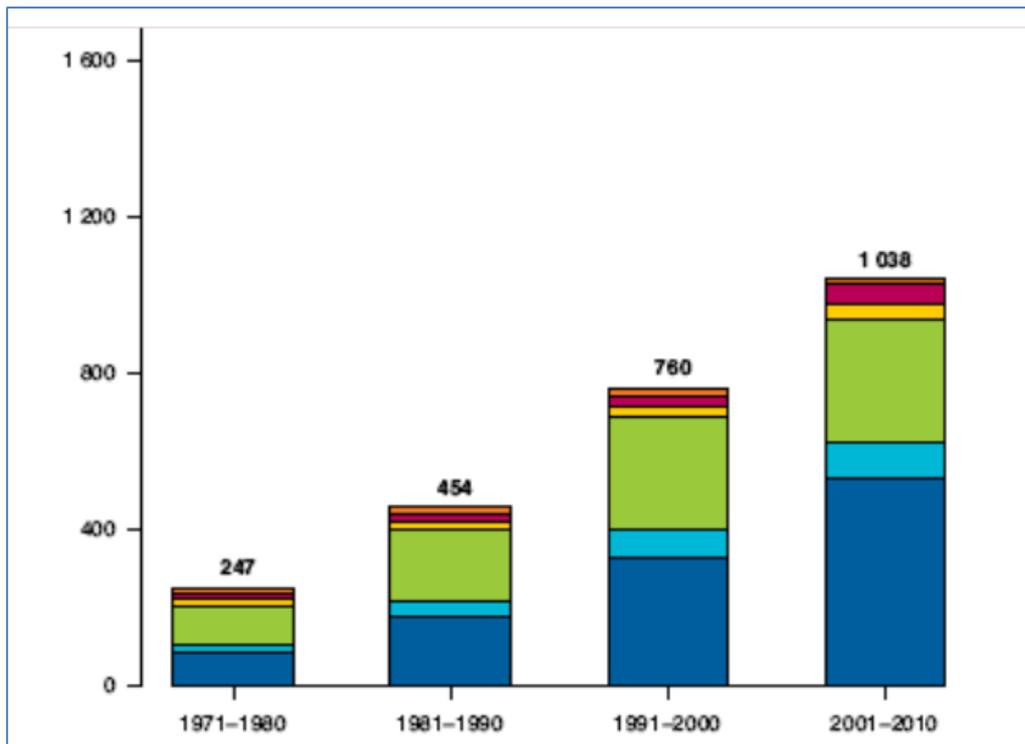
Figure 2-4   The number of reported disasters by decade in WMO Region II – Asia, 1971 to 2010. (WMO, 2014).
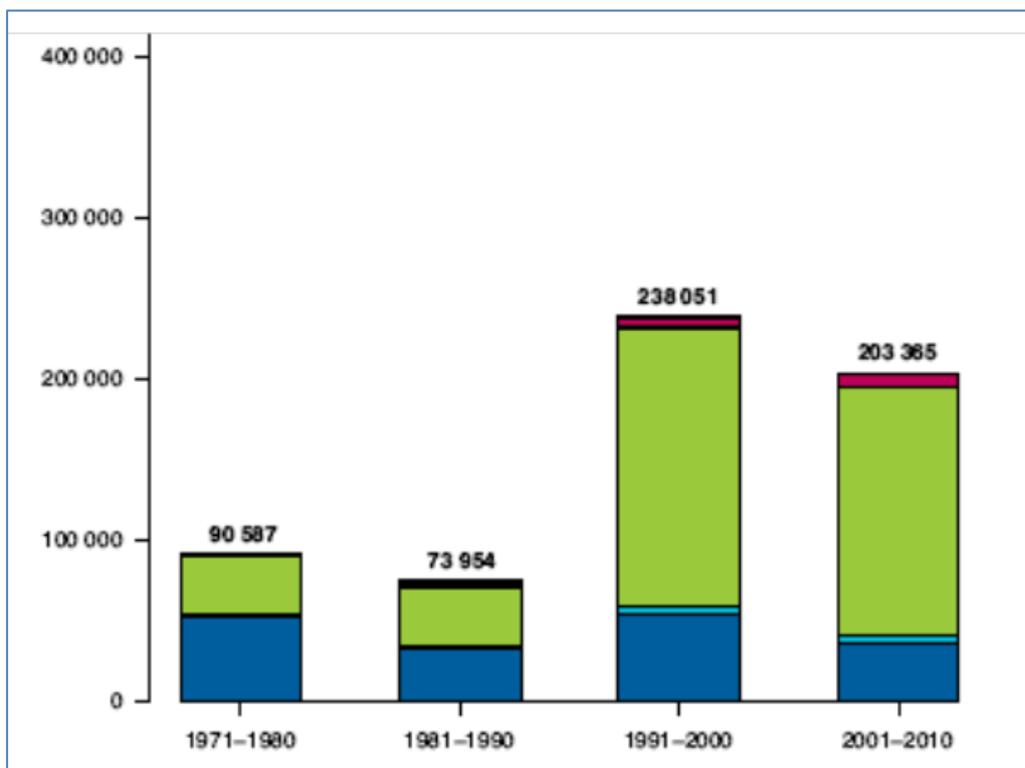
Figure 2-5   The number of reported disaster related fatalities by decade in WMO Region II – Asia, 1971 to 2010. (WMO, 2014).
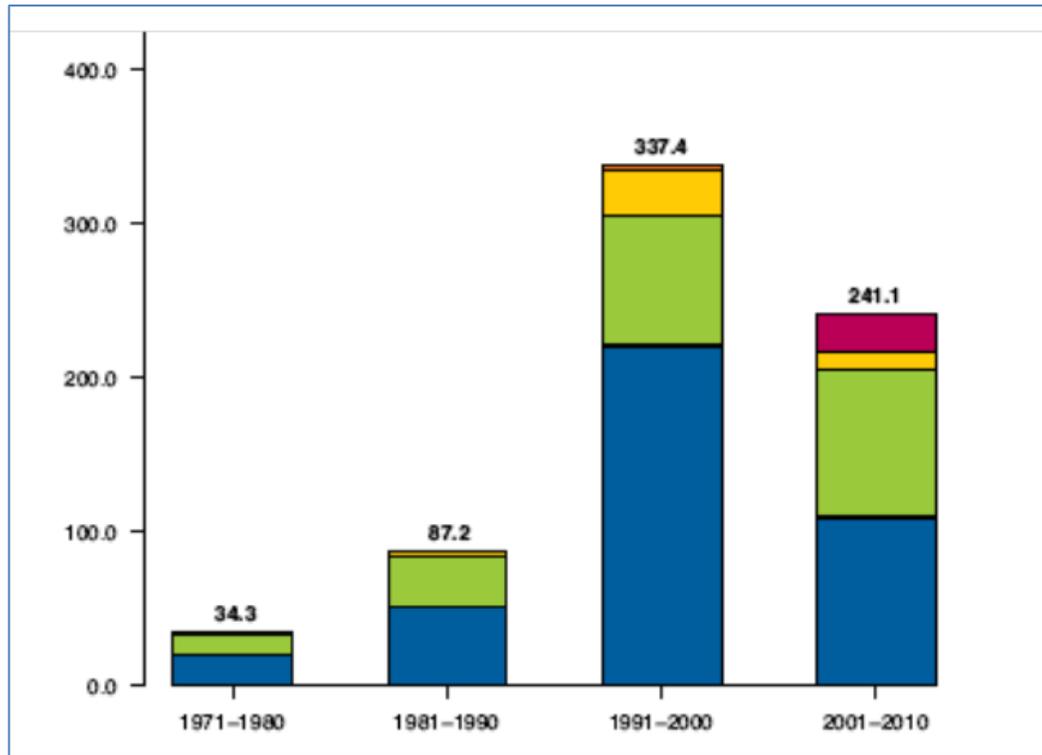
Figure 2-6   Economic losses by decade by hazard type in WMO Region II – Asia, 1971 to 2010. (WMO, 2014). Billions of US$ adjusted to 2012.

2.2   Tropical storms and typhoons – some definitions, characteristics and long term regional history

The English word "typhoon" originates from the Japanese word "taifu", which means "great wind".   The equivalent term "hurricane" comes from the Carib language of Domica in the Caribbean where "huracán" relates to intense storms "from the sea".   The intensity classifications of typhoons and the associated intense low pressure systems of lesser intensity is as a consequence based upon a measure of sustained wind speed, usually averaged over ten minutes. The Japanese Meteorological Agency (JMA) classification of the various systems is given in Table 2-2 below.

Table 2-2   Tropical cyclone / typhoon intensity scale according to the classification of the Japanese Meteorological Agency (JMA).

Classification	Sustained wind speed
Super typhoon	➢ 190 km / hour
Severe typhoon	➢ 150 km / hour
Typhoon	120 – 150 km / hour
Severe tropical storm	➢ 90 km / hour
Tropical storm	60 – 90 km / hour
Tropical depression	< 60 km / hour

Typhoon is the regional name in the northwest Pacific for a severe (or mature) tropical cyclone, whereas *hurricane* is the regional term in the northeast Pacific and northern Atlantic.

The spatial extent or size class of such systems that has been adopted by the JMA is as follows, based upon the radius with wind speeds of 54 km / hour and above:

- Large: 500 to 800 km.
- Super: > 800 km.

The terrestrial speed of movement of these low pressure events, which in the western Pacific is to the west, north and northwest, is typically less than 25 km / hour or 600 km / day. Yet there is considerable variability. As a general rule systems move more slowly during the early phase of their life but then gain speed on reaching maturity (Terry, 2007).

Considerable research has been directed at the potential relationship between ENSO and the incidence and severity of typhoons. The expectation is that warmer sea surface temperatures during El Niño episodes would lead to the genesis of an increased number of events. The results have not been consistent (Wang and Chan, 2002). More conclusive is the evidence that points towards a tendency for more intense typhoons with longer lifetimes in El Niño years (Camargo and Sobel, 2005).

Of the global incidence of tropical storms and more intense low pressure systems, by far their greatest frequency is observed in the northwest Pacific, compared to other areas such as the north east Pacific, Indian Ocean and Atlantic. Based upon observations of their mean annual frequency between 1970 and 2000, Marks (2003) provides the following results.

Table 2-3   Mean annual geographical frequency (%) of the global total of tropical storms according to WMO zone – 1970 to 2000. (Adapted from Marks, 2003).

Classification	Tropical Zone				
	Atlantic	NE Pacific	NW Pacific	Indian Ocean	Australia - east and west coast zones
Tropical storm	11%	20%	**32%**	18%	19%
Hurricane / typhoon	12%	21%	**36%**	15%	17%
Severe / super hurricane / typhoon	11%	23%	**41%**	11%	15%

These figures are authenticated quite graphically in Figure 2-7 below.
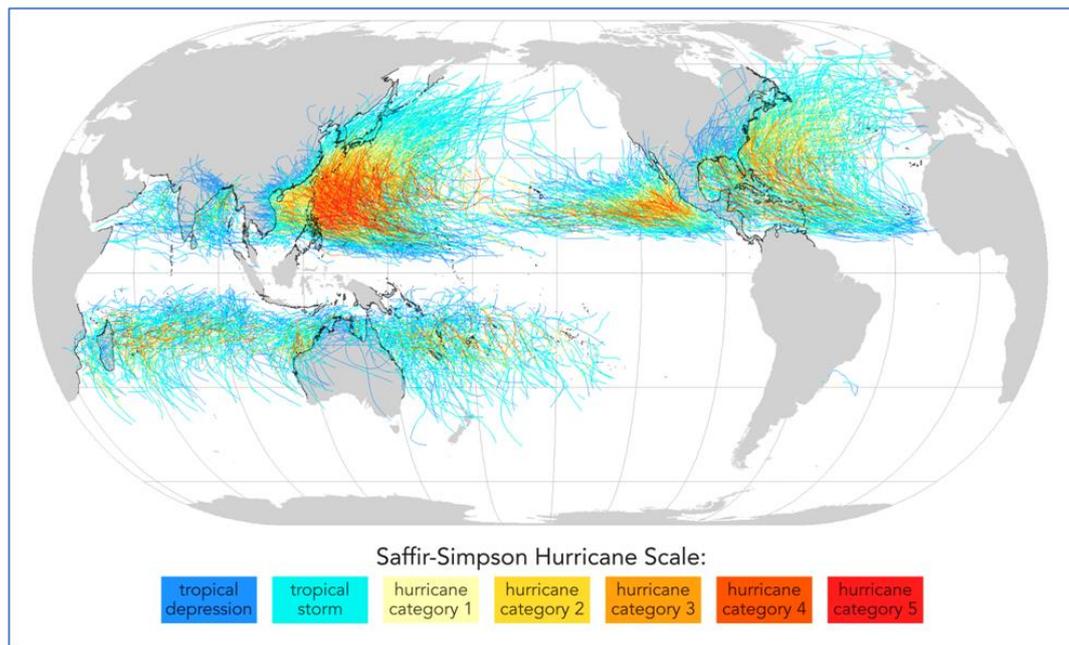
Figure 2-7   Global tropical cyclones 1945 to 2006, their tracks and classification. (Data from the Joint Typhoon Warning Centre and the US National Oceanographic and Atmospheric Administration. March, 2008).

A tropical cyclone can cease to have tropical characteristics in several different ways. One such way is if it moves over land, thus depriving it of the warm water it needs to power itself, quickly losing strength. Most strong storms dissipate quite rapidly after landfall and become disorganized areas of low pressure within a day or two as the system degrades to a tropical depression. None the less these less intense systems, as measured in terms of their lower wind speed classification, usually generate intense storm rainfall associated with wind speeds that can still cause immense destruction. It is in this genre that typhoons and their remnants cause the most damage and loss in the Lower Mekong Basin, in terms of riverine floods, flash floods, landslides and mud flows. As the systems make landfall across the coast of Viet Nam, storm surges add a very real and potent hazard.

The long term historical incidence of typhoons within the Indochinese region and SW China can be assessed using Chinese documentary sources which provide the longest historical records of tropical cyclones available. Records compiled during the Ming (AD 1368–1644) and Qing (AD 1644–1911) dynasties have been examined by Liu et al (2001), which chronicle those events as a result of which large scale public works were required to repair the damage. Using these sources and some from the earlier Song dynasty, it has been possible to elaborate a 1000 years high resolution typhoon chronology for the province of Guangdong. The chronicles indicate that the most active decades for the incidence of typhoons were from 1660 to 1680 and from 1850 to 1880.

These findings are significant with respect to the long term history of typhoon incursions into the Lower Mekong Basin. The landfall of such tropical systems over Guangdong would be linked to those which alternatively track towards the coast of Viet Nam (Figure 2-8) in any given sequence of years. Figure 2-9 shows a year-by-year compilation of typhoon frequencies for the period 1000–1900. It is clear that the record was sporadic and probably very incomplete during the early centuries of record keeping, but became more continuous after about AD 1400. The storm events recorded in the historical documentary evidence mainly represent landfalls by strong tropical cyclones (i.e., typhoons) and not tropical storms.

During the 510- year period from AD 1400 to AD 1909, the frequency of typhoons is about 10.9 strikes per decade, or about 1.1 strikes per year. If the weaker tropical cyclones, or tropical storms, are excluded from the observation period and only the Guangdong typhoons are considered, then the frequencies contained in the documentary and those post 1910, when direct instrumental records began, are quite comparable. This reinforces the conclusion that the long term evidence from the chronicles provides a significant quantitative insight into long term regional typhoon history.

Although less formal, in the sense that they are not official chronicles, as are those in China, long term records of typhoon occurrences in the NW Pacific are also available for the Philippines (Garcia – Herrera, et al, 2000). These were compiled by Jesuit missionaries, covering the years from 1556 to 1900. Prior to 1865, when the Manila observatory and its associated network throughout the islands, were established, the incidence of typhoons was certainly underestimated. None the less, the devastating impacts were recorded in great detail. Since 1865, the annual incidence of severe tropical storms and typhoons within the Philippines archipelago has had an annual average frequency of 4.7 and therefore the highest number of incidents in global terms.
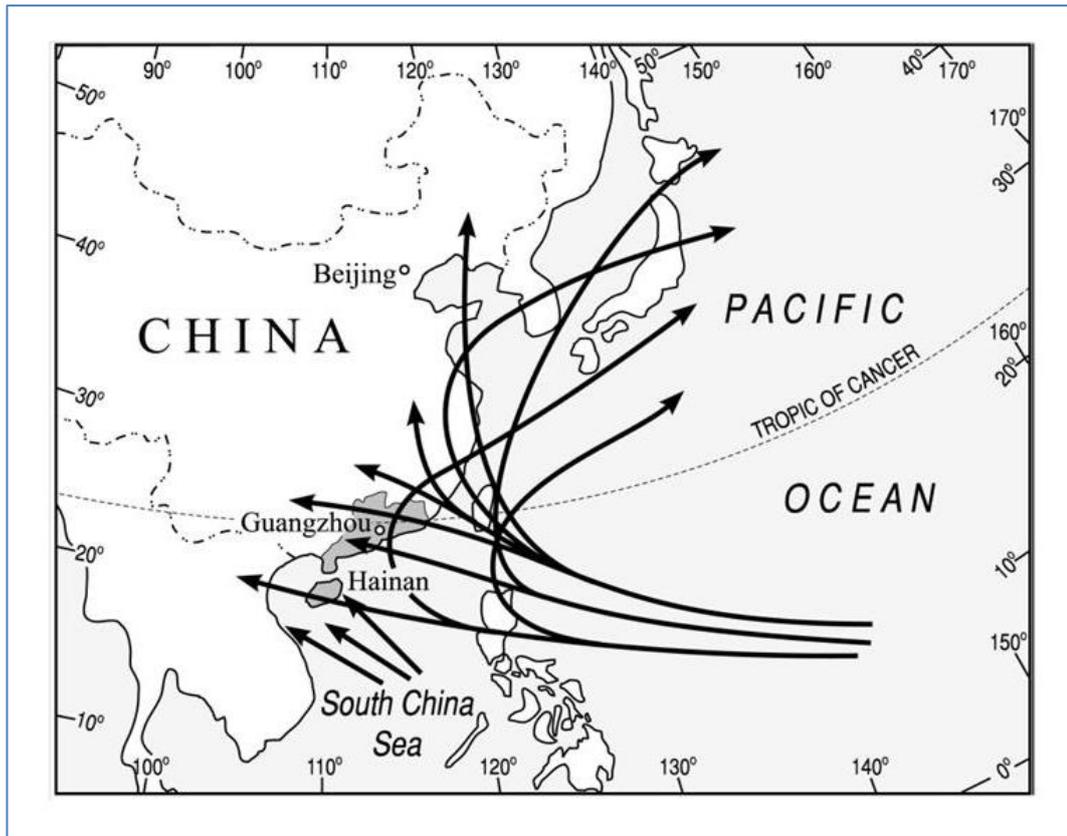
Figure 2-8   Location of Guangdong Province, including Hainan Island and Hong Kong (shaded), in relation to the generalized tracks of typhoons in the Northwest Pacific Basin (after Jiao 1984).
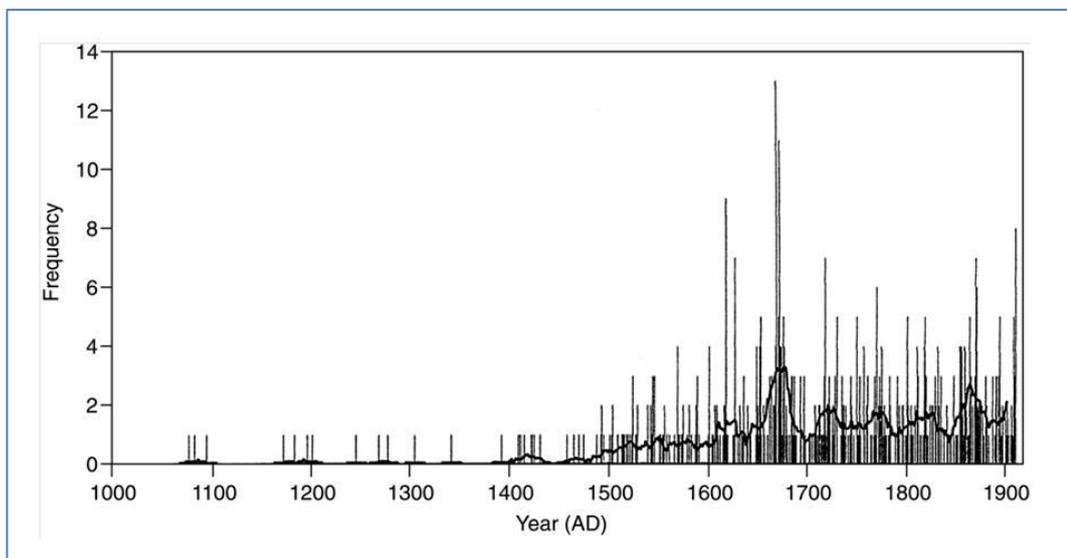
Figure 2-9   Year-by-year plot of typhoon strikes in Guangdong during AD 1000–1900, compiled from the historical documentary record. The continuous curve shows the twenty-one-year moving averages smoothed from the annual time series.

2.3 Tropical storms and typhoons – regional geography and incidence

The incursion of tropical storms and typhoons into the Mekong Basin is a major factor in the development of major regional flood events. These intense low pressure systems form in the western Pacific and East Sea (also South China Sea) and make landfall over the coast of Viet Nam, with a peak seasonal incidence in September and October. As the season progresses their path from west to east tends to move from north to south (Figure 2-10).
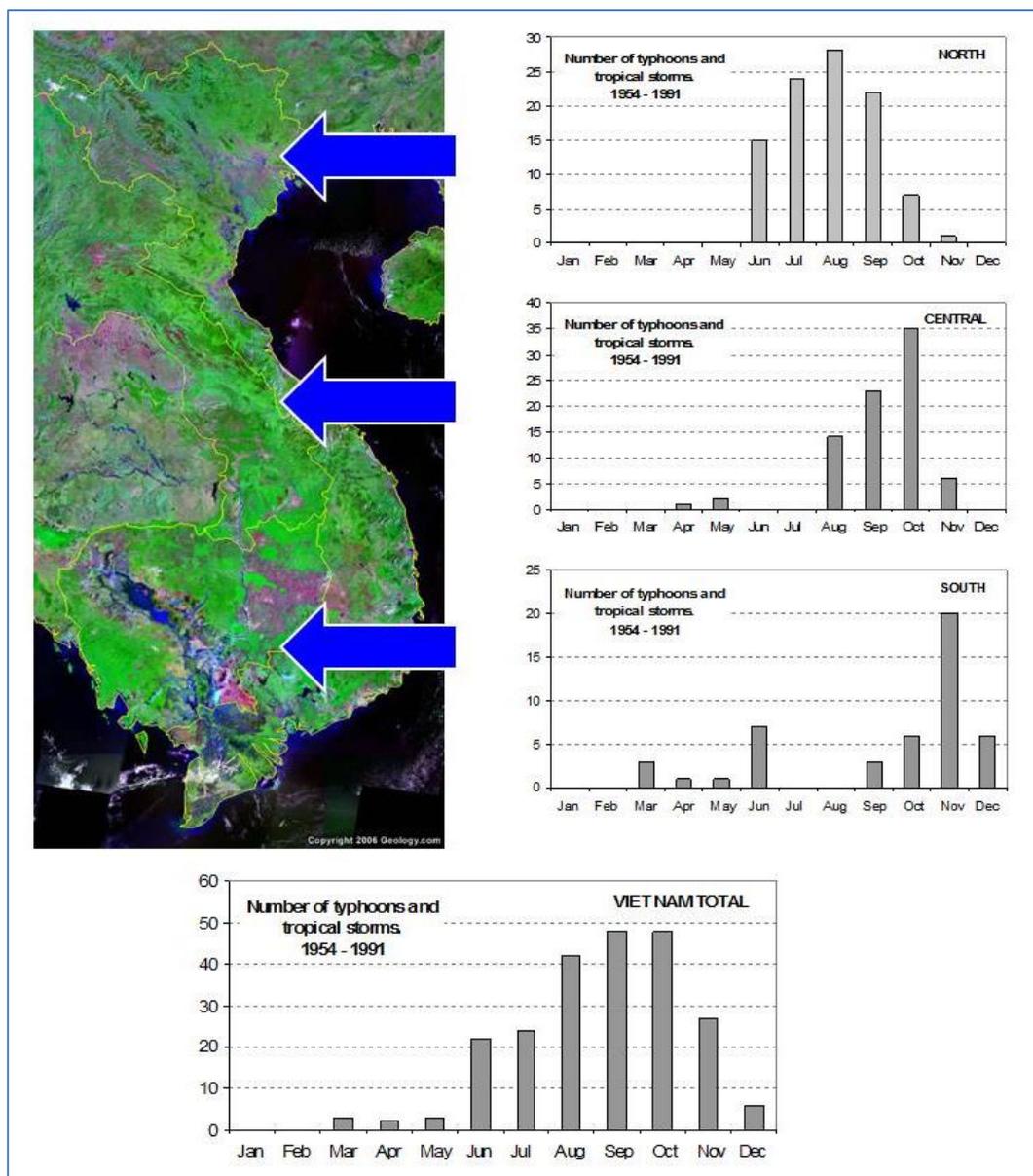
Figure 2-10   The seasonal frequency of typhoons and severe tropical storms making landfall in Viet Nam. As the season progresses the storm systems moving westwards from the East Sea tend to make landfall progressively further south along the coast. Based on data in ADPC (2000), Giang, (2005) and Imamura and Van To (1997).

Chin (1958) has summarized tracks of tropical cyclones for the period 1885-1953. All the tracks which appeared to possibly affect the rainfall in the Mekong were noted. The number of such disturbances for September and for the May through September season was then related to areal rainfall over Eastern Thailand, it being the portion of the Mekong drainage with the longest continuous period of rain records. No significant relationship of total monthly or seasonal rainfall to the number of such disturbances was obvious. This suggests that the lesser disturbances play an important role in the monthly rain production in the Mekong. A statistical analysis was made of tropical cyclonic storms approaching Southeast Asia from the east. Between 1884 and 1967, approximately 500 disturbances of this type affected the area. The resulting seasonal distribution of the tropical storms had a maximum activity in September but with October as a close second, an independent confirmation of the result in Figure 2-10. All of these had distinct cyclonic wind circulations at sea; most were fully developed typhoons. In some the cyclonic wind circulation could still be identified overland. In others this feature was lost, but the disturbed conditions producing rain remained.

The geographical distribution of tropical disturbances was summarized in terms of the number passing through 2-1/2 degree latitude-longitude squares. If a storm passed through two squares, it was counted twice. Figure 2-11 shows the results which convey two particular characteristics:

- There is a considerable decrease in the number of storms passing inland from the coast.
- Also to be noted is the sharp decrease both to the north and south of the mean point of landfall during September, the month of maximum regional typhoon incidence.

Maximum daily rainfall at most stations in the Mekong drainage was observed by Chin (1958) to range between 125 and 250 mm, although a few locations recorded more than 500 mm. This contrasts with Vietnam coastal stations to the east of the basin where amounts over 400 mm in a day are more common.

The mean impact time of a weather generating system at a point on the ground, such as tropical convective cells, is of the order of three days, though this clearly depends upon their areal extent and terrestrial speed of movement. Characteristically, maximum rainfall occurs within a 200 km radius of the storm center (US Corps of Engineers, 1970).

Regionally typhoons and severe tropical storms are most frequent late in the monsoon season when river flows are already high and the soil already saturated. In these circumstances, the greatest threat for flood flows on the Mekong appears to be a succession of tropical storms in September. In fact, storms in close succession are much more common in Southeast Asia than elsewhere in the Tropics. Studies of

storm tracks indicate that after a tropical storm passes at latitudes between Luang Prabang and Kratie there is a 1 percent probability of another storm with its center within 500 km of the first within 2 days, a 10 percent probability within 4 days and a 20 percent probability within 6 days (US Corps of Engineers, 1970). In this regard, within the Mekong region, two of the heaviest typhoon rainfalls occurred due to a sequence of three storms in 1964. Typhoon TILDA of September 21st - 25th had been preceded by typhoon VIOLET a week earlier. A third storm developed off the coast of Viet Nam on 25th September.

Figure 2-12 shows the genesis points of tropical storm systems in the NW Pacific and East Sea during 2012 and over the 61 years since 1951. This geography of storm formation indicates that there are two major source areas, one to the east of the Philippines and another within the East Sea. Those forming in the latter would be more likely to make land fall along the coast of Viet Nam. Those forming further east have much more variable trajectories and can strike anywhere from Korea, Japan and south China to the Indochina peninsular.
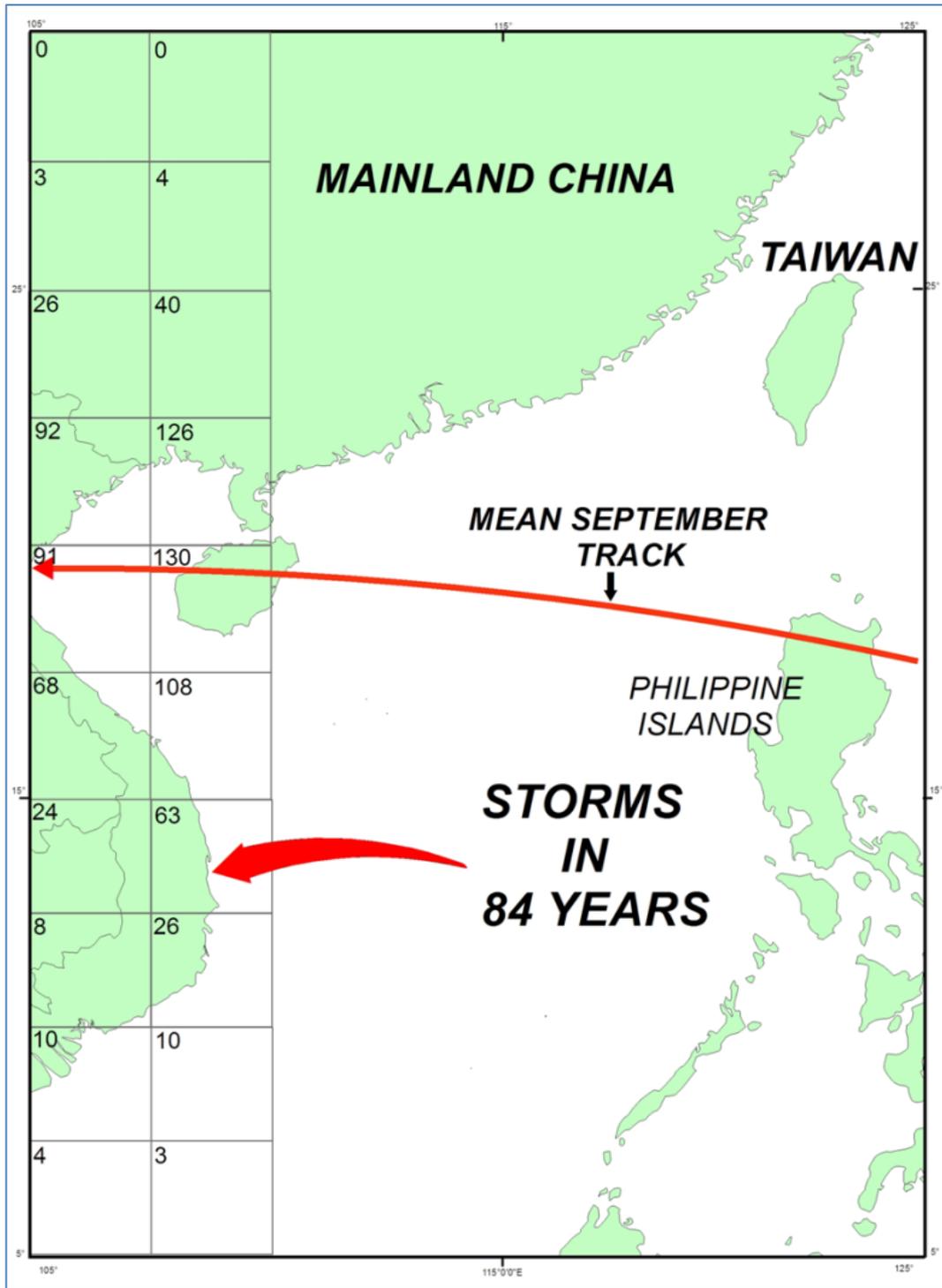
Figure 2-11   The geographical distribution of typhoon and tropical storm landfalls in Viet Nam and part of south China by 2.5 degree squares of latitude and longitude, 1884 to 1967 (US Corps of Engineers, 1970 and Chin, 1968).
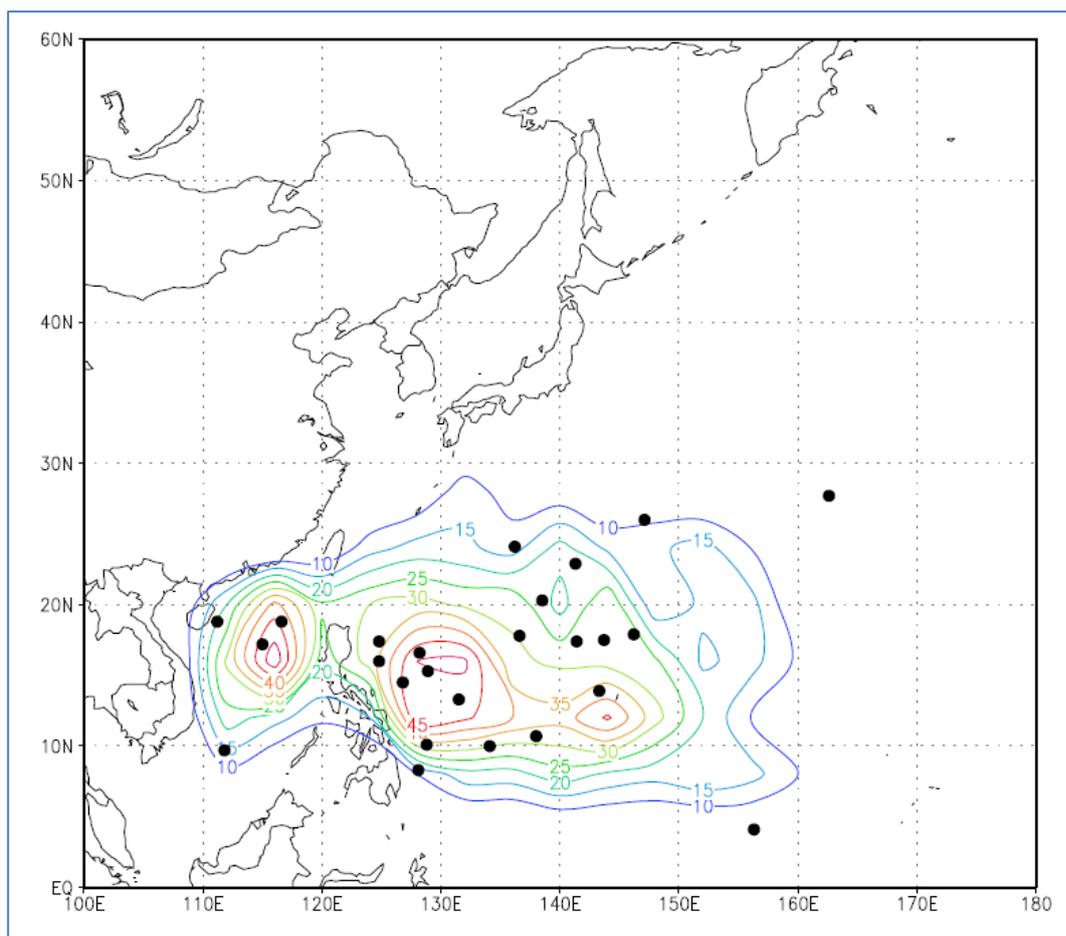
Figure 2-12   Genesis points of the 25 tropical storms that formed in 2012 (dots) and related frequency distribution for 1951 – 2011 (isolines). Source. JMA, 2013.

2.4   Regional tropical storms, typhoons and climate change

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).

There is no convincing statistical evidence to suggest that the frequency of typhoons and tropical storms is currently increasing. The data plotted in Figure 2-13 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. The same conclusion is drawn by Wu et al (2006) in a study of trends in cyclone intensity in the western Pacific as a whole between 1965 and 2004. ENSO's period varies between 2 and 7 years, with the average being quite robust at around 4 years (MacMynovski and Tziperman, 2008). A quasi-periodicity with a frequency of around 11 years is evident in Figure 2-13, though there has never been any suggestion that tropical storm genesis in the western Pacific has any link to solar activity.
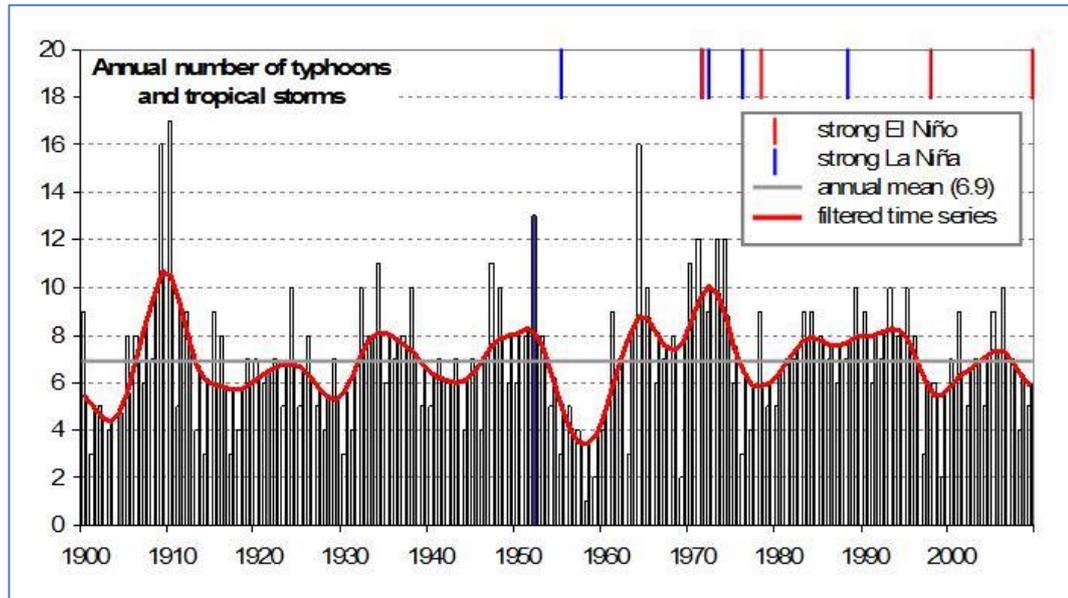
Figure 2-13   The number of tropical storms (wind speed > 16 m/sec) and typhoons (wind speed > 33 m/sec) approaching the coast of Viet Nam (specifically entering the latitude / longitude box 7.5 to 22.50 N and 105.0 to 115.00 E). The data from 1900 to 1995 are drawn from the CD-Rom Global Tropical and 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

Further confirmation that there has to date been no historical systematic increase in typhoon genesis in the NW Pacific and East Sea is available from the Japanese Meteorological Agency (JMA, 2012). The regional annual count data of significant and extreme tropical low pressure systems are available from 1951 to 2012. These are plotted in Figure 2-14.
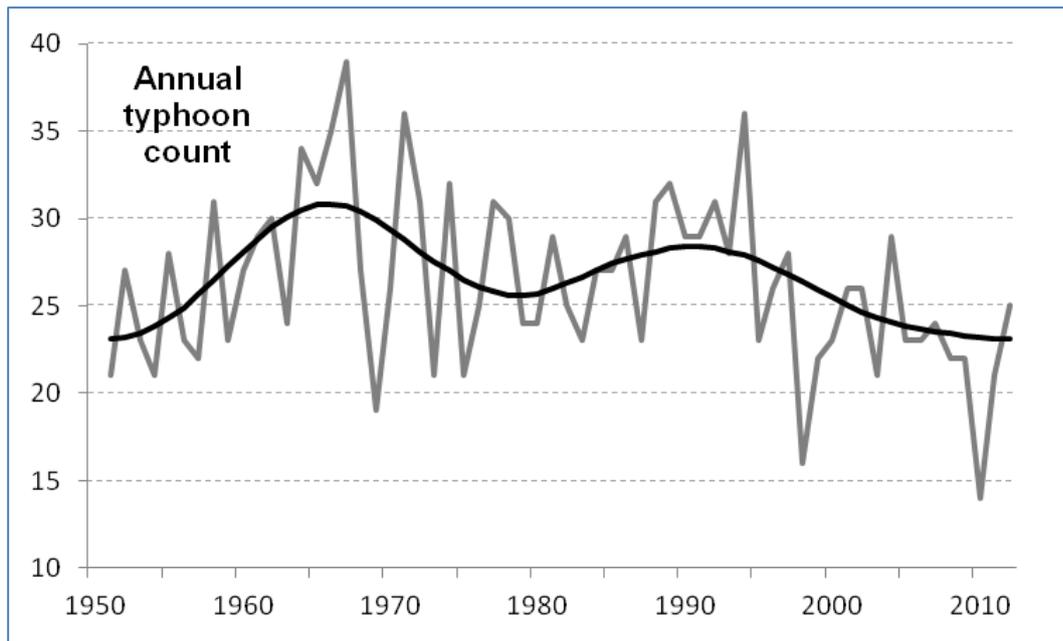
Figure 2-14   The annual count (1951 to 2012) of tropical storm and typhoon genesis in the NW Pacific and the East Sea. The smooth function is the embedded residual trend. The mean annual rate of regional system formation is 26.6 events per year. (Source of data, JMA, 2012).

- There is no evidence at all that the incidence of such events has increased over the last 63 years.
- In fact the data reveal that over the last 15 years, since 1998, regional storm incidence has been generally considerably less than the long term annual average.

This finding is consistent with those quoted elsewhere (see Figure 2-13). However, although the regional count of tropical storms shows no impact so far of climate change influences, it could be that storm severity is increasing. This latter argument has been advanced more strongly in recent years, of late in the aftermath of super typhoon HAIYAN which struck the central Philippines in 2013. This was the most intense tropical system to make landfall since authoritative records began, with wind speeds as high as 310 km/h.

It is these extreme wind speeds that cause most of the damage in coastal regions along with the associated storm surges. Further inland it is the intense storm rainfall and consequent flooding that generates the major impacts. In effect, the classification of tropical low pressure systems according to wind speed has only an indirect relationship with their hydrological consequences, although as a measure of their energy and intensity wind speed is no doubt broadly linked to the consequent storm rainfall.

There is a widely acknowledged though complex relationship between ENSO events and the number of typhoons making landfall in Viet Nam and Guangxi and Guangdong provinces in China and then potentially passing into the Mekong Basin (see Elsner and Liu, 2003). Fewer but more intense storms occur during strong El Niño years but weaker multiple occurrences have a higher probability in strong La Nina years (Camargo and Sobel, 2005). Because the number and intensity of storms is closely linked to sea surface temperatures any intensification of the ENSO cycle as a result of global warming is expected to increase the annual risk of severe tropical storms entering the Mekong region.

The synoptic scale of tropical storms compared to the area of the Mekong basin means that their direct impact is confined to just a part of the region. For example, typhoon PHYLLIS in September 1966 and tropical storm KAMMURI in August 2008 tracked over the northern parts of the basin upstream of Vientiane, where mainstream flood discharges were by far the highest observed in the last 100 years. These conditions dissipated downstream such that in each year the annual maximum flow at Kratie in Cambodia was no more than average. In 1978 typhoon JOE moved passed over the major Mekong tributaries in southern Lao PDR and the Se Kong, Se San and Sre Pok river basins resulting in the highest annual flood peak recorded at Kratie over the past 80 years. In the northern regions, in contrast, the 1978 flood season was unremarkable.

Figure 2-15   Flooding in Vientiane following tropical storm KAMMURI in August, 2008.

Inevitably, such events cause extreme damage and considerable loss of life. Typhoon LINDA is generally regarded as the most severe in recent decades[1]. It hit the extreme south of Viet Nam in November 1997, with extreme rainfall and storm surges measured at 3 to 4 m causing huge agricultural damage in the delta, conservatively estimated at several billion. Over 4 500 people died.

In more recent years tropical storm KETSANA was the most damaging event. The system made landfall over Central Viet Nam at the end of September 2009, causing three day rainfalls widely in excess of 600 mm and in some areas as much as 900 mm was recorded. Damage and losses in Viet Nam were estimated to be US$ 800 million. The storm then passed into northern Cambodia and southern Lao PDR where accumulated rainfalls continued to exceed extreme thresholds causing widespread flash flooding and landslides. Damage and losses in Cambodia alone amounted to US$ 132 million. In total more than 200 people died. Interestingly, LINDA and KETSANA both occurred in strong El Niño years when the region was experiencing severe drought conditions.
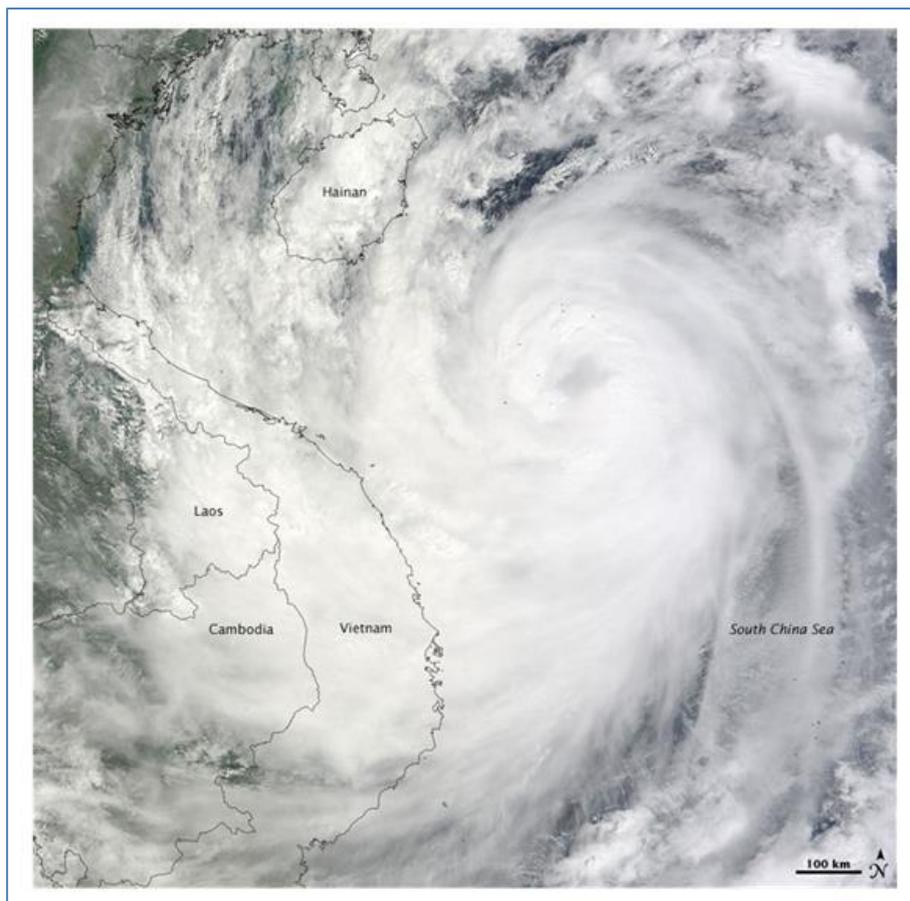
Figure 2-16   Typhoon KETSANA moving westwards towards the coast of Viet Nam at the end of September, 2009.

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[1] The most severe storm to hit Viet Nam was the Haiphong super typhoon in September, 1881, which killed 300 000 people and is ranked the third most deadly storm in recorded world history. http://www.wunderground.com/hurricane/deadlyworld.asp.

The damage caused by intense tropical weather systems is not always the result of the associated storm rainfall and consequent flooding. As tropical storm DURIAN moved over the delta in Viet Nam in the first week of December 2006 the associated rainfall for the period was less than 100 mm. High winds and coastal storm surges required the evacuation of some 6,000 households and structural damage was extensive.

Figure 2-17   Damage caused by Tropical Storm DURIAN in the Mekong Delta during the first week of December, 2006.

Räsänen et al. (in press) used palaeoclimatological data to find that the inter-annual variation between very wet and very dry years in the Mekong have significantly increased in recent decades, to levels which have not been experienced in the last seven hundred years. The findings of both Delgado et al. (2010, 2012) and Räsänen et al. (in press) suggest that the climate variability in the Mekong has increased, together with the likelihood of large floods.

The Mekong Basin is under the influence of El Niño Southern Oscillation (ENSO) (Räsänen and Kummu, 2013). ENSO influences the Mekong regional climate by moderating monsoon intensity. During El Niño the rainfall is generally below average and the flood season shorter than average. During La Niña the rainfall is generally above average and the flood season longer than average. For example, the recent major flood years of 2000, 2001 and 2011 in the Mekong were La Niña years.

Räsänen and Kummu (2013) suggest that there is a good potential for predicting ENSO impacts on the Mekong's hydrological regime.

2.5   Scale effects of tropical storms and typhoons within the context of the Lower Mekong Basin

The total area of the Lower Mekong Basin is 616 000 km^2. Typically the synoptic scale of tropical low pressure systems is far less, with the exception of "super typhoons" and very large systems.

Table 2-4   The classification of tropical low pressure systems on the basis of their area of influence.

Tropical low pressure system classification	Radius (km)	Area (km^2)
Moderately large	250	196 000
Very large	➢ 400	➢ 500 000

As a consequence small and moderately large systems impact upon only a part of the Basin and therefore the flooding that ensues is geographically confined to just part of the region. Characteristically, systems that pass to the north will result in hydrological impacts at Vientiane and further upstream, as in 2008. At the time the Mekong flood peak further downstream, at Kratie for example, was significantly below average. Conversely, during 2000 the severe flooding was confined to southern Lao, Cambodia and Viet Nam, while the upstream regions were not affected at all. This pattern is historically well established (see the 2006 and 2007 Annual Flood Reports).

On the basis of the Mekong mainstream flood data since 1960 the region has not been affected by "super typhoons" and systems large enough to affect the Lower Basin as a whole. Never the less, such "mega" systems are not uncommon within the NW Pacific. Figure 2-16 shows the area of impact of super typhoon USAGI which tracked to the north into SW China in 2013. The areal scale of this event, if it had made landfall in Viet Nam, would have had far reaching and potentially devastating consequences for the Lower Basin as a whole.
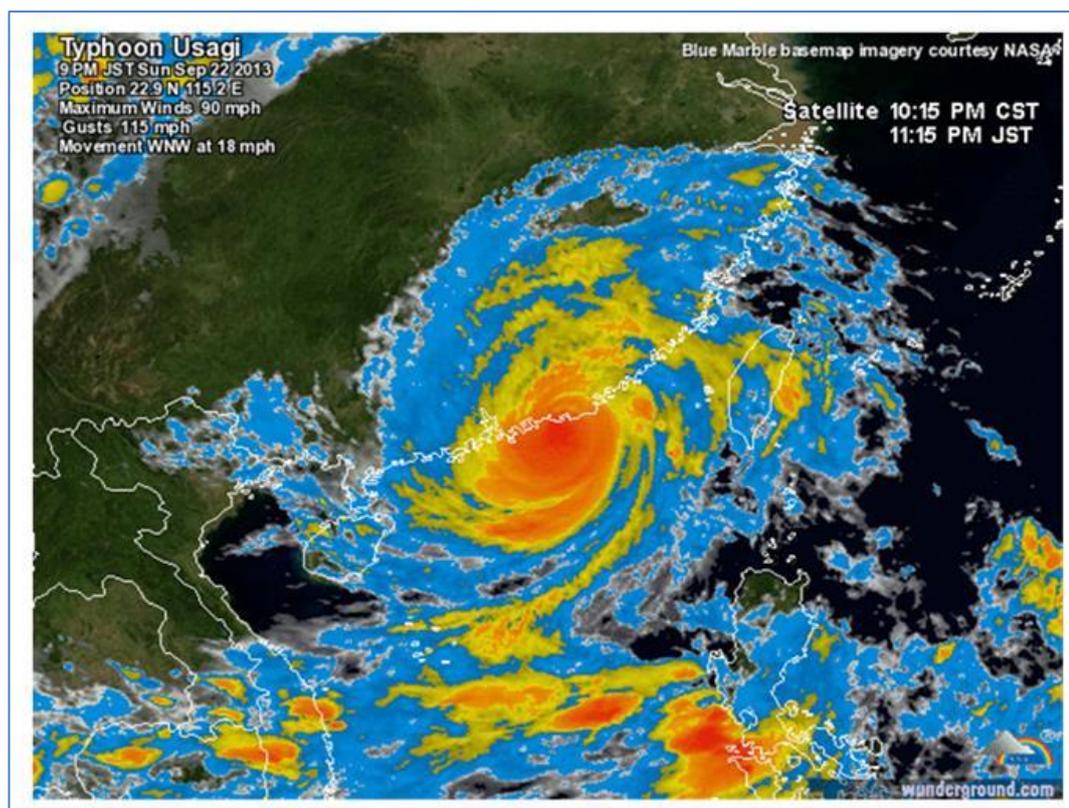
Figure 2-18   Super typhoon USAGI making landfall over SW China on 22nd September, 2013.

2.6   The long term history of tropical storms, typhoons and extreme floods in the Mekong Region, 1924 to 2005

Reflecting this generalized geography of flood incidence in the Lower Mekong and the historical distinction between events in the more northern parts on the one hand and those further downstream on the other, it is sufficient in principle to consider significant historical events on the mainstream at Vientiane and at Kratie respectively.

Table 2-4 indicates the rank ordered maximum flood peaks recorded at Vientiane (1913 to 2013) and at Kratie (1924 to 2013):

Table 2-5   The five highest flood peak discharges historically observed on the Mekong
             mainstream at Vientiane and at Kratie.

VIENTIANE		KRATIE	
Year	Maximum peak discharge cumecs	Year	Maximum peak discharge cumecs
1966	25 900	1978	77 100
1924	25 600	1939	66 700
2008	23 600	1991	67 100
1929	23 500	1940	64 000
2002	23200	1941	60 300
Mean annual flood peak	16 600		51 000

- The main feature of these figures is that there is no coincidence with respect to the years during which these extreme discharges were observed at the two mainstream locations.
- Also noteworthy is that at Kratie of the five greatest peak discharges, three occurred in the sequential cluster of years 1939, 1940 and 1941.
- These extreme events represent as much as 150% of the mean annual flood peak.
- The event of 1974 at Kratie, when a peak discharge of more than 77 000 cumecs was observed, is quoted in the World Catalogue of Large Floods as globally one of the largest on record for the equivalent catchment area of 646 000 km^2. (See the 2006 Annual Flood Report).

The extent to which these excessive flood events were linked to typhoon and intense tropical low pressure system incursions into the Basin is hard to establish since a number of them predate authoritative historical records of extreme regional weather systems. It is known that the maximum flood peak observed at Vientiane in 1966 was the result of the passage of typhoon PHYLLIS over northern Laos and southern Yunnan during September of that year. It seems reasonable to assume, though, that the majority of these maximal floods were linked in some way to intense tropical storm systems.

A clue lies with the fact that the historical incidence of such flood episodes is geographically independent between the two mainstream locations. This strongly points towards localized or at least sub-regional synoptic influences. Major regional flood episodes caused by a particularly strong SW monsoon would tend to be basin wide. For example, at the time of the 1978 record peak at Kratie, that during the same year at Vientiane was 21 000 cumecs, which although 28% above average does not compare with the Kratie figure. Similarly in 1966 at Vientiane, when the flood peak was in excess of 150% of the average figure, that at Kratie was a far more modest 10% above average. Both incidences tend to confirm the observation that extreme flood years tend not to be regional in extent, in the sense that that they correspond across the wider Basin, but that they are relatively localized at a sub-

regional scale. Once again, to underscore the point already made, the sub-regional impact of tropical low pressure systems appears to be the major influence upon the generation of extreme flood events.
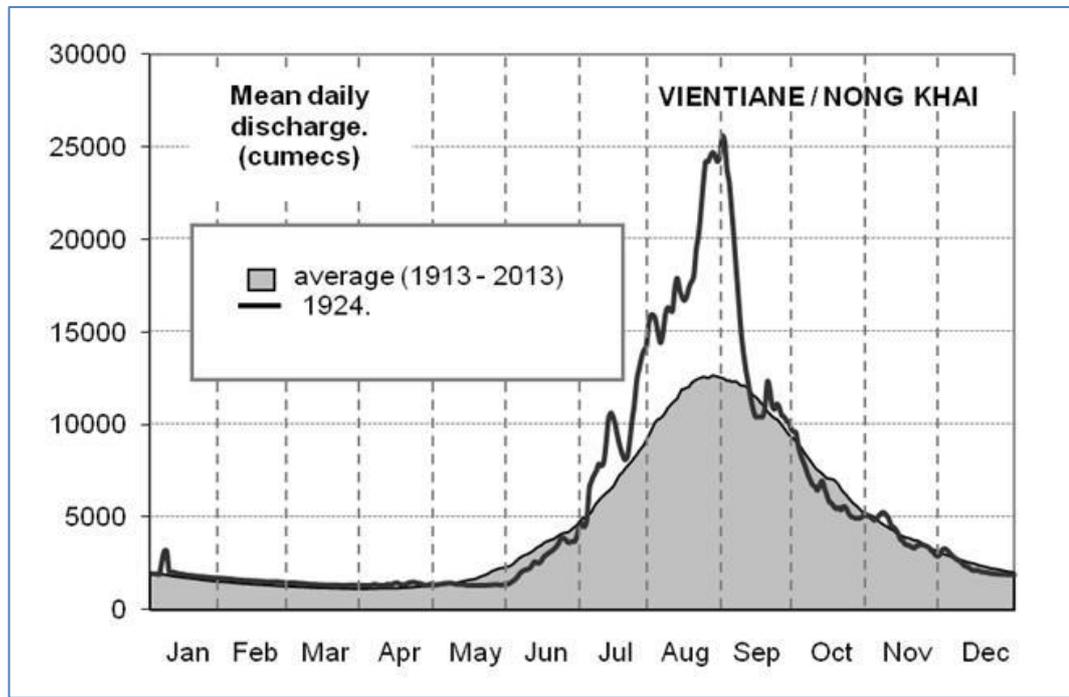
Figure 2-19   Mekong at Vientiane – the 1924 daily discharge hydrograph compared to the long term average. This was the second highest flood peak on record.

This "disconnect" between the upstream and downstream parts of the Lower Mekong Basin in terms of annual flood incidence and severity is encapsulated in Figure 2-20. Here a plot of the joint distribution of the annual maximum flood peak as a percentage of the long term mean year on year (1924 to 2013) at Kratie with the same statistic on the Mekong at Vientiane shows very little agreement. There is virtually no correlation of any statistical significance.

Table 2-5 indicates the historical sequence (1924 to 2013) of "significant" flood peaks on the Mekong mainstream at Vientiane and Kratie, where "significant" is defined as an event that exceeded 120% of the mean annual flood:

- By and large the incidence of these "significant" events at the two sites is mutually independent.
- No "significant" event in terms of a flood defined as exceeding a peak discharge threshold of 120% of the mean annual event has been observed at Kratie since 1991.
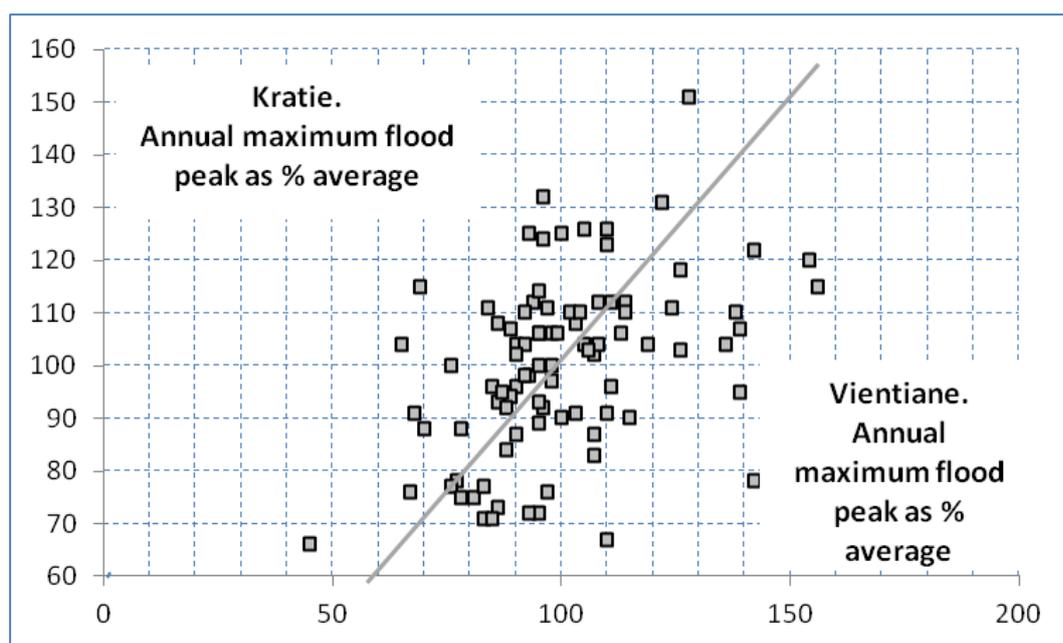
Figure 2-20   Scatter plot of the joint distribution of the annual maximum flood peak at Kratie as a % of the average compared to that at Vientiane for the same year, 1924 to 2013.

Table 2-6   Mekong mainstream at Vientiane and Kratie. The historical incidence of "significant" annual flood peaks that exceeded 120% of the mean annual flood and the average waiting time between them.

Year	Annual maximum discharge as % of the mean annual flood	
	Vientiane	Kratie
1924	154	120
1929	142	122
1937	-	126
1940	-	126
1941	126	-
1942	136	-
1945	139	-
1946	126	-
1961``	-	123
1966	156	-
1978	128	151
1980	124	-
1981	-	125
1991	-	132
2002	139	-
2008	142	-
Mean waiting time	9.2 years	11.6 years

- The devastating events at Kratie, across the Cambodian flood plain and the delta, in 2000, 2001 and 2002 were in fact defined by their excessive volume of flood water and their duration. The food peaks were modest or average

(see Figure 3-6). This tends to point towards an exceptionally strong monsoon season in each of these years. Tropical low pressure systems and their associated intense storm rainfall over a relatively restricted timeframe would have tended to result in significant peak discharges, which was not the case.

- The mean waiting time between these "significant" floods at the two sites are comparable at 9 to almost 12 years. However, there has been considerable historical variability. For example, at Vientiane during the 1940's four such peak floods occurred between 1941 and 1946.

In an early study of Probable Maximum Precipitation or PMP over the Lower Mekong Basin (US Corps of Engineers, 1970), attention was focused on three typhoons that passed across the region in the 1950's and 1960's, namely:

- VAE   20th – 22nd October, 1952.
- VIOLET   14th – 17th September, 1964, and
- TILDA   21st – 25th September, 1964.

The situation in 1964 was of particular interest to the study, when typhoon VIOLET preceded TILDA by just a few days, thus providing antecedent conditions for maximizing the subsequent flood runoff. This feature of storms in such close succession is much more common in the NW Pacific and East Sea than elsewhere in the tropics, for example the Caribbean and western Atlantic.

The areal mean rainfalls associated with these three events are indicated in Table 2-6. The figures for VAE and TILDA are broadly comparable over areas of 5,000 to 50,000 km^2. VIOLET, on the other hand, was a much weaker system. It is informative to compare these figures to regional estimates of Probable Maximum Precipitation, as discussed in Section 2.8.

Table 2-7   Areal mean rainfall estimates (mm) for tropical systems VAE, VIOLET and TILDA in 1952 and 1964. (US Corps of Engineers, 1970).

Typhoon	Area	Duration	
	km^2	24 hours	48 hours
VAE	5 000	275	370
	20 000	210	330
	50 000	150	290
VIOLET	5 000	150	190
	20 000	130	170
	50 000	110	150
TILDA	5 000	315	360
	20 000	250	290
	50 000	190	230
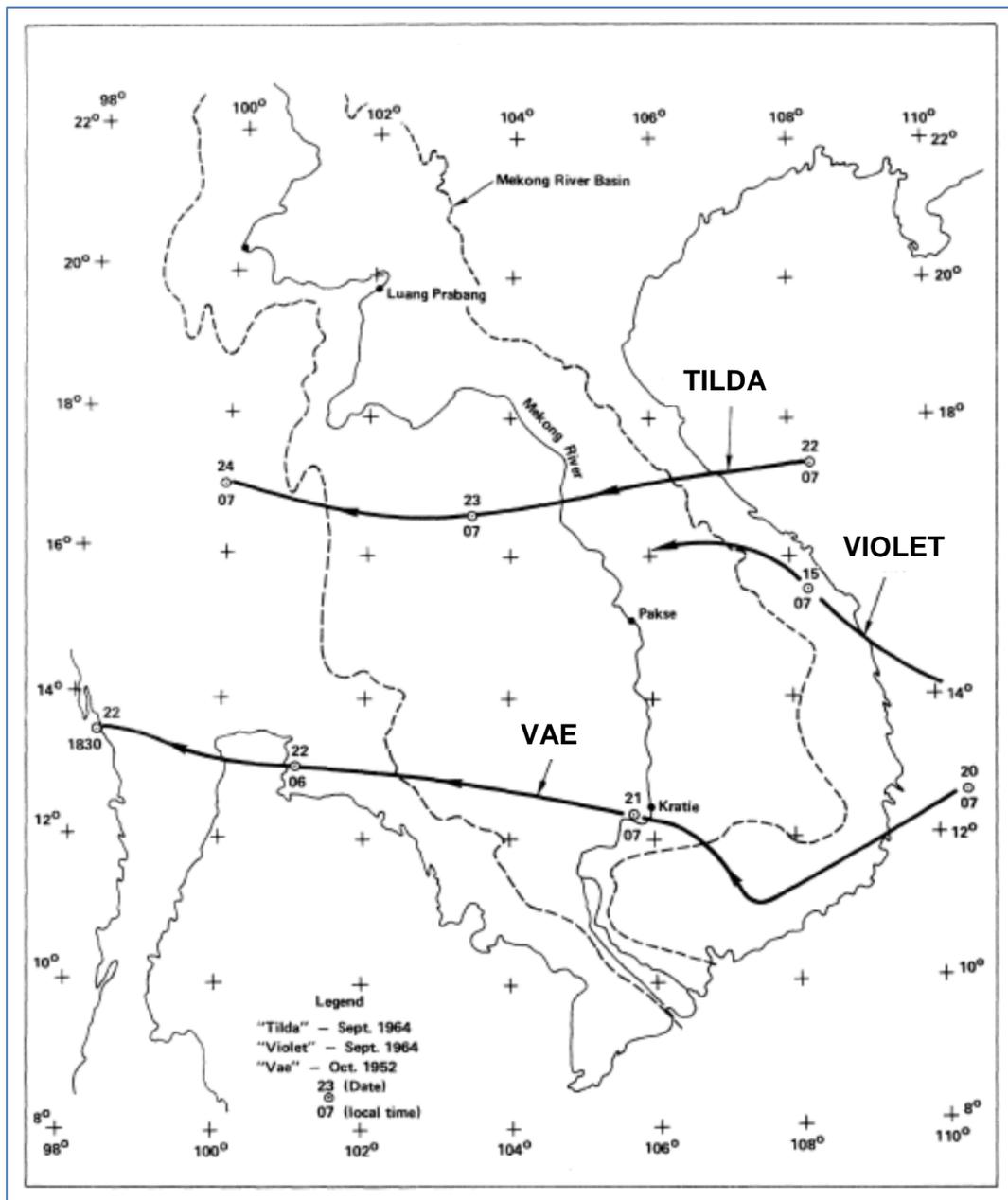
Figure 2-21   The tracks of tropical storms VAE (20th to 22nd October, 1952), VIOLET (14th to 17th September, 1964) and TILDA (21st to 25th September, 1964).

The tracks of these three systems across the Lower Basin are shown in Figure 2-21. VIOLET dissipated quite early on after making landfall, while the other two systems transited the entire Basin from east to west. The geographical distribution of the accumulated storm rainfalls estimated for VIOLET and TILDA are shown in Figure 2-22. Those for VIOLET were comparatively modest, though none the less significant as a precursor to TILDA a few days later. Passing much to the south, the hydrological impact of VAE in 1952 appear to have been unexceptional. The peak discharge for the year at Kratie was close to the average figure of 52 000 cumecs.
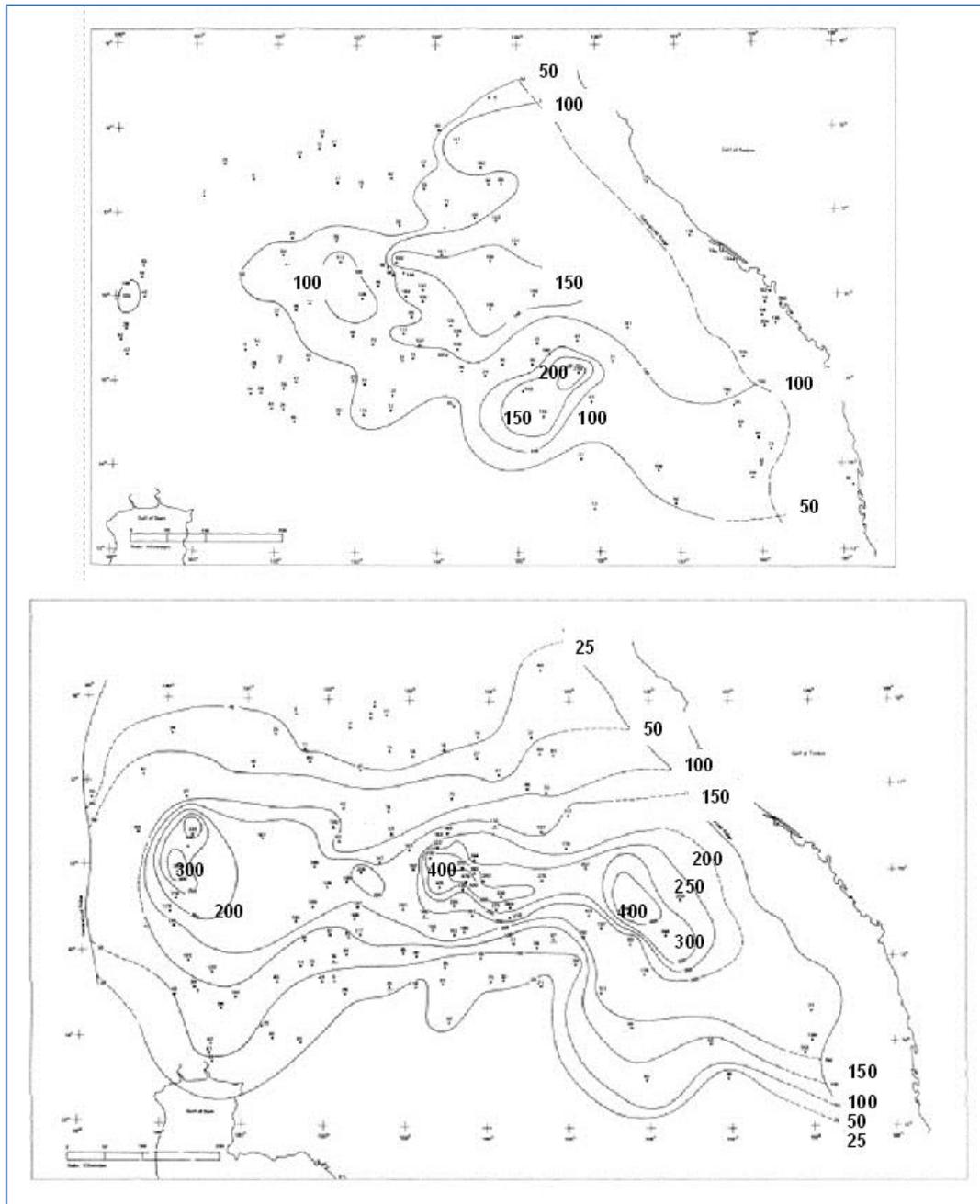
Figure 2-22   The distribution of storm rainfall during the passage of typhoons VIOLET (top) 14th to
17th September, 1964, and TILDA, (bottom) 21st to 25th September, 1964.

The impact of the combination of VIOLET and TILDA is apparent from the daily discharge hydrograph recorded at Pakse in 1964. In the latter half of September the flows increased more than two fold to reach a peak of over 44 000 cumecs (Figure 2-23). Such a figure lies amongst the 10 largest events observed in the 91 years since 1923.
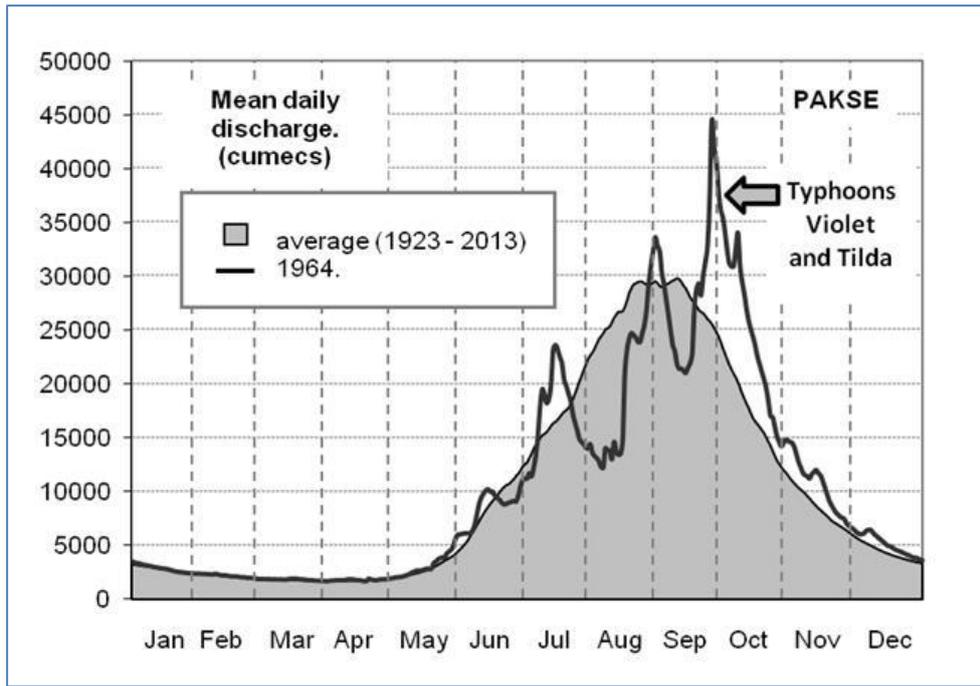
Figure 2-23   The discharge response on the Mekong mainstream at Pakse to typhoons VIOLET and
               TILDA in 1964.

The 1966 flood, which was associated with the passage of Typhoon PHYLLIS across
the northern parts of the Lower Basin resulted in the highest peak discharge observed
at Vientiane since records began in 1966 (see Section 2.6). The associated annual
hydrograph is shown in Figure 2-24.
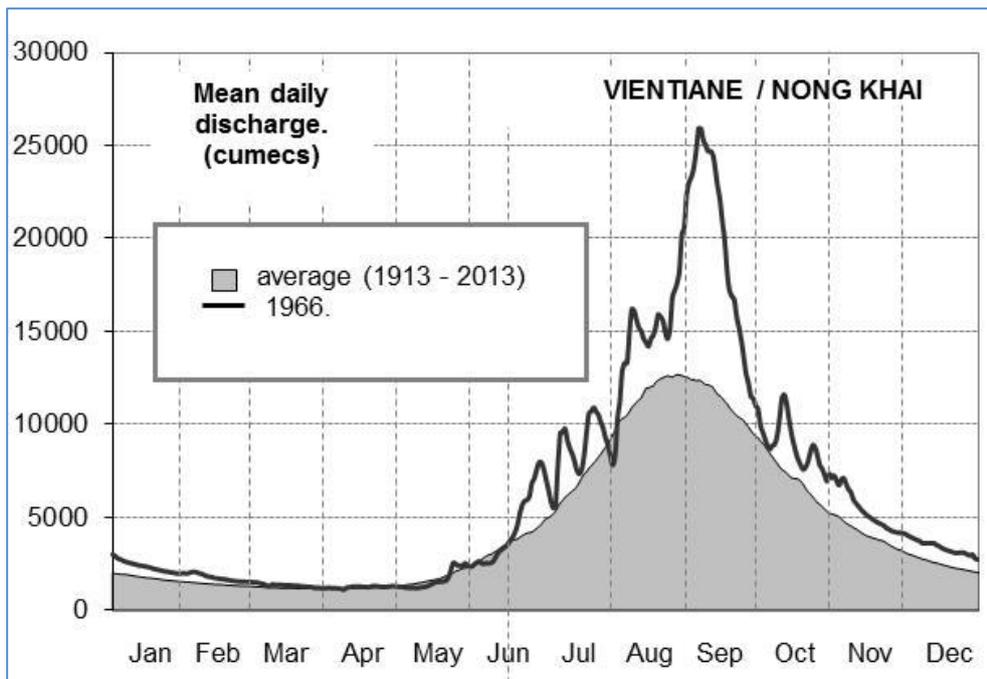
Figure 2-24   The 1966 annual hydrograph on the Mekong at Vientiane that was the result of the
               passage of Typhoon Phyllis across the northern regions of the Lower Basin.

Severe Tropical Storm LINDA was the worst typhoon to make landfall in southern Vietnam in at least 100 years, killing thousands of people and resulting in huge damage. It formed on 31st October 1997 in the East Sea between Indochina and the Philippines. Strengthening as it moved westward, LINDA struck extreme southern Vietnam on 2nd November with winds of 100 km/h, associated heavy rainfall. Once in the Gulf of Thailand it strengthened further to minimal typhoon status, but weakened to tropical storm strength before crossing the Malay Peninsula into the Bay of Bengal, the first storm to do so in five years. The worst of LINDA's impact was in Vietnam, where over 3,000 people were killed, and damage totaled US $385 million. LINDA was reportedly the most powerful low pressure system to occur over southern Viet Nam since 1904.

Figure 2-25   The track of typhoon LINDA during November, 1997.

2.7   The recent history of tropical storms and typhoons in the Mekong Region, 2006 to 2012

In **2006** the monsoon was generally rather weak and ended untypically early in early September Three major tropical storm systems tracked across the Mekong Basin during the year:

- during the last week of August PRAPIROON entered the region as a tropical storm, but was quickly downgraded to an intense tropical depression as it weakened. Intense storm rainfall (150 to 200 mm) was confined to Northern Thailand, Northern Laos and Eastern Cambodia. This system was responsible

for some severe tributary flash floods in Northern Thailand, particularly on the Nam Mae Kok at Chiang Rai.

- tropical storm DURIAN was not linked to widespread rainfall during its passage over the Vietnam Delta during the first week of December, but principally to very high wind speeds and a storm surge which caused extreme sea levels and widespread inundation and damage as a result (see Figure 2-17).

- the major event of the 2006 season was severe tropical storm XANGSANE which moved into the central and southern parts of the region during the first week of October. The rainfall and flood runoff associated with this system were responsible for a second peak to the annual flood hydrograph. Significant storm rainfall was widespread, particularly towards the south. The regional distribution of the associated storm rainfall, the track of the system and its affect upon the flood season hydrograph at Pakse are shown in Figure 2-26. Seasonal flood discharges had been decreasing rapidly throughout September, from more than 30 000 cumecs at the beginning of the month to less than 12 000 at the end. As a consequence of XANGSANE, these then increased by 12 000 or so cumecs in less than a week from the end of October onwards.

From a hydrological perspective, in many ways, flood conditions during **2007** were comparable to those of 2006. The flood season, in response to decreasing monsoonal rainfall, saw systematically decreasing discharges during late September, which then rose again significantly during early October in response to typhoon / tropical storm LEKIMA. This was the only low pressure system during the course of the year that had any large scale hydrological impact. It resulted in the 2007 peak discharge at Kratie and the only time in the year that water levels in Cambodia and the Delta rose above average. The associated heavy rainfall within the many of the large left bank tributaries, particularly the Xe Bang Hieng, Xe Bang Fai, Se Done, Se Kong and Se San resulted in extreme local water levels and discharge. Three day rainfalls in excess of 250 mm were widespread. Details of LEKIMA and its impacts are indicated in Figure 2-27.

The Mekong flood regime of **2008** provided historically exceptional circumstances, with maximum water levels and discharges at Vientiane that have only been recorded previously in 1924 and 1966. Discharges in the mainstream had been considerably above average, at least in the more northern parts of the Lower Basin, from mid July onwards. Given this situation, during the first week of August tropical cyclone KAMMURI tracked across the Basin to the far north and into southern Yunnan downstream of Jinghong. The consequence was a rise in discharge from 15 000 cumecs to more than 23 000 cumecs in the space of just three or four days, taking into consideration the fact that the mean daily discharge at this point during the flood season is just 12 000 cumecs (Figure 2-22). These circumstances brought about an

emergency civil defense response in order to protect the central business district of Vientiane from overbank inundation, as occurred in 1966. Villages in the sub urban areas upstream and downstream of the city center were, however, affected considerably by flooding, which lasted for more than two weeks. Incidents such as this clearly reveal that geographically extreme flooding within the Lower Mekong system is almost never basin wide but confined either to the northern or southern parts. This feature arises because the synoptic scale of flood generating events such as intense low pressure systems, be they typhoons or less intense systems , is not sufficient to affect the Basin as a whole, as they track from east to west.. This aspect of the regional geographical nature of the flood regime is quite evident from Figure 2-30.
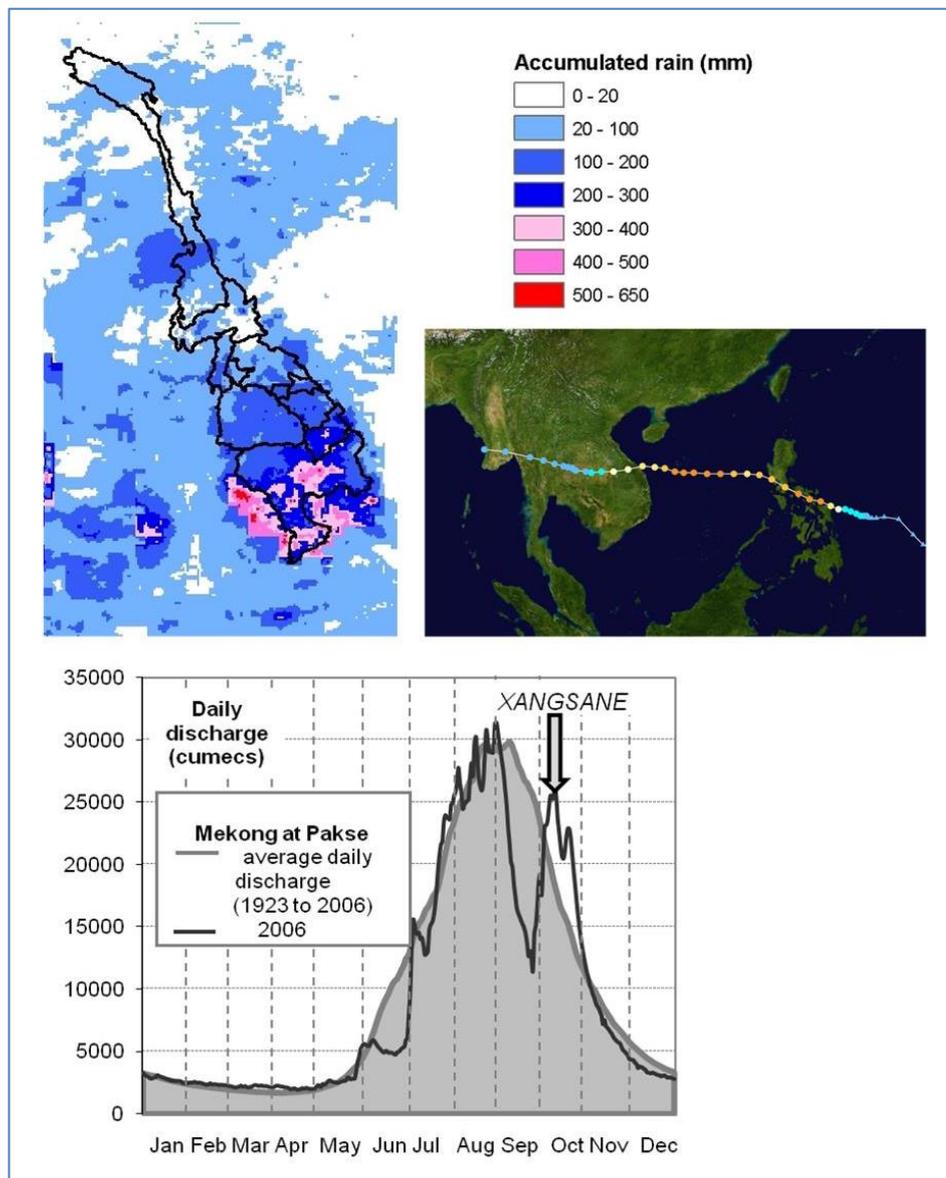
Figure 2-26   Typhoon / tropical storm XANGSANE – accumulated rainfall during the first week of October, 2006, storm track and the impact on the flow hydrograph at Pakse.
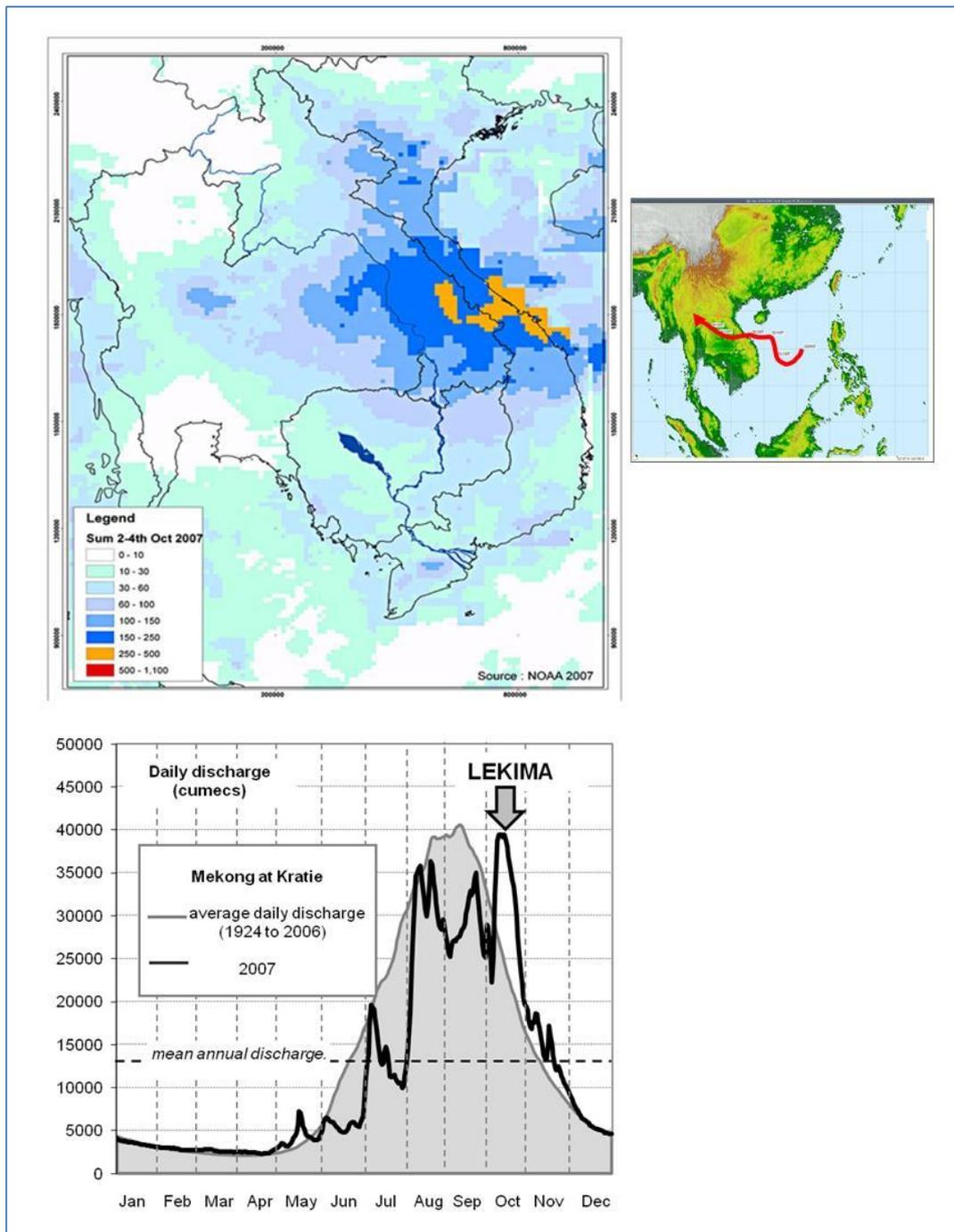
Figure 2-27   Typhoon / tropical storm LEKIMA – accumulated rainfall during the first week of October, 2007, storm track and the impact on the flow hydrograph at Kratie.
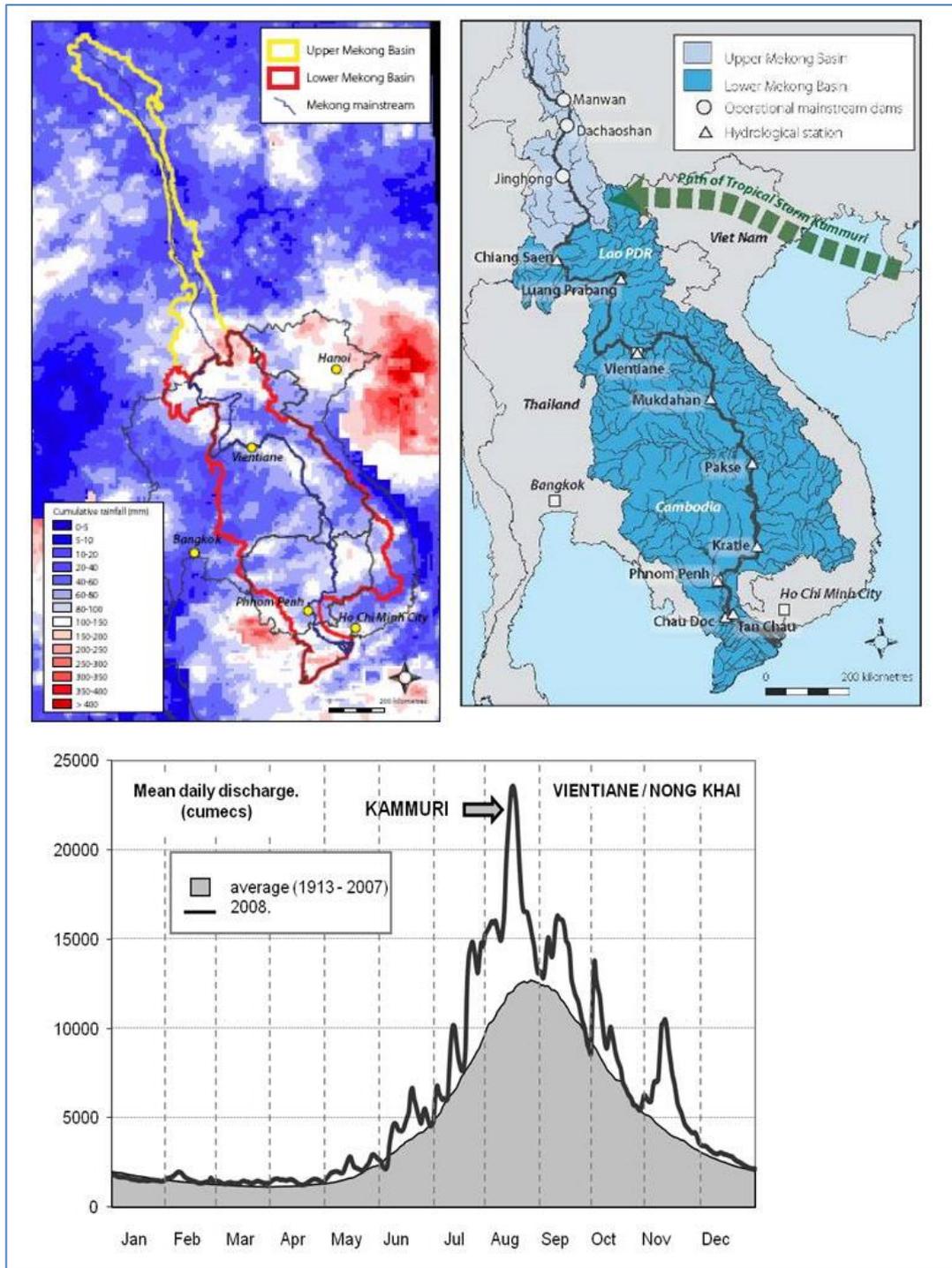
Figure 2-28   Typhoon / tropical storm KAMMURI – accumulated rainfall during the first week of
mid August, 2008, storm track and the impact on the flow hydrograph at Vientiane.

Figure 2-29   The Mekong at Nong Khai (top) and at Vientiane (bottom), mid August 2008. The discharge was estimated to be of the order of 23 500 cumecs.
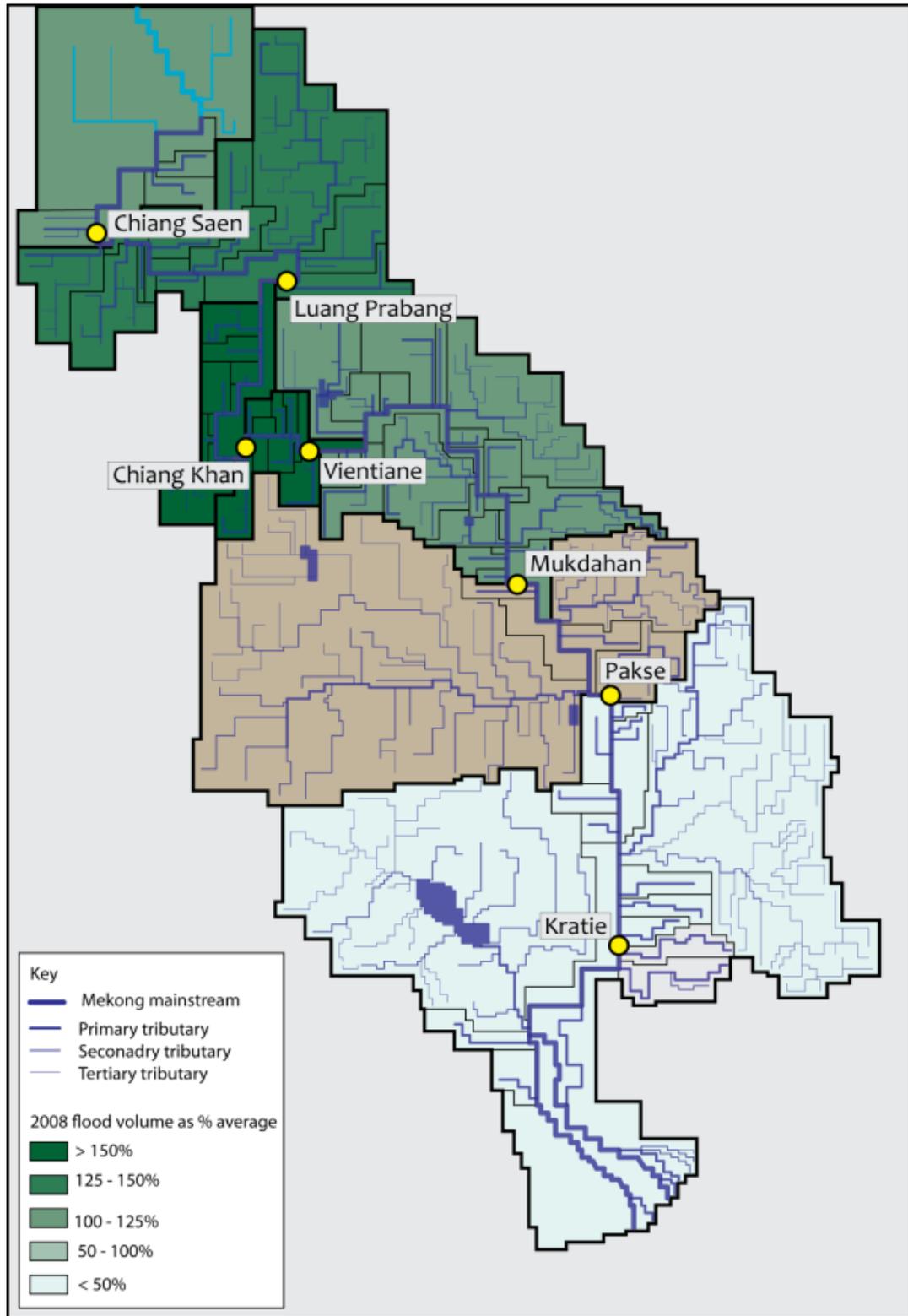
Figure 2-30   The geographical distribution of flood runoff for 2008 as a percentage of average.

During **2009** five tropical storms made landfall in Viet Nam: 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.
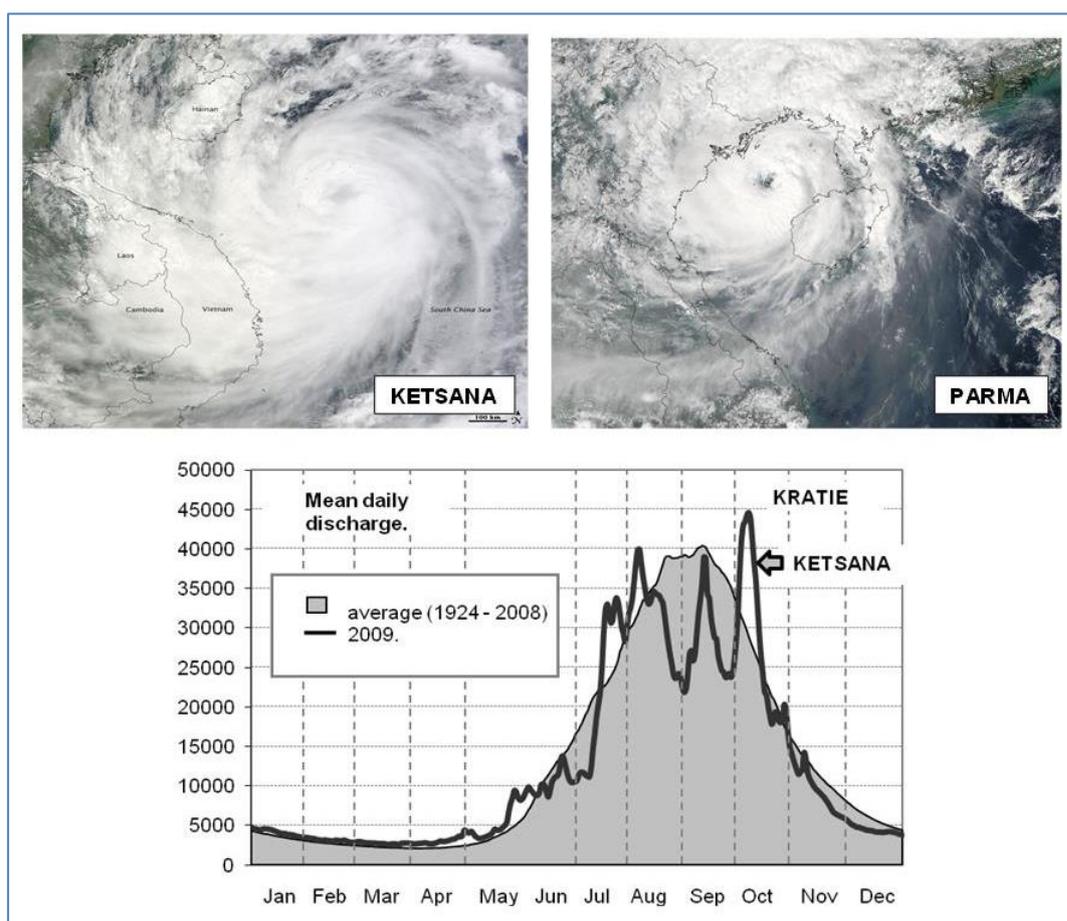
Figure 2-31   KETSANA moving SW towards the coast of Viet Nam on the 28th September. This storm system was quickly followed by PARMA seen moving west towards the northern provinces of Viet Nam on the 13th October. 2009. (Source: NASA). http://earthobservatory.nasa.gov/NaturalHazards). KETSANA resulted in the highest discharge of the season on the Mekong at Kratie.

- Damage and losses in Viet Nam were estimated to be US$ 800 million. 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.

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.

Figure 2-32   Flooding along the Se Kong during September 2009 as a consequence of cyclones KETSANA and PARMA.

During **2010** two tropical storm systems passed across the Mekong Region :

- In mid July tropical storm CONSON moved toward to the northeast through the Indochina Peninsula and affected the central and northern areas of Lao PDR causing rapid inundation over the low plain areas of Xieng Hone District and Xayaburi Province. Flash flooding also occurred over Meuang Mat, Kasy and Vangvieng districts in Vientiane province with rainfall of 40 mm recorded at Xayaburi and 63mm at Phonhong stations in Vientiane province on the 17th July.
- Tropical storm MINDULLE made landfall over central Viet Nam, downgrading to a tropical depression as it passed over northern Laos the 26th August, bringing local heavy rainfall of up to 80 mm and more, resulting in flash floods through Sing and Long districts, Luangnamtha Province. Northern and northeastern Thailand were also affected by heavy storm rainfall and flooding.

The annual flood situation during 2010 illustrates a not uncommon set of circumstances with respect to the seasonal flow regime. In hydrological terms, flood flows along the mainstream were critically below average throughout the year, as a result of a weak SW Monsoon. The quite independent passage of the tropical storm systems resulted in a rapid increase in discharge, although in this case flows remained below average throughout the season. Clearly, the impact of tropical storms on the severity of the consequent flood conditions depends not only upon the intensity of the storm itself but also upon the prior discharge conditions that prevail at the time of impact, including the levels of catchment saturation, which in 2010 appear to have been moderate given the prevailing monsoonal rainfall.
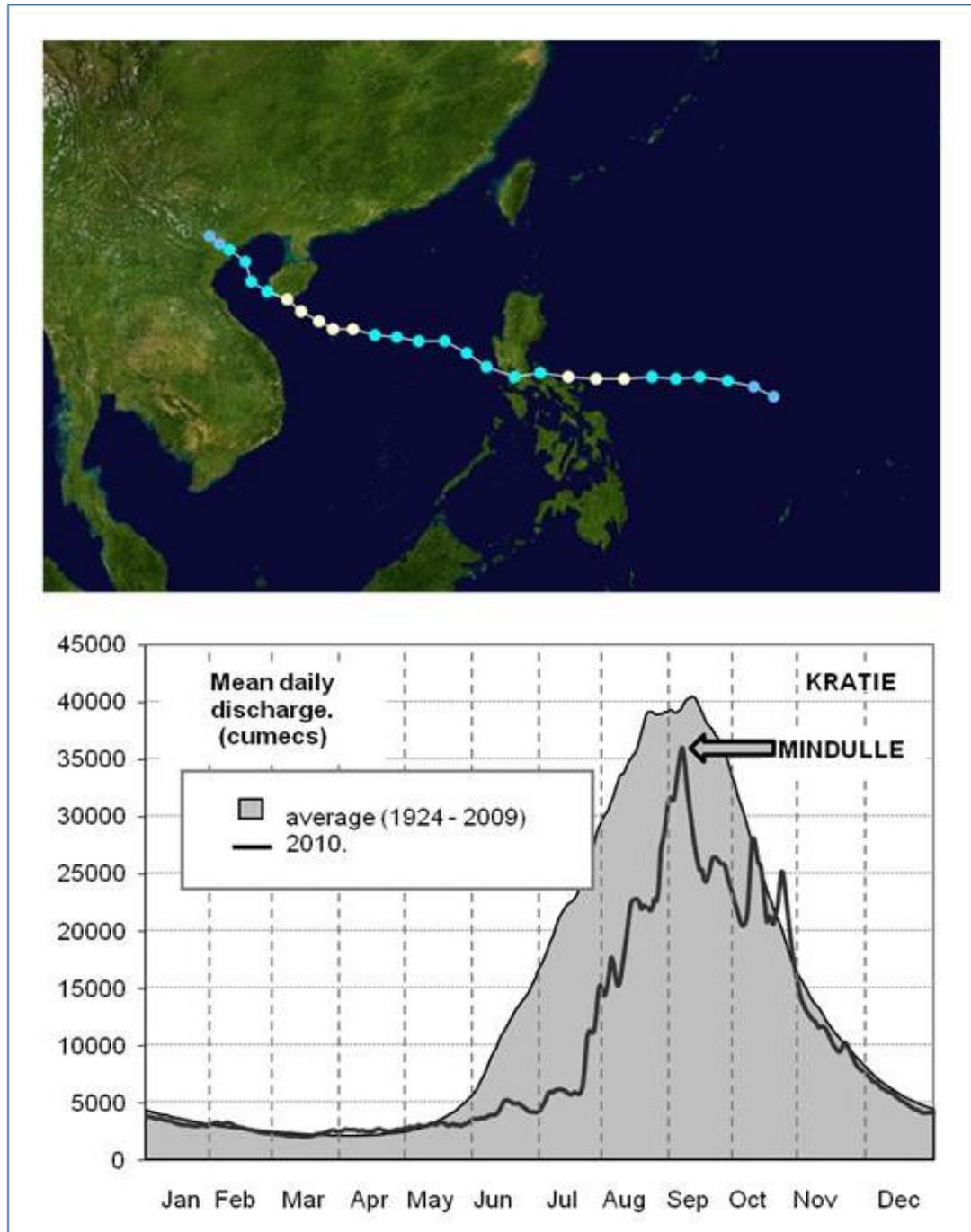
Figure 2-33   The track of tropical storm CONSON during mid July 2010 and the impact of tropical
storm MINDULLE on the daily discharge hydrograph at Kratie.

Conditions during the flood season of **2011** were the converse of those of the previous year.   There was widespread argument at the time that they were comparable to those of 2000, perceived as the most devastating of recent decades. They were not quite, but were in hydrological terms fairly close. Losses and damage, particularly in Cambodia and Viet Nam, were not dissimilar, however. A number of tropical low pressure systems passed across the Lower Basin during the year, of which HAIMA during late June and NOCK-TEN at the end of July had the most

impact in terms of storm rainfall. In addition, the region was also affected by tropical storm HAITANG during September and typhoons NESAT and NALGAE during October, creating an exceptional sequence of storm systems within a single season.

In northern and central Laos, during the course of tropical storm HAIMA, daily rainfalls in excess of 180 mm were recorded, with 18 fatalities confirmed. Northern and NE Thailand were affected to a similar degree. Within just a few weeks NOCK-TEN followed with cumulative rainfall over a three day period as high as 250 mm.
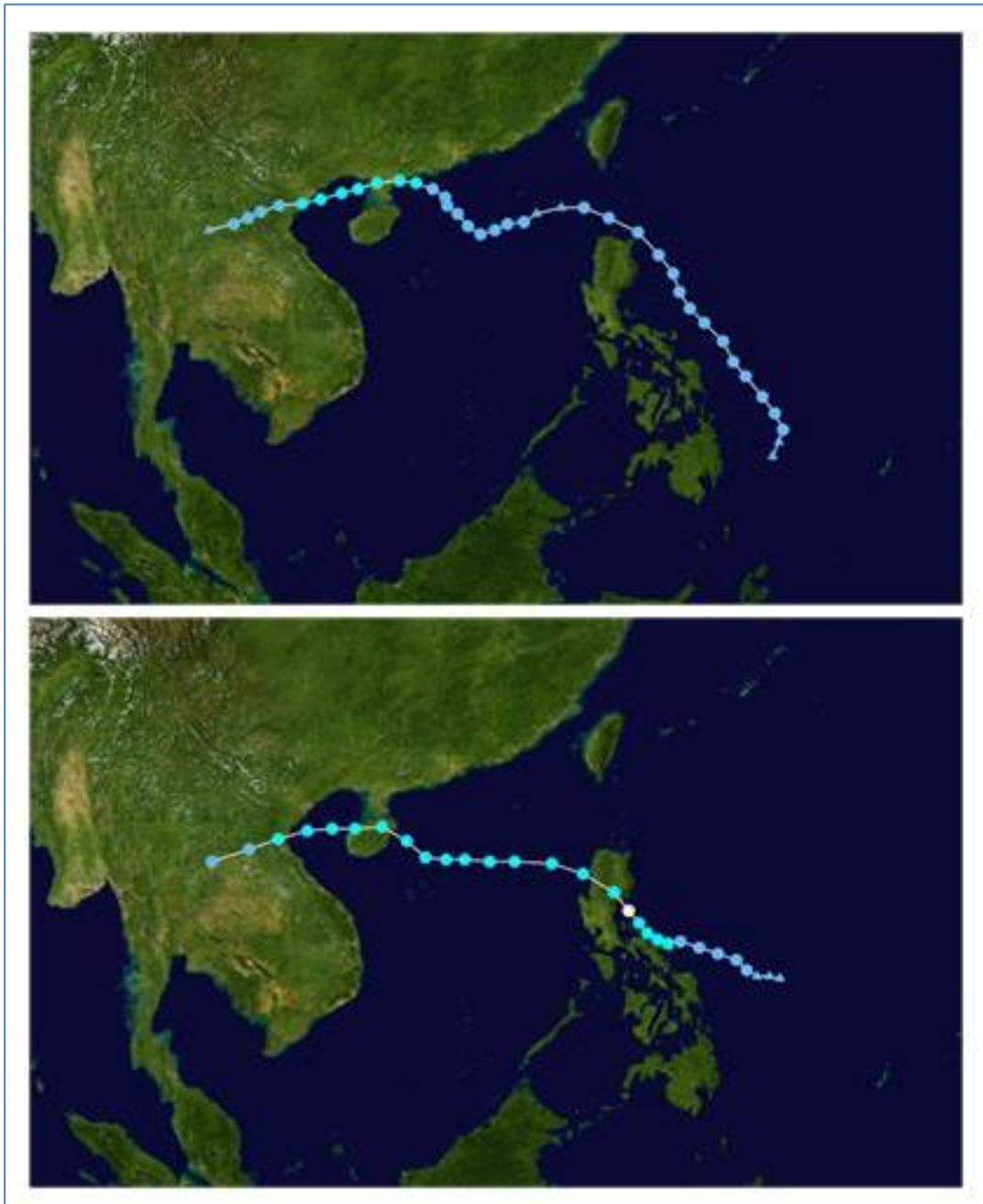
Figure 2-34   2011 – the tracks of tropical storms HAIMA at the end of June (top) and NOCK-TEN at the end of July (bottom).
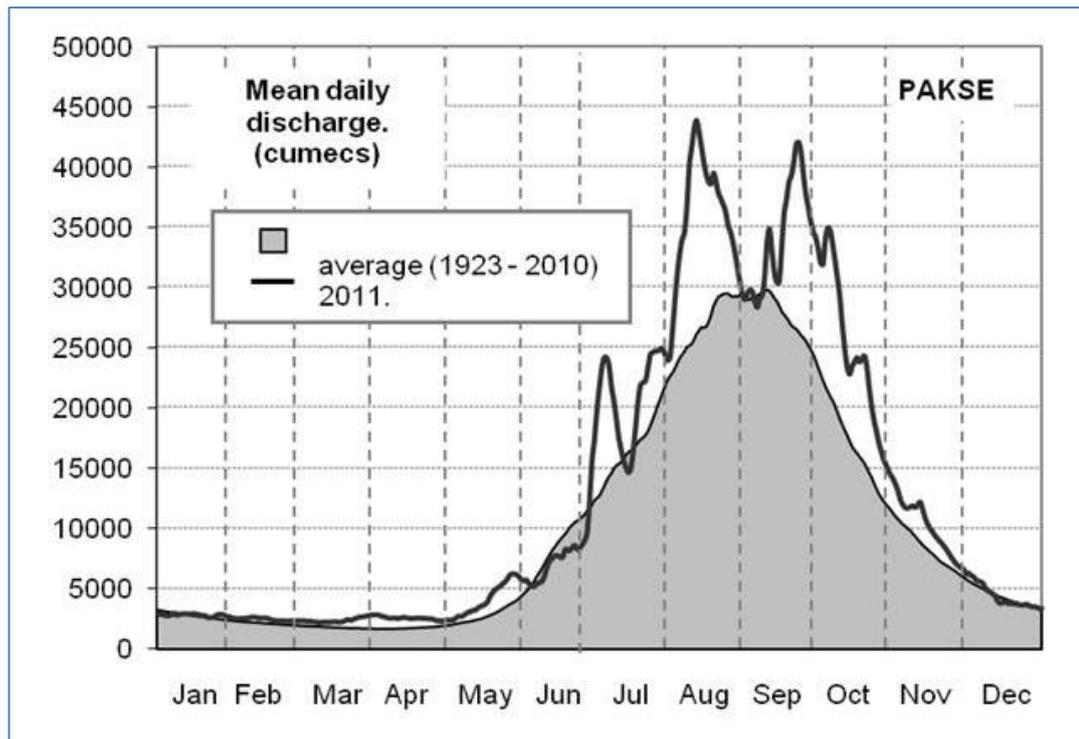
Figure 2-35   The 2011 daily discharge hydrograph at Pakse.

The hydrograph at Pakse for the year (above), which reflects the features of those elsewhere on the Mekong mainstream, indicates two significant peaks in mid August and at the end of September. Neither of these corresponds to the timing of the passage of HAIMA or NOCK-TEN, although the second peak during late September is possibly associated with tropical storm HAITANG. Therefore, although flood conditions during 2011 were significant to extreme, particularly in the more southern parts of the Lower Basin, they appear to have been as much the consequence of a strong monsoon rather than being exclusively linked to intense tropical storm systems.

The situation that developed during the course of the **2012** season defined hydrological conditions on the Mekong that were "extreme' in so far as they were critically below average. No significant tropical low pressure systems passed into the region during the year beyond some weaker cells that affected the coastal regions of Viet Nam. These were principally associated with strong winds rather than with flood generating storm rainfall extremes.
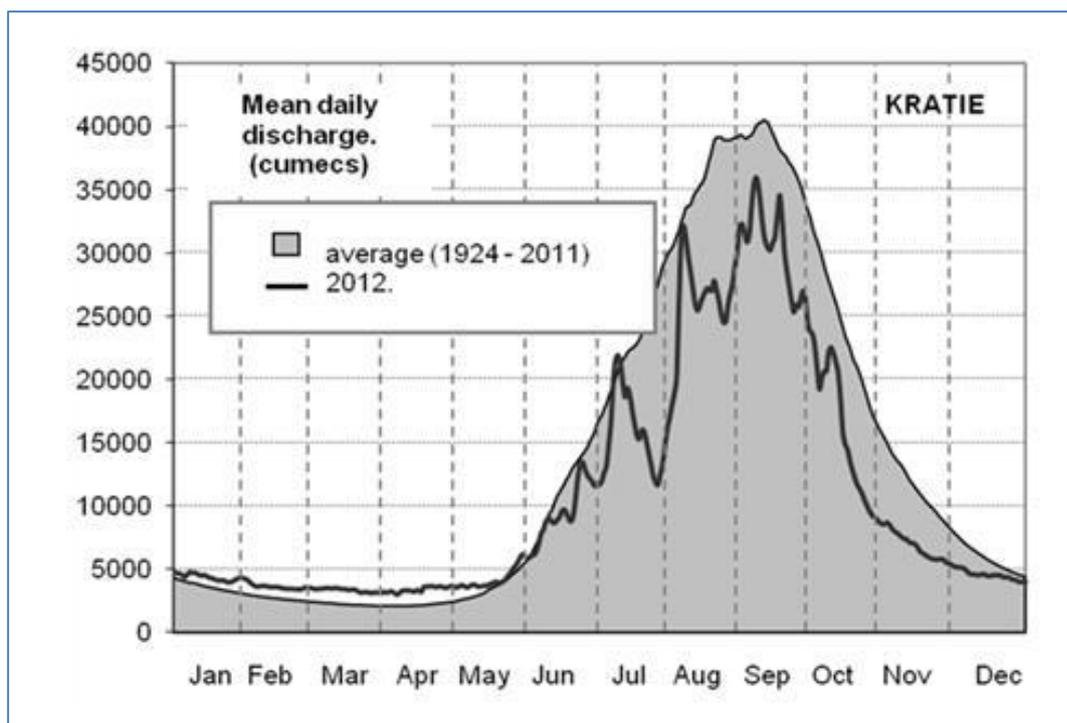
Figure 2-36   The 2012 daily discharge hydrograph at Kratie.

2.8   The typhoon as a PMP prototype

Typhoons and severe tropical low pressure systems are the most important source of severe storm rainfall with several days duration in the Lower Mekong region. By and large there are several incursions in every year. Their frequency and intensity is independent of the strength of the SW Monsoon. They can, for example, affect the Basin even when the monsoon is weak. In their genesis areas in the NW Pacific and East Sea (refer to Figure 2-12) systems can form in close succession such that it is not uncommon for one such storm to be followed by another in just a matter of a few days. This for example, occurred during August 2013 when two tropical storms and a tropical depression passed across the Basin (see Table 4-1).

Such storm sequences, particularly if they are associated with a strong monsoon, are not only relevant to the assessment and forecasting of potential flood conditions and the provision of timely warnings. They are also potentially the source of storm rainfalls close to the potential upper limit of short duration storm rainfall in meteorological terms. This latter figure is referred to as the Probable Maximum Precipitation (PMP). One of the major applications of PMP figures is with regard to the estimation of the Probable Maximum Flood (PMF). This is often the standard to which spillway discharge capacity on large dams is designed in order to achieve operational safety. The assessment of typhoon risk therefore extends beyond the purely hydro-meteorological into the fields of civil and hydraulic engineering.
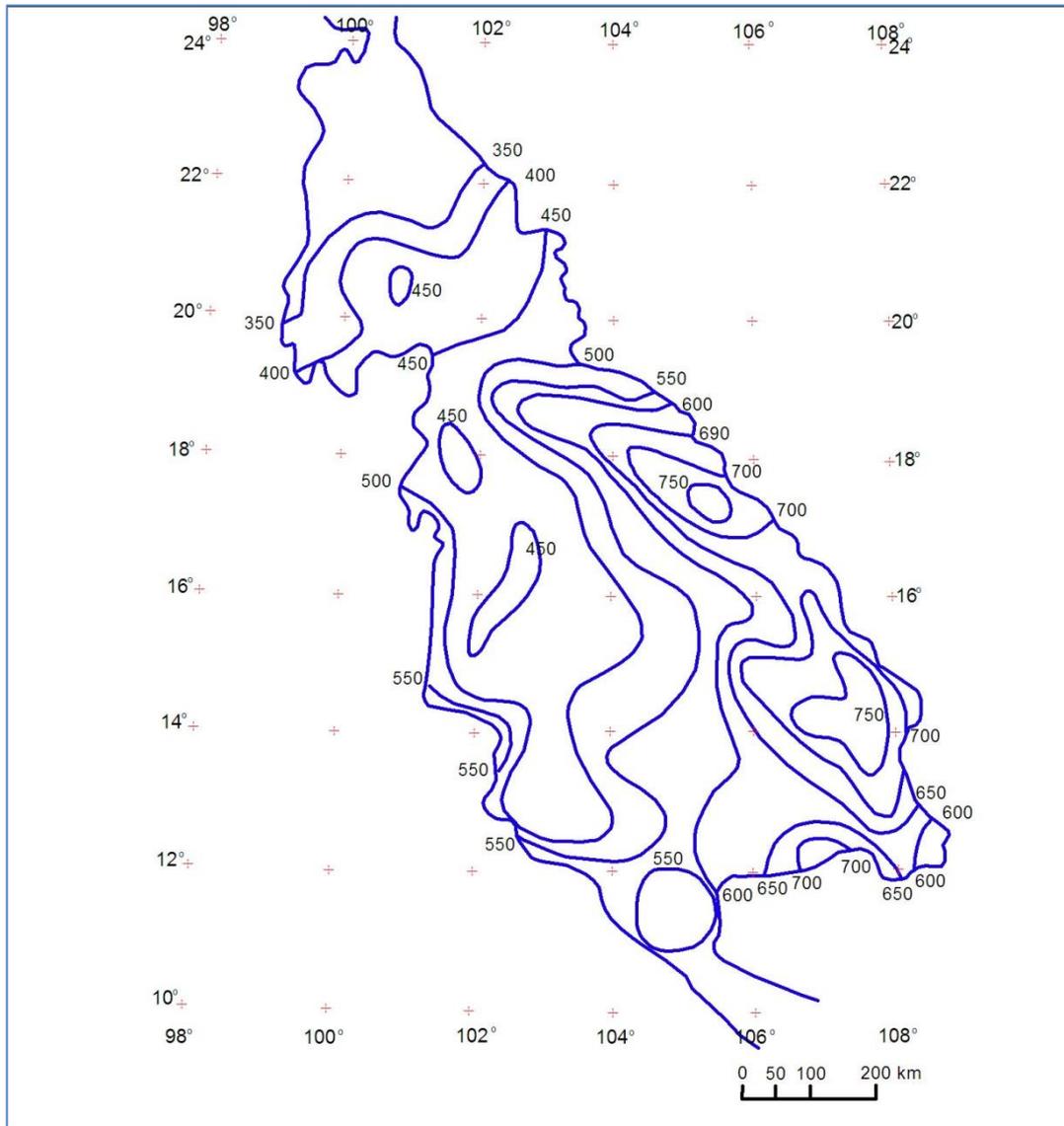
Figure 2-37   Lower Mekong Basin - Twenty four hour Probable Maximum Precipitation (PMP) over areas of 50 000 km². (Source WMO, 2009).

A detailed study of the potential magnitude of PMP across the Lower Mekong Basin is contained within the WMO, 2009, Report. The definitive map is of the geographical distribution of the estimated 24 hour PMP over areas of 50 000 km² (Figure 2-37). Factors taken into account included the distance inland from the Vietnamese coastline, moisture source, latitude, moisture inflow barriers and basin topography. A complimentary map indicating 24 hour PMP over areas greater than 5 000 km² was also prepared and this is presented here as Figure 2-38.
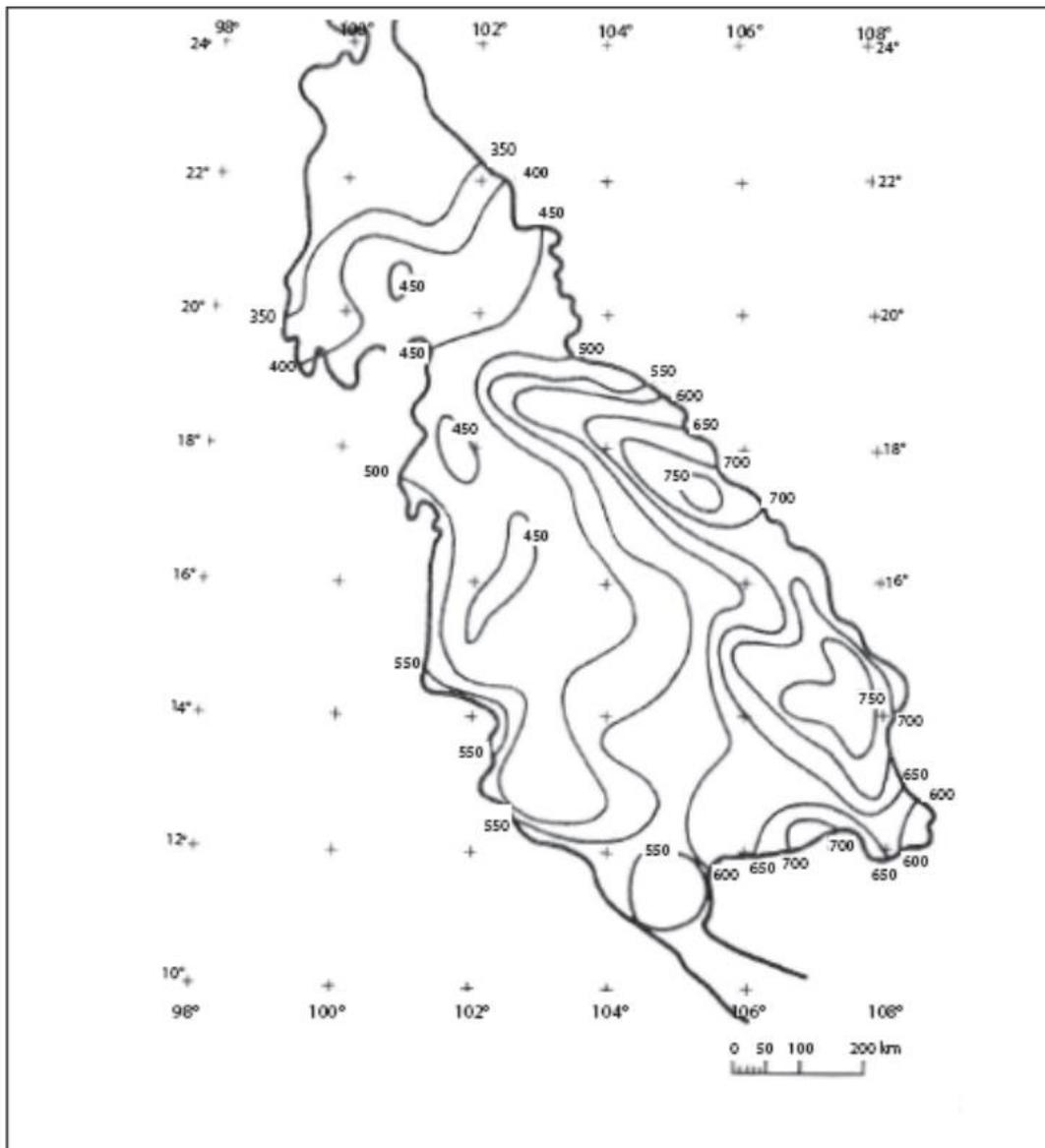
Figure 2-38   Lower Mekong Basin - Twenty four hour Probable Maximum Precipitation (PMP)
over areas of 5 000 km^2. (Source WMO, 2009).

Such depths of storm rainfall could only practically be caused by typhoons and very intense tropical low pressure systems, the maps being useful in prescribing the practical meteorological upper limits of short duration precipitation. Regional studies of the relationship between PMP and the 100 year 24 hour rainfall (US Corps of Engineers, 1970) indicate that the ratios range from 0.23 to 0.54 and average 0.36. For 3 days the ratios vary between 0.23 and 0.69 and average 0.43. Larger ratios generally occur near to up-slope areas with lower figures in lowland and flatter areas, In order to compare these upper envelope PMP estimates with observed "period of record" historical storm rainfall maxima, the latter were collected from 400 rain gauge locations within the Lower Mekong region and assessed in terms of their frequency distribution. By far the greater proportion of these would have been

associated with typhoons and severe tropical storms. The sample percentage frequency histogrammes for 1 and three days are shown in Figure 2-39.

- Both sample distributions are highly skewed to the right such that the Normal model is not an appropriate approximating distribution.
- Modal values (the most frequent) for the one day storms lie between 140 and 160 mm and for three days between 200 and 250 mm.
- The histogrammes are complimented by the box-plots shown in Figure 2-40. These indicate that 50% of one day storms lie between 125 and 200 mm (the upper and low 4ths or quartiles indicate the range of the central 50% of the data) and that 50% of the 3 days storms fall between 180 and 310 mm.
- The observed maxima are 555 and 1070 mm respectively. The latter figure was observed at a site in the highlands of Vietnam and would, if confirmed, be quite close to the Probable Maximum 3 day point rainfall.

An alternative way of looking at extreme rainfalls at a point is to consider the Lower Mekong Basin as a whole and then to find the maximum rainfall that occurred within the whole region in each year for which data are available. A regional probability analysis could then be undertaken to estimate the risk that at least at one point rainfall above a particular threshold would occur. This is arguably a more meaningful statistical approach to assess the risk and severity of extreme regional storms and consequent floods.

Care has to be taken with this type of analysis since the number of operational rain gauges amongst which the regional maximum storm rainfall during each year is established increases over time. Consequently, the sample space increases geographically and therefore the likelihood of detecting more extreme events is sequentially enhanced. This is the case here.

The temporal distribution of gauges available to the analysis is shown in Figure 2-41. This increases systematically from 1920 onwards, until around 1980 when the regional network reached its current density. The decrease from 2006 onwards merely reflects the last year that some records have been incorporated into the database and not a reduction in the network coverage.

The impacts of this evolution in network coverage are clear from Figure 2-42. More intense storms are identified as time progresses. In earlier years the much more sparse network coverage would have been unable to detect them.

In effect the network only reached its present coverage from 1980 onwards, after which time the average annual maximum one and three day storm rainfalls observed at any site in the Lower Basin was 370 and 570 mm respectively. It is interesting to compare the distribution of the regional maximum point storm risk (Table 2-8) with

the WMO estimates of PMP over 5 000 and 50 000 km^2 illustrated in Figure 2-37 and 2-38. The latter figures are subject to the application of an Areal Reduction Factor (ARF) which reduces the point figure to that applicable over a larger area. The adjustments vary but for tropical regions the WMO suggest a factor of 70% for areas of 5 000 km^2 and less than 50% for areas of 50 000 km^2. The historical evidence tends to suggest that occasionally typhoon induced regional storm rainfall has been quite close to the possible Probable Maximum.
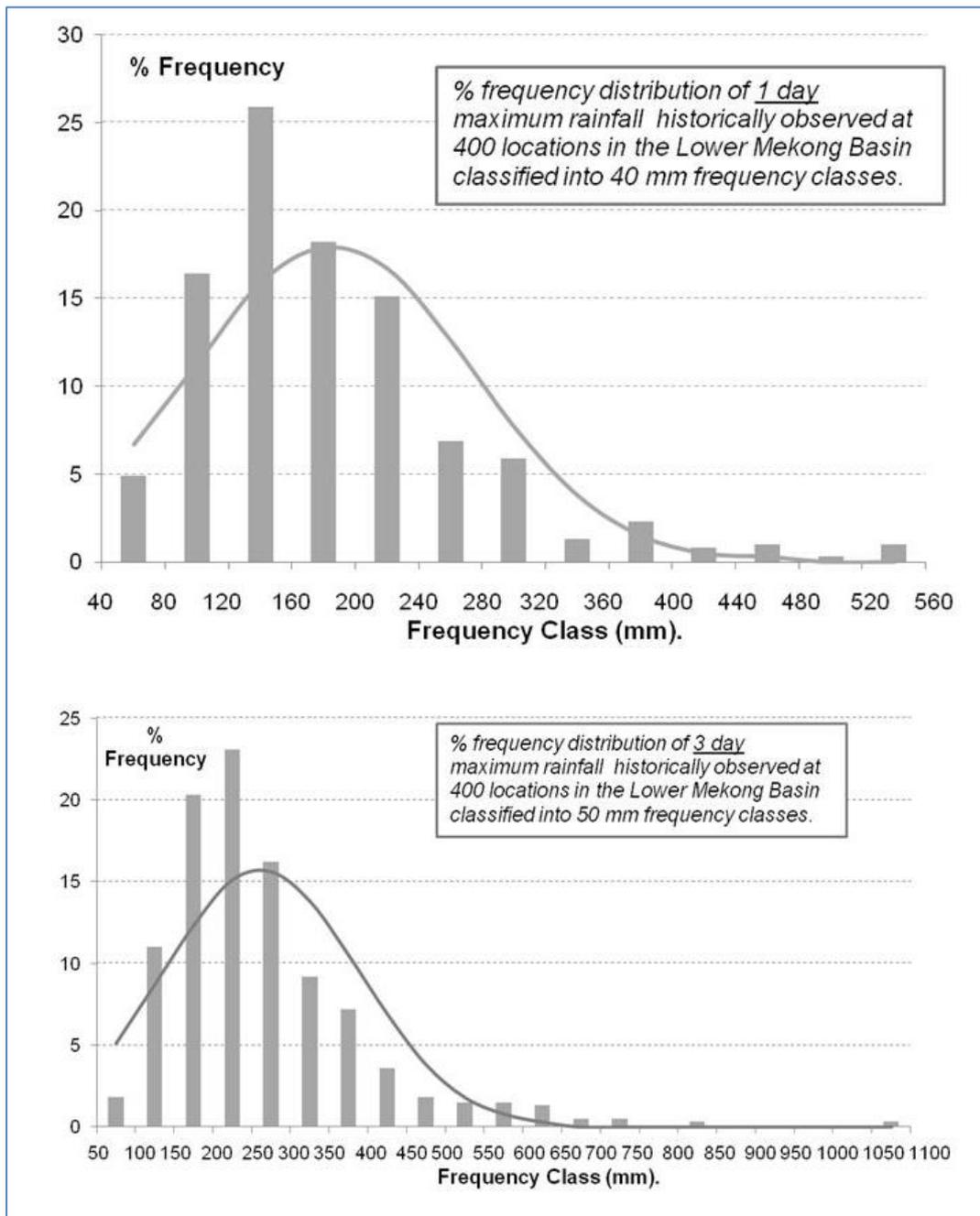
Figure 2-39   The percentage frequency distribution of 1 and 3 day maximum rainfall historically observed at 400 locations in the Lower Mekong Basin classified into frequency classes. The smooth function is the approximating Normal distribution.
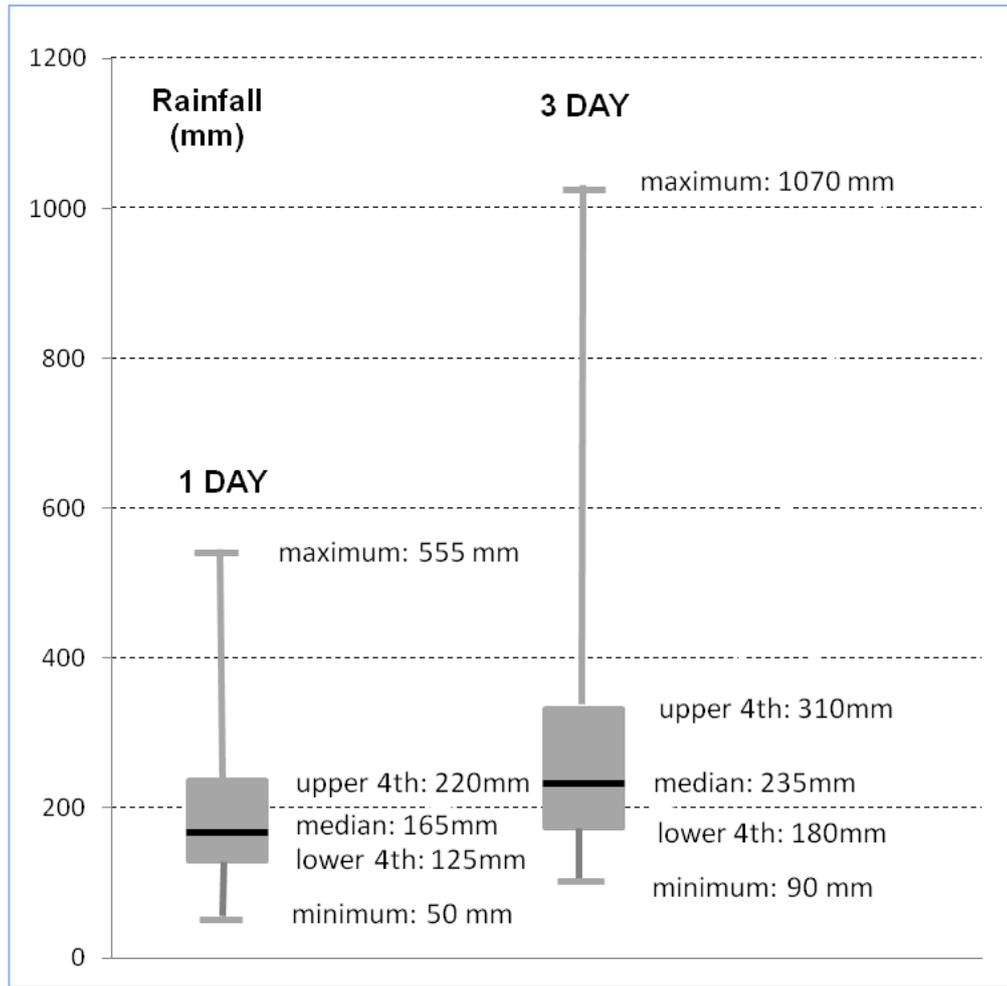
Figure 2-40   Summary Boxplots of the sample distribution of the historically observed maximum
                1 and 3 days rainfalls at 400 sites in the Lower Mekong Basin.
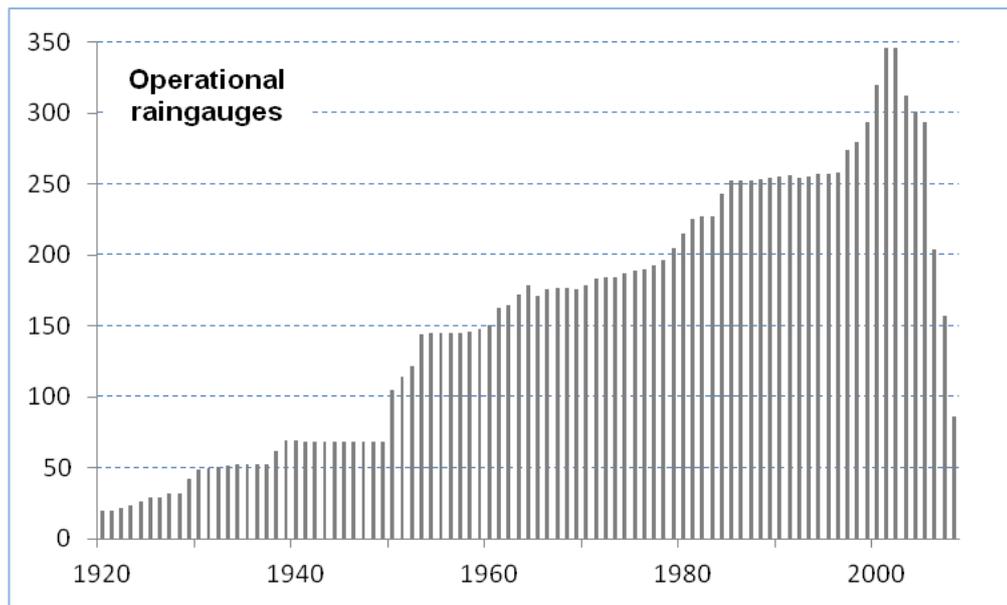
Figure 2-41   The number of operational rain gauges available to the basin wide analysis, 1920 to
                2008.
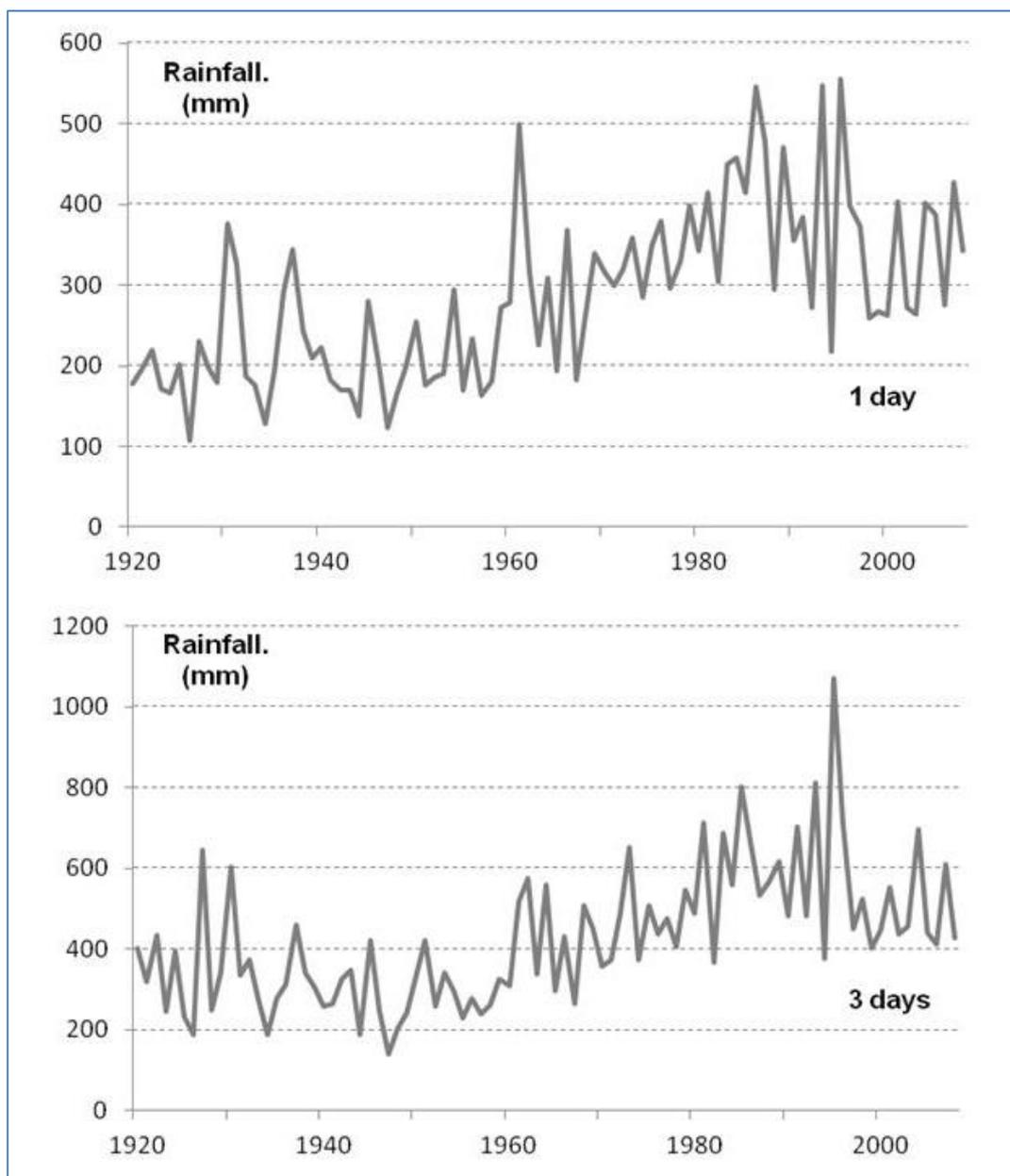
Figure 2-42   The annual maximum one and three day storm rainfalls recorded anywhere within the Lower Mekong Basin (1920 to 2008). The increasing trend is simply a reflection of the number of operational rain gauges available over the years and is not indicative that the magnitude of the regional maximum storm rainfall has increased over time

Table 2-8   One and three day distribution of storm risk in the Lower Mekong Basin, indicating the maximum point rainfall (mm) that might be expected to be observed anywhere in the region.

Duration	Recurrence interval (years)						
days	2	5	10	20	50	100	200
1	360	450	500	560	640	690	750
3	540	680	780	870	990	1 080	1 170

2.9 Has the regional incidence of storm days increased in recent years?

Significant daily storm rainfall depths are usually the result of more intense monsoonal conditions and tropical low pressure systems such as deep depressions and typhoons. The number of such "storm days" during the season appears to be reasonably consistent throughout most of the region, although upland and highland areas no doubt indicate a higher count.

If we arbitrarily define a "storm day" as one upon which more than 25 mm of rainfall is recorded, a "significant storm day" as one upon which more than 50 mm occurs and an "extreme storm day" as one upon which more than 75 mm occurs, then the average annual count is between 20 and 25, less than 10 and less than 5 respectively (Table 2-7).

Table 2-9   The mean annual number of storms days (>25mm), significant storm days (>50mm) and extreme storm days (>75mm) at Vientiane (1949 to 2013) and Pakse (1961 to 2013).

Location	Mean annual number of storm days		
	>25mm	>50mm	>75mm
Vientiane	22	7	2
Pakse	26	9	4

The question arises as to whether the incidence of such events has systematically increased over time as a consequence of climate change. The results in Figure 2-43 and Figure 2-44 indicate that there is no evidence to suggest any long term change, at least so far as the data at Vientiane and Pakse are concerned.

Such assessments are important, and obviously need to be expanded, since the case is usually made that climate change will lead towards an increase in the frequency and intensity of "storm days" and that short and long term weather conditions will become more variable. The vast majority of climate change studies that have been undertaken, including those carried out within the Mekong Region, have tended to deal more or less exclusively with changes to mean annual and monthly rainfall. Its pattern in terms of storm frequency and the potential impacts upon the onset, end and intensity of the SW Monsoon remain in the realm of qualitative conjecture. Yet it is these aspects that are the major influence upon the hydrological response to potential climate change, rather than seasonal changes to average rainfall.
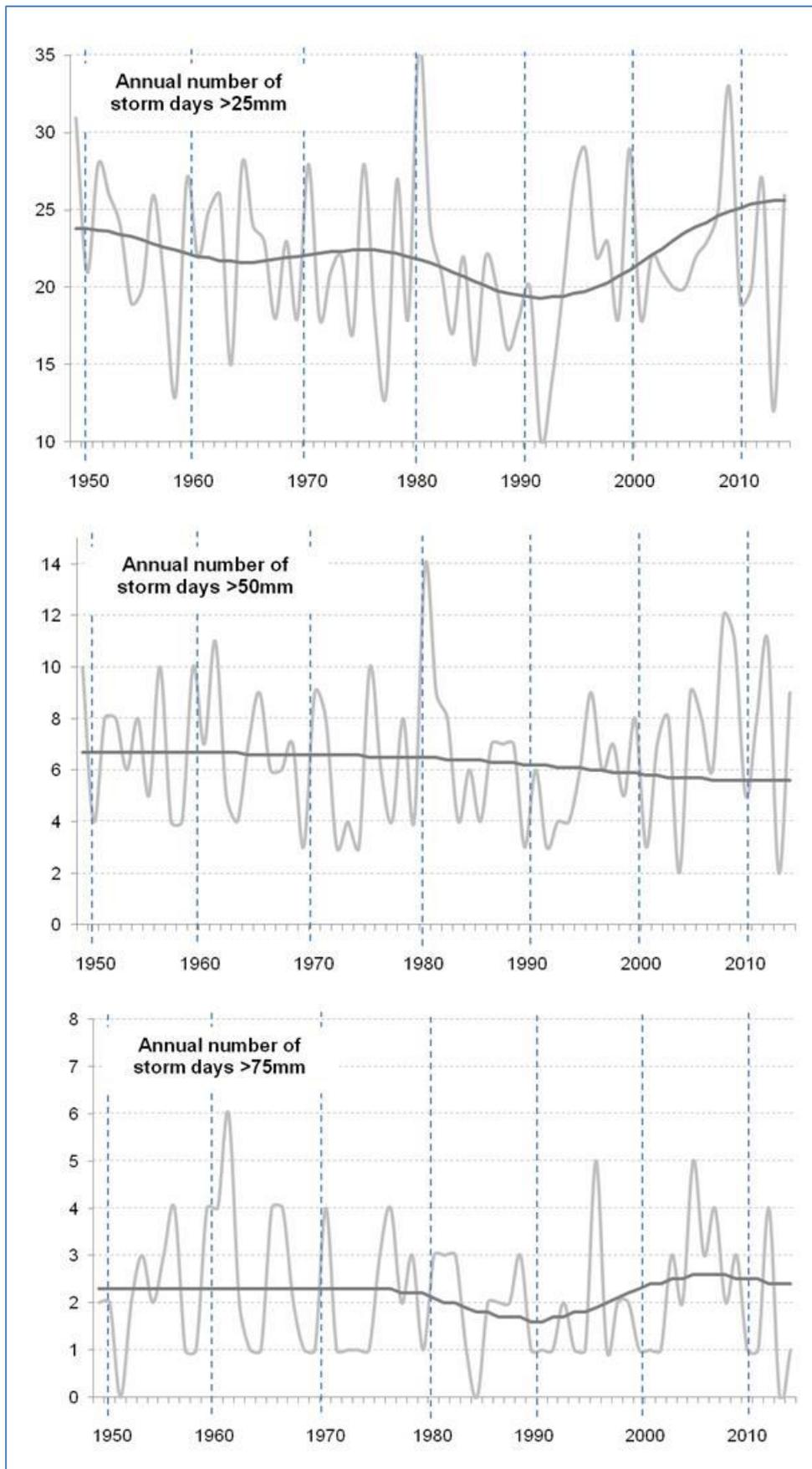
Figure 2-43   Vientiane – Annual number of storm days >25mm. >50mm and >75mm with embedded trend, 1949 to 2013.
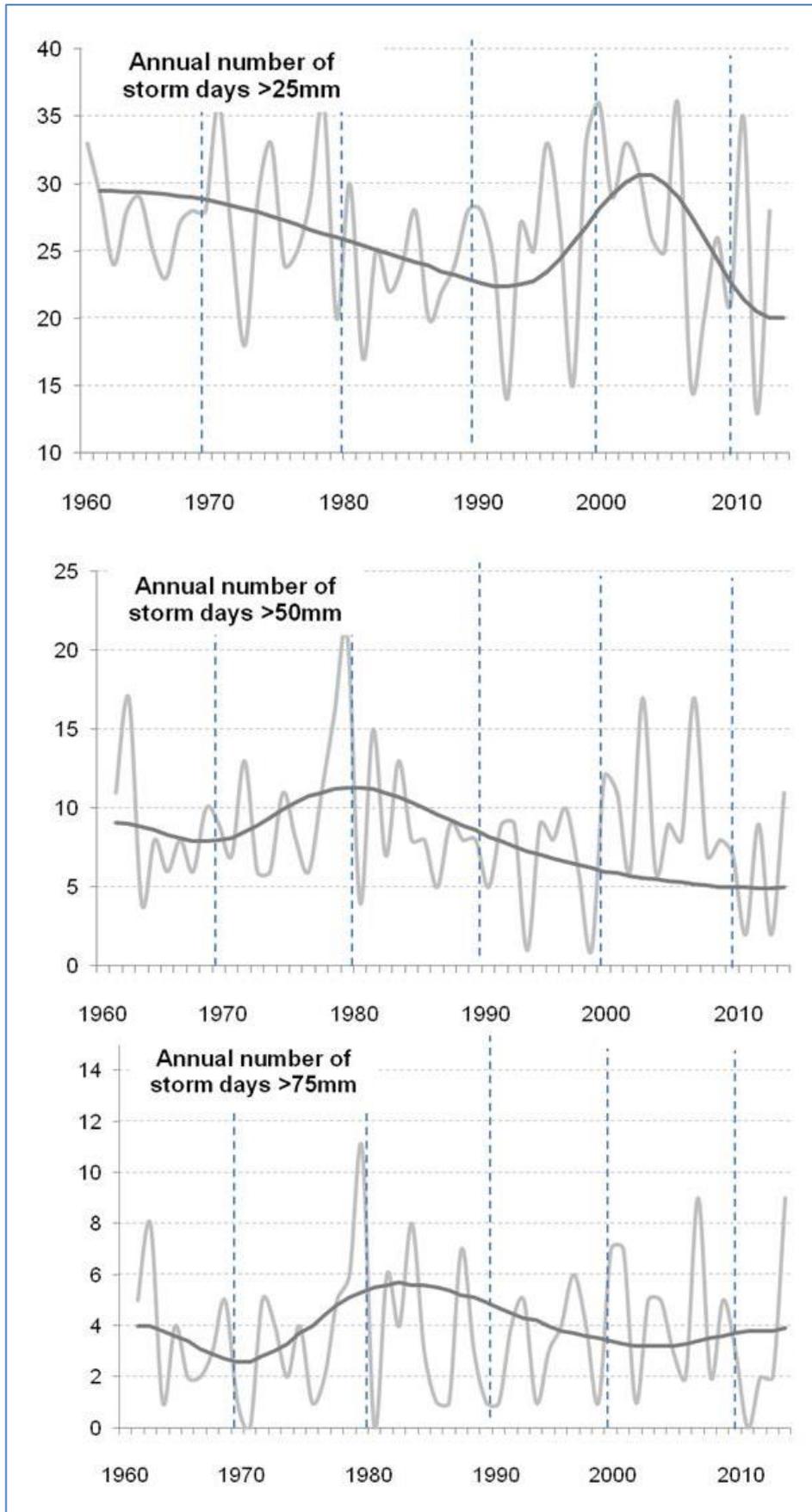
Figure 2-44   Pakse – Annual number of storm days >25mm. >50mm and >75mm with embedded trend, 1961 to 2013.

2.10   Storm surge

Storm surge is a recurrent issue in the coastal regions of the Mekong Delta and associated with tropical storms and typhoons. Green and Benn (undated) identified two different types of storm surge affecting water levels in the region. Firstly, typhoon activity, such as from Typhoon LINDA in 1997, causes increased water levels for short periods of time of several hours often primarily impacting at only one or two gauge sites. For this type of 'classic surge' analysis suggested that the speed of movement of the typhoon was most critical as opposed to wind speed or storm category. Sustained high winds from the north cause the second type of storm surge, of lower intensity 'surge' that can last for up to a week.

Nobuoka et al (2013) undertook a hydrodynamic model study of existing storm surge impacts across the Delta and those that would follow a 1m rise in sea level. Their principal results are shown in Figure 2-45 and Figure 2-46.
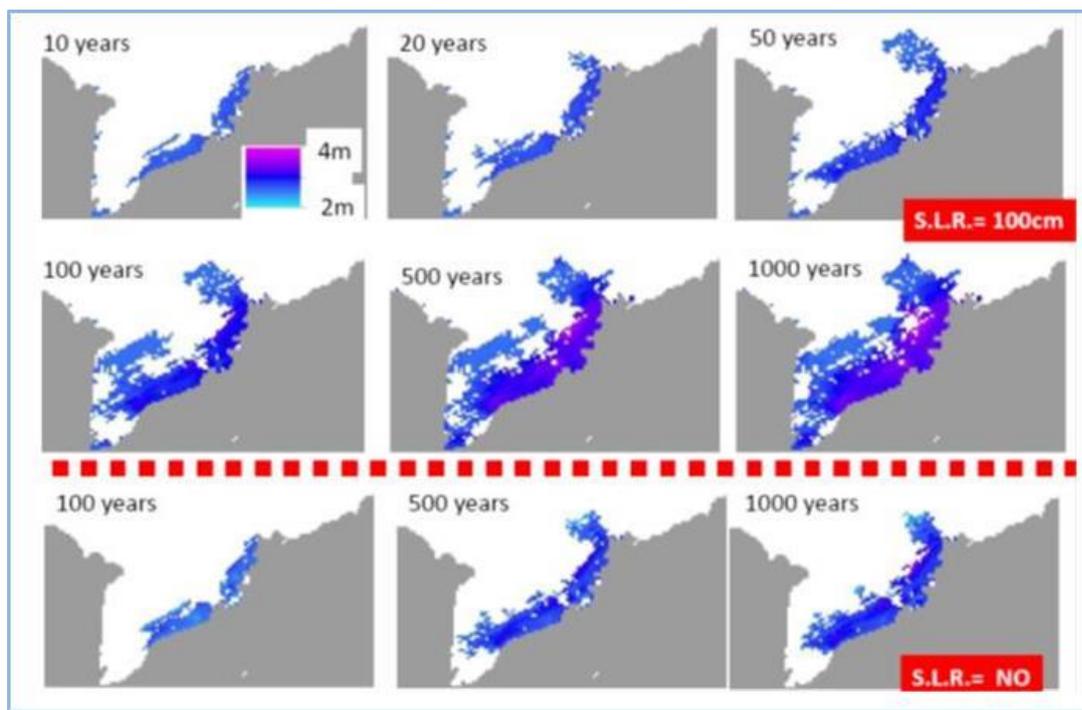
Figure 2-45   The geographical extent and depth of storm surge inundation across the Mekong Delta at selected risks of occurrence, with and without a 1m rise in seal level.
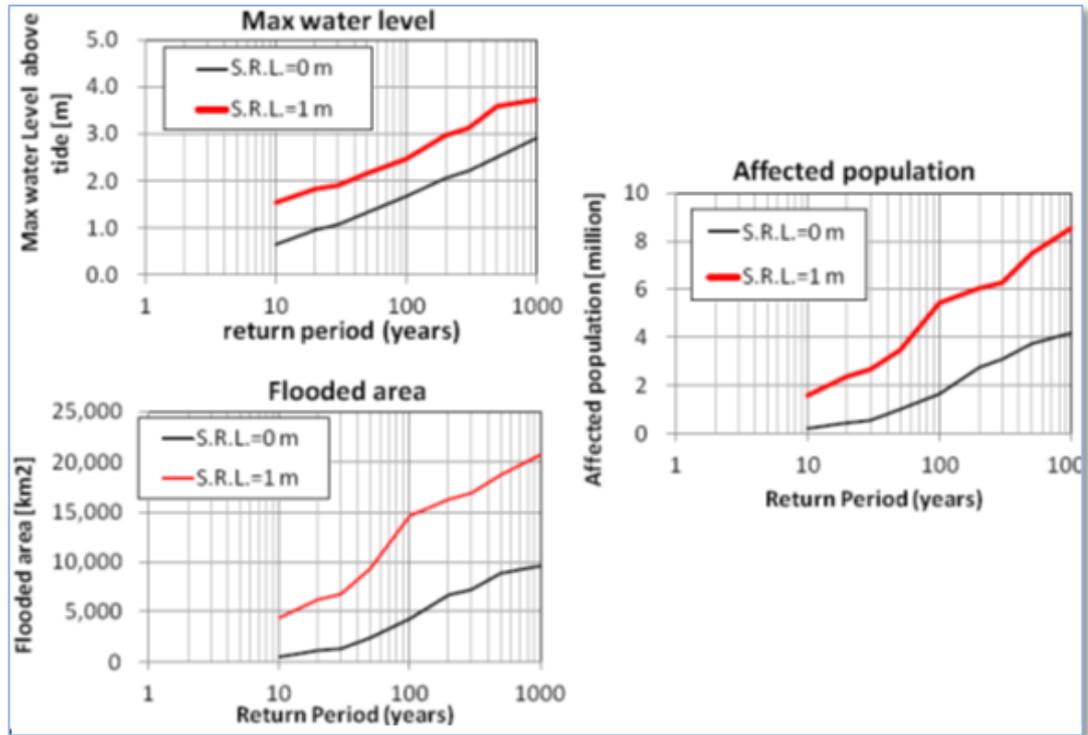
Figure 2-46   Maximum water level, flooded area and the affected population resulting from storm surges at selected levels of probability across the Mekong Delta, given no increase and a 1m rise in mean sea level.

The estimated potential consequences of a 1m rise in mean sea level are severe.

- The geographical extent of storm surge inudation increses dramatically. In effect it increases by a factor of two.
- The maximum water levels also double.
- Most significantly the population that becomes potentially vulnerable increases two fold.

These results underscore the vulnerability of the Delta to rising sea levels. The problems are aggravated by the fact that the topography is in fact sinking due to a number of factors, but primarily as a result of the over abstraction of ground water and accelerated compaction due to development (Woodroffe et al, 2006).

3.   THE REGIONAL FLOOD SITUATION, 2013

3.1   The regional rainfall climate during 2013

Amongst the principal issues that need to be addressed with regard to the hydro-meteorological data base within the Lower Mekong Basin is to establish an improved daily rainfall catalog. By any comparable standard the regional hydro-met network is impressive, arguably much superior to those in any international river basin of comparable size. In common with those elsewhere, however, the network is geographically concentrated within low lying areas. Systematic observations within the more remote upland and mountainous zones, where most of the river runoff is generated, are limited for obvious reasons. This fact though, potentially inhibits the development of predictive rainfall / runoff models, not least in the context of flood forecasting. The obvious recourse, which has been pursued by the MRC, is to combine the ground data with satellite based estimates in order to achieve a detailed mapping of storm rainfall.

During 2013 regional rainfall over the monsoon season was very much of an average order, as the data at the selected sites in Table 3-1 confirm. It was also the case that the onset of the SW Monsoon occurred generally during the first week of May, which is the long term norm. The end or withdrawal of the monsoon usually occurs during November October. However, during the year the monsoonal retreat was somewhat later towards the northern and southern parts of the Basin and did not take place until the middle of December (Table 3-2). An interesting observation is that that long term average onset date is remarkably consistent right across the region which points towards the fact that the transition to the summer atmospheric circulation is large scale and its timing consistent geographically. The average end date of the monsoon rains is rather more variable from place to place. This tends to arise due to localized end of season convectional storms which can occur later in the year.

The map of total seasonal rainfall during the course of 2013 (Figure 3-1) more or less exactly replicates the depth and geographical distribution of long term mean annual rainfall, thus confirming that the regional rainfall climate was very close to average throughout the Lower Mekong Basin, with the exception of the Delta where it was significantly below average. This latter point is confirmed in Figure 3-3 where the accumulated figure for the year at Tan Chau was 900 mm, compared to the long term mean figure of 1,150 mm.

Six tropical storms and tropical depressions affected the lower Basin during 2013:

- Tropical storm JEBI during the first week of August.
- Tropical storm MANGKHUT, which followed days later on the 8th – 9th August.
- A tropical depression on the 19th – 20th August.
- A tropical depression on the 17th – 19th September.
- Tropical storm WUTIP on the 30th September – 1st October.
- Tropical storm NARI on the 16th October.

These tropical low pressure systems and their impacts are considered in detail in Section 4.

Table 3-1   Annual rainfall during 2013 compared to the long term average at selected sites in the Lower Mekong region.

Location	Annual rainfall (mm)		
	Average	2013	2013 as % long term average
Chiang Saen	1 710	1 720	101
Luang Prabang	1 280	1 650	122
Vientiane	1 650	1 580	96
Mukdahan	1 505	1 600	106
Pakse	2 010	2 110	105
Tan Chau	1 160	900	77

Table 3-2   Onset and end dates of the SW Monsoon during 2013 compared to the long term average at selected sites in the Lower Mekong region.

Site	Monsoon onset				Monsoon end		
	Average Date	Standard Deviation	2013	Delay (days)	Average Date	Standard Deviation	2013
Chiang Saen	7th May	9 days	3rd May	none	7th Nov	25 days	16th Dec
Luang Prabang	7th May	9 days	27th Apr	none	24th Oct	33 days	16th Dec
Vientiane	4th May	8 days	2nd May	none	10th Oct	16 days	17th Oct
Mukdahan	6th May	8 days	1st May	none	8th Oct	16 days	16th Oct
Pakse	5th May	11 days	2nd May	none	15th Oct	17 days	17th Dec
Tan Chau	18th May	12 days	16th June	28 days	18th Nov	13 days	17th Dec
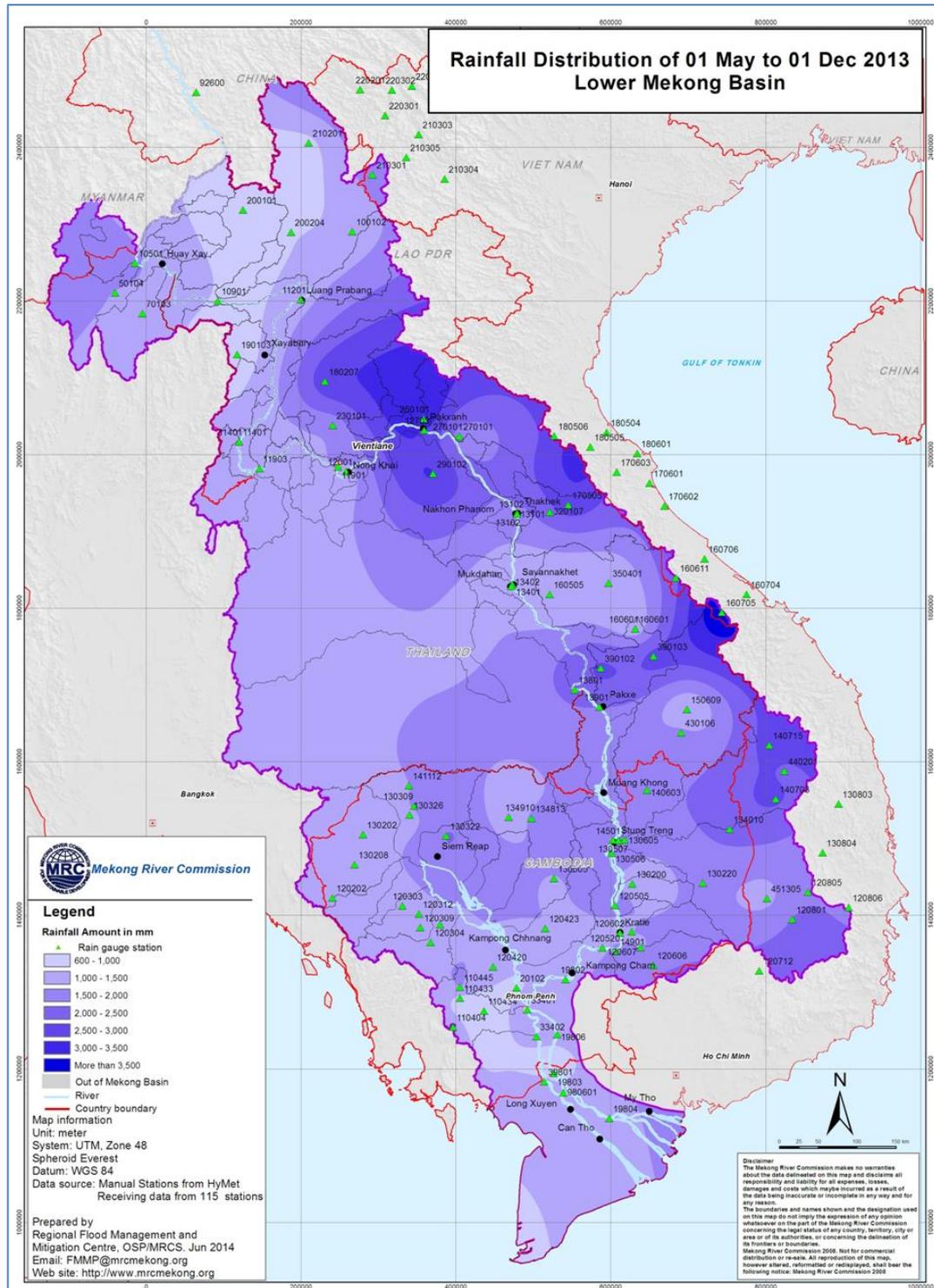
Figure 3-1   Rainfall across the Lower Mekong Basin during the 2013 wet season.
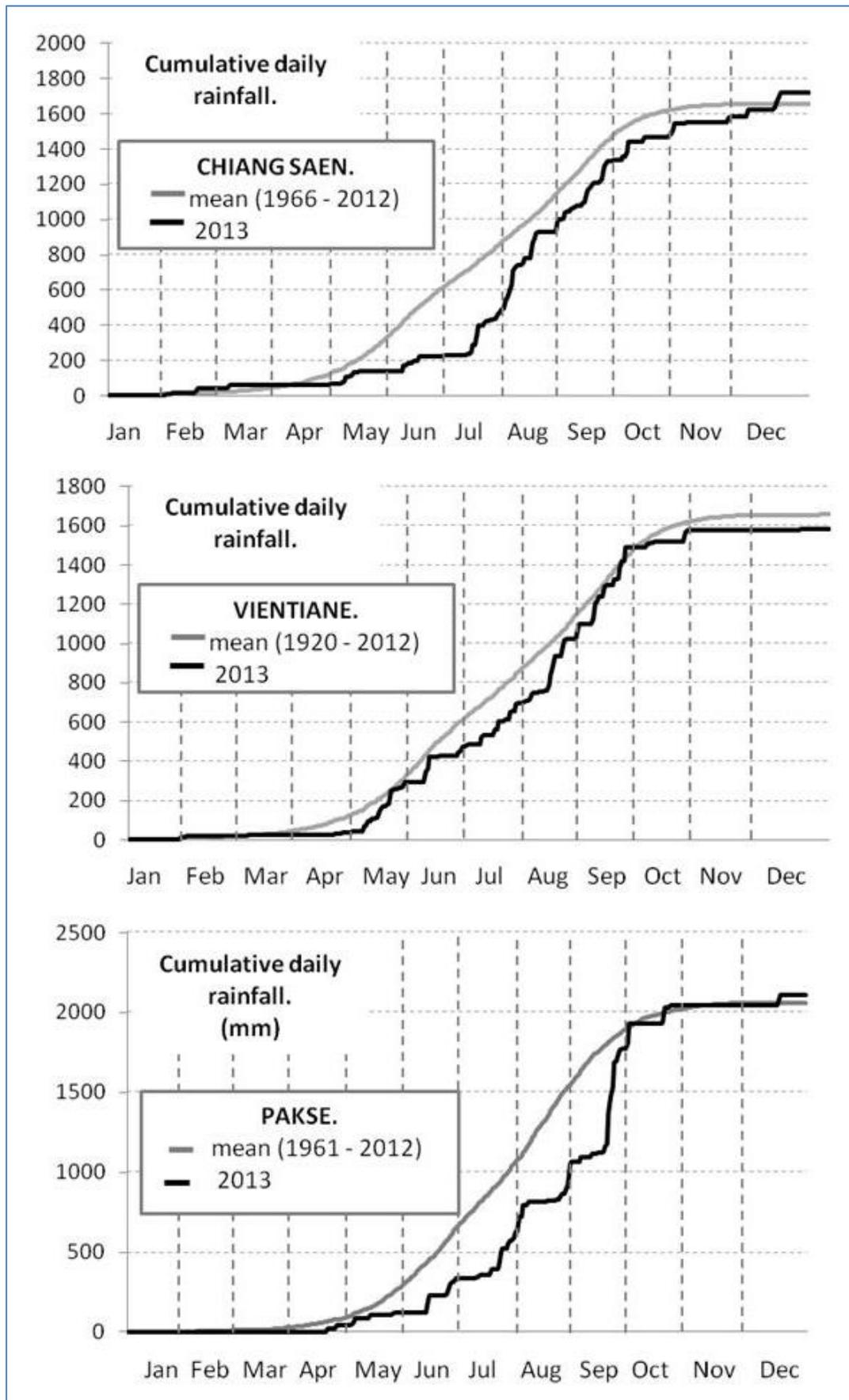
Figure 3-2   Chiang Saen, Vientiane and Pakse – cumulative daily rainfall pattern during 2013.
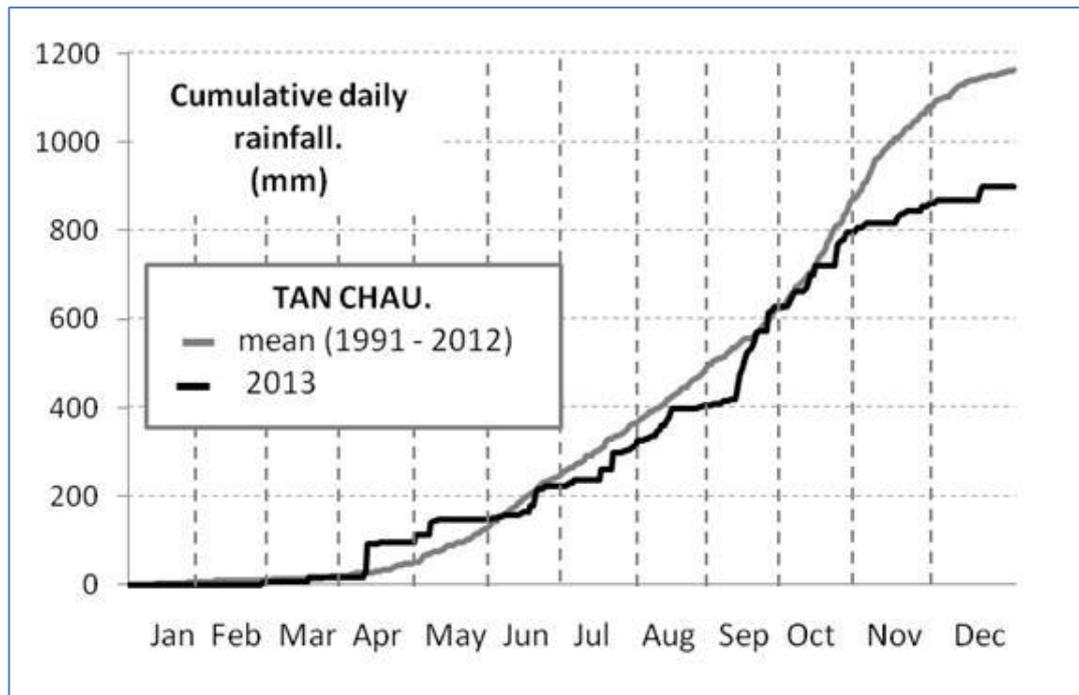
Figure 3-3   Tan Chau – cumulative daily rainfall pattern during 2013.

3.2   The flood hydrology of 2013

Reflecting the geography of the seasonal rainfall conditions during 2013 daily stream flows during the flood season across the Lower Basin varied between average to significantly below average. Peak discharge in the north, represented by Chiang Saen and Vientiane, were very much below normal. Further downstream at Krate conditions were much closer to the long term average (Table 3-3 to 3.5).

- At Chiang Saen the peak discharge was just 61% of the long term figure of 10 300 cumecs. The flood volume during the year amounted to just 49% of the 57 km^3 average. This is the second lowest flood volume that has been observed since records began in 1960. Only the flood of 1992, one of the most significant basin wide drought years, was the annual flood volume lower.

- At Vientiane the peak was 76% of the average of 16 600 cumecs and the volume 70% of the average figure of 101 km^3.

- At Kratie the annual peak matched the long term average of 50 900 cumecs exactly, though the volume was 12% below the average figure of 330 km^3.

Once again the geographical variability of flood conditions across the Lower Basin is clearly illustrated, with a commonly occurring distinction between those prevailing in the northern and southern parts. In recent years, for example, two such situations were particularly noteworthy. In 2008 the northern sector experienced one of the

largest floods on record, whereas towards the south at Kratie the annual flood was significantly below average. In 2011 the situation was reversed with the flood hydrology in the northern parts below normal but in the south severe flooding occurred.

The onset, end and duration of the flood season are important variables which are fairly consistent from year to year on the whole. Significant deviations though do periodically occur which can result in substantial socio-economic consequences. During 2013, however, these temporal aspects of the annual flood were well within the expected narrow range.

The daily discharge hydrographs at Chiang Saen, Vientiane, Pakse and Kratie for the year are illustrated in Figure 3-4 and Figure 3-5. These underscore the north/south distinction between below average and average, with conditions at Chiang Saen being particularly deficient. Here the "spike" in discharge in mid December is worthy of note, not least because it resulted in the maximum discharge over the year. Though rare such an unseasonal event is not unprecedented. Since the contribution to the mainstream flows between Manwan, the most downstream of the Yunnan reservoir cascade, and Chiang Saen is quite small it is likely that this "hydrological incident" was generated further upstream within the Upper Mekong and the flows would have been routed through the cascade of dams.

Figure 3-6 and Figure 3-7 place the flood conditions of 2013 within their full historical context. Those at Chiang Saen are identified as being historically extreme according to the proposed criteria. Meanwhile, those at Vientiane would be defined as significantly deficient. At Kratie, the flood both in terms of peak and volume was close to average overall.

Table 3-3   The Mekong River at Chiang Saen. Peak and volume of the 2013 flood season and the onset and end dates, compared to the long term average figures.

Mean annual discharge cumecs	2013 flood season				
	Peak discharge cumecs	Flood volume km^3	Start date	End date	Duration days
2 600	6 300	28.1	29th July	20th Dec	145
	Long term average (1960 – 2013)				
-	10 300	57.4	12th June	13th Nov	155

Table 3-4   The Mekong River at Vientiane. Peak and volume of the 2013 flood season and the onset and end dates, compared to the long term average figures.

Mean annual discharge cumecs	2013 flood season				
	Peak discharge cumecs	Flood volume km³	Start date	End date	Duration days
4 500	12 600	71.1	17th July	25th Dec	162
	Long term average (1913 – 2013)				
-	16 600	101.1	23rd June	10th Nov	142

Table 3-5   The Mekong River at Kratie. Peak and volume of the 2013 flood season and the onset and end dates, compared to the long term average figures.

Mean annual discharge cumecs	2013 flood season				
	Peak discharge cumecs	Flood volume km³	Start date	End date	Duration days
13 500	50 900	290.6	20th July	15th Nov	119
	Long term average (1924 – 2013)				
-	50 900	330.0	24th June	7th Nov	137
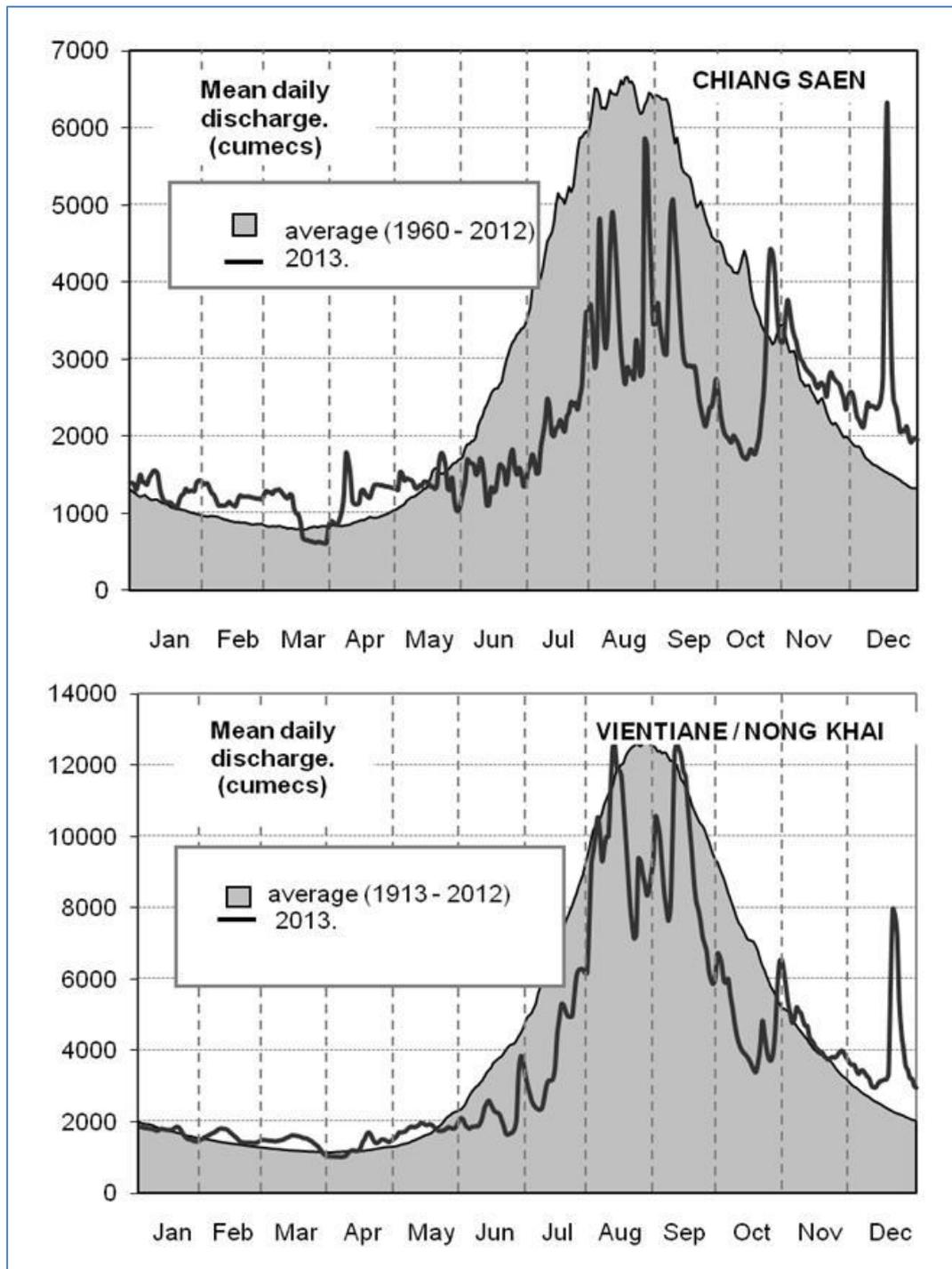
Figure 3-4   The 2013 annual hydrographs at Chiang Saen and at Vientiane / Nong Khai, compared to their long term average.
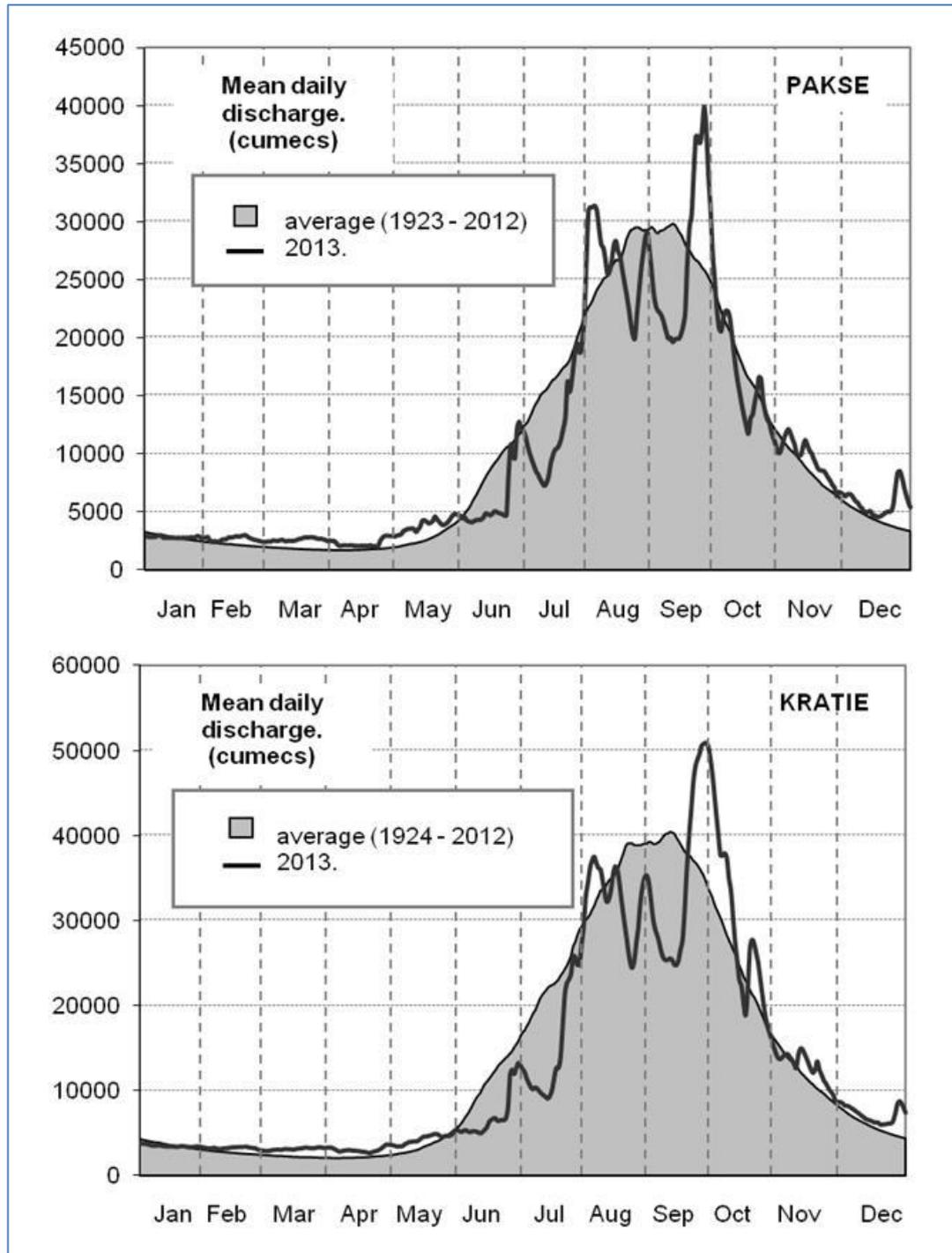
Figure 3-5   The 2013 annual hydrographs at Pakse and at Kratie compared to their long term average.
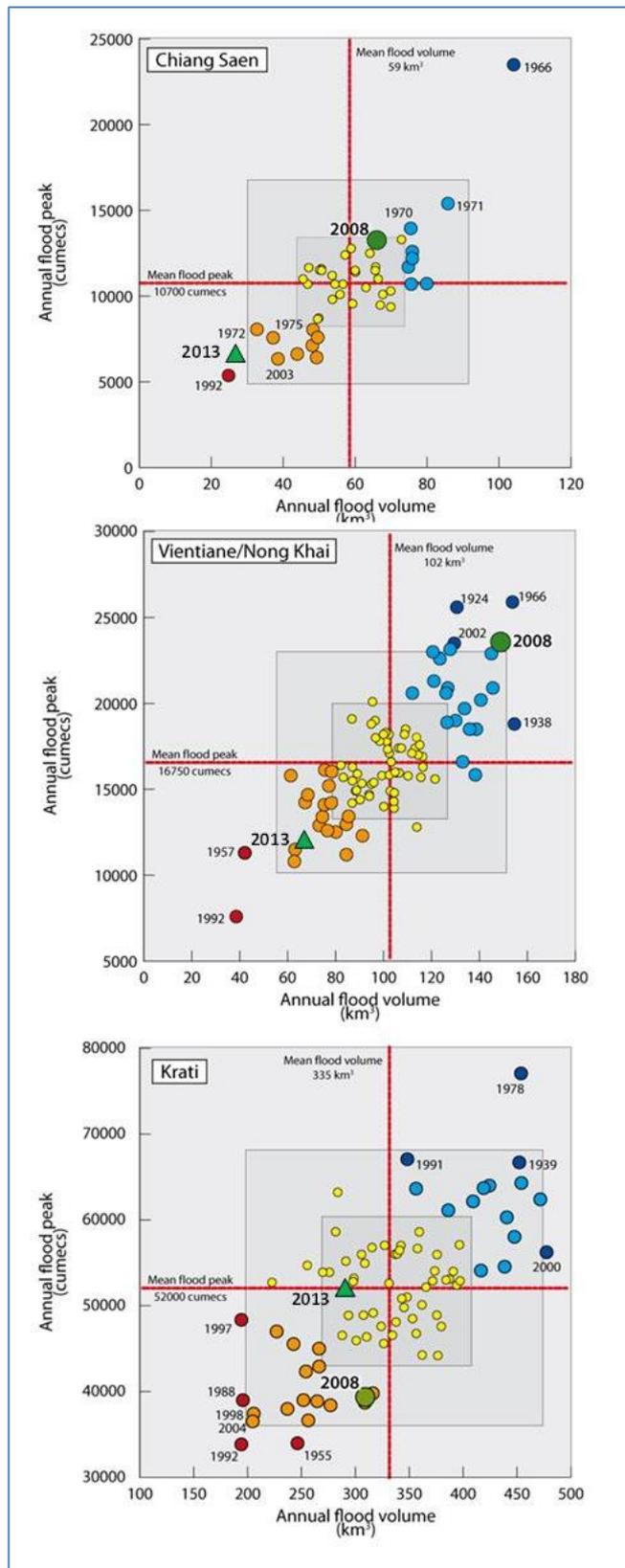
Figure 3-6   Scatterplots of the joint distribution of the annual maximum flood discharge (cumecs) and the volume of the annual flood hydrograph (km3) at selected sites on the Mekong mainstream. The 'boxes' indicate one (1δ) and two (2δ) standard deviations for each variable above and below their respective 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 3-7 places this bivariate relationship between flood peak and volume into a probabilistic framework. Selecting the Mekong at Kratie as indicative of hydrological conditions within the Lower Mekong Basin as a whole, then those of 2013 were fundamentally average, with a recurrence interval of about once in two years or a 50% exceedance probability.
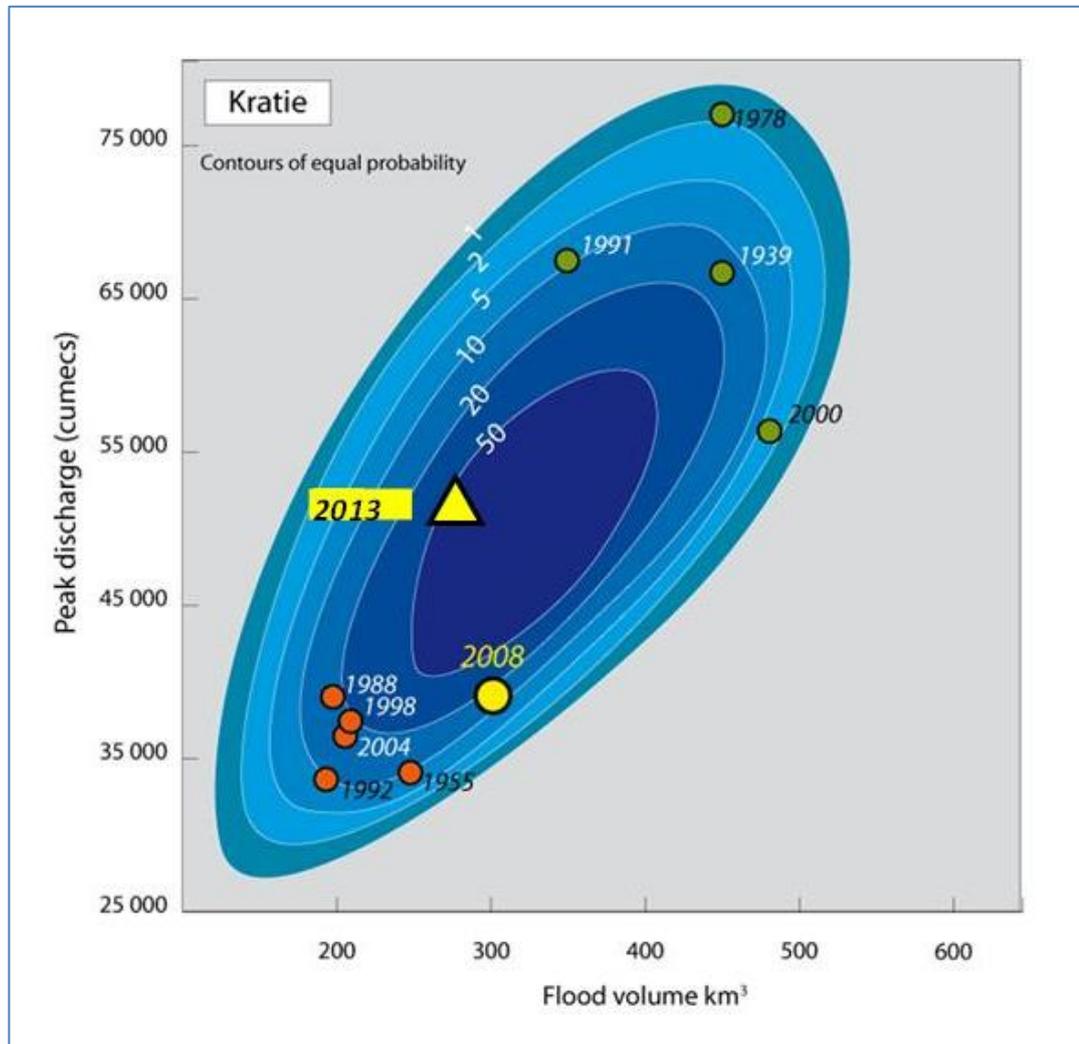
Figure 3-7   Mekong River at Kratie - the bi-variate distribution of annual flood peak and volume, 1924 to 2013. The estimated recurrence interval of the 2013 event in terms of the joint distribution of the two variables is 1 : 2 years.

3.3   Water levels across the Cambodian floodplain and the Delta in Viet Nam during 2013

Replicating the 2013 seasonal flow conditions at Kratie, water levels within the Cambodian flood plain and the Delta were quite close to their long term average, as Figure 3-7 and Figure 3-8 and Table 3-6 indicate. The variability of the annual maxima from year is quite narrow, in the sense that their standard deviation is

typically just 15% of the mean. Of course much wider deviations occur periodically which define significant to extreme hydrological circumstances, such as those of 2000, 2001 and 2011. Water levels during 2013 were, however, well within their "typical" inter-annual range.
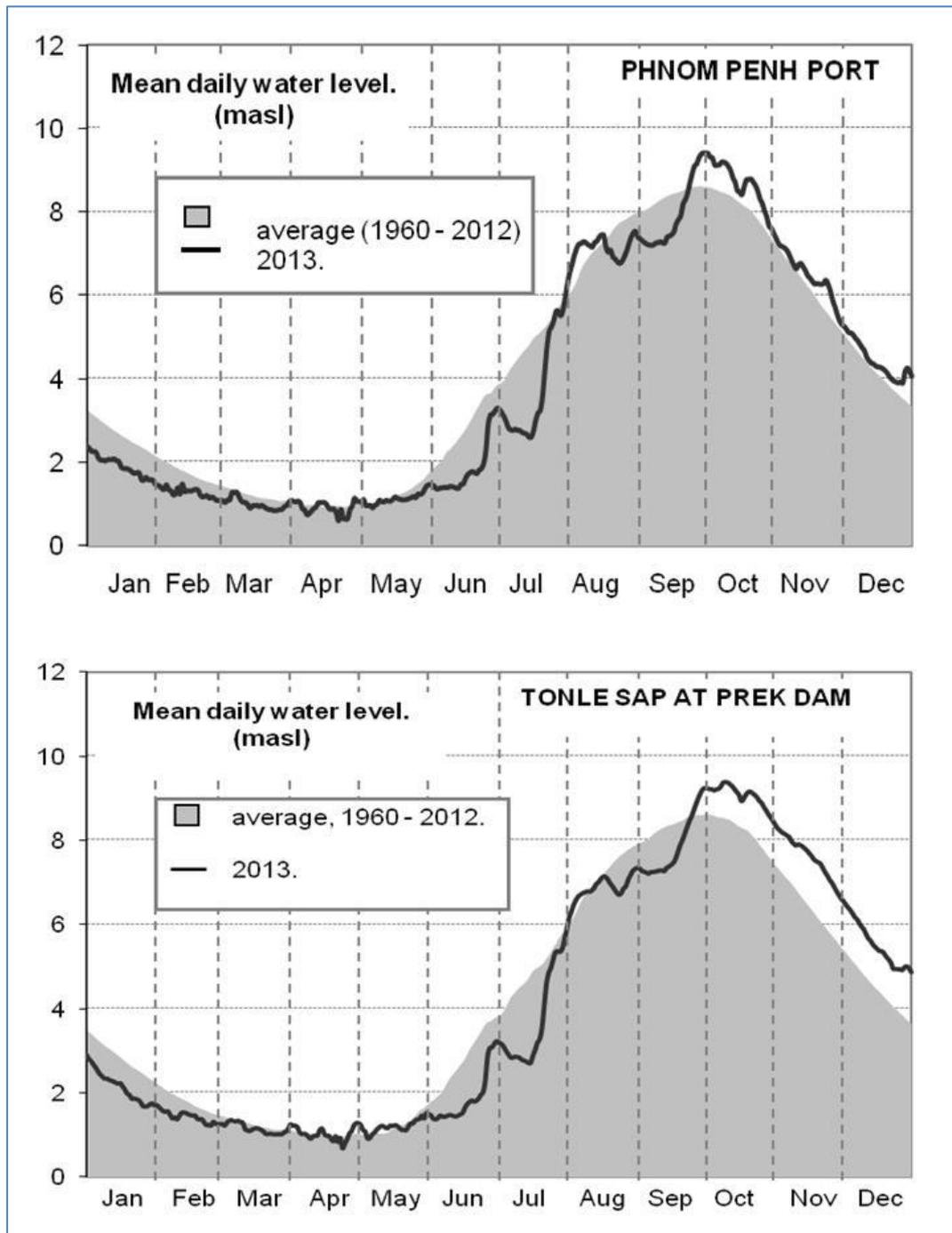
Figure 3-8   The 2013 annual hydrograph at Phnom Penh and on the Tonle Sap at Prek Dam, compared to the long term average.
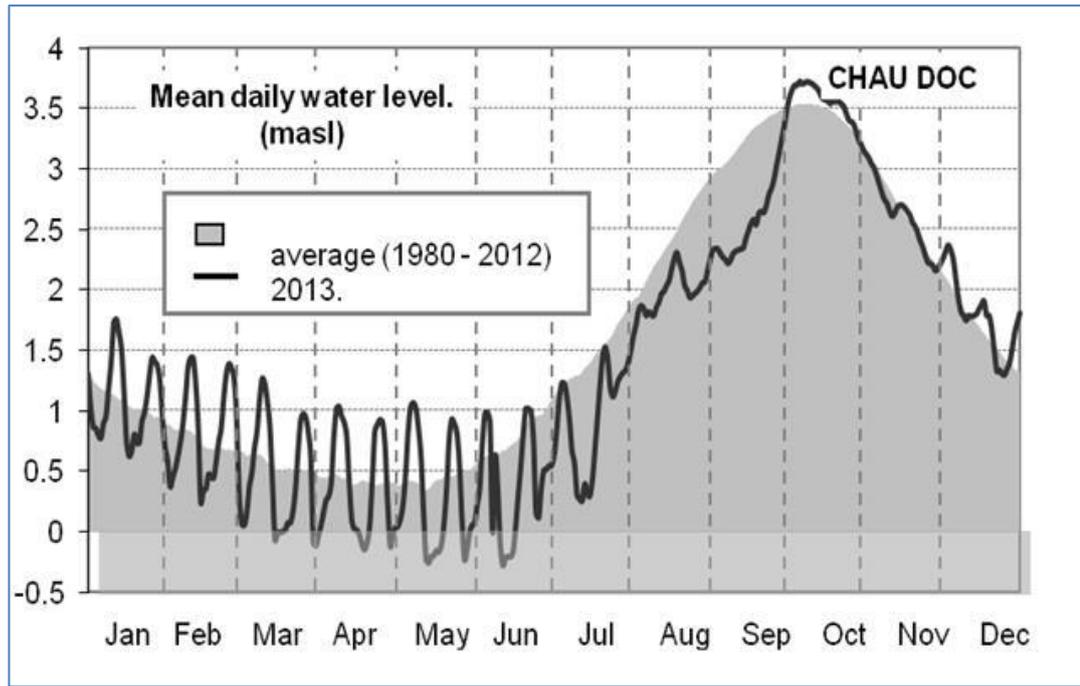
Figure 3-9   The 2013 annual hydrograph at Chau Doc, compared to the long term average.

Table 3-6   Annual maximum water level and the duration of the flood season at three sites in the Cambodian floodplain and the Delta in Viet Nam.

Site	Annual maximum water level (masl)		Duration of flood season (days)	
	Average	2013	Average	2013
Phnom Penh Port	9.0	9.5	157	155
Prek Dam	8.9	9.5	162	163
Chau Doc	3.8	3.8	148	144

4.   COUNTRY REPORTS

4.1   Cambodia

As Figure 3-7 reveals the water levels for the year at Phnom Penh Port on the Mekong mainstream were only marginally above the long terms average. The same picture emerges on the Tonle Sap at Prek Kdam and in the Delta at Chau Doc (Figure 3-7 and Figure 3-8 respectively). At Kratie the maximum discharge attained during 2013 was 50 900 cumecs, exactly equal to the long term average flood peak (Table 3-5). Typhoons WUTIP on the 26th September and NARI on the 14th October had degraded to significant tropical storms by the time they passed over Cambodia. Never the less they were the cause of widespread flash flooding which resulted in a reported 168 fatalities.
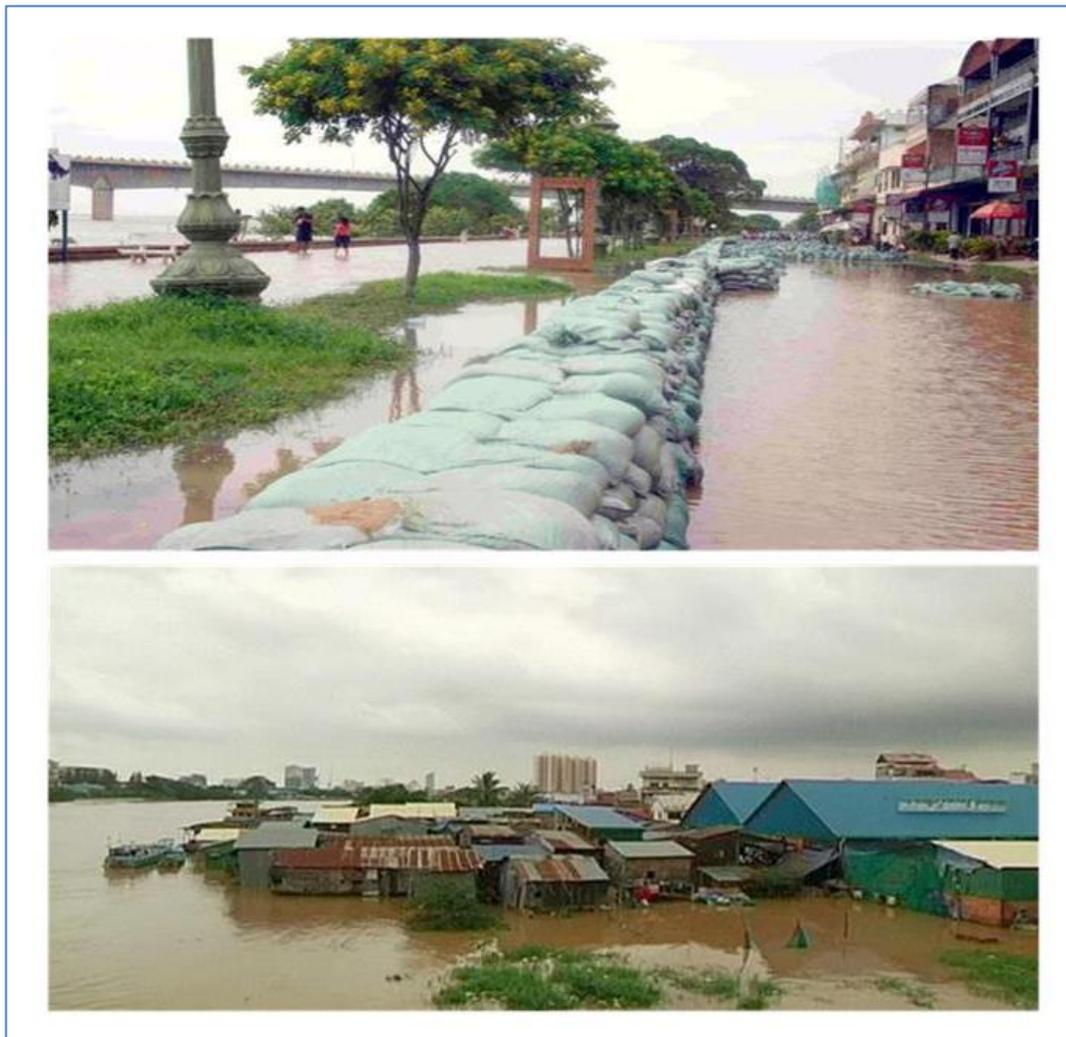
Figure 4-1   2013 –flooding along the Mekong mainstream in Kampong Cham (photo above) and in Phnom Penh (photo below).

Water levels in the Tonle Sap Great Lake during the year reached their peak on 16th October, about one week later than 2012 (12th October) at 9 m or 1.5 m higher than during 2012 when the peak level was 7.5 m.

Flash floods were the major cause of damage and loss and occurred during September and October, with daily rainfalls locally in excess of 120 mm. However, the ability and capacity of the relevant institutions remains limited with not much improvement over the past five years or so. During recent years, flash floods rather than riverine flooding along the Mekong has been the major national hazard However, there remains no generally accepted methodology for the assessment of the actual damages caused by floods and flooding. The emerging realization of the role of flash floods as a natural hazard brings into focus the need for improved forecasting, risk assessment and preparedness. In particular support and training is called for with regard to the application of the RFMMC's Flash Flood Guidance System by the relevant line agencies, such as the Department of Meteorology. In so doing improved technical capacity can systematically be built up.

The apparent contradiction between the assertion that flood conditions during 2013 in Cambodia were significantly above average and the fact that both upstream and downstream (in the Delta) they were average or below calls into question the alarm and flood levels at sites along the Mekong mainstream and within the Tonle Sap system. These may need to re-evaluated to reflect more realistic definitions of the significance of flood water levels.

Figure 4-2   Overbank flood inundation along the Mekong – 2013.

4.2 Lao PDR

During 2013, Lao PDR was affected by four major tropical storms and two tropical depressions, as detailed below:

Table 4-1   The incidence of tropical storms (TS) and tropical depressions (TD) across Lao PDR during 2013.

Event	Date	Affected zone	Comments
TS JEBI	4th Aug	North	Tropical Storm JEBI swept through the northern provinces and brought heavy rain which caused flash floods which resulted in extensive damage, particularly in Oudomxay and Luang Prabang provinces. However, the sparse rain gauge network failed to record the associated rainfall.
TS MANGKHUT	8th – 9th Aug	North / Central	Heavy rain occurred in Northern and Central areas of the country, such as Oudomxay, Xayabouly, Bolikhamxay, Khammouanne, Xiengkhouang, Luang Prabang and Vientiane provinces. The flooding caused by heavy rainfall occurred on 9th – 10th August causing landslides and flash floods. Total 3 day rainfalls widely exceeded 100 mm.
TD	19th – 20th Aug	North	On 15th August a low pressure system formed over the East Sea and upgraded to tropical depression on the 17th. Its passage in Lao PDR on the 19th affected central and northern parts of the country. Seventeen people were killed by flash flooding.
TD EIGHTEEN	17th – 19th Sep	South	Due to the heavy rainfall caused by tropical depression EIGHTEEN, five provinces in southern parts of the country were affected, namely Champasack, Saravan, Sekong, Attapeu and Savanakhet. Rainfall at Pakse was indicated to exceed 300 mm.
TS WUTIP	30th Sep – 1st Oct	NE, Central, Southern	Once again the critical storm rainfall associated with this event went unrecorded. Flash flooding and tributary flooding were relatively widespread, however.
TS NARI	16th Oct	Southern	Tropical storm NARI passed over the central and southern parts of Laos on 16th October, bringing heavy rain to the south and in particular Saravan Province. Locally rainfall exceeded 100 mm over three days, though this is probably an underestimate given the serious flood damage that occurred.

From July to October 2013, there were four tropical

storm (TS) and two tropical depressions (TD) affected

12 provinces of Lao PDR, namely:

1. TS JEBI on 4 August 2013 (Northern)

2. TS MANGKUT on 8-9 August 2013 (Northern and central)

3. TD on 19-20 August 2013 (Northern)

4. TD Eighteen on 17-19 September 2013 (Southern)

5. TS Wutip on 30 September - 1 October 2013

   (Northeast, central and southern)

6. TS Nari on 16 October 2013 (Southern)

Figure 4-3   Lao PDR - Provinces affected by flooding in 2013.
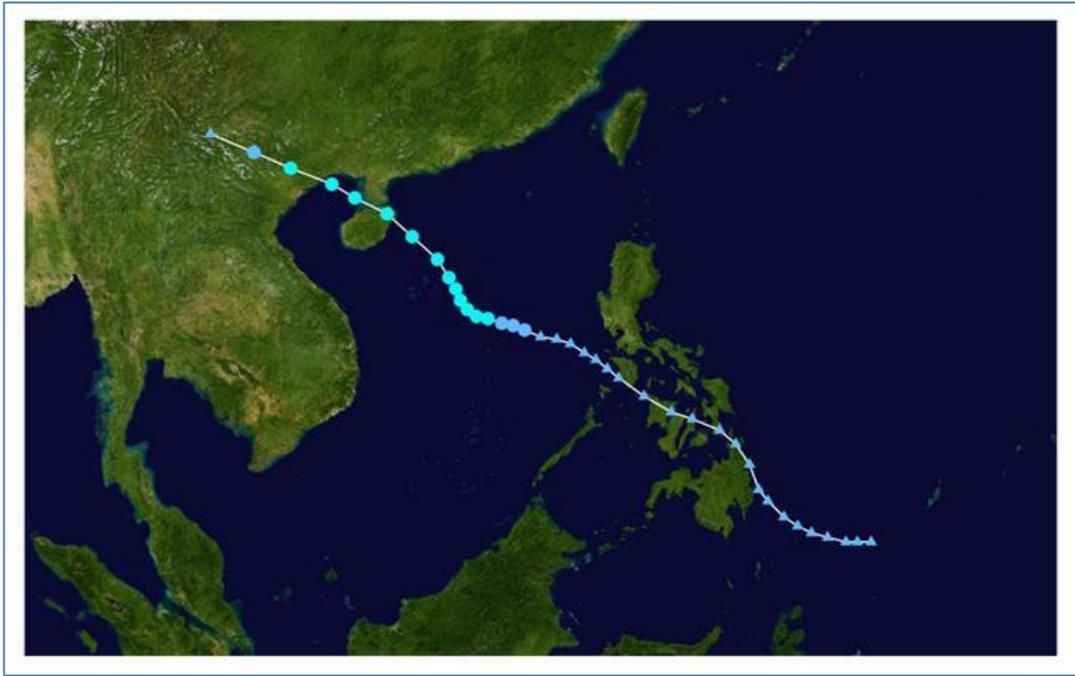
Figure 4-4   The track and progression of Tropical Storm JEBI during early August. (Source: NASA).

Two points emerge from the events in Lao during 2013, though both are fairly long established facts:

- The first is that due to the highly localized storm rainfall that causes flash flooding, the rain gauge network does not often detect the causative events in terms of the critical precipitation.
- The second is that, as pointed out in Section 2 (above), it is often the case that intense low pressure systems such as tropical storms and depressions can follow on from each other with a short intervening timeframe of just a few days. Such was the case, for example, regarding tropical storm JEBI during the first week of August, which was followed by a second system in the form of tropical storm MANGKHUT just four days later (Figure 4-3 and Figure 4-4).

This sequence of four tropical storms and two tropical depressions during the 2013 season resulted in as many as thirty fatalities. Total losses were estimated to be of the order of US$ 62 million, largely as a result of infrastructure and agricultural damage. Flooding in 2013 is recorded one of the worst flooding in the south of the country in the last 35 years according to the Department of Meteorology and Hydrology (DMH).

Figure 4-5   Flash flood damage in Okanoi village, Kongsedone district, Saravan province. (Source: French Red Cross, 2013).

A number of conclusions were drawn from the experiences with regard to floods and flooding during the year:

1. In Laos, the radio is the most appropriate and effective means of communicating weather, flood forecasts and flood warnings.

2. In particular the timely dissemination of information by the DMH is particularly effectual.

3. The hydro-metric and meteorological networks do, however, require additional investment and upgrading, particularly with regard to the monitoring and evaluation of tributary and flash floods and the steps to be taken towards their mitigation.

4. Flood risk mapping remains a major task to be undertaken, though in this regard the Flash Flood Guidance System of the FMMP provides fundamental support towards identifying those zones and sub-catchments that are most vulnerable on a real time basis.

5. Capacity building with respect to flood prevention and flood preparedness for local line agencies requires investment, as does the development of the technical expertise of hydro-meteorological staff at the provincial level.

6. Education and awareness is as important at the village and commune level as the technical aspects of early warning systems.

4.3   Thailand

As tropical storms JEBI and MANGKHUT moved eastwards from Laos into Thailand during the first week or so of August they were downgraded to tropical depressions. During this period the northern and north eastern provinces, in particular Chiang Rai, Chiang Mai and Lampang experienced heavy to very heavy rainfall, with daily maxima as high as 175 mm. Fairly widespread flash flooding followed.

At the end of August, under the influence of a more intense southwest monsoon, a period of intense storm rainfall again prevailed in upper Thailand and the north east. The maximum daily rainfall observed was 125 mm, in Nakhon Phanom Province on 21st August with flooding in Chiang Rai and Nong Khai provinces on 22nd August.

Figure 4-6   Flooding in Chiang Rai Province – 8th to 11th August.

During late September tropical storm WUTIP moved into the country from the east and although it soon degraded to a tropical depression, it again caused heavy rainfall in the northern and northeastern provinces. WUTIP had followed on from a tropical depression which affected large areas during the middle of August. This system resulted in as much as 280 mm that was recorded in Surin Province on the 19th August. Flash flooding was widely reported. Maximum daily rainfalls associated with WUTIP were of the order of 190 mm.

The whole of the Mekong Basin situated in Thailand was affected by extensive flooding during the year, principally the northern river basins such as the Nam Mae Kok and Nam Ing and those to the north east, including the Nam Songkhram, Nam Mum and Nam Chi. Official figures indicate that almost 429 000 people were displace and that there were 17 fatalities.
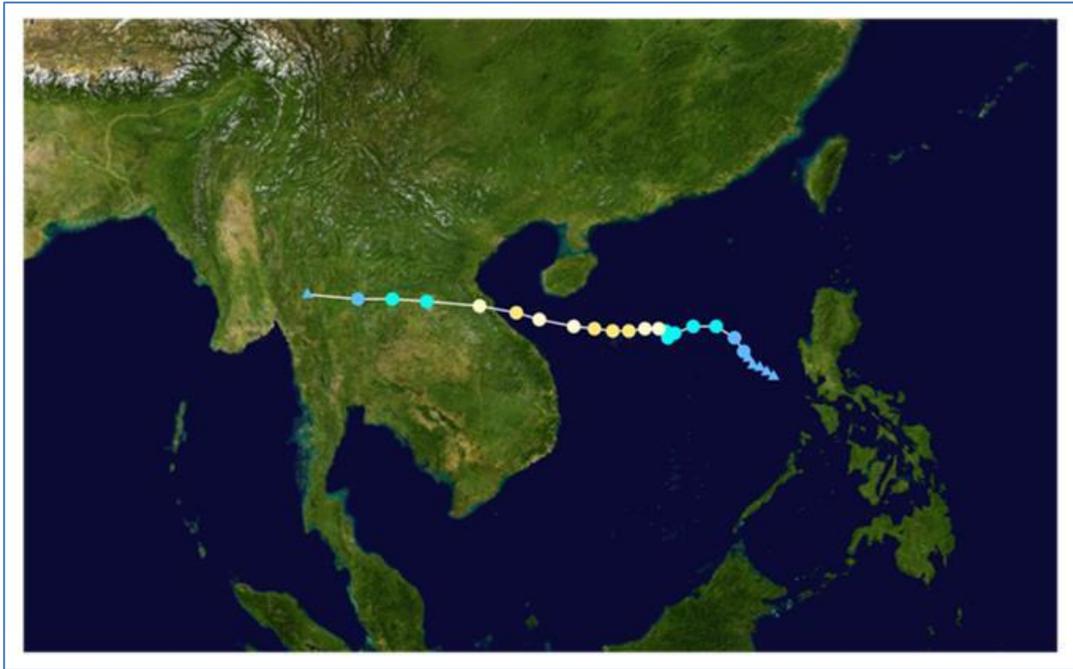
Figure 4-7   The track of tropical storm WUTIP during late September to early October. (Source. NASA).

The seasonal sequence of storms damaged over 7 500 domestic properties in addition to more than 301 000 hectares of agricultural land. Preliminary estimates of the costs of the overall damage and loss amount to the order of US$ 210 million.

A diverse number of national agencies and departments have a responsibility for flood management, mitigation and emergency response. This is not considered to be optimal since it can lead to duplication and is not the best possible use of the available resources. Consequently, the following improvements to national policy are proposed:

1)   To increase the efficiency of flood management, there is a need for a single agency that alone takes direct responsibility for planning and coordination amongst the related organizations at the community, basin and national level. This will serve to improve stakeholder participation and act as the key bureau to manage flood related issues and more effectively oversee the development of surveillance, monitoring, forecasting and early warning systems.

2)   Flood impacts and costs concern many sectors, including agriculture, transport, urban and rural infrastructure and so on. As a consequence a range of ministries are drawn into the process of mitigation, repair and recovery. Policies vary amongst the various ministerial agencies which can often lead to legal issues with regards to the definition of responsibility. There is a developing need for overarching planning and responsibility and a far more integrated approach to disaster management implementation and coordination.

4.4   Viet Nam

During 2013 as many as fifteen tropical storms and three tropical depressions developed in the East Sea, though not all of these tracked into the Mekong Basin as significant low pressure systems, and therefore as storm rainfall inducing events. The season began early, with the passage of tropical storm SONAMU in early January. Though this passed to the south of the Mekong Delta (Figure 4-8), some southern coastal regions did experience significant and unseasonal storm rainfall.

Figure 4-8   The track of tropical storm SONAMU during early January.

The next system of consequence was tropical storm RUMBIA, which tracked into south China (Figure 4-9) at the end of June. Although it did not land in Viet Nam, there were climate impacts, with as much as 255 mm recorded in a single day at one site in the north.

Figure 4-9   The track of tropical storm RUMBIA at the end of June.

These early season storm systems were followed by tropical storm JEBI during early August (see Figure 4-4 for a map of its track), which made landfall over NE Viet Nam. Accumulated rainfall over the three days that it influenced the weather pattern reached figures as high as 212 mm. During the course of the event, four people were killed by flash flooding.

JEBI was followed within the space of just a few days by tropical storm MANGKHUT which made landfall on the 7th - 8th August. During its passage accumulated rainfalls in excess of 330 mm were observed.

Tropical storm WUTIP made landfall over central Viet Nam on the 30th September (Figure 4-7) causing local storm rainfall figures of almost 330 mm.

The final low pressure systems of consequence in terms of their impact upon Viet Nam during the year were tropical cyclones NARI and HAIYAN. The former landed over central Viet Nam on the 15th October and resulted in local accumulations of rainfall of more than 400 mm. The latter made landfall on the 11th November in SE Guangdong Province in China, but its wider effects affected the far north of Viet Nam resulting in ten fatalities.
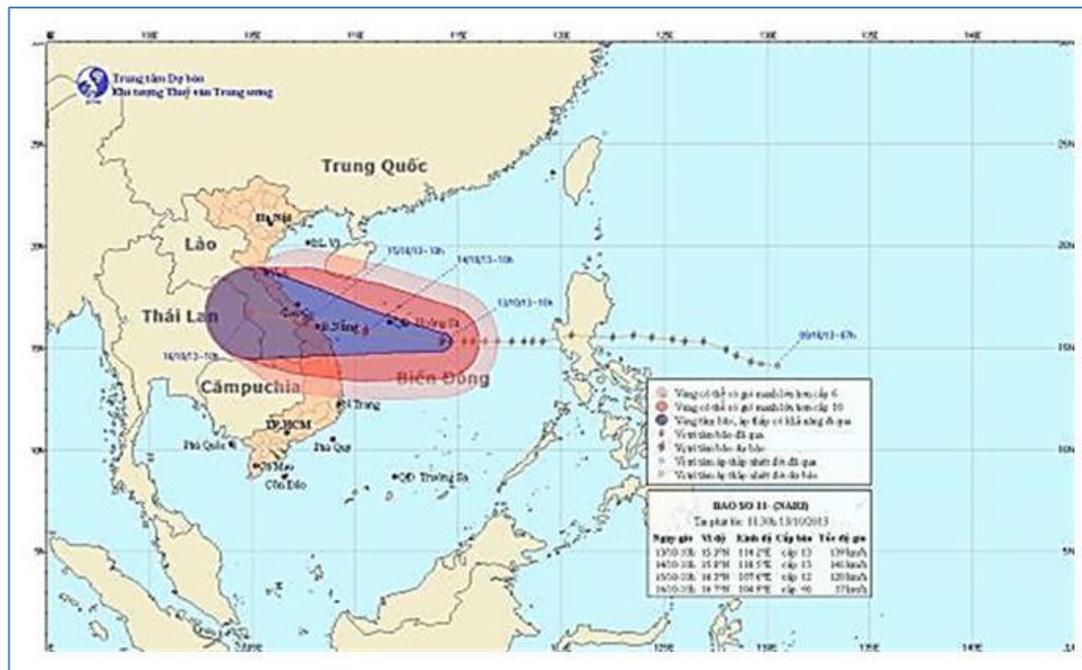
Figure 4-10   The track of tropical storm NARI during mid October.

During 2013 eighteen tropical low pressure systems of varying intensity affected Viet Nam, which historically is a very high figure. For example, in 2010 there were 11 such events, in 2011, 14 and in 2012, 10. As to whether the incidence and severity of these episodes is increasing, there is insufficient statistical evidence to date.

Despite this high number of tropical storm systems during 2013, peak water levels in the Delta were average or slightly above average. On those occasions when they approached alarm levels it was the combination of flood discharge from upstream and high incoming tidal levels. These combined to inflict some of the most extensive flooding in over a decade. Flood damages in the Mekong Delta in Viet Nam in 2013 were limited.

In the Central Highlands three particular events shaped the 2013 flood hydrology, namely a tropical depression during the 3rd week of September and tropical storms WUTIP and NARI. These caused extensive and often severe flooding and flood levels close to or exceeding alarm level 2 or higher. Locally, daily rainfall exceeded 200 mm. Flash floods were the major regional hazard.

Figure 4-11   The consequences of bank erosion – Can Tho City.

Based upon figures from the Water Resources Department and the Ministry of Agriculture and Rural Development, 257 people were posted as dead or missing. Preliminary estimates the total value of material damage was of the order of US$ 222 million. These figures point towards the following provisional conclusions:

- Although the water levels achieved during the 2103 season were anything but extreme, their combination with high tidal conditions in the Delta resulted in extensive inundation, damage and erosion.
- The sequence of eighteen tropical storm systems during the year, the highest count in recent times, and which often followed on from each other over a period of just a few days, led to the formation of optimal conditions for the development of flash floods in the Central Highlands. These were amongst the principal causes of death and damage.

This latter observation underscores the recommendation, put forward many times in recent years, that flash flooding in upland and highland areas needs to be better understood, forecasting and warning systems improved and training and education provided at the village and commune level.

5.   CONCLUSIONS

The role of typhoons and severe tropical storms in the hydrological history of the Mekong region is established. The majority of the most significant and extreme flood episodes have historically been associated with the passage of such low pressure systems across the Basin. This said, the exploratory assessment undertaken here has served to emphasize that a considerable amount of research remains outstanding. A key issue is to gain a greater insight into the geographical distribution of storm rainfall during such events and its relationship with flood runoff. This in itself would amount to a significant piece of research involving mapping and storm rainfall/ runoff modeling. A major challenge is the overcome the constraints posed by the density of the rain gauge network which, though by international standards is amongst the most comprehensive within a large river basin, still only permits the generalized mapping of rainfall. The careful use of satellite data could, however, improve the accuracy of the mapping.

Typhoons and tropical storms are classified according to their associated wind speed, which is not directly relevant in the hydrological context. While much historical data exist this tends to focus upon storm tracks and system classification. The material is difficult to draw together in part because it generally refers to the North West Pacific and East Sea as a whole. It is something of a challenge to separate out those events which have affected the Lower Mekong.

Despite widespread claims that the incidence and severity of tropical storms is increasing in response to global warming, the historical time series that are available reveal no such evidence. If this was the case then it would be expected that the annual frequency of significant storm days would increase over time. Analyses undertaken here reveal that there is no evidence in this regard.

The flood season throughout the Mekong region during 2013 was average or below average both in terms of peak and volume and with respect to its onset and end. Six tropical storm systems affected the Lower Basin during the year, though none of these had any great bearing upon flood flows in the mainstream. Their major impact was to cause widespread flash flooding due to intense localized storm rainfall. Flash floods were the major cause of flood related fatalities, with 168 fatalities in Cambodia alone. The total number of people killed in the region was 500.

In the past the focus of attention has lain with mainstream and large tributary floods. However, in recent years the flash flood hazard has come far more into the spotlight. The four Country Reports together emphasize the need for improved warning and mitigation at the local level, while at the same time recognizing the value of the RFMMC's Flash Flood Guidance System.

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