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1. SYNOPSIS

Following the significant flood conditions of 2011, the situation during 2012 proved to be quite the opposite. The flood peak and volume were between 30 and 40% below the long term average. The flood season was a month shorter than usual. All in all 2012 turned out to be one of the most deficient annual floods of the last 25 years, matching the situation during 1992, 1998 and 2010.

The deficient hydrological conditions reflected a meteorologically dry year overall. Geographically, rainfall was variable during the monsoon season with only limited areas of the Basin recording monthly totals of any significance. In general total precipitation was well below average, in places by as much as 40%. Locally, however, rainfall was close to average, due largely to mesoscale storm events that are events which extend over no more than 1,000 km^2. The onset of the SW Monsoon took place during late April / early May as is normal but ended up to a month early in mid to late September over the greater part of the region. This early ended to the Monsoon combined with low seasonal rainfall in general provided the combination that has defined some of the lowest annual floods over the last two decades.

Maximum water levels across the Cambodian floodplain and the Delta reflected the hydrological conditions further upstream and were 1m and more less than the long term average. On the Tonle Sap at Prek Kdam the maximum flood level during the year was the fourth lowest that has been observed since 1960. This would lead to the depth and areal extent of the Great Lake that were at low levels.

Such annual flood deficits are not, however, uncommon. The question that arises, though, is whether they are becoming more common. A parallel query might be whether the inter-annual variability of the flood regime is increasing in any significant way. During the last three years, 2010 was exceptionally dry, 2011 exceptionally wet and 2012 exceptionally dry again. Such a pattern is unusual. Wet years tend to follow wet years and drier conditions tend to replicate themselves according to a semi-periodic pattern. These aspects are considered here.

There is a growing body of evidence that the Chinese hydropower cascade on the mainstream in Yunnan is having an impact the downstream low flow regime. This shows itself in “spikes” or spates of flow at Chiang Saen which are difficult to explain since between there and the upstream dams there are no large tributaries that would generate such events naturally. These spates are still evident at Vientiane, but dissipate further downstream.

All in all, 2012 was a “dry year” and the flood was comparable to events over the last 20 years that were classified as “extreme”, in the sense of being much below average.

The theme of the Report is “Flash Floods” and particularly their relation with Tributary and Mainstream Floods. The distinction between these and riverine floods is emphasized, while various impacts upon their incidence and severity, such as land use changes and climate change, is discussed. It is emphasized that given their very fast response times, forecasting is difficult. The strategy adopted in the Lower Mekong Basin has been to develop a Flash Flood Guidance System, which maps the areas at risk.

2. FLASH FLOODS

2.1 Definitions and general characteristics

The most common definition of flash floods is that they are localized events that occur with little, if any, warning. Within the general domain encompassing "*the flood hazard*", flash floods are more often than not the most devastating and responsible directly for considerable loss of life. Riverine floods, that is those generated over longer periods of time over much larger areas tend, at least in tropical regions, to lead to what might be defined as "*indirect*" fatalities as the result of water borne diseases that develop during prolonged periods of inundation. In China some estimates suggest that approximately two thirds of flood related casualties arise from flash floods, landslides and mud flows (Li, 2006), while in Europe over the period from 1998 to 2008 it has been estimated that of the 1 000 flood related casualties, 40% arose from flash floods (Barredo, 2007).

Table 2-1 presents some definitions of the flash flood hazard as set out by various international agencies. The common theme is that they are defined in terms of the short time over which they develop following intense storm rainfall, with values of 4 to 6 hours being the most widely quoted. An associated perception is that they are flood events where there is insufficient time to implement an effective emergency response. This short catchment response time is, however, just one factor to consider, along with other issues such as public awareness of the actions that need to be taken on receiving warnings, the lead or lag times ideally required and the readiness of the civil protection authorities.

Within the Lower Mekong Basin region, as is widely the case elsewhere, flash floods are most prevalent in steep upland catchments. These are likely to be remote, such that any emergency response is difficult to implement and inevitably delayed. The velocity and erosive force of such events can severely damage property and cause an exceptional number of casualties. Debris and sediment add to the life threatening hazard.

A general precursor to a flash flood is that the catchment is already saturated, with little potential therefore to absorb or store any further storm rainfall excess. Flood runoff is therefore close to 100% and is rapid. Most such floods occur in small basins of 100 to 200 km^2, where exceptional convective storm rainfall prevails. Topography plays a major role, with steep terrain accelerating the storm runoff process.

Such floods events are difficult to monitor because they develop at spatial and temporal scales that conventional measuring networks of rainfall and river discharge are not able to sample effectively. The required high resolution observation networks are simply not available. In the Lower Mekong Basin, for example, there are only a very small number of hydrometric gauges that monitor stream flow from tributary catchments of less than 1 000 km^2. When there is an incentive to estimate peak flash flood discharge it has to be carried out indirectly, based upon the identification of maximum flood levels, slope area surveys, measurements of channel geometry and the application of the appropriate hydraulic methods. On this basis a catalogue of flash flood magnitudes can be built up.

In addition to hydro-meteorological factors, the incidence and severity of flash floods is influenced by physiographic effects. Of these there are two main mechanisms (Marchi et al, 2010), namely orographic and relief factors.

Table 2-1 Some definitions of flash floods (based on Sene, 2012).

Reference	Definition
ACTIF (2004)	A flash flood can be defined as a flood that threatens damage at a critical location in the catchment where the time for the development of the flood from upstream is less than the time to activate warning, flood defense or mitigation measures. The achievable lead time is not sufficient to implement preventative measures such as evacuation.
APFM (2006)	Flash floods occur as a result of the rapid accumulation and release of runoff from upstream, usually upland or mountainous areas, caused by heavy rainfall, landslides or the failure of river works. They are characterized by a rapid rise and a sharp recession and associated with high flow velocities. Discharges quickly reach a maximum and diminish rapidly. Flash floods are often more destructive than other types of flood event because of their unpredictable nature, strong currents and the fact that they carry large amounts of debris and high concentrations of sediment. There is little or no time for communities to prepare.
NOAA (2010)	Rain induced flash floods are excessive flow events that develop within a few hours, typically less than 6 hours of the causative storm event.
WMO (2009)	Flash floods are rapidly rising and falling events that usually occur in steep catchments as a result of excessive rainfall. They develop usually within 6 hours of the onset of the causal event with often catastrophic impacts downstream.

The distinctions between riverine and flash floods are significant. Table 2-2 sets these out in terms of their comparative features, causes and impacts etc. Other than the rapid development of flash floods and the forecasting difficulties which have already been highlighted, it is the impacts that distinguish the two types of event, no more so than in the Mekong region:

- Riverine floods, particularly within the Cambodian floodplain and the Delta in Viet Nam are at their most destructive not only as a result of maximum water levels but also by virtue of the fact of prolonged periods of inundation. This was certainly the case in 2000 and 2011. The majority of effects which can augment storm rainfall and topographic relief which can promote the rapid concentration of flood runoff. Flood related fatalities are "indirect", in so far as they arise from communicable water borne disease, polluted water, reduced food supply and exposure when domestic properties are rendered uninhabitable. Juveniles account for by far the great majority of the fatalities.

Table 2-2 The distinctions between riverine and flash floods.

	Riverine floods	Flash floods
Features	• Relatively slow rise in water levels • Peak discharge reached over hours to days • Slow recession over hours or days. • Usually coincide with high base flow levels. • Medium to long lag times.	• Rapid increases in water level • Peak discharge reached within minutes to hours. • Rapid rates of flow recession. • Rapid flood dissipation. • Not necessarily related to base flow levels. • Short lag times.
Causes	• Prolonged seasonal precipitation of modest intensity overall.	• Very high intensity of storm rainfall.
Associated issues	• Widespread over bank inundation	• High sediment and debris loads. • High flow velocities with significant erosive power.
Frequency	• Annually, during the monsoon season.	• Occasional to frequent.
Affected areas Impacts	• Local to regional areas can be inundated. • Long periods of inundation result in water borne disease which mostly affects juveniles. • Agricultural and secondary economic impacts.	• Generally of local extent, over small to medium areas. • High water velocities and erosive power contribute directly to loss of life and property damage.
Forecasting	• Hydrological forecasting and flood routing generally possible.	• Difficult to impossible forecast

- Flash floods are a far more direct hazard. There is, in general, little scope for escape or refuge. Fatalities occur through people being washed away, the collapse of property and injury due to debris and mud flows. Flow velocities can reach as much as 3 m/sec (Marchi et al, 2010) and more, giving rise to exceptional erosive power with consequent impacts upon domestic and industrial property, bridges and the like. These floods are usually associated

> with widespread slope failures and flood power and flow velocities are sufficient to cause significant erosion leading to high sediment loads and therefore downstream sedimentation. Consequently, they often result in significant morphological changes to river channels.

The hydrological “geometry” of the flash flood hydrograph is succinctly captured in the figure below. This shows two events on a catchment in northern Lao PDR draining a catchment area of 520 km^2. Both events are more than three standard deviations greater than the mean annual flood peak and lasted for just one or two days. The impacts of events such as these can be locally devastating.

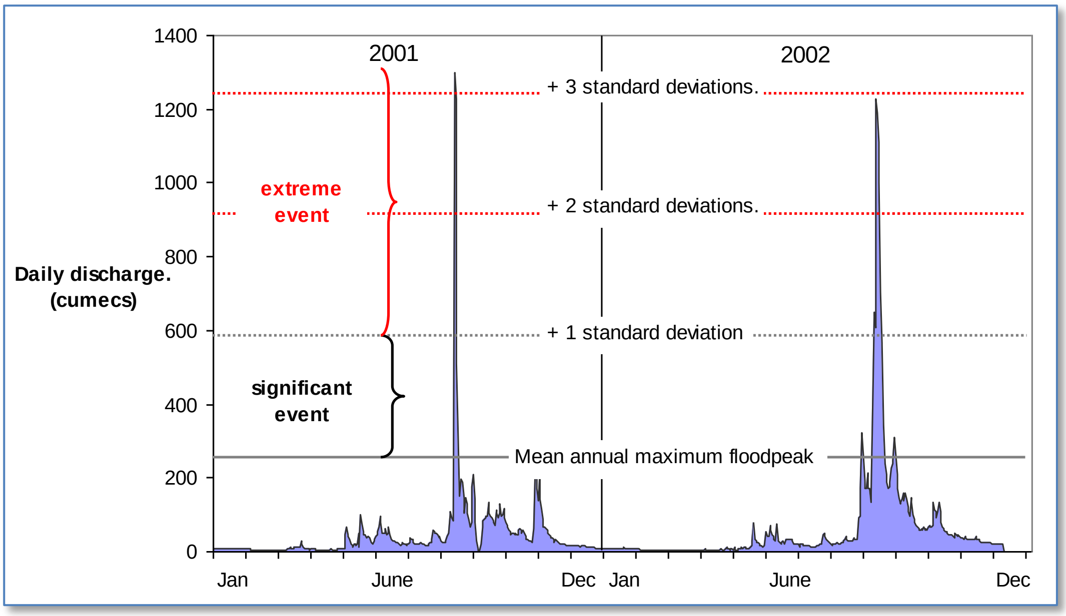


Figure 2-1 Characteristic flash flood hydrographs for a 520 km^2 catchment in Laos.

2.2 On flood forecasting and flood risk assessment

The distinction between riverine and flash floods in terms of management and mitigation is relatively straightforward. Riverine floods can be forecast using rainfall runoff models combined with flood routing to predict the timing and magnitude of peak water levels. This is the strategy adopted in the Mekong Basin. Flash floods cannot be predicted in the same way. The emphasis is therefore placed upon the assessment of risk and vulnerability using satellite images of soil moisture levels and the development and track of convective storm cells. Flash flood hazard maps are then prepared. The methodology that has been implemented in the MRC’s Flash Flood Guidance (MRC-FFG) system is discussed in Section 2.8.

Generally, once the SW Monsoon is well established in the Basin from early May onwards (usually) soils are typically quite highly saturated. However, events can occur when levels of saturation are low or the soils dry. Under these conditions excessive storm rainfall which exceeds the maximum soil infiltration capacity results in overland flow and the risk of flash flooding.

Figure 2-2 Search, rescue and clearing up in Lao Cai Province, Viet Nam, after the flash flood of 03.09. 2012. Source People's Army newspaper online, dated 05.09.2012.

Figure 2-3 An indication of the debris loads carried by flash floods. Trash being cleared after being trapped in Luangnamtha diversion weir, Lao PDR, during an event in 2006.

The impact of rapidly evolving precipitation systems on the complex hydrological processes that take place in fast response basins makes the flash flood phenomenon a challenging forecasting problem, thus the emphasis on mapping risk and vulnerability on a real time basis. Basin characteristics, such as physiography, geology, soil type and depth along with vegetation are arguably as important as the nature of the storm rainfall itself.

Total accumulated precipitation can vary from less than 50 mm to more than 400 mm. However, rainfall intensity is regarded as a more important causative parameter. It is, however, much more difficult to measure. In the tropics, where convective conditions dominate, rainfall intensities in excess of 150 mm/hour to 200 mm/hour are not uncommon. In the mid-latitudes weather systems generally move more quickly than in the tropics, such that intense rainfall producing systems can become semi-stationary, which can exacerbate the potential for flash flood generation.

In larger basins the storage capacity of the drainage system and the staggered arrival of sub-basin flood water at the outlet reduces both the amplitude and response time of the flood event, so as to lose the principal characteristics that are needed to identify the event as a flash flood.

2.3 Flash flood monitoring and remote sensing tools

A variety of meteorological remote sensing tools are available to assist with flash flood risk monitoring and the mapping of potentially intense precipitation. Of these, satellite imagery is the most widely applied, allowing some diagnosis of the location and magnitude of intense rainfall in poorly instrumented areas. However, the available resolution of satellite data is not always suitable for the small spatial and temporal scales associated with flash floods. Furthermore the intensity of the precipitation does not have a direct correlation with the depth of the cloud cover. Intense convection and thunderstorms are typically linked to strong vertical motions and therefore very tall cloud systems with exceptionally cold cloud top temperatures. Intense rain systems however, are often linked with only moderately strong vertical motion that produces only moderately deep convective clouds. Thus cloud top temperatures are warmer and as a consequence may appear less intense. Satellite data provide only an estimate of dangerous precipitation systems but need to be combined with other tools to discriminate between significantly intense rainfall conditions and those that are truly extreme. Such data are, however, of exceptional value for evaluating the critical parameters of the pre-storm environment, including the spatial distribution, movement (track) and magnitude of available atmospheric moisture.

Radar data are not as widely available, but offer high resolution information on precipitation systems that is more appropriate to the scale of flash flood processes. The magnitude of radar measurement is more directly proportional to the magnitude of the rainfall intensity. The limitations of radar with respect to convective storm rainfall are primarily related to the propagation of the radar beam through the atmosphere (Borga et al, 2011).

Point source measurements, based on rainfall and stream flow gauges offer specific “at site” data. However, except for automatic systems that transmit data in real time such information is not available at the time scale required for flash flood warning. Such networks are sparse anyway and subject to electronic and mechanical malfunction caused by extreme weather and poor maintenance.

The application of spatially distributed hydrological models in the context of flash flood forecasting is impractical, except in the case of highly instrumented experimental catchments. It is very rarely the case that drainage areas of less than 100 km^2 are provided with any sort of rainfall, water level or discharge tele-metering device. In the case of flash floods the identification of the structure of rainfall fields at small scales is key, since their areal extent can typically be not much wider in extent than that of a vulnerable catchment (Borga et al, 2011). Other modeling challenges to consider include the meaningful geomorphological and soils characterization of the catchment in terms of their hydrological response to storm rainfall.

The diagnostics of flash food risk is clearly complex and by reasons of practicality is limited to the geographical assessment of risk as opposed to any determination in terms of predicting probability or magnitude. Flash floods are by their very nature unpredictable and in general cannot be predicted or even less assessed in advance in quantitative terms.

2.4 A regional history of flash floods

Flash flood events are an integral part of the hydrological landscape of the Lower Mekong Basin and are observed during most years. Of the flash floods observed in northern Thailand between 1994 and 2006, that of 2002 in Chiang Rai and Loei Provinces was amongst the most severe with 40 people reported killed. Five thousand people had to be evacuated and three thousand properties were damaged. Flash floods in 2001 were responsible for over 100 deaths.

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

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

Figure 2-4 shows the incidence of both riverine and flash floods in Northern Thailand between 1994 and 2006 and indicates that flash flooding in at least one or more catchments in the region is a frequent annual hazard. Table 2-3 to 2.8 describe the incidence, geography and character of flash floods throughout the Lower Mekong region between 2007 and 2012. In effect all seven years indicate that flash floods are a recurrent risk throughout the region, with some areas more vulnerable than others. These include northern Thailand, the upper reaches of the large left bank Lao PDR tributaries, the upper Se San and Srepok in Viet Nam and parts of the eastern Tonle Sap Basin in Cambodia defined by the Cardoman Uplands.

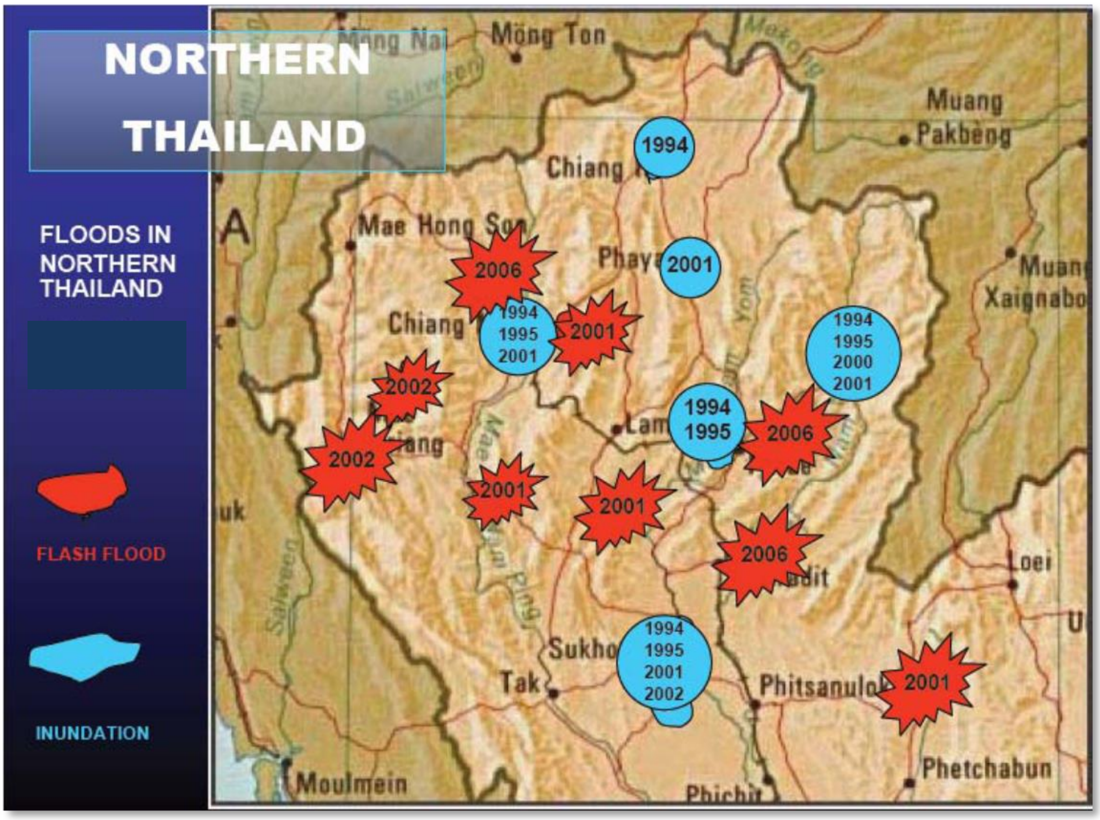


Figure 2-4 Flash and riverine (inundation) floods recorded in Northern Thailand, 1994 to 2006.

Table 2-3 Summary of flash flooding in the Lower Mekong region during 2007.

Year	Country	Flash flood incidence and geography
2007	**Cambodia**	Tropical storm PABUK resulted in some exceptional daily rainfall totals, which in turn produced widespread flash floods and extensive inundation. In Preah Vihear 360 mm was recorded on the 5th August. The main provinces affected were Koh Kong, Mundulkiri, Preah Vihear, Ratanakiri and Stung Treng.
2007	**Lao PDR**	As a consequence of Tropical Storm LEKIMA flash flooding and extensive flood inundation as a result of 3 day rainfalls, locally in excess of 250 mm and widely above 150 mm during the first week of October principally affected the catchments of the Xe Bang Hieng, Xe Bang Fai and Xe Done. At the Mahaxay stream gauge on the Xe Bang Fai water levels rose almost 1 m above the danger level and the average depth of the consequent inundation was 1.5 m. Water levels on the Se Bang Hieng rose 7 m in less than 36 hours, causing very rapid inundation, typical of a flash flood situation. On the Xe Done the river level increased by 13 m in the first five days of the month, while the Xe Bang Fai rose by 10 m.
2007	**Thailand**	In Loei Province a flash flood occurred on the 9th September, killing four people, 600 persons had to be evacuated and there was significant damage to property, including houses and schools. Locally floodwater was reported to be up to 5 m deep.
2007	**Viet Nam**	Seven typhoons and three tropical depressions, originating in the South China Sea, affected the Vietnamese regions of the LMB during 2007, of which those designated Typhoon Numbers 2 (PABUK in Cambodia) and 5 during August and November caused major flash floods in the Upper Se San and Srepok basins. In August flash floods occurred within tributaries of the Upper Se San and Srepok rivers caused by exceptional storm rainfalls between the 2nd and 5th associated with Typhoon No.2. Over wide areas total rainfall over the three days was between 300 and 400 mm resulting in local flash floods and water levels on the Srepok exceeding alarm level III. The most serious loss and damage occurred in Dak Lak Province. Heavy rain of between 100 and 300 mm over four consecutive days from the 7th to 11th November occurred over Kontum Province as a result of Typhoon No 5. Devastating deluges followed in the Upper Se San tributaries, particularly the Dak Bla and Krong Poko. Several floodplain villages were rapidly inundated to a flood depth 1 to 1.5 m, with the Kon Plong District the worst affected. The flash floods, landslides and debris flows that took place in November as a result of Typhoon No 5 caused extensive damage in the Upper Se San. In Kon Plong one person died, 4 bridges were either damaged or completely destroyed and several villages flooded and cut off. The remoteness of many of the villages was a challenge to rescue and repair.

Table 2-4 Summary of flash flooding in the Lower Mekong region during 2008.

Year	Country	Flash flood incidence and geography
2008	**Cambodia**	Flash floods occurred in early August in some provinces as a result of tropical storm PABUK which produced heavy rainfall of up to 340 mm per day locally, causing damage to infrastructure and livelihoods. During the last two weeks of September a low pressure system and a tropical storm resulted in intense rainfall with flash flooding causing crop damage over 10 500 hectares.
2008	**Lao PDR**	Wide spread heavy rainfalls in mid July in the upper Nam Ngum basin, with a total of more than 300 mm observed on the 18th and 19th July at Vang Vieng, caused extensive flooding as the Nam Ngum, Nam Lik and Nam Song rivers rose above critical levels. Flood depths widely exceeded 1 m, inundating over 2,000 households in the Kasy, Vangvieng, Hinheup, Fenang and Thoulakhom districts. Landslides in the Kasy district caused four deaths Local flash flooding in the northern and central regions of the country during June, July and September affected 11 districts, 90 villages and 2 500 households and 4 people were killed by landslides. In the agricultural sector 2.250 hectares of crops were damaged and some livestock lost.
2008	**Thailand**	No instances of serious flash flooding were reported from the north or east of the country.
2008	**Viet Nam**	In the Central Highlands, specifically in the upper Se San and Sre Pok river basins, a number of local flash floods occurred, with those of mid May, early August and late November being the most damaging. Generally, however, 2008 was a year that saw the lowest levels of flood losses observed in recent years.

Table 2-5 Summary of flash flooding in the Lower Mekong region during 2009.

Year	Country	Flash flood incidence and geography
2009	Cambodia	During the year two main flash flood events occurred during early and late September, the latter due to the influence of typhoon KETSANA. The most affected provinces were Preah Vihear, Kampong Thom, Banteay Meanchey, Oudormeanchey, Ratanakiri, Mundulkiri, Stung Treng, Kraties, Kampong Cham, Siem Reap, and Battambang. There were severe crop losses, infrastructure damage and a number of deaths reported.
2009	Lao PDR	During 2009 localized flash flooding occurred in Luangnamtha, Bolikhamxay and Khammouanne provinces during July and mid August caused by origraphically induced monsoonal storms which produced 80 to 1800 mm per day. Local inundation occurred but losses were minimal except along mountain rivers where crops close to the banks were washed away. Lowland rice padi also suffered some damage.
2009	Thailand	As elsewhere in the region KETSANA proved to be the major event of the 2009 flood season in the Thai part of the Lower Mekong Basin. It moved into Thailand as a severe tropical storm but was soon downgraded to a tropical depression. Never the less there was widespread heavy rainfall and flash flooding between the 29th September and the 4th October resulting in damage and losses of US$ 21 million. Two deaths were reported.
2009	Viet Nam	The accumulated rainfall generated by KETSANA over the country between the 28th and 30th of September over large areas of the central regions locally exceeded 400 mm and reached amounts in excess of 500mm. It is likely that such figures occurred equally widely in the upper reaches of the Se San and Srepok tributaries in Viet Nam and Cambodia and locally in the Xe Kaman and Xe Kong in Lao PDR. As a consequence water levels in the Central Highland rivers widely exceeded Alert Grade 3 (the most severe) thresholds. Most rivers exceeded this critical level by at least 1.5 m, many by as much as 3m and in the Upper Se San by as much as 7 m. Historical maximum levels were widely exceeded. Flash flood conditions followed and inundation to depths of 1.5 and 2 m were widespread.

Table 2-6 Summary of flash flooding in the Lower Mekong region during 2010.

Year	Country	Flash flood incidence and geography
2010	**Cambodia**	During October and November heavy rain, particularly during the second week of October caused localized flash flooding in a number of provinces which caused significant damage to infrastructures and agriculture in Takeo, Kandal, Pursat, Battambang, Banteay Meanchey, Siem Reap, Kampong Speu and Phnom Penh. Rainfall in some of these areas exceeded 150 mm per day and intense storms often continued for more than three days. At Siem Reap the rainfall observed on the 11th October was 140 mm. On the same day 105 mm occurred in Takeo and 76 mm in Kampong Cham.
2010	**Lao PDR**	In mid July tropical Storm CONSON number 2 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. In the last week of August extremes monsoonal rainfall up to 133 mm was measured at Phonhong station and caused local flash flooding affecting 10 villages in the Thoulakhom District of Vientiane Province. Tropical Storm MINDULLE No. 05 made landfall over central of Viet Nam, downgrading to a tropical depression as it passed over northern Lao on 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. Losses due to flash flooding, although localized, were significant. During the year more than 80,000 persons were directly affected and 7 storm-related deaths were reported.
2010	**Thailand**	During the year two major flood episodes occurred: 1) Tropical storm MINDULLE tracked east across Laos on 26th August as a tropical depression causing widespread heavy rainfall and flash floods in 9 provinces, mostly in the northern and north-eastern parts of the country. 2) During the first two weeks of October an intense low pressure system resulted in intense storm rainfall and flash flooding in 38 provinces, again mostly in the northern and north- eastern regions. These conditions directly affected over five million people and seventy nine deaths.
2010	**Viet Nam**	No flash floods were observed in the tributary basins during 2010.

Table 2-7 Summary of flash flooding in the Lower Mekong region during 2011.

Year	Country	Flash flood incidence and geography
2011	**Cambodia**	Local areas were affected by flash flood during October-November due to heavy rain, especially during second week of October which caused severe damages to infrastructures and agriculture in Takeo, Kandal, Pursat, Battambang, Banteay Meanchey, Siem Reap, Kampong Speu. The rainfall during that period reach up to more than 150 mm per day in some places and continuously for more than three days. Daily rainfall on 11th October observed in Siem Reap station was 140 mm, 105 mm in Takeo and 76 mm in Kampong Cham.
2011	**Lao PDR**	In 2011, Laos was badly affected by two major tropical storms, namely HAIMA and NOCK-TEN. On 24th – 26th June, the tropical storm HAIMA hit the northern and central provinces, on 30th July – 1st August, the tropical storm NOCK-TEN hit central and southern provinces. They brought heavy rains, which had caused the rise of water levels in many rivers including Mekong. In addition, Laos was also affected by tropical storm HAITANG in September and typhoon NESAT and typhoon NALGAE in October. As a result, many provinces had been significantly affected by floods and landslides. There were twelve provinces across the country (Phongsaly, Oudomxay, Luang Prabang, Xayaburi, Xiangkhouang, Vientiane, Bolikhamxay, Khammouanne, Savannakhet, Champasak and Vientiane Capital) affected by flash and riverine floods.
2011	**Thailand**	Five significant tropical storms occurred during the year: HAIMA, NOCK-TEN, HAITANG, NESAT and NALGAE. Especially at the end of June 2011 the northern and northeast areas of Thailand were hit hard by the tropical storm HAIMA. The water level increased significantly in the Yom River as a result. Then, in the late July, runoff in the northern areas continued to drain. The storm NOCK-TEN was a blow struck in the same area and also increased the water volume. After that, the storm HAITANG was another blow, which affected the northeast area of the Mekong River Basin during 27th – 29th September 2011. Next, the storm NESAT combined with the storm HAITANG and continued to impact the northeast and east of Thailand. Lastly, the storm NALGAE influenced a southwest monsoon, which intensified the rain in the central and eastern areas during 5th – 7th October 2011. Flash flooding in upland areas in the N and NE.
2011	**Viet Nam**	From 13th – 20th October 2011, flash floods occurred widely the Central Highlands region, with considerable losses.

Table 2-8 Summary of flash flooding in the Lower Mekong region during 2012.

Year	Country	Flash flood incidence and geography
2012	**Cambodia**	Parts of the country were affected by flash floods during September-October, specifically during second week of September causing some damage to infrastructure and agriculture in Preash Vihear, Kampong Thom, Banteay Meanchey, Siem Reap, Pursat, Svay Rieng and Pailin provinces. The rainfall exceeded 170 mm per day.
2012	**Lao PDR.**	On 4th September the Houay La River rose suddenly due to the heavy rainfall at about 2 AM on 2nd September. This flooding killed four people in the Nan district of Luang Prabang province. The flooding also swept away five houses, affecting 10 others and a secondary school along its path.
2012	**Thailand**	Generally riverine floods with local flash flooding in the north in September and October.
2012	**Viet Nam**	The Central Highlands of Vietnam suffered from several tropical storms with associated intense rainfall. Flood water levels reached critical alarm thresholds over 2-3 days, as on the Srepok River at Ban Don.

This said, flash flooding is not entirely confined to what might be termed to be steep mountain torrents. Intense rainfall which exceeds soil infiltration capacity can result in extremely rapid flood runoff even in moderately steep terrain. Such incidences are not unknown, for example, in parts of the Mun-Chi Basin in Thailand.

Once channel slope decreases flow velocities decelerate and debris and sediment are deposited on a considerable scale (Figure 2-5). Consequently channels are blocked and hydraulic conveyance is reduced significantly. Unless the channels are cleared and restored their ability to convey floodwater decreases to the extent that water spills over the banks and the area inundated increased as a consequence.

Figure 2-6 indicates, very broadly, the principal sub – areas and tributaries within the Lower Mekong Basin that have seen regular flash flooding in recent decades. In effect, the upper regions of most of the major tributaries have been affected, since their physiographic features and storm rainfall climates are conducive to this type of extreme flood events. Historically, two areas have stood out:

Figure 2-5 Channel blockages caused by a flash flood in the Long District of Luangnamtha Province, Lao PDR, last week of August, 2010.

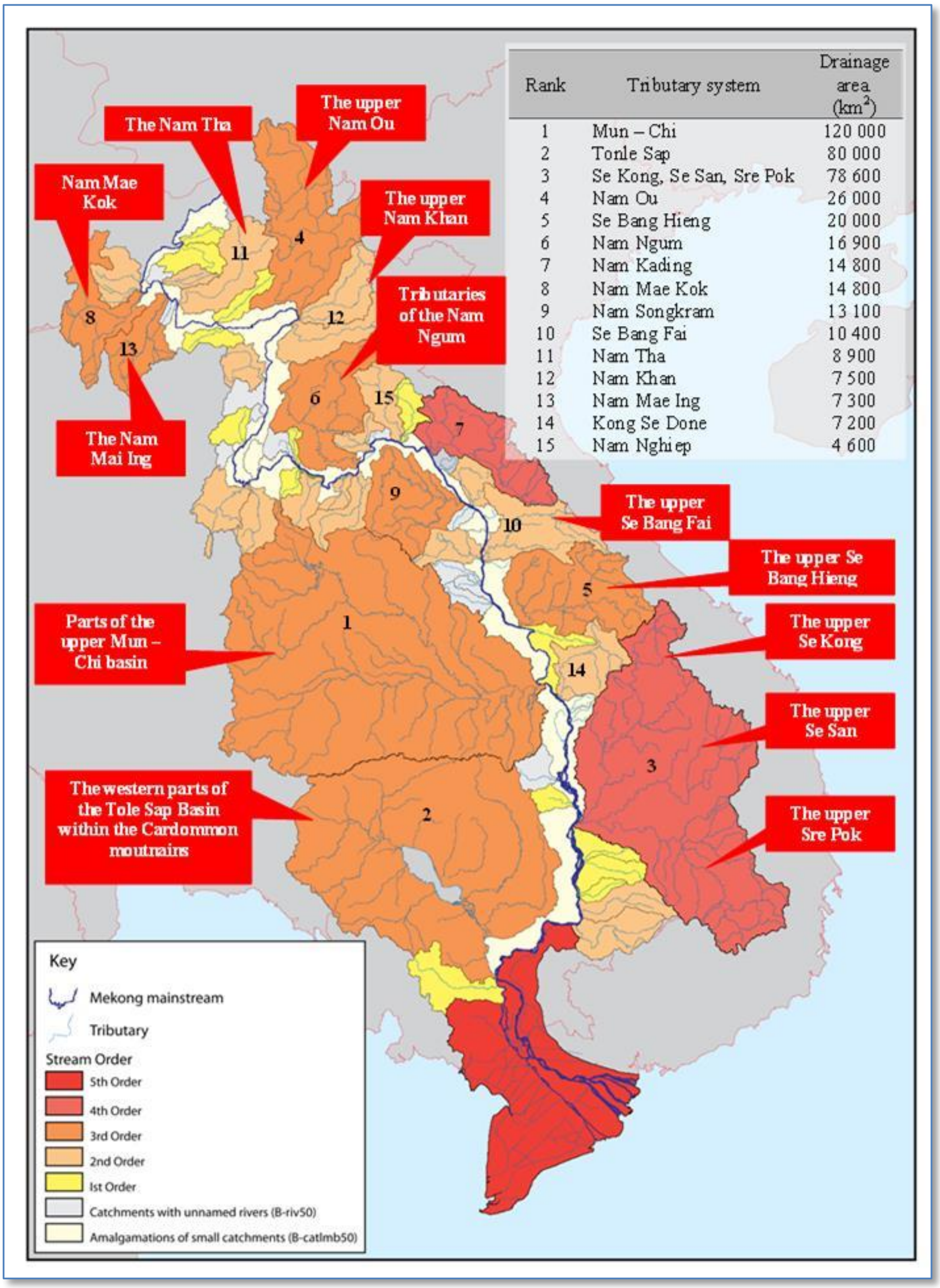
1) The tributary river systems of northern Thailand, in particular those of the Nam Mae Kok and Nam Mae Ing which has regularly caused devastating flooding in Chiang Rai and Chiang Mai.
2) The upper reaches of the Xe Kong, Se San and Srepok, which are by and large remote, where flash flooding is virtually perennial event and where relief efforts are difficult to implement due to poor communications and infrastructure damage to roads and bridges.

In the final analysis flash floods are a recurrent regional hazard, the effects of which need equal focus in terms of management and mitigation relative to riverine flooding, specifically from the Mekong mainstream.

2.5 The potential impacts of land use change and catchment degradation

Flash floods have been much in the news in recent years with the view widely held that their incidence and severity is increasing due to regional deforestation and landscape change. This is difficult to prove. The reality is that pressure on land resources and increased economic well-being means that an increasing number of people are vulnerable to the hazard and the value of the property and goods exposed to damage and loss is increasing year by year. The socio-economic consequences of floods and flooding is certainly now much higher.

The conventional view is that deforestation results in a decrease in the natural water storage capacity of a river basin which in turn leads to an increase in water yield, the magnitude of which varies with the local rainfall climate, the topography and the proportion, type and density of the removed forest cover (Newson 1997). In principle therefore, there are two potential hydrological impacts of deforestation that might be distinguished:



Rank	Tributary system	Drainage area (km^2)
1	Mun – Chi	120 000
2	Tonle Sap	80 000
3	Se Kong, Se San, Sre Pok	78 600
4	Nam Ou	26 000
5	Se Bang Hieng	20 000
6	Nam Ngum	16 900
7	Nam Kading	14 800
8	Nam Mae Kok	14 800
9	Nam Songkram	13 100
10	Se Bang Fai	10 400
11	Nam Tha	8 900
12	Nam Khan	7 500
13	Nam Mae Ing	7 300
14	Kong Se Done	7 200
15	Nam Nghiep	4 600

Figure 2-6 Major tributary systems of the Lower Mekong Basin and the sub-areas that have been most prone to the incidence of flash flooding since 1990.

1. the total water yield is increased as annual evapo-transpiration decreases, and
2. the seasonal distribution of flows is modified as flood runoff increases and dry season flows decrease.

It is also widely believed that the impacts of tropical land-use change on hydrological processes are easily observable. However, rigorous analysis of the few case studies that are available indicates that many impacts are often not significant at the landscape-scale or are short-lived, and often obscured by data quality and natural system dynamics (Chappell and Tych. 2003). On a country by country basis in the Mekong region the decline in the national area prescribed as forested from 1960 onwards is indicated in Table 2-9. The conclusion from such figures would be that the river regime must have already undergone considerable change if the general views on the hydrological impacts of deforestation are supported.

Table 2-9 Change in forest cover over continental SE Asia from the 1960's to 2000. (after Stibig et al 2004) 1 Meyer and Panzer (1990); 2 Klankamsorn and Charuppat (1994); 3 Perrson (1974); 4 FAO (2001); 5 MRC 2003 ; 6 Chinese National Bureau of Statistics.

Country	Period			
	1960's – 1970's	circa 1980	circa 1990	circa 2000
Cambodia	>70%[1]	>70%[1]	67%[1]	53%[4]
Laos	60%[1]	-	47%[1]	41%[5]
Thailand	53%[2]	34%[2]	28%[2]	29%[4]
Vietnam	42%[1]	-	28%[1]	30%[4]
Myanmar	58%[3]	-		52%[4]
Yunnan	55%[6]			33%[6]

At the Basin scale there is no statistical evidence to confirm that deforestation has had any impact on the flow regime of the Mekong mainstream in the direction that would suggest the impacts of deforestation, such as an increase in mean annual discharge and flood flows. Lower mean annual flows post 1984 confirm that these decades were generally drier.

Table 2-10 Split sample means for selected hydrological variables for the Mekong mainstream at Vientiane and Kratie within the period 1960 to 2009. The dry season flow is defined as the annual minimum 90 day discharge. The lower flows post 1984 indicate a generally drier sequence of years. Under the effects of deforestation flows in this period would be expected to be higher than in the earlier sub-period.

Hydrological variable	Vientiane		Kratie	
	1960 – 84	1985 - 2009	1960 – 84	1985 - 2009
Annual flow.	146.7 km^3	134.8 km^3	431.3 km^3	402.0 km^3
Maximum discharge.	17 200 cumecs	15 300 cumecs	54 200 cumecs	45 900 cumecs
Dry season flow.	1 250 cumecs	1 220 cumecs	2 350 cumecs	2 450 cumecs

Reducing the scale from the mainstream to the tributaries might be thought to reveal the hydrological impacts of the loss of forest cover. The four catchments indicated in Figure 2-7 in northern Thailand and Lao PDR have undergone significant land use change since 1960 with respect to deforestation, while the upper Nam Khan has historically seen extensive “slash and burn agriculture leading to widespread land degradation.

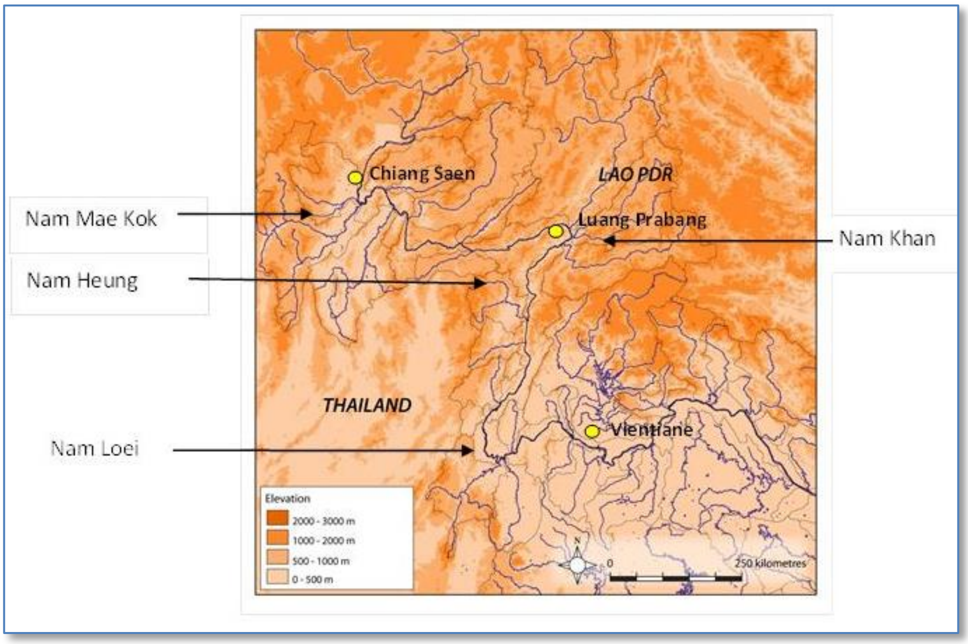


Figure 2-7 Tributaries in the northern part of the Lower Mekong Basin in which have seen extensive deforestation since 1960.

The results presented in Table 2-10.indicate that even at this much reduced catchment scale they do not reveal any general systematic trends that can be accredited to human activity such as deforestation. Where some systematic drift in the data is statistically evident it is either relatively weak (just significant at the 5% level) or not in the direction expected, for example the historically significant decrease in the peak flows on the Nam Khan.

Table 2-11 Mann Kendal trend test results on selected aspects of the annual hydrology of four Mekong tributary systems identified as having undergone significant historical deforestation since 1960 (see Figure 2-7).

River	Site	Catchment km^2	Period of record	Annual Flows	Peak Flows	Low Flows
Nam Mae Kok	Ban Tha Thon	3 000	1969 - 2004	×	×	×
Nam Khan	Ban Mixay	6 000	1960 - 2004	✓ down	✓✓ down	✓ down
Nam Heuang	Ban Pak Huai	4 100	1967 - 2003	✓ up	×	×
Nam Loei	Wang Saphung	1 250	1960 - 2003	×	×	×

×: no trend. ✓ up / down significant at the 5% level. ✓✓ up / down significant at the 1% level.

Other regional studies have failed to find any statistically significant evidence of the impact of deforestation on flow regimes. Wilk et al (2001) acknowledge that small scale experiments have demonstrated that forest clearance leads to an increase in water yield. However, they failed to establish that this result holds for river basins greater than 1 000 km^2 in North East Thailand. For example, in the 12 100 km^2 Nam Pong catchment, despite a reduction in the area classified as forest from 80% to 27% between 1957 and 1995, no hydrological changes were detected. A research review (Kiersch, 2001) indicates that land-use effects on catchment hydrology were observable only in relatively small basins, while impacts on water quality were detectable over much larger areas (Table 2-12).

Table 2-12 The spatial dimension of land-use effects on catchment hydrology and water quality. Adapted from Kiersch. (2001).

Variable	Catchment Area. km^2				
	1	10	100	1000	10 000
Average flow	✓	✓	✓	✗	✗
Peak discharge	✓	✓	✓	✗	✗
Base (low) flow	✓	✓	✓	✗	✗
Sediment and nutrient load	✓	✓	✓	✓	✗
Water quality (eg pesticides, salinity)	✓	✓	✓	✓	✓

✓ observable impact. ✗ no observable impact

These results tend to suggest that at the 100 to 200 km^2 scale at which flash floods most frequently occur there is likely to be a direct impact upon their frequency and severity as a consequence of deforestation and land degradation. However, insufficient data are available to prove this to be the case without any real doubt. There is though a need to manage the catchment landscape at this scale, particularly in remote upland areas where social vulnerability is usually the most acute.

Figure 2-8 Structural damage from flash floods in northern Thailand and the Central Highlands of Viet Nam.

2.6 The potential impacts of climate change

If there is, as there probably is, an increase in the regional incidence of regional flash flooding then it will be the result of a combination of human impact at the local scale and climate change impacts induced at the global scale. Until recent times by far the greater emphasis of regional flood management and mitigation policy has focused on riverine flooding on the Mekong mainstream and much less on the tributaries. This is not to imply that the flash flood hazard on small catchments has not been generally acknowledged. However, it is only in recent years that practical risk assessment tools and geographical vulnerability measures have been developed, evaluated and put into practice. See Section 2.7 below.

The potential impacts of climate change on the incidence and severity of floods in the Lower Mekong Basin has not been specifically addressed except as part of the wider potential changes to hydrological regime driven by modification of the rainfall climate. In recent years there have been three key regional assessments:

- The Intergovernmental Panel on Climate Change Study (IPCC, 2007) considered the projections for the wider SE Asia region rather than focusing specifically on the Lower Mekong Basin. The principal conclusions were that on average seasonal (monsoonal) rainfall would increase by an average figure of 7% combined with a greater inter-annual variability. However, significant sub-regional variation is evident in the results.
- The Commonwealth Scientific and Industrial Research Organization Study (CSIRO, 2008) focused upon the Lower Mekong region. Under the projected climate in 2030, total annual runoff from the basin is likely to increase by 21%, an increase of ~107, km^3. Runoff increases are projected for all catchments, primarily resulting from increased flood season flows. It is likely that increased flooding will affect all parts of the basin under the projected climate for 2030. We may expect the impact to be greatest in downstream catchments on the mainstream of the Mekong River, because of the cumulative impact of runoff increases from catchments upstream. We have quantified the impact at Kratie, where the frequency of ‘extreme wet’ flood events is likely to increase from an annual probability of 5% under historic conditions to a 76% probability under the future climate.
- The MRC 2010 Study combined the impact of climate change on selected ‘basin development scenarios’ which makes the consequences of climate change difficult to separate out. It would have been far clearer and more digestible if a single report dealing only with likely climate change had been first produced separately. The study results suggest that mean annual flood season discharge could increase by 10-15 % along the entire length of the Mekong mainstream

The levels of uncertainty in each of these studies render the results, in quantitative terms, speculative at best. As a consequence, they indicate the need for well thought out, robust and flexible contingency plans that are regularly updated in the light of future research findings and that are capable of being adapted to future climate outcomes (MRC, 2012).

The confidence in such climate predictions, such as it exists, decreases significantly as geographic scale decreases. (IPCC, 2007). In this context we note that flash floods are a small scale phenomenon in relative spatial terms. In addition, none of the above regional studies address the issue of potential change to storm rainfall intensity which is the major meteorological factor in the generation of flash flood runoff. They, like most such studies, consider changes to mean annual rainfall and storm incidence, without any specific definition of what constitutes a "storm" as opposed to a "wet day".

Much of the significant research on flash floods and the potential impact of climate change upon their incidence have been undertaken in Mediterranean Europe, where historically they have been a perennial hazard. In general terms these European results are meaningful within the tropics and offer pertinent material for consideration. Of course, there are differences. Not least amongst these is that the potential for flash flood casualties and damages is not increasing in Europe as in many developing regions where due to social and economic development and the implied pressure on land use, vulnerability and exposure to the flash flood hazard remains.

Staying with these Mediterranean studies:

- In a study of the impact of climate change on storm intensity rather than overall depth (Gordon et al, 1992) found that in all regions (of the Mediterranean) the frequency of extreme rainfall events increases, and the return period of such events decreases markedly. If realistic, the findings have potentially serious practical implications in terms of an increased frequency and severity of flash floods as a consequence of climate change.
- Furthermore, evidence of increasing heavy precipitation at regional (Groisman et al., 2004) and global scales (Groisman et al., 2005; Beniston, 2009) supports the view that the global hydrological cycle is intensifying as a result of global warming (Huntington, 2006). Consequently, the flash flood hazard is expected to increase in frequency and severity, through the impacts of global change on climate, severe weather in the form of heavy rains and river discharge conditions (Kleinen and Petschel- Held, 2007; Beniston et al., 2011).

The small spatial and temporal scales of flash floods, relative to the sampling characteristics of conventional rain and discharge measurement networks, make also these events particularly difficult to observe and to predict (Borga et al., 2008). In an investigation of twenty-five major flash floods that occurred in Europe in the last twenty years, Marchi et al. (2010) showed that less than one half of the cases were properly documented by conventional stage measurements. In many cases, the rivers were either ungauged or the stream gauge structures were damaged by the event. Similar considerations apply to the rainfall estimation, as the spatial and temporal scales of the events are generally much smaller than the sampling potential offered by even supposedly dense rain gauge networks (Anagnostou et al., 2006).

2.7 Flash flood risk – forecasting, assessment, management and policy

"*The mortality rate for flash floods is significantly higher than for other kinds of flooding.*" (Sene, 2012). This argument may be valid in temperate and mid latitude regions but it is not necessarily appropriate in the tropics. The point has already been made that during riverine flooding, particularly across the Cambodian floodplain and the Mekong delta, indirect fatalities due to post event water borne disease far exceed those caused by direct causes such as drowning. The distinction is a key element within the overall design and implementation of regional flood management policy.

Flood risk management policy is based on considerations of flood risk management measures, roles and responsibilities of government agencies and departments. (See Flood Risk Management explained in Volume 2 of the FMMP 2011-2015 Programme Document).

As particularly flash floods affect the local communities in rural and remote areas, the resilience of local communities against the negative effects of flash floods is a relevant issue to deal with. The flood risk management policy element "resilience" is relevant in order to enhance the resilience level of local communities through a cycle of systematic actions:

- Preparedness,
- Response,
- Relief, and
- Recovery.

Preparedness: in the case of flash floods needs to recognize that by their very definition an event cannot be predicted at any given location within any great degree of confidence. In other words, they are spatially random events, modest in spatial scale but often devastating in terms of impact. The strategy is therefore to assess the local physical risk given the state of a catchment in terms of soil saturation and the prospects of intense storm rainfall. On this basis society can instigate the required mitigation measures given appropriate warning of exposure to the hazard.

Response: inevitably, flash floods are prevalent in the more remote upland regions, which is not only the case in the Lower Mekong Region but is, by and large, the circumstance worldwide. Inevitably, this slows down the response since accessibility can be a problem due to damaged communication infrastructure. Direct fatalities can be significant as can be structural damage, which requires a civil response including medical care, the provision of shelter, food, water and medication. These "response" issues are exacerbated by the fact that regionally those exposed to the flash flood hazard are amongst the most poor, with no meaningful reserves to draw upon.

Relief: in case of flash floods effective response by disaster management agencies, NGOs and others of both immediate and longer-term necessities—food, water, shelter, protection and physical as well as mental health care— provides relief to the affected communities.

Recovery: recovery implies some degree "restitution" of the damaged infrastructure, which generally applies to public works and not to private property. It also implies land management policies that reduce exposure to risk. This phase is key to the incremental development of national flood defense policy.

In order to mitigate fatalities during flash floods from drowning and structural collapse, risk analysis has a crucial role to play. However, this is much more complex than that of predicting the impacts of cumulative rainfall excess .and the potential for riverine flooding. Forecasting potential is implicitly limited by both the fast response of the catchment and the uncertainty in the temporal and spatial variability of both rainfall and soil properties. High rainfall intensity is more important the than total accumulated rainfall on small, fast response river basins. Basin characteristics are easily as important as the rainfall climate for determining the timing and magnitude of the potential flood runoff. Additional deterministic factors are the size of the basin, slope and permeability and the nature of the land use. (See Gruntfest and Handmer, 1999).

While flash flood warning systems can substantially assist in reducing loss to life and property, they need to be integrated into a more general framework of flood risk management. (Borga et al, 2011). Other risk management tools are complementary to warning systems. Also, there will be instances when there is not enough warning time and people may not be reached or will ignore warnings. Similar to the forecasting and warning component, risk management should be based on a fully integrated approach which recognizes the specificities of flash floods. These include:

(i) the difficulties of relying on traditional physical flood defense infrastructure;
(ii) the multi-hazard nature of flash flood risk, particularly when it involves upland and highland settings;

(iii) the need to develop specific preparedness strategies which incorporate event management.

The identification of flash flood risk areas should inform the risk management process. The difficulties of relying on flood protection works places emphasis on land-use planning and flood event management. It is important to combine these two steps of flash flood risk management into one synthesized plan to enable the sharing of information between land-use planning and water management and civil protection authorities and to exploit the synergies between these two management fields (Samuels et al., 2008).

Storm quasi-stationarity is a characterizing feature of several flash flood-generating rainfalls, with very intense precipitation occurring on the same locations for enough time to produce heavy accumulations. One of the elements that favour the anchoring of convective system is the orography, which plays an important role in regulating of atmospheric moisture inflow to the storm and in controlling storm motion and evolution (Smith et al., 1996; Davolio et al., 2006). Relief is necessary for promoting flow concentration along drainage ways, which results in high unit discharges and relevant geomorphic effects of flash floods in sloping watersheds. Heavy convective precipitation may occur also in plain areas, but the ensuing flood generally lacks the kinematic component, which characterises the propagation and the hazard potential of flash floods. Collier and Fox (2003) and Collier (2007). A key element of risk assessment is therefore the tracking of such slow moving convective cells.

Observational difficulties regarding flash floods and the lack of a comprehensive archive of flood events across the Lower Mekong Basin hinder the development of a coherent framework for the analysis of flood climatology, hazard and vulnerability. This situation is not unique, however. It is also the case in Europe. (See, for example, Barredo 2007). Often, flash floods, landslides and debris flows occur in conjunction which may cause amplification of the hazard – for instance, by inducing drastic changes in stream bed morphology during flash flood events. Such changes can increase the future risk of damage and loss.

Flash flood mitigation policy is inevitably “bound up” with flood management policy in general, which at the national scale is assimilated within strategies and response mechanisms to the wider spectrum of geophysical hazards, which would include drought and earthquakes. There is though, in the case of flood exposure, the clear mitigation option of land use management , that is reducing, as far as is practically possible, social vulnerability. In the developing world, this is easier said than done. Floodplains and riparian lands are generally amongst the most agriculturally productive and have therefore been a focus of historical settlement despite the risks. Pressure on land resources given high population growth rates aggravates the situation.

The flood proofing of private houses, schools and clinics is a policy option that is being increasingly applied with respect to riverine flooding, particularly across the Mekong Delta in Viet Nam. However, such structural options are limited in the case of flash floods. Their erosive power, debris loads and very high kinetic energy, with average flow velocities in excess of 3 m/second, precludes flood proofing as a practical engineering and financial option (Marchi el al, 2010).

2.8 Flash flood guidance systems in the Lower Mekong Basin

In order "*to respond to regional and national needs and ... to address the problems of flash floods in the Lower Mekong region, the MRC and the Hydrological Research Centre (HRC) in San Diego, California, , with the financial support from the Office of US Foreign Disaster Assistance (OFDA) of the US Agency for International Development (USAID) have jointly implemented a flash-flood guidance system in Cambodia, Lao PDR, Thailand and Vietnam under the MRC Flood Management and Mitigation Programme (FMMP).*" (MRC – FMMP, 2012).

In late 2009 the computational and dissemination servers for the MRC-FFG system were installed at MRC's Regional Flood Management and Mitigation Centre (RFMMC) in Phnom Penh, which allowed the line agencies of the MRC member countries and the RFMMC to obtain access to the FFG products for training as well as for operational purposes.

The system is driven by satellite imagery, which provides:

- Mean areal precipitation, updated hourly.
- Average Soil Moisture, updated every 6 hours.
- Flash risk indices, updated every 6 hours

The information received from the system is processed, updated and then posted to the MRC flood forecasting webpage in parallel with the Mekong mainstream flood forecast. An example of the output is illustrated in Figure 2-9 and Figure 2-10.

The system implicitly acknowledges the fact that flash floods cannot be forecast in any practical deterministic way but that tributaries and sub-basins that are at vulnerable at a given time can be identified. "*as at risk*".

Over the three years that the system has been evaluated, it has performed very well. It is recognized that confirmatory data from the tributary hydro-metric network is less than ideal as water level data are only reported once a day, whereas flash flood events characteristically have a much shorter duration, typically less than six hours.

Non the less the system can be confirmed as highly effective. On occasions were flash floods were “missed” the conditions are investigated.

The Thai government’s National Policy statement on Land, Natural Resources and the Environment of December 2008 heeds the lessons of recent national disasters and calls for a greater emphasis upon preventive measures, such as early warning systems and the use of geo-informatics to identify and monitor areas at risk. Amongst the approved measures is the installation of an early warning system for flash flood and landslide risk which was designed to cover 2 300 villages by 2012, the establishment of the ‘Mekhala Centre’ for water crisis management which will exploit modern IT technology and Decision Support Tools and improved flood warning in the Mun-Chi Basin based on an expanded telemetry system.

Accounting for the multi-hazard nature of flash floods is particularly important. Often, flash floods, landslides and debris flows occur in conjunction which may cause amplification of the hazard – for instance, by inducing drastic changes in stream bed morphology during flash flood events. However, mapping of flood risk zones, which is an essential element in many national legislations, is generally based only on flood hazard assessment (Neuhold et al., 2009). There is therefore a need to develop a multi-risk approach which can tackle possible ‘‘simultaneous’’ and ‘‘cascade’’ effects due to coincident, or induced, occurrence of flash floods, landslides and debris flows that amplify the risk in some areas, and may be not accounted for by single hazard estimations.

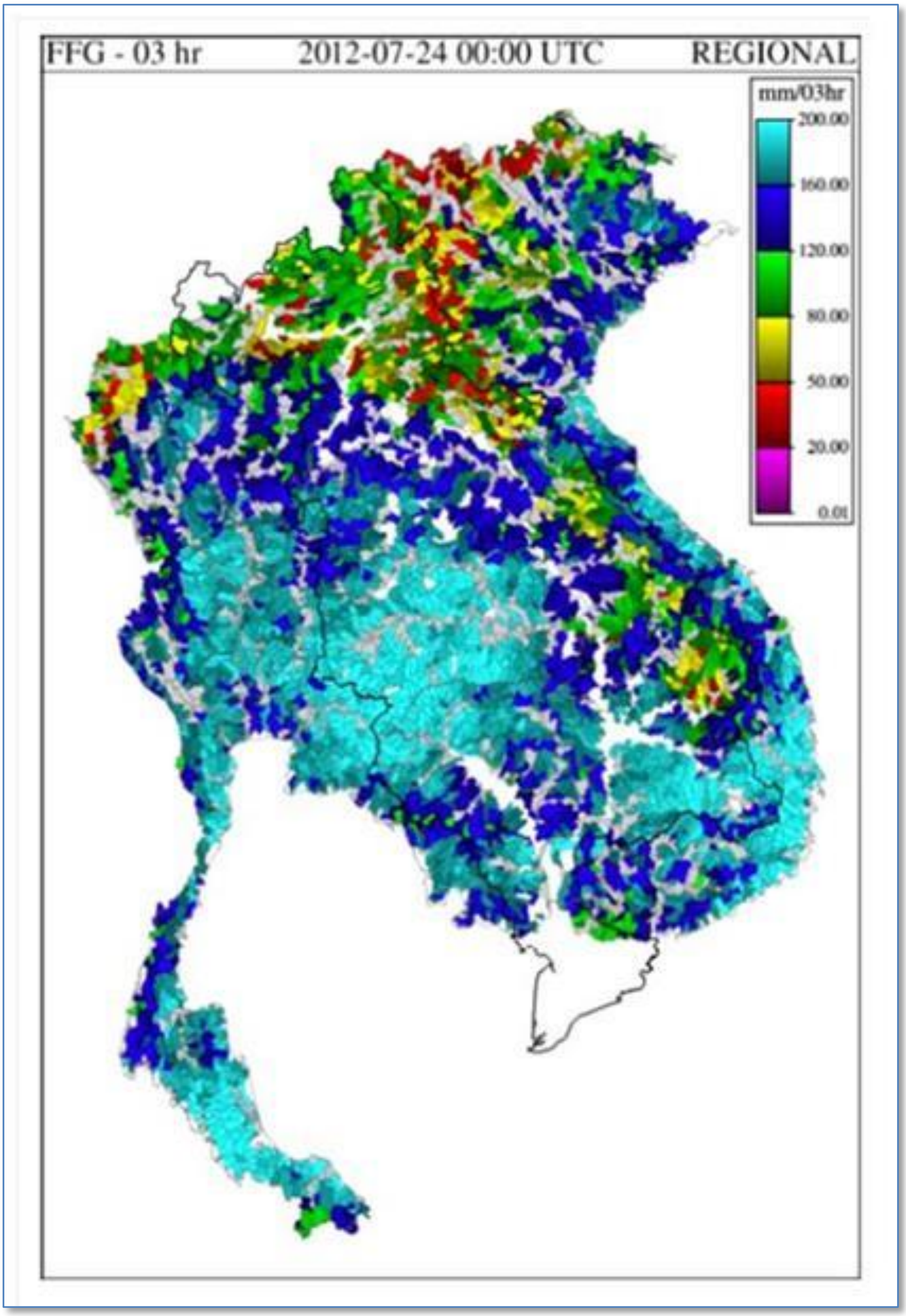


Figure 2-9 Three hourly regional rainfall on the 24th July, 2012 observed at 00:00 hours local time (UTC). (As produced to the MRC – FMMP flood website by the Flash Flood Guidance System).

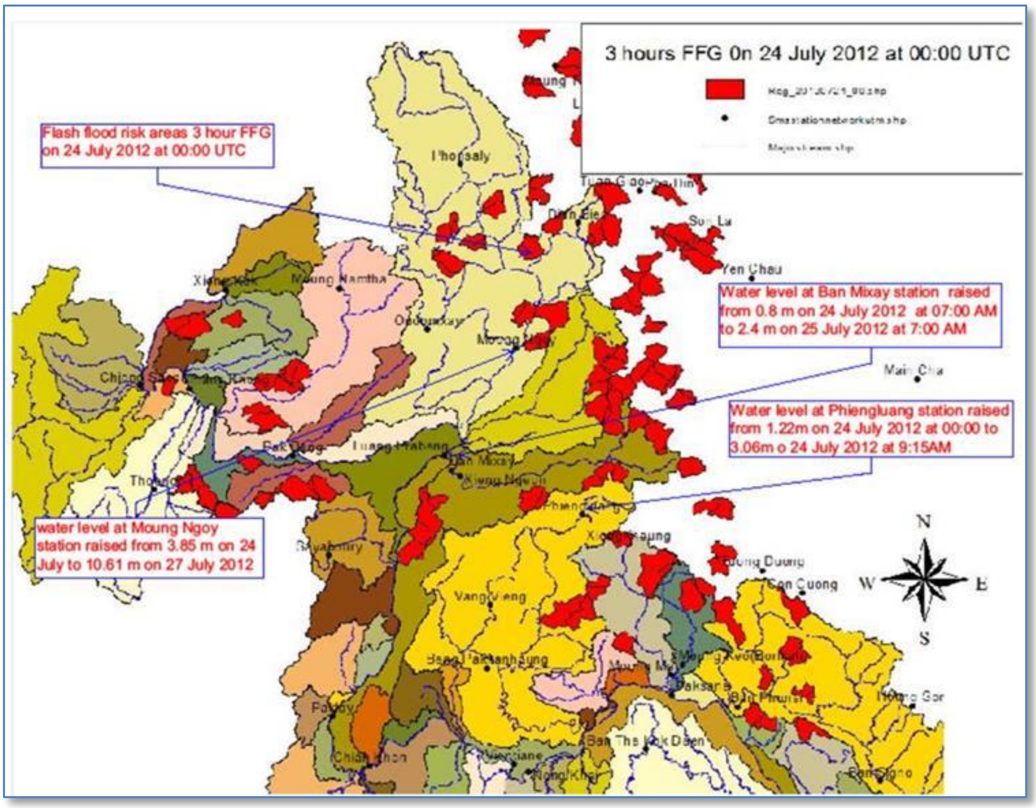


Figure 2-10 Map of flash flood risk areas (in red) on the 24th July 2012 on sub catchments of the Nam Ou, Nam Khan, Nam Ngum and Nam Xong tributaries in the north of Lao PDR. (As produced to the MRC – FMMP flood website by the Flash Flood Guidance System).

Figure 2-11 A component of the flash flood and landslide monitoring network in Thailand.

2.9 Flash floods and riverine floods in the Lower Mekong Basin

By their very nature, flash floods have a high peak discharge but a relatively small volume. They would not, therefore, be expected to provide a significant contribution of flood water to the Mekong mainstream in volumetric terms. Never the less the meteorological conditions that cause major regional riverine flooding would also tend to favour the development of flash flood runoff in the steeper upland tributary areas. Intense convectional activity, deep tropical low pressure systems and typhoons have historically been the principal cause of major flooding within the Mekong system. At the local scale, therefore, flash flood conditions are an integral component of major regional flooding and as such contribute significantly to the overall figures with respect to fatalities, economic loss and damage.

Conversely, local flash floods can, and often do, occur quite independently of the wider regional flood situation. The latter, in flooding terms, may be quite unremarkable, with mainstream discharge and water levels average or less. Even so, localized flash flood events can prevail. The situation during 2012 is a case in point. Hydrological conditions on the Mekong mainstream during the flood season were considerably below average, such that the season would be classified as “dry”. In all respects the flood season of 2012 was one of the “weakest” on record in terms of the wider regional “picture” (see Section 3.4, below). Notwithstanding this, serious small scale flash flooding did take place. See Section 3.6, below.

Flash floods can and do dissipate quite rapidly. Initiated (usually) in the steeper tributary uplands they rapidly translate as a high velocity hydraulic wave of relatively short duration but with disproportionate kinetic energy. They often lead to significant changes in river channel geomorphology while the associated sediment and debris loads add to their destructive capacity. However, once the hydraulic gradient decreases and velocities decelerate sediment and debris are deposited acting as a restraint to flood wave celerity. The damage resulting from flash floods is a combination of excessive hydraulic energy combined with often enormous debris loads. This mixture leads to, for example, the undermining of structural foundations and, as debris accumulates against bridge piers, the destruction of transport and communication systems.

That such floods are a recurrent feature of the regional hydrological landscape and one of the major geophysical hazards is well established. However, the fact that they usually occur on small, un-gauged tributary catchments means that there is little, if any, directly observed hydrological data. This hampers the process of understanding and learning from past events. The recent commissioning of the regional Flash Flood Guidance System (FFGS) is a major step forward towards bringing about a deeper understanding of this type of event in terms of their risk, geographical distribution, the antecedent conditions necessary and the causative meteorology. One initiative that has been implemented as part of the MRC-FFG system has been to verify the localities indicated to be at risk and then "follow up" what actually occurred using news media reports. During the 2012 flood season the system performed commendably in that flash flood events reported in the media occurred in local areas that had been identified as "at risk".

Borga et al (2011) investigated the relationship between the catchment area and the unit peak discharge during flash floods across Mediterranean Europe either observed directly by gauge measurement or estimated indirectly using flood marks. The results were plotted in log space and the upper envelope curve determined. This took the form:

$$\mathbf{Q_u = 97\ A^{-0.4}}$$

where $\mathbf{Q_u}$ is the unit peak discharge in cumecs/km^2 and **A** is the upstream area in km^2. Selected values provided in this relationship are indicated in Table 2-12. They are far higher than those obtained by the analysis of a sample of European riverine floods (Herschy, 2002), thus pointing out the extreme intensity of runoff generation during flash floods. The situation in the tropics is unlikely to be much different.

Table 2-13 Peak unit area discharge for flash floods estimated from data across Mediterranean Europe, based on Borga et al (2011).

Upstream drainage area km^2	Peak unit area runoff cumecs / km^2
50	20
100	15
200	12
500	8

3. THE 2012 FLOOD SEASON

3.1 Overview

Following the significant flood conditions of 2011, the situation during 2012 proved to be quite the opposite. The flood peak and volume were between 30 and 40% below the long term average. The flood season was a month shorter than usual. All in all 2012 turned out to be one of the most deficient annual floods of the last 25 years, matching the situation during 1992, 1998 and 2010.

The deficient hydrological conditions reflected a meteorologically dry year overall. Geographically, rainfall was variable during the monsoon season with only limited areas of the Basin recording monthly totals of any significance. In general total precipitation was well below average, in places by as much as 40%. Locally, however, rainfall was close to average due largely to mesoscale storm events that are events which extend over no more than 1 000 km^2. The onset of the SW Monsoon took place during late April / early May as is normal but ended up to a month early in mid to late September over the greater part of the region. This early ended to the Monsoon combined with low seasonal rainfall in general provided the combination that has defined some of the lowest annual floods over the last two decades.

Maximum water levels across the Cambodian floodplain and the Delta reflected the hydrological conditions further upstream and were 1m and more less than the long term average. On the Tonle Sap at Prek Kdam the maximum flood level during the year was the fourth lowest that has been observed since 1960. This would lead to the depth and areal extent of the Great Lake that were at low levels.

Such annual flood deficits are not, however, uncommon. The question that arises, though, is whether they are becoming more common. A parallel query might be whether the inter-annual variability of the flood regime is increasing in any significant way. During the last three years, 2010 was exceptionally dry, 2011 exceptionally wet and 2012 exceptionally dry again. Such a pattern is unusual. Wet years tend to follow wet years and drier conditions tend to replicate themselves according to a semi-periodic pattern. These aspects are considered here.

There is a growing body of evidence that the Chinese hydropower cascade on the mainstream in Yunnan is having an impact upon not only the downstream low flow regime but also on the flood regime during drier years, such as 2012. This shows itself in “spikes” or spates of flow at Chiang Saen which are difficult to explain since between there and the upstream dams there are no large tributaries that would generate such events naturally. These spates are still evident at Vientiane, but dissipate further downstream.

All in all, 2012 was a "dry year" and the flood was comparable to events over the last 20 years that were classified as "extreme", in the sense of being much below average.

3.2 The temporal aspects of the SW Monsoon over the Lower Mekong Basin during 2012

The onset and end dates of the SW Monsoon across the Mekong region have a remarkably low variability from year to year. It normally begins during the first week of May and ends in mid to late October. Any delay in the onset of more than a week or two is significant. However, it is the early withdrawal of the Monsoon that leads to the most serious consequences, particularly in the agricultural sector. Soil moisture rapidly becomes depleted at one of the most important periods of the growing season, generally referred to the "grain filling stage". As a consequence, crop yields are considerably reduced.

The situation in 2012 combined a very weak Monsoon in terms of total rainfall being much less than average with, in addition, the "wet season" ending a month early over most of the region as the data at selected sites in the Basin illustrate in Table 3-1.

Post monsoon rain that is beyond mid to late October, still continues in the southern part of the Indochina Peninsula until the latter part of November indicated by the withdrawal date in the Delta at Tan Chau.

Table 3-1 The onset and end of the 2012 SW Monsoon at selected sites in the Lower Mekong Basin.

Site	Monsoon onset				Monsoon end		
	Average Date	Standard Deviation	2012	Delay. (days)	Average Date	Standard Deviation	2012
Chiang Saen	7th May	9 days	5th May	none	7th Nov	25 days	6th Oct
Luang Prabang	7th May	9 days	17st May	10	24th Oct	33 days	27th Sep
Vientiane	4th May	8 days	3rd May	none	10th Oct	16 days	10th Sep
Mukdahan	6th May	8 days	6th May	none	8th Oct	16 days	15th Sep
Pakse	5th May	11 days	26th Apr	none	15th Oct	17 days	16th Sep
Tan Chau	18th May	12 days	6th Jun	19	18th Nov	13 days	17th Nov

3.3 The regional rainfall climate during 2012

Geographically total seasonal rainfall across the region can be quite variable. Monsoonal rainfall is characterized by strong convection cells which tend to be classified as "mesoscale", that is they extend over no more than 1 000 km^2. As a consequence just a few such events centered over a local area can boost precipitation to figures considerably above that over other areas.

Generally, during 2012 rainfall was significantly below normal by as much as 30 to 40%. Indicative figures at selected sites in the Basin are presented in Table 3-2. This small sample tends to indicate that the more central parts (Mukdahan and Pakse) were the driest, while the north and south were either wetter or average. As Figure 3-1 reveals the accumulation of rainfall at Vientiane and Pakse the wet season ended early during mid August.

Table 3-2 Lower Mekong Basin – 2012 rainfall compared to the long term annual mean at selected sites.

Raingauge	Mean annual rainfall (mm)	2012 (mm)	2012 / average
Chiang Saen	1 750	1 490	86%
Luang Prabang	1 250	1 733	139%
Vientiane	1 650	1 669	101%
Mukdahan	1 500	1 020	68%
Pakse	2 040	1 607	79%
Tan Chau	1 220	1 100	90%

Figure 3-2 to Figure 3-6 indicate the total monthly rainfall throughout the Lower Mekong Basin during each of the wet season months:

- In June rainfall was generally low with just a few highly localized exceptions. Conditions across NE Thailand were particuly dry.
- During July the poor rainfall over Thailand continued, with only the Nam Theun Basin and adjascent areas indicating even modest figures.
- The pattern for August was very similar to that of July, with no rainfall of any consequence over the greater part of NE Thailand.
- In September the more southern and eastern areas defined by the Central Highlands experienced reasonable amounts of rainfall. Elsewhere the relatively drier conditions continued.
- By October the monsoon season had ended over most parts, though large areas of the west did receive some precipitation, though probably no more than 100 mm or so over one, two or three days.

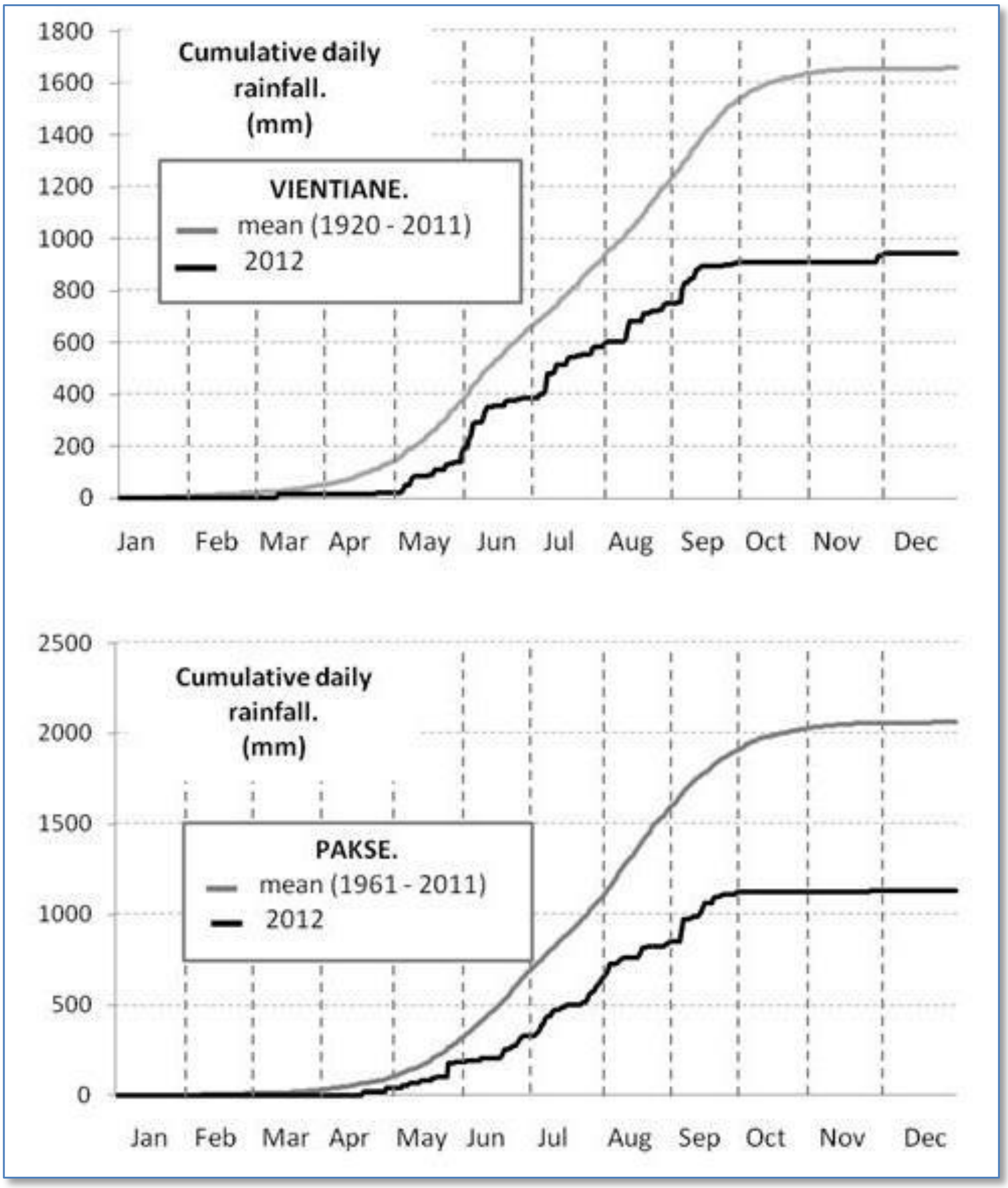


Figure 3-1 Cumulative daily rainfall at Vientiane and at Pakse during 2012 compared to the long term pattern. At Vientiane the 2012 SW Monsoon began at the start of May but rainfall followed the average pattern and amount for the whole season. The monsoon ended very early during mid August. At Pakse the pattern of cumulative rainfall is similar to that at Vientiane, but the seasonal total was some 20% below the long term average.

The total area of the Lower Mekong Basin down stream of Chiang Saen is of the order of 570 000 km^2. The rainfall maps are based on data recorded at 119 sites meaning that in principle each gauge “represents” the rainfall climate over 4 800 km^2. In practice of course this is not the case. The raingauge network density is far higher in NE Thailand than elsewhere such that a more accurate “picture” of the geography of the Monsoon is available there. The major constraint with respect to the regional network as a whole is the limited coverage across Lao PDR where most of the flood runoff is generated. The gauges here are also concentrated at lower altitudes with relatively sparse coverage in the highlands where the rainfall and therefor the runoff is much higher. Nevertheless the maps do provide a practical and informative macro assessment of the geographical distribution of monthly rainfall.

Storm rainfall generated by the mesoscale convective systems that typify the Monsoon tends to be highly variable in its spatial extent and depth. This is clearly illustrated by the two radar images of precipitation observed over Cambodia from the Phnom Penh installation shown in Figure 3-7. Ground based observation networks are obviously never dense enough to replicate such detail but are key to obtaining point rainfall figures and to “ground truthing” the radar figures.

Other than mesoscale convection the other synoptic component of the climate are Monsoonal Depressions (or troughs) which account for rainfall over wider areas, typically of between 1 500 and 3 000 km^2. Characteristically, there are six or so such events per year and they account for 45 to 55% of total seasonal rainfall. However, Jin-Ho and Wan-Run (undated) found that in India there was no significant correlation between the annual number of such depressions and total seasonal rainfall. Tropical cyclones often form in the vicinity of such troughs in the western Pacific.

During the course of the Monsoon season the probability that a day will be wet (> 1 mm) reaches figures as high as is high as 60% and more during the core months of June to early September (Figure 3-8 and Figure 3-9). Similarly, the probability of storm days during which rainfall exceeds 25 mm and significant storms days when it exceeds 50 mm is considerable compared to other climatic regimes.

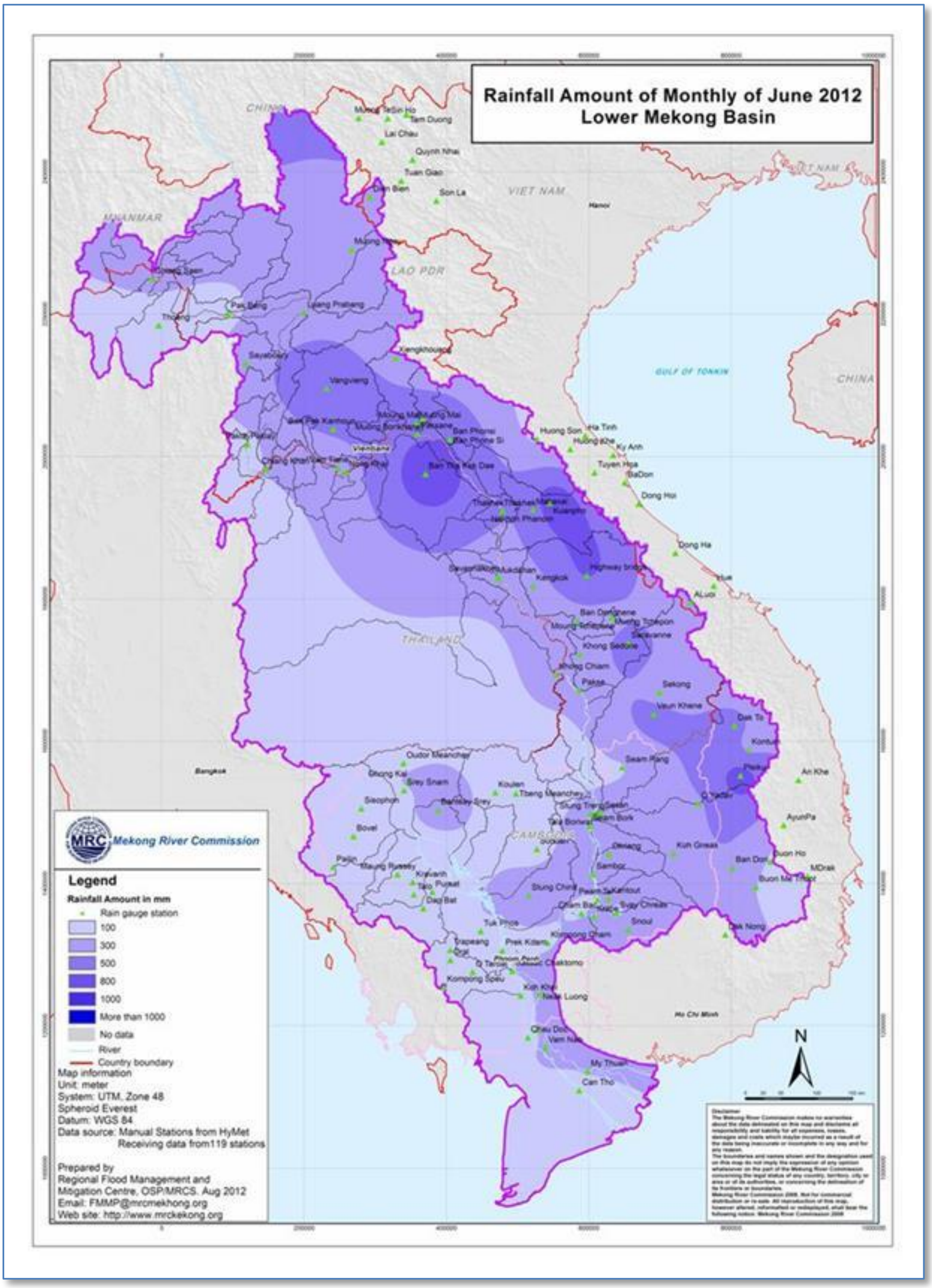


Figure 3-2 Rainfall over the Lower Mekong Basin – June 2012.

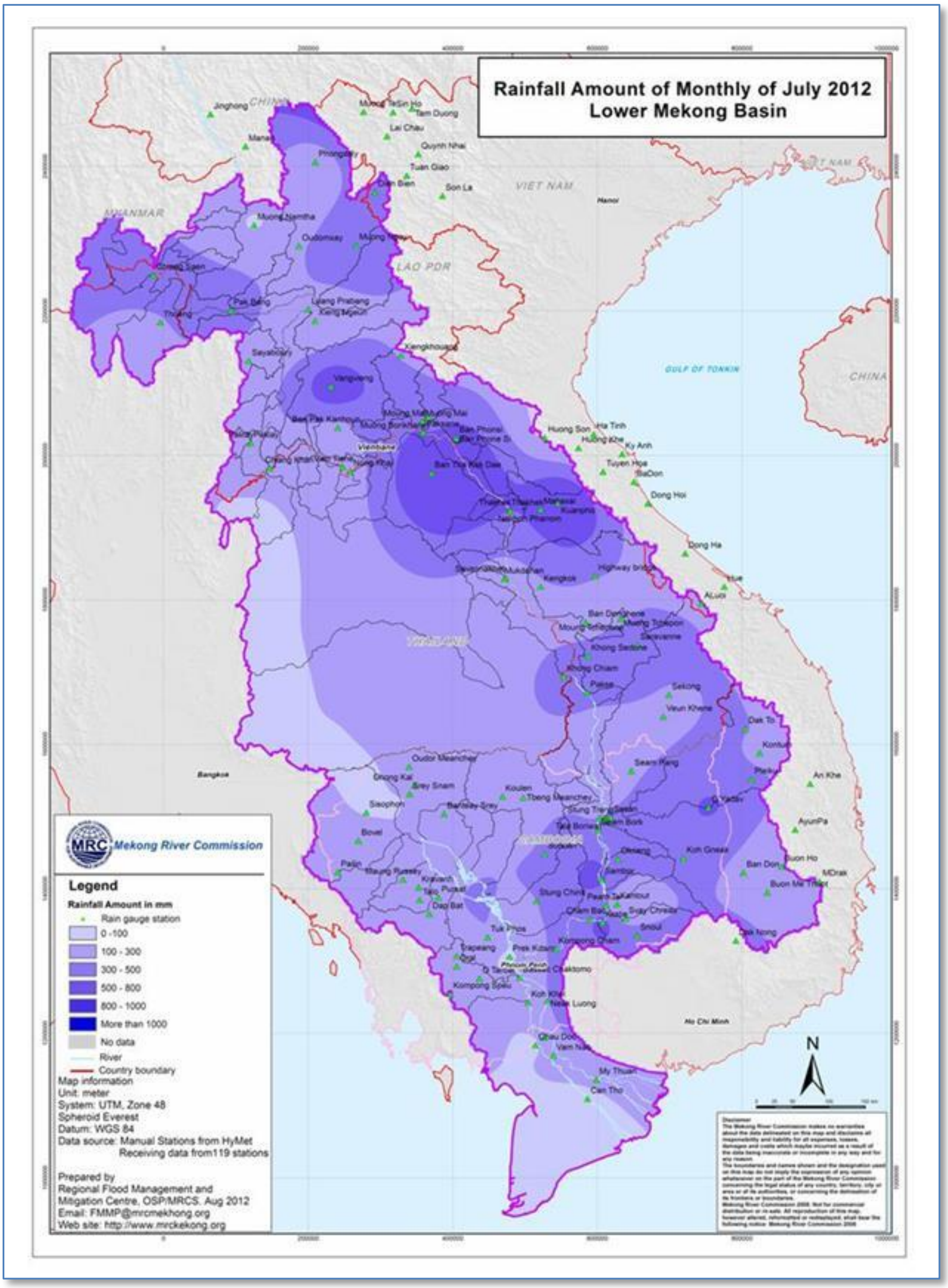


Figure 3-3 Rainfall over the Lower Mekong Basin – July 2012.

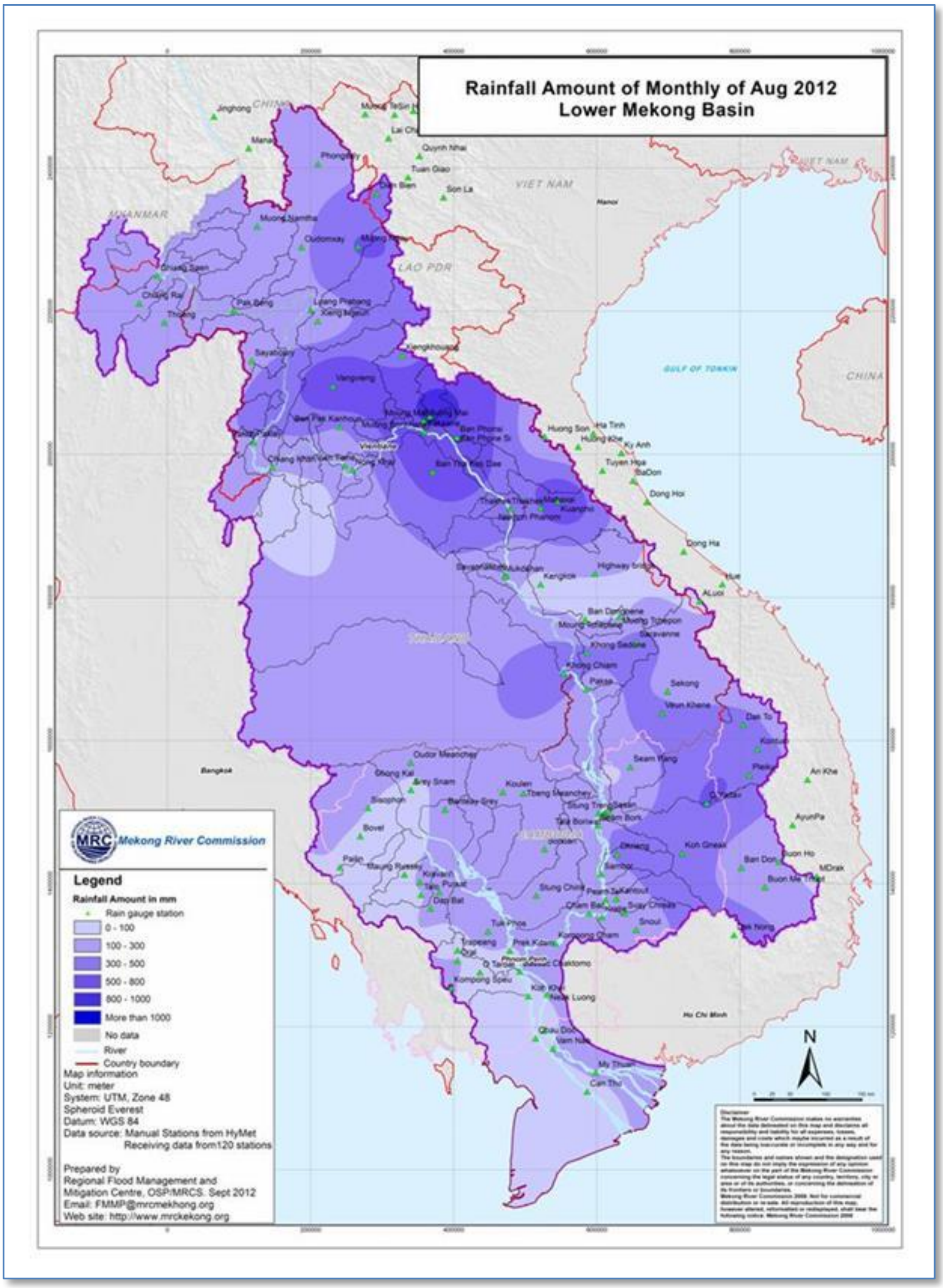


Figure 3-4 Rainfall over the Lower Mekong Basin – August 2012.

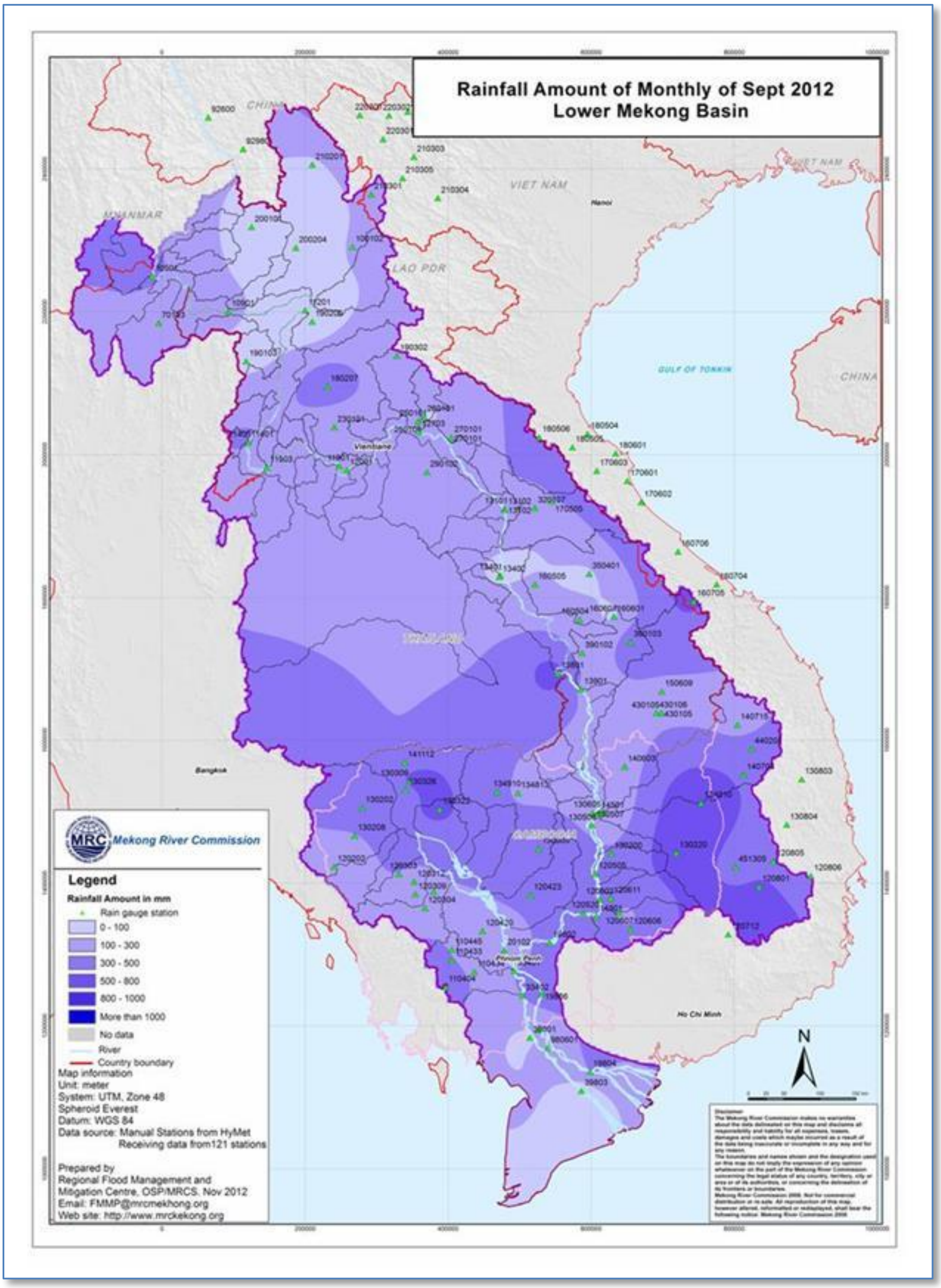


Figure 3-5 Rainfall over the Lower Mekong Basin – September 2012.

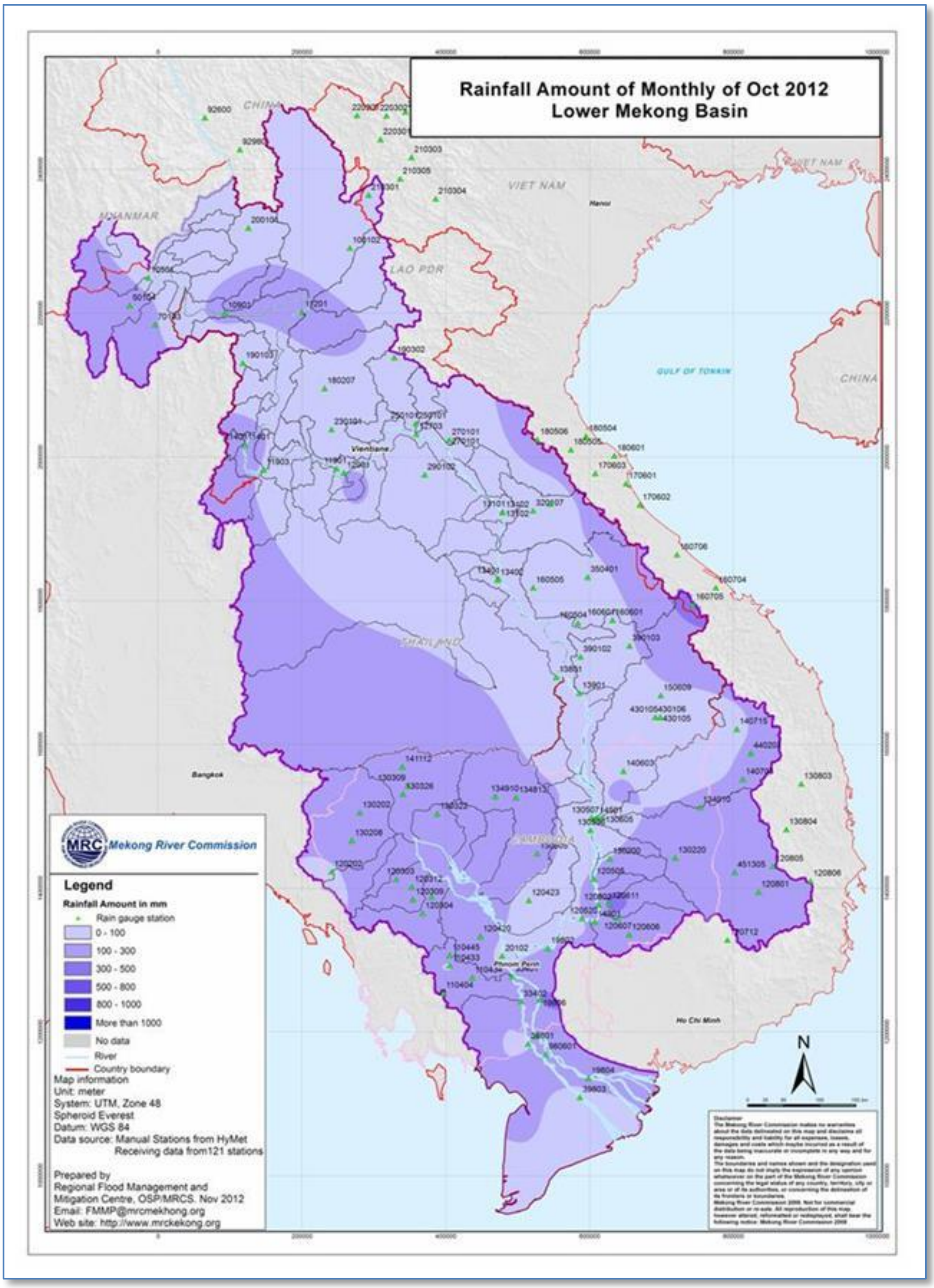


Figure 3-6 Rainfall over the Lower Mekong Basin – October 2012.

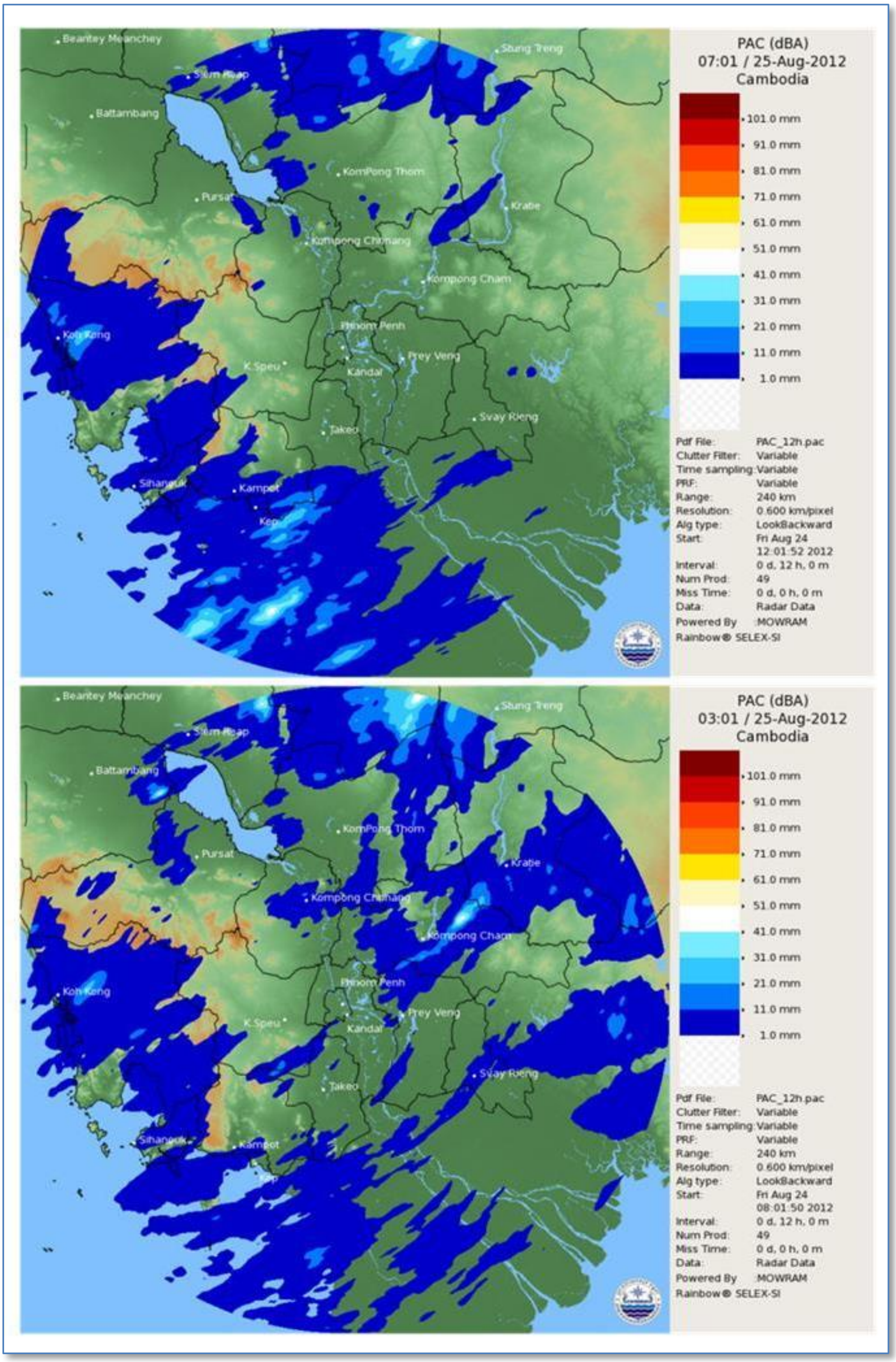


Figure 3-7 Rainfall over Cambodia tracked by the radar installation in Phnom Penh at 7 am and at 3 pm on the 25th August, 2012.

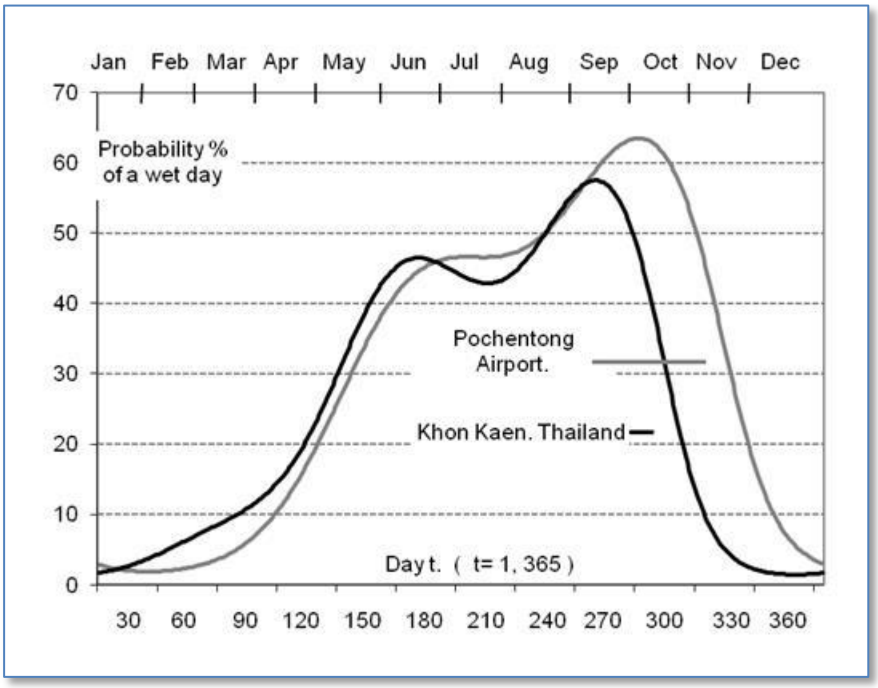


Figure 3-8 The probability of a wet day at Khon Kaen and at Pochentong airport, Phnom Penh.

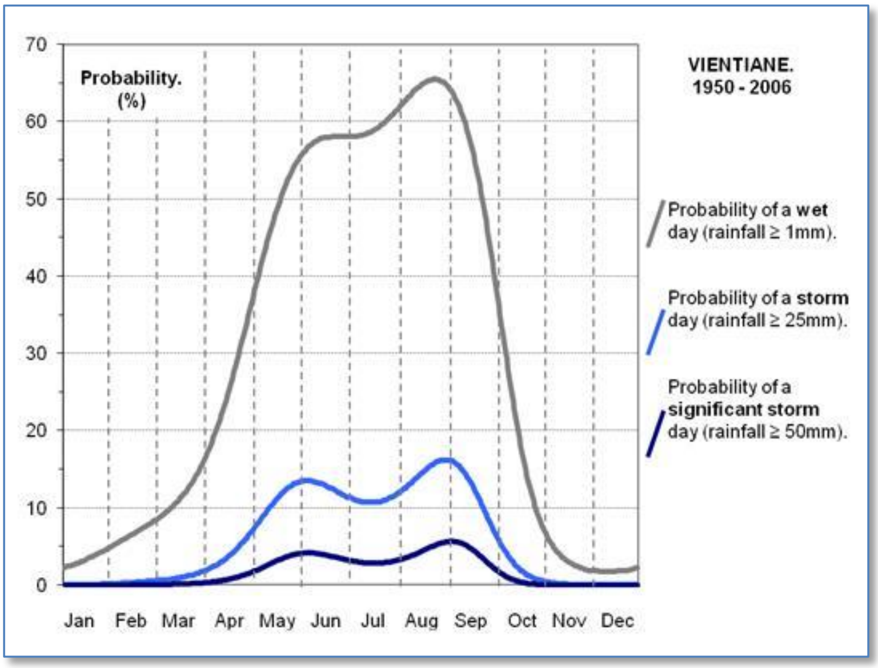


Figure 3-9 The probability of wet day and storm days at Vientiane, with the historical sample data smoothed using a truncated Fourier series. The bi-modal seasonal pattern of storm days is linked to Monsoonal 'break' and 'active' phases.

The bimodal feature apparent in the seasonal probability of wet days and storm events is widely observed and acknowledged. This modulation pattern represents the average timing over the season of so called 'break' and 'active' phases in Monsoon intensity, when the incidence of monsoonal depressions is either lower or higher, which is in turn linked to evaporation rates over the northern Indian Ocean and the Bay of Bengal. This same pattern, with the monsoonal break when it occurs evident most commonly in July is also a feature of the rainfall climate of the Indian subcontinent. (See Kumar et al, 2009). When the Monsoon withdraws early, as in 2012, the second rainfall peak in September is much diminished, leading to a much lower seasonal rainfall total as was the case.

3.4 The flood hydrology of 2012

In response to the weak and curtailed Monsoon the flood conditions of 2012 were well below average in terms of both peak and volume. As Table 3-3 to Table 3-5 indicate the statistics at three indicative sites on the mainstream representing the northern, central and southern reaches of the Mekong in the Lower Mekong Basin:

- Peak discharges at Chiang Saen and Vientiane were 15 to 20%,below normal while at Kratie the annual flood peak was as much as 30% below the long term average.
- Flood volumes were similarly deficient, almost 40% below normal at Kratie.
- Critically, given these deficits, the flood season itself was a month and more shorter than usual. At Vientiane the season lasted for just 85 days compared to the average figure of 142 days, such that 2012 saw the shortest flood season in 100 years of observation.

Table 3-3 The Mekong River at Chiang Saen. Peak and volume of the 2012 flood season and the onset and end dates, compared to the long term average figures.

Mean annual discharge cumecs	2012 flood season				
	Peak discharge cumecs	Flood volume km^3	Start date	End date	Duration days
2 600	8 000	31.3	20th July	2nd Nov	106
	Long term average (1913 – 2012)				
-	10 300	57.4	12th June	13th Nov	155

Table 3-4 The Mekong River at Vientiane. Peak and volume of the 2012 flood season and the onset and end dates, compared to the long term average figures.

Mean annual discharge cumecs	2012 flood season				
	Peak discharge cumecs	Flood volume km^3	Start date	End date	Duration days
4 500	14 100	60.3	24th July	16th Oct	85
	Long term average (1913 – 2012)				
-	16 600	101.1	23rd June	10th Nov	142

Table 3-5 The Mekong River at Kratie. Peak and volume of the 2012 flood season and the onset and end dates, compared to the long term average figures.

Mean annual discharge cumecs	2012 flood season				
	Peak discharge cumecs	Flood volume km^3	Start date	End date	Duration days
13 500	35 950	207.7	25th July	17th Oct	105
	Long term average (1913 – 2012)				
-	50 900	330.0	24th June	7th Nov	137

In all respects the flood season of 2012 was one of the "weakest" on record. The widely accepted "benchmark" drought year in the Lower Mekong Basin is 1998, largely because this was one of the few events that extended across the whole of the Lower Basin from north to south. With the data at Kratie indicative of the hydrological conditions in any given year over the greater part of the region, those of 2012 join a small group of years when hydrological conditions were far below what is normally expected, though such circumstances are not that exceptional. During the last two decades four such years stand out, 1992, 1998, 2010 and 2012. On these occasions the key measures of the annual Mekong flood magnitude - peak, volume and duration - were 30% or more below average (Table 3-6).

Table 3-6 The Mekong River at Kratie. The most deficient annual floods of the last two decades. (the figure in brackets indicates the annual statistic as a proportion of the long term average).

Year	Peak discharge cumecs	Flood volume km^3	Duration of flood season days
1992	33 850 (67%)	195.4 (59%)	113 (80%)
1998	37 430 (74%)	205.6 (62%)	93 (68%)
2010	35 990 (71%)	193.1 (59%)	97 (71%)
2012	35 950 (71%)	207.7 (63%)	105 (77%)

The 2012 daily discharge hydrographs at Chiang Saen, Vientiane, Pakse and Kratie are illustrated in Figure 3-10 and Figure 3-11. Other than the fact that hydrological conditions were very much below average throughout the season, the "stand out" feature is the two or three spikes or flood flow spates evident at Chiang Saen that are still marked at Vientiane, but which are not obvious further downstream. Whether these are entirely "natural" or not is an open question. Between, the mainstream dams on the mainstream in Yunnan and Chiang Saen there are no large tributaries of any consequence that might generate such relatively large but short lived spates. It might therefore be contended that these discharge "spikes" were the result of upstream reservoir operation as much as anything else.

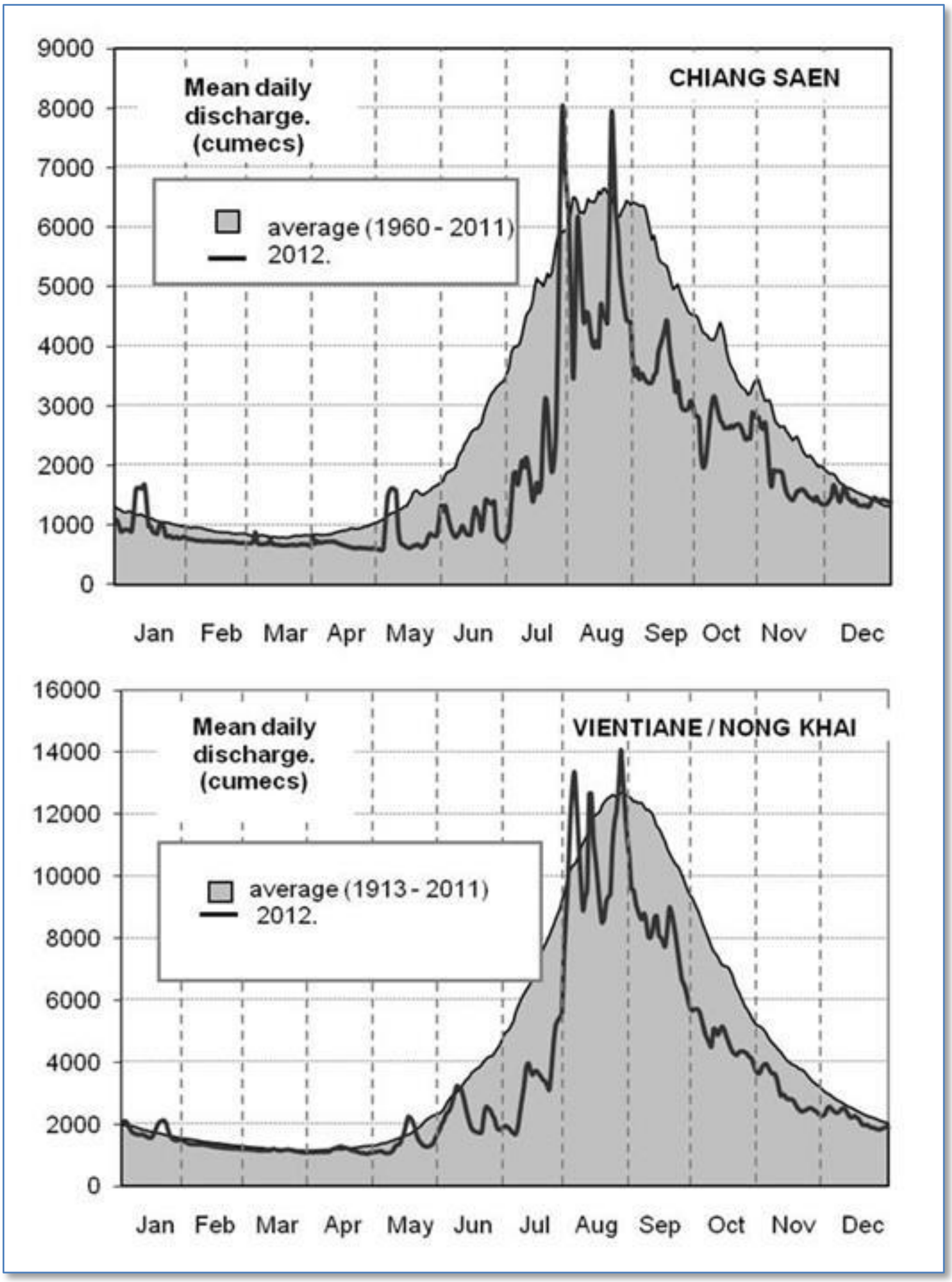


Figure 3-10 The 2012 annual hydrographs at Chiang Saen and at Vientiane / Nong Khai, compared to their long term average.

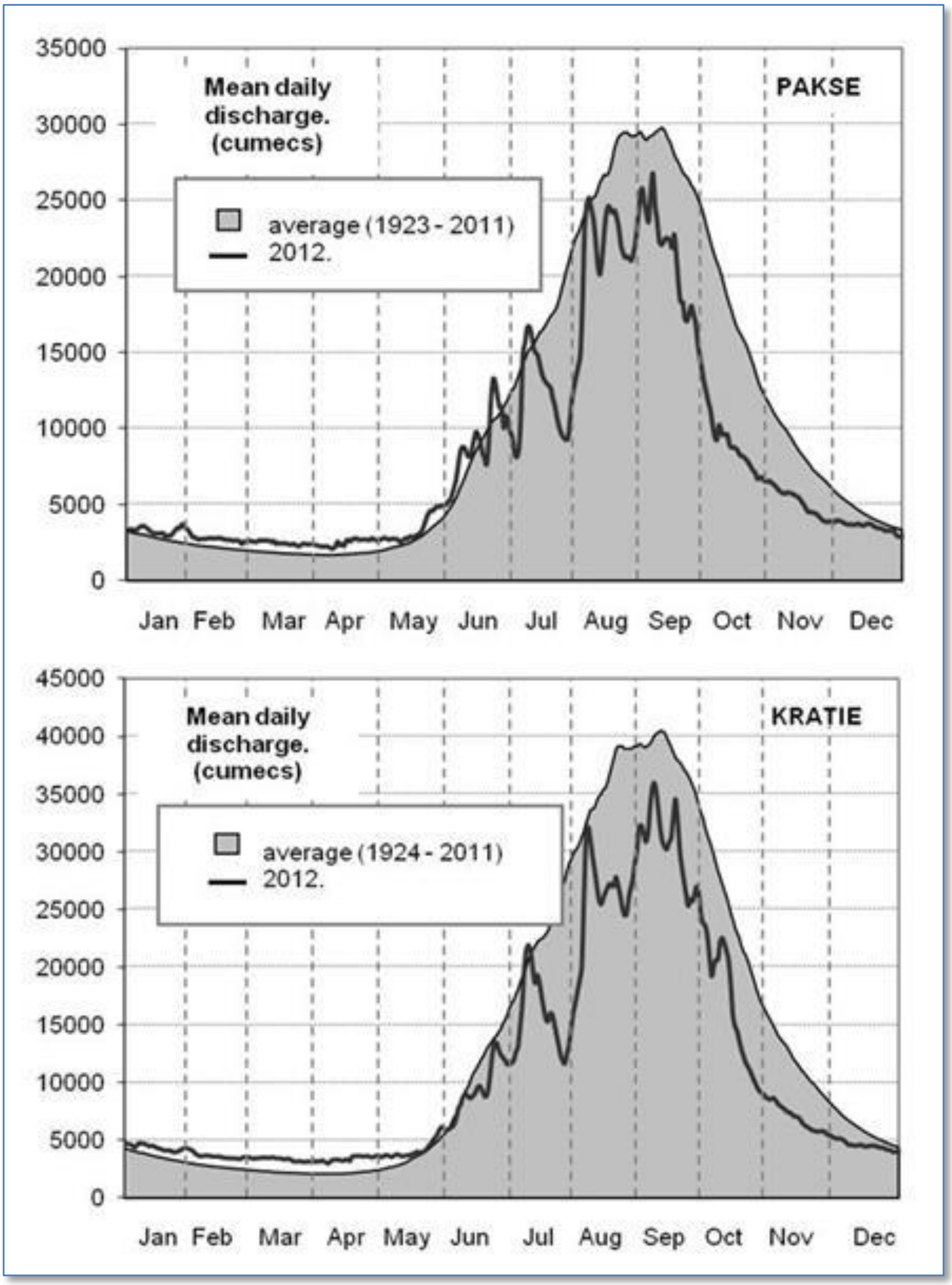


Figure 3-11 The 2012 annual hydrograph at Pakse and at Kratie, compared to the long term average.

The four “drought years“ listed in Table 3-6 reveal a very similar pattern in terms of their daily discharge hydrographs. The flood season is short and the flows in deficit, which is obvious. The peak discharge, such as it is, remains in September, which is the “norm” but the early end to the Monsoon sees flows decreasing rapidly in the latter weeks of late September and early October. A comparison of the 1998 and 2012 hydrographs as shown in Figure 3-12 confirms that the pattern and magnitude of daily discharge in such years is analogous. An interesting feature is the fact that flows during the low flow season of 2012 were significantly higher than those of 1998. It is tempting to conclude that the flood season conditions of the previous year provide an explanation. The annual flood volume during 2011 was very much above average, that in 1997 little more than average. It may therefore be argued that there is a "carry over" of these higher flows into the following low flow season. However, studies reveal that there appears to be no systematic link or at least any relationship that could be used to predict dry season flows based on the flood of the previous year (see MRC Lower Mekong Basin Drought Study: Analysis, Forecasting, Planning and Management. August 2005).

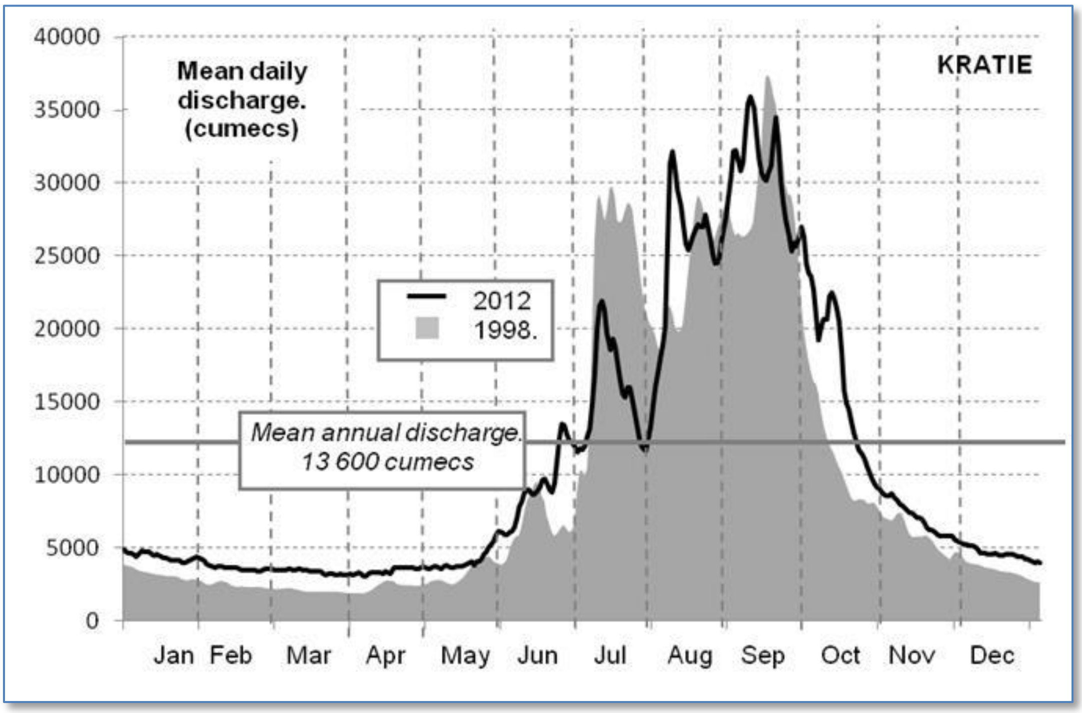


Figure 3-12 The Mekong River at Kratie: the 2012 and 1998 daily discharge hydrographs compared.

Figure 3-13 places the flood of 2012 in the full historical context in terms of a scatter plot of the 'period of record' annual flood peak and volume. At the three mainstream locations considered conditions during 2012 are indicated to be "extreme". This joint distribution of the two flood variables can be expressed in statistical terms as a bivariate probability distribution, as illustrated in Figure 3-14. On this basis the estimated recurrence interval of the 2012 flood event is 1 : 10 years.

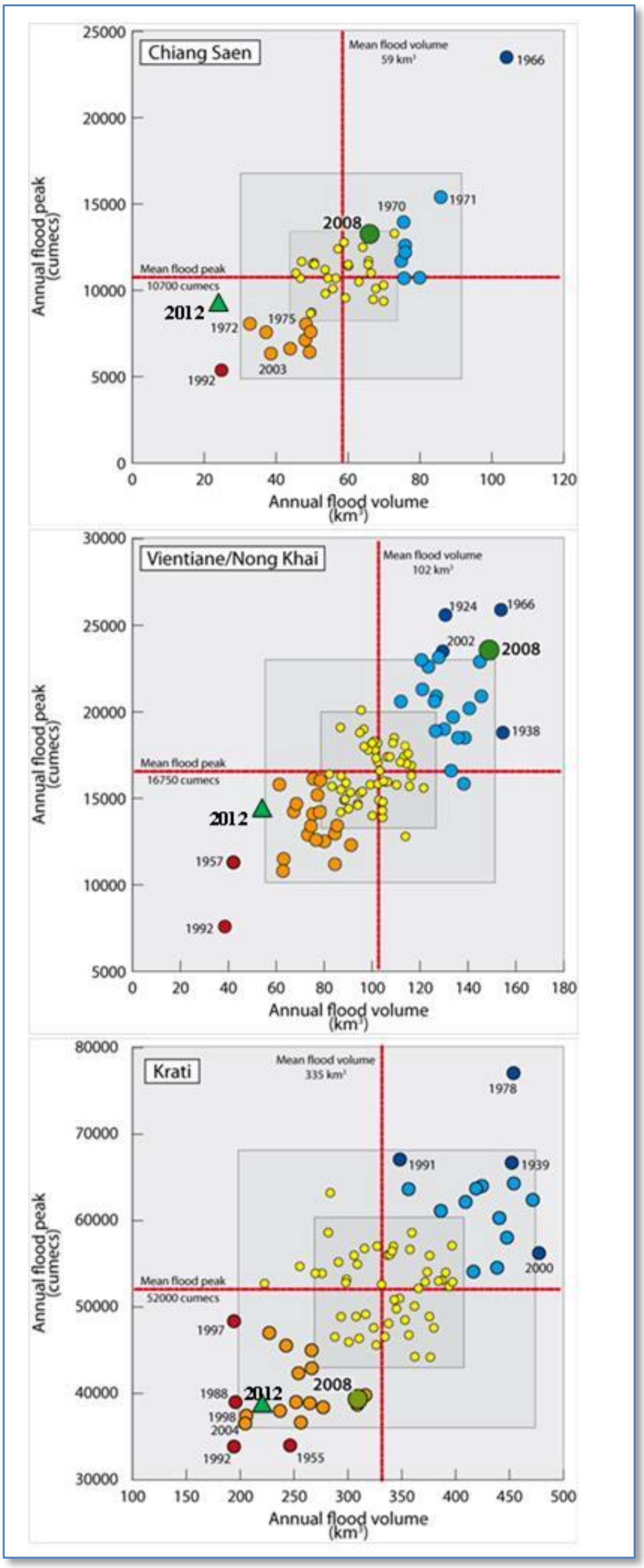


Figure 3-13 Scatterplots of the joint distribution of the annual maximum flood discharge (cumecs) and the volume of the annual flood hydrograph (km^3) at selected sites on the Mekong mainstream. The 'boxes' indicate one (1δ) and two (2δ) standard deviations for each variable above and below their respective means. Events outside of the 1δ box might be defined as 'significant' flood years and those outside of the 2δ box as historically 'extreme' flood years.

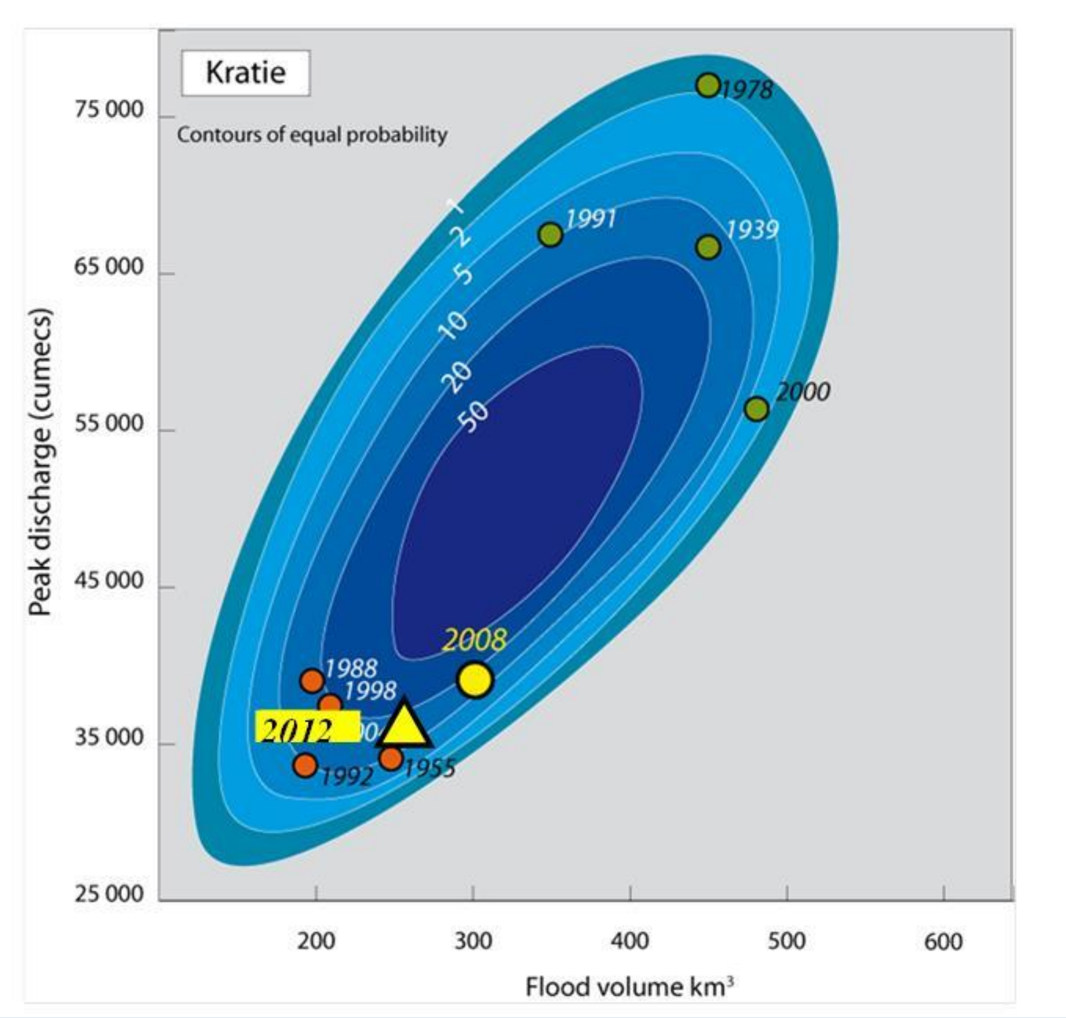


Figure 3-14 Mekong River at Kratie - the bi-variate distribution of annual flood peak and volume, 1924 to 2012. The estimated recurrence interval of the 2012 event in terms of the joint distribution of the two variables is 1 : 10 years.

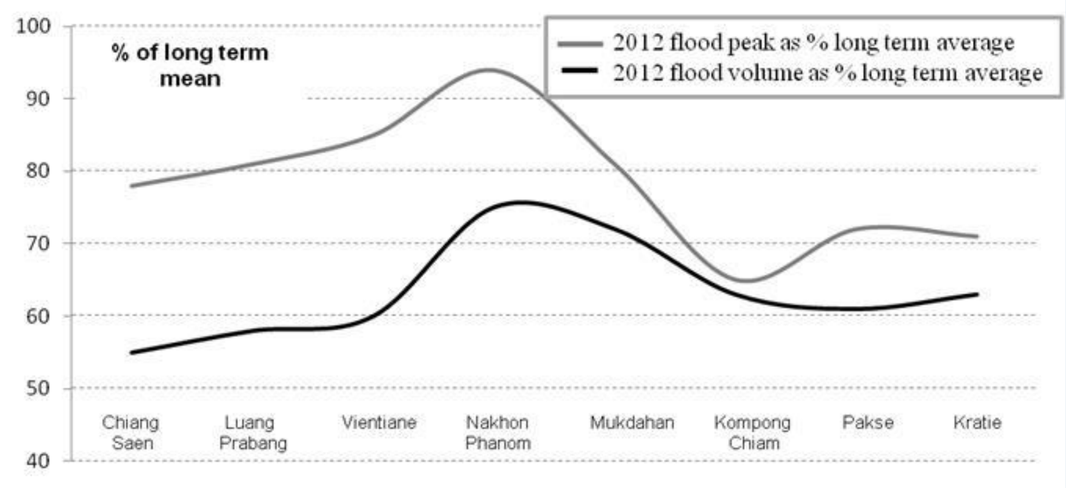


Figure 3-15 Annual maximum discharge and flood volume as a percentage of the long terms average along the Mekong mainstream between Chiang Saen and Kratie.

The translation of these deficient flood flows downstream from Chiang Saen to Kratie is indicated in Figure 3-15. Throughout, the flood volume was well below normal, though somewhat higher in the central parts around Nakhon Phanom. The flood peak decreased significantly downstream of Mukdahan, indicating that the contribution of the large tributaries in the south of Laos as well as the Se Kong, Se San and Srepok system was considerably in deficit.

Although the flood of 2012 was "weak" it was not in any sense abnormal. Comparative conditions applied as recently as 2010 and especially during the 1990's. It would be difficult to apply the term "drought year" since this implies far more than hydrological deficits. Nonetheless drought in terms of monsoon failure and therefore crop losses and socio economic disaster are well documented in the historical annals of India and China. The regional failure of the SW Monsoon in 1992 did indeed lead to huge social disruption throughout the Mekong Basin.

3.5 Water levels across the Cambodian floodplain and the Delta in Viet Nam during 2012

Reflecting the upstream hydrological situation, water levels across the Cambodian floodplain and in the Delta were below average maximum levels by between 14 and 25% or so (Table 3-7).

Table 3-7 Maximum water levels reached during 2012 on the floodplain in Cambodia and the Mekong Delta compared to their long term average.

Site	Period of Record	Annual maximum water level. (masl)		
		Historical average	2012 (m)	2012 as % long term average
Phnom Penh Port	1960 – 2012	9.00	7.78	86
Prek Kdam	1960 – 2012	9.08	7.84	86
Tan Chau	1980 – 2012	4.30	3.27	76
Chao Doc	1980 – 2012	3.82	2.94	77

The maximum water levels in the Tonle Sap observed at Prek Kdam rank ordered in terms of the lowest figures observed since 1960 (Table 3-8) reveal that that of 2012 was the fourth lowest. Only those of 1988, 2010 and 1992 were lower. The figure for 2012 was more than 1.25 m below the long term average which would have had a considerable impact upon the seasonal depth and extent of the Great Lake.

The water level hydrographs at Phnom Penh Port, Prek Kdam and Chau Doc are illustrated in Figure 3-16 and show the season long below average pattern, with the exception of January to March. These latter features at Phnom Penh Port and Prek Kdam reflect the large flood conditions of the previous year when flows and storage on the floodplain and in the Great Lake were considerably above normal. As a consequence floodplain drainage and, in particular significant outflows from the Great Lake extended into the following year.

Table 3-8 Tonle Sap at Prek Kdam: The lowest annual maximum water levels observed since 1960.

Year	Annual maximum water level masl
1988	7.46
2010	7.66
1992	7.70
2012	7.84
1993	7.95
1989	7.96
Average	9.05

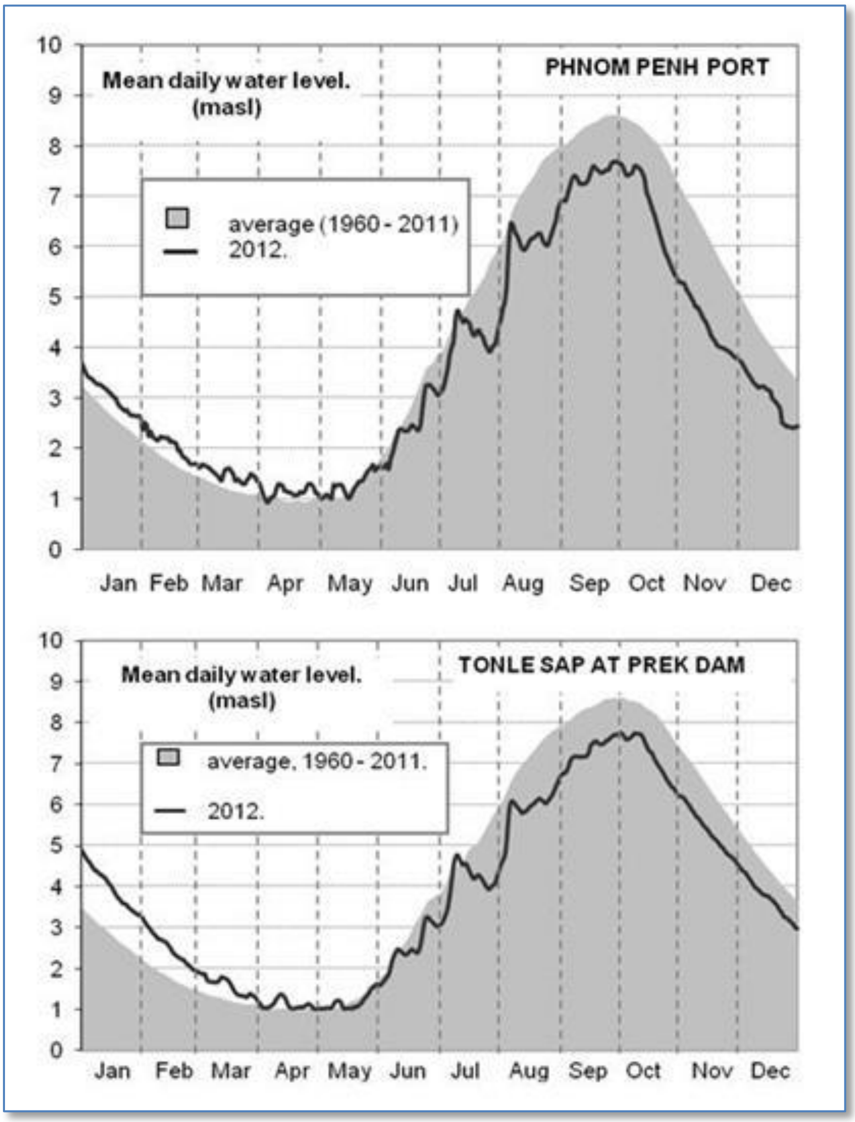


Figure 3-16 The 2012 annual hydrograph at Phnom Penh Port and at Prek Kdam, compared to the long term average.

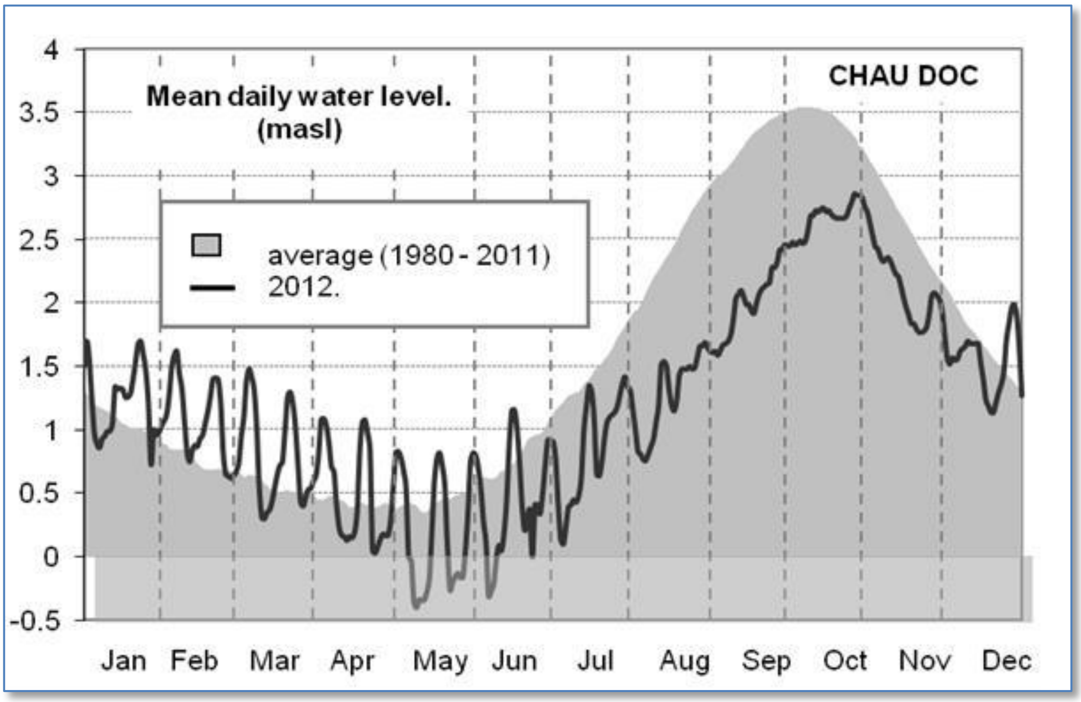


Figure 3-17 The 2012 annual hydrograph at Chao Doc, compared to the long term average.

3.6 Regional flash flooding during 2012

Despite regional flood conditions during 2012 being much below normal, a number of localized flash flood events did occur during the year, thus demonstrating that flash floods can and do occur quite independently of the wider situation across the Lower Mekong Basin.

- On the 24th - 25th July a tropical depression linked to typhoon VICENTE dissipated and moved eastwards. Heavy rain occurred in the northeast of Thailand, northern Lao PDR and Viet Nam. Rapid increases in water level at hydrometric stations located in the Nam Ou, Nam Nam Khan, Nam Ngum sub-catchments were observed.
- From the end of first week of August to the middle of the month August 2012 the MRC-FFG system detected several flash flood risk areas in the upper Mekong Basin. For example on 8th August 2012 at 00:00 UTC (7:00 AM local time) the MRC-FFG system detected flash flood risk areas in some villages in Luang Prabang Province in the northern part of Lao PDR. Electricity supplies were cut and more than 100 families were evacuated along the Nam Khan River. Landslides caused the blockage of a number of key roads in and out of Luang Prabang.
- A flash flood occurred on 31st August in the northern Lao province of Lao Cai, killing four people and leaving nine others missing. This is a remote mountainous area populated by ethnic minorities. Rough terrain and poor

communications links make such areas very vulnerable to the flash flood hazard,

- During 2012 some parts of Cambodia were reported to be affected by flash floods (see 4.1 below) during October, with a death toll of 29 according to the National Disaster Management Agency.

In Cambodia it is suggested the damage and losses caused by flash floods observed over the last 5 years rivals that resulting from riverine / Mekong mainstream flooding (Cambodian National Flood Report, 2012).

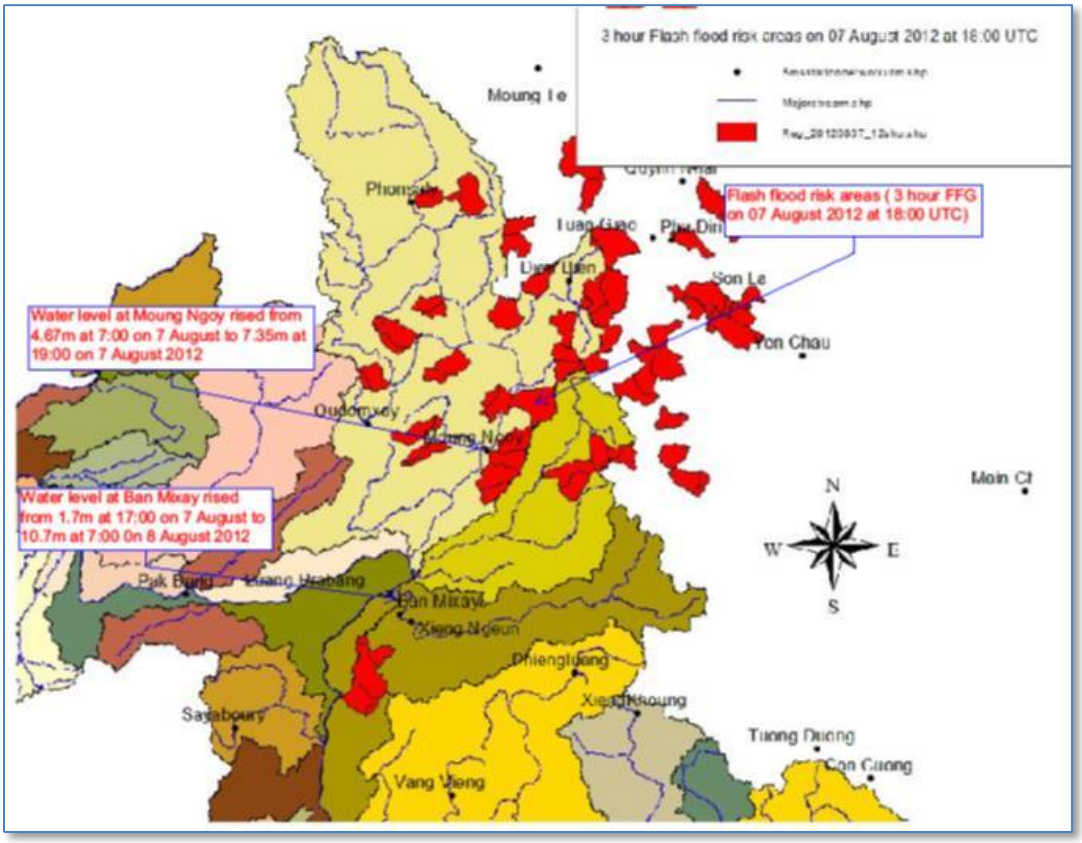


Figure 3-18 Flash flood “at risk” areas in northern Lao PDR on 17th August, 2012, as produced by the MRC-FFG system.

4. COUNTRY REPORTS

4.1 Cambodia

Compared with floods in previous years, conditions during 2012 were modest, with 2000 and 2001 the most extreme while the "driest" year was observed in 1998. During 2012 water levels were exceptionally low at all mainstream stations along the Mekong, Bassac and Tonle Sap River and never approached the flood alarm level.

During 2012 some part of the country were affected by flash flood during September-October 2012 due to heavy rain, especially during second week of September 2012 which caused some damage to infrastructure and agriculture products in some provinces, specifically Preah Vihear, Kampong Thom, Banteay Meanchey, Siem Reap, Pursat, Svay Rieng and Pailin. Storm rainfall reached as much as 170 mm per day in some places and reached comparable figures three days in succession. For example, daily rainfall on 4th September was 103 mm in Pursat, 123 mm in Ratanakiri and 117 mm in Kampot. The National Committee for Disaster Management (NCDM) reported that 29 persons were killed.

The National Committee for Disaster Management, established in 1995, is responsible for providing timely and effective emergency relief to disaster victims and also to develop preventive measures to protect or reduce the effects of such national crises. The NCDM currently has developed down from national level to commune level and from early 2007. This network even has taken the role of the Cambodian Red Cross (see the 2011 Flood Report) in terms of warning and dissemination of flood information. The Committee for Disaster Management at the provincial level, that is the Provincial Committee for Disaster Management (PCDM), organizes annual seminars to prepare the provincial preparedness plan before each flood season. Under the Flood Management and Mitigation Programme 2004-2010 Component 4 "Flood Preparedness Management Strengthening" the provincial and district Committees for Disaster Management of each province along the Mekong were facilitated to implement provincial and district Flood Preparedness Plans; these plans are annually revisited in the context of the recurrent updates of the socio-economic development plans.

The key gaps in the flood preparedness measures are as follows:-

- The establishment of a systematic flood preparedness planning process at provincial, district and commune levels remains a work in progress.
- Coordination between the relevant institutions and agencies concerned needs to be improved.
- Timely access to and understanding of flood information is limited.

- There remains a lack of funds to support daily activities with regards to flood management, prevention and mitigation.
- Interventions between the various agencies are often uncoordinated.
- Without realistic levels of financial support the sustainability of the proposed flood mitigation measures remains in doubt.
- Flood damage assessments need to be more systematic.
- Land use planning policy in general does not take flood risk into account.
- In principle, the policies regarding flood mitigation stated in the National Water Resources Policy are:
- Phnom Penh and other localities with a high concentration of people and / or economic assets will be fully protected against flooding.
- Other urban or industrial centers with lesser concentration of people and assets will be provided with levels of protection which are economically justifiable.
- All people and institutions will be encouraged and enabled, by means such as education and demonstration, to adopt flood mitigation measures appropriate to their circumstances.
- All public facilities will be constructed above the estimated 50-year flood level and will provide for unimpeded drainage.

4.2 Lao PDR

During 2012 the flooding that occurred in the country was localized and the result of heavy convectional storm rainfall. Three provinces in north were the most affected, namely Luangnamtha, Luang Prabang, and Phongsaly.

- On 23rd – 24th July, Luangnamtha District was hit by heavy rains which caused flooding to local communities. The flooding damaged domestic property, crops, and livestock in Poung, Pasack, May, Luang and Donekhoun villages. Local roads were blocked by landslips and floodwater. There were no reports of deaths or injuries. People in the targeted villages had received warnings from the meteorology and hydrology sector beginning on 19th July, making sure they were alert to the possibility of rapidly rising rivers. The flood damage was not quantified.
- On 3rd August, flooding occurred in Namdeua and Nakheua villages in Pakkading District, Bolikhamxai Province. The widespread rain over several days resulted in the flooding of hundreds of hectares of farm land. Economic damage was not reported.
- On 7th August, flooding occurred in Luang Prabang Province, caused by isolated heavy rainfall. In the Nam Khan River there were considerable debris loads. The provincial authorities suggested that the damage would be largely restricted to the Phonxay and Xieng Ngeun districts. Many families living along the Nam Khan River in Luang Prabang Province were affected, with

hundreds of hectares of rice and other crops inundated. Flooding was principally confined to the Nam Khan, Nam Ming and Nam Bak rivers. Road No. 13 North was cut in the Xieng Ngeun area around 15 km from Luang Prabang Town and it was not possible to travel from Luang Prabang to Vientiane by road for several days.

- On 4th September flash flooding occurred on the Houay La River by suddenly rising water levels due to the heavy rainfall, killing four people and left one girl missing in Keomany Village of Nan District, Luang Prabang Province. The flooding also swept away five houses, affecting 10 others and a secondary school along its path in Nan District. The initial assessment by local authorities suggested that the cost of the damage was in excess of $60 million kip, provincial media reported.

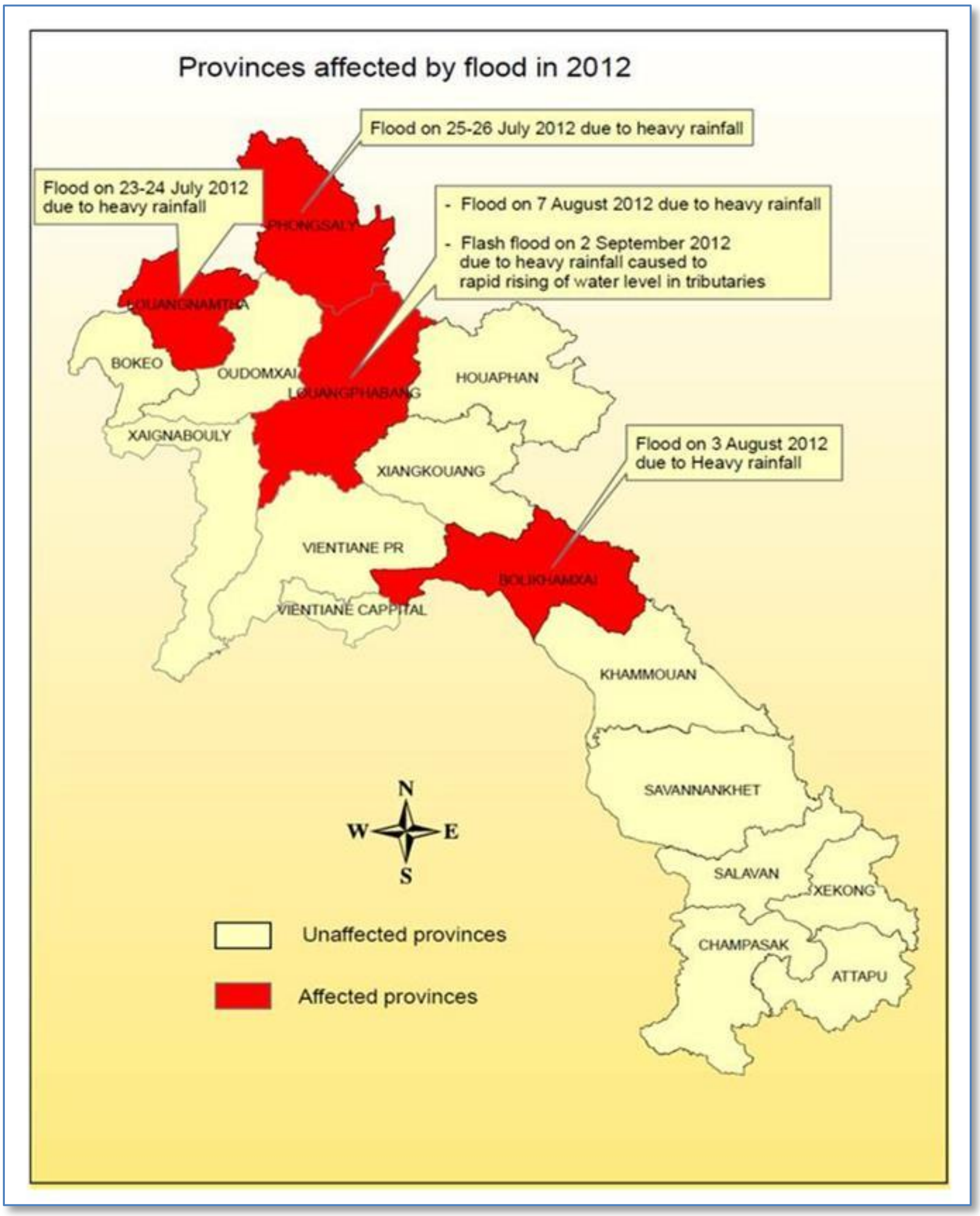


Figure 4-1 Lao PDR - Provinces affected by flooding during 2012.

Preliminary damage estimates for the year are given in Table 4-1 below.

Table 4-1 Preliminary flood damage and loss in Lao PDR for 2012.

Description	Assessment methodology is based on data reporting from National Disaster Management Office (Ministry of Labor and Social Welfare) and Vientiane Time Newspaper.
Provinces affected	Phongsaly, Luangnamtha, Luang Prabang, Bolikhamxay
Districts affected	9
Villages affected	55
Household affected	283
People affected	3,047 (Women 1,466 persons)
People killed	5
People missing	1
Agriculture	
Hectares of Rice paddy fields affected	147,739 ha
Hectares of crop damaged	Crop field 60.56 ha
Farmer’s houses rice stock affected	10 sites
Livestock	
Cattle	N/A
Poultry	453 head lost
Fish ponds	5 sites
Infrastructure	
Electricity post affected	57 posts
House affected	More than 10 houses affected by flash flood
Overflow weir damaged	30 sites
Irrigation systems damaged	34 canals, 2,528 m length

With the mandate to oversee disaster management, the National Disaster Management Office (NDMO) has closely coordinated with line agencies at central and provincial level, NGOs, and others in implementing non-structural measures for disaster management. The 2003-2020 disaster management action frameworks have placed absolute emphasis on the promotion of a Community Based Disaster Risk Reduction Approach.

The principal recommendations are that:

1. Community based flood risk management should further strengthened.
2. The disaster management committee should focus on building capacity of the local community in flood preparedness and emergency responses.

3. In order to improve the flood forecasting and warning, the review of hydromet network coverage is needed to ensure sufficient data input for more accuracy of forecasting analysis.
4. The national flood hazard mapping should be developed to facilitate the implementation of flood preparedness planning.
5. The MRC Flood Management and Mitigation Programme should consider establishing the flood risk management curriculum at National University of Laos to benefit the local levels by providing a supportive role in building the capacity of local authority and community in flood management and mitigation.
6. Capacity building for hydro-meteorological staff given more intention, especially at the provincial and district level.

Boys in Xieng Ngeun move their personal possessions to higher ground by boat, with flood waters reaching the roof of their house. ***--Photo Koutkeo Sengthavy***

Figure 4-2 Flooding in the north of Lao PDR during 2012.

4.3 Thailand

The GOES-9 satellite image revealed that between the 1st and the 9th of June there was thick cloud cover over many areas of Thailand, especially in Nan, Phrae, Sukhotai, Pichit and Pitsanulok provinces in the Central and North east associated with heavy storm rainfall. See Figure 4-2.

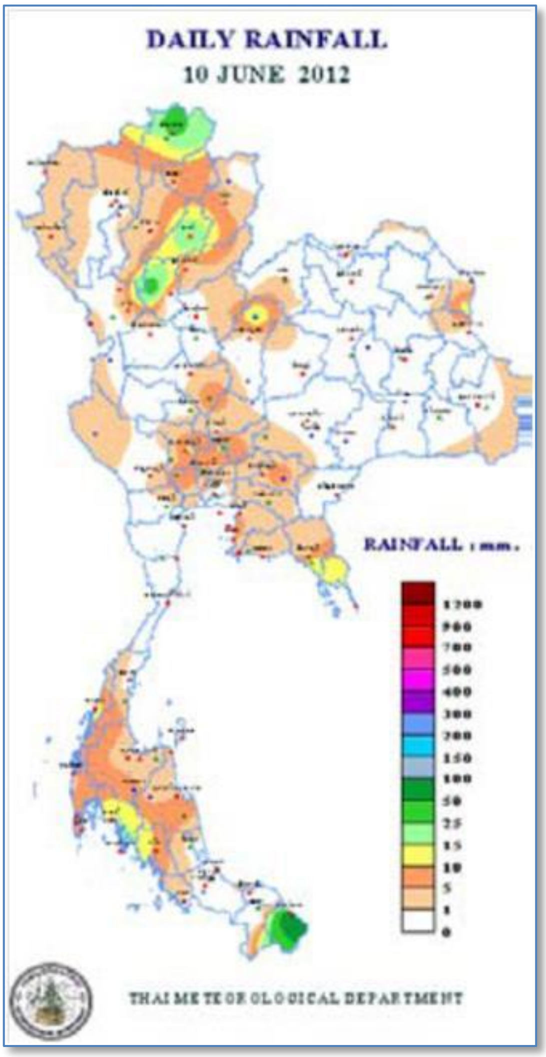


Figure 4-3 Thailand – rainfall on the 10th June.

Heavy rainfall during September in north-eastern and east part areas caused flooding in Chanthaburi, Trad, Prachinburi and Chachoengsao provinces. In the eastern regions total precipitation for the month was as high as 470 mm causing some of the most serious flooding recorded over the last 10 years.

Figure 4-4 Flooded areas in Nakhon Ratchasima province on 6th October as a result of tropical storm GAEMI.

Tropical storm GAEMI caused the most serious flooding during the year. The GAEMI tracked toward to Thailand on 6th October 2012 as a tropical depression. Storms were widespread with heavy rainfall and flash floods, especially in the lower northern, central and eastern parts of the country. Fifty eight provinces suffered some degree of flooding and nationally over 371 000 people were affected. Total damage during the year was estimated to have been almost US$ 177 million. Five deaths were recorded.

Following the much more extreme national flood situation during 2011, the National Flood and Water Management Act, 2012 was instigated, to be implemented by the Committee on National Water and Flood Policy. The key objectives are to determine a water management action plan including national policy on flood prevention and resolution to be implemented by the government at the national level.

As elsewhere it is recognized that the flood management and mitigation process should focus on local stakeholders and community based action plans. These would be based upon three phases 1) prevention, 2) preparedness and 3) response.

4.4 Viet Nam

Tropical storms and depressions were the major cause of flooding in Viet Nam during 2012.

- Storm No. 1 (PAKHAR) formed from tropical depression in the northeast of the Spratly Islands area on 29th March. The storm weakened after landed on the Binh Thuan-Tien Giang coastal region on 1st April, and became tropical depression. After that it landed on the coastal area of Binh Thuan - Ba Ria Vung Tau, the tropical depression was going into the land of the South Eastern provinces and impaired. Due to the influence of Storm No. 1, the provinces of Ba Ria - Vung Tau, Dong Nai, Binh Duong, Ho Chi Minh City, had strong winds at level 6, level 7, gust level 8. The provinces Ba Ria Vung Tau, Dong Nai, Binh Duong, Ho Chi Minh City and Binh Phuoc have rain from heavy to very heavy.
- Storm No. 4 occurred on 21st July on East Sea with moving West – Northwest. It caused heavy rain in the north of Laos.
- Storm No. 7: On 29th September, a tropical depression had formed, about 450 km to the northeast of Nha Trang (Vietnam). During the next two days, the depression moved slowly to the Northeast, about 5 km/h. Tropical storm No. 7 had formed over Bien Dong Sea (BDS) and reached 9 - 10 Category intensity, gust 11 – 12 Category strength. It made landfall at Quy Nhơn City as a tropical depression. The half-hourly observations along the coastline showed that the areas from Da Nang to Binh Thuan *and the Central Highlands had* strong

> winds of 6 – 7 Category intensity, gust 8 Category strength. The Tropical Storm No. 7 contributed extreme heavy rains for the areas included *the Central Highlands*. The total precipitation from 5th October to 8th October was 100 – 200 mm.

The main feature of the 2012 flood season in the Mekong Delta was the influence of tidal effects. Water levels at Tan Chau and Chau Doc were lower than 2011 but for cities such as Can Tho, Bac Lieu, Soc Trang, Vinh Long, Long Xuyen tidal influences caused some of the most serious urban flooding observed in the past decade.

In Vinh Long Province, the highest water level appeared during high tide at the beginning of September, though the level was lower than that in 2011. At My Thuan on the Tien River, the tidal peak reached 1.92 m; about 0.12 m higher than the alarm level III but 0.11 m lower than the flood peak in the previous year. Water levels also exceeded alarm level III at Phu Duc (1.78 m), at Tan Thanh (1.81 m) and at Vung Liem (1.7 m).

During the monsoon season the Central Highlands of Viet Nam suffered from several tropical storms which caused heavy rain across wide areas resulting in high river levels. Storm No.7 entered the area from Quang Binh - Hoa Khanh and caused to moderate and heavy rain over 3 days. Flood peaks on most rivers in the Central Highlands region reached alarm level I - II, for example on the Srepok River at Ban Don.

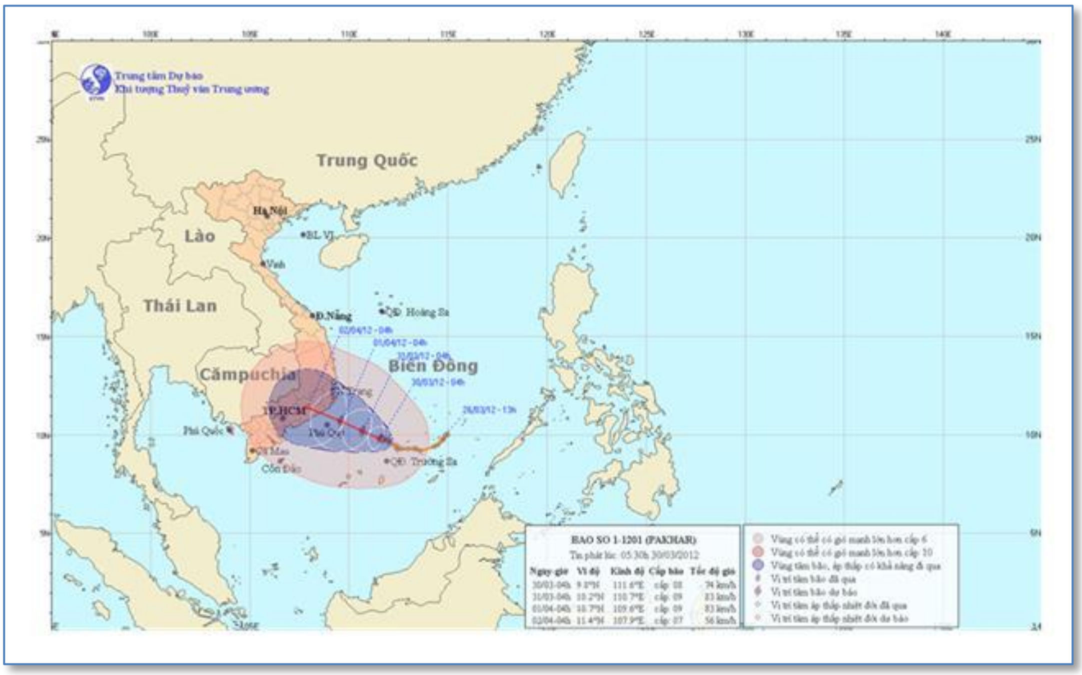


Figure 4-5 The track of the tropical storm PAKHAR during the first week of April.

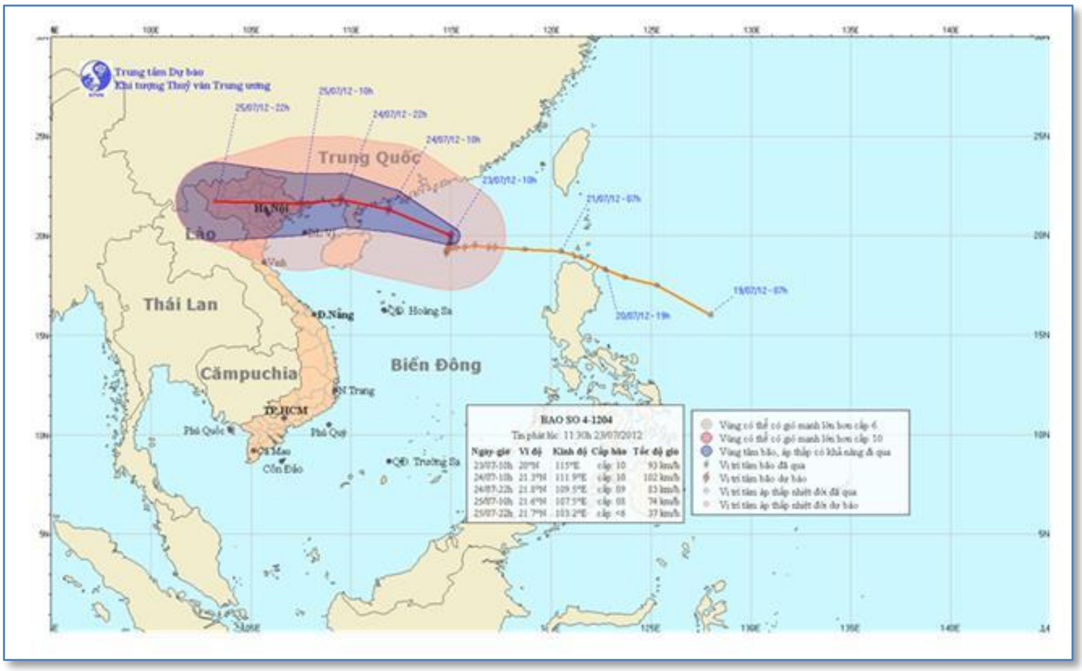


Figure 4-6	The track of the tropical storm Number 4 during the last week of July.

Table 4-2	Summary of damage in the Mekong Delta region during 2012.

Category	Item damaged	Unit	Total
People	Killed	Person	**38**
	Injured	Person	**176**
	Missing	Person	**0**
Housing	Houses collapsed, drifted	No	**1,656**
	Houses submerged and damaged	No	**12,118**
School	School collapsed	Room	**6**
	School submerged and damaged	Room	**32**
Hospital, clinics	Clinics collapsed	No	**0**
	Clinics submerged and damaged	No	**0**
Agriculture	Rice fields submerged	Ha	**65,654**
	Farms submerged, damaged	Ha	**252**
	Salt water damage to food stocks	Ton	**29,516**
Irrigation	Dyke damage	m	**9,798**
	Small channel damaged	m	**441**
Transportation	Land drifted	m3	**2,362,077**
	Bridge, sewer collapsed	Unit	**1**
	Roads damaged submerged	m	**15,911**
tic product	Shrimp and fish farms damaged	Ha	**4,689**
	Total damage	**US$**	**16 million**

5. CONCLUSIONS

Following the significant flood conditions of 2011, the situation during 2012 proved to be quite the opposite. The flood peak and volume were between 30 and 40% below the long term average. The flood season was a month shorter than usual. All in all 2012 turned out to be one of the most deficient annual floods of the last 25 years, matching the situation during 1992, 1998 and 2010.

The deficient hydrological conditions reflected a meteorologically dry year overall. Geographically, rainfall was variable during the monsoon season with only limited areas of the Basin recording monthly totals of any significance. In general total precipitation was well below average, in places by as much as 40%. Locally however, rainfall was close to average due largely to mesoscale storm events that are events which extended over no more than 1 000 km^2. The onset of the SW Monsoon took place during late April / early May as is normal but ended up to a month early in mid to late September over the greater part of the region. This early ended to the Monsoon combined with low seasonal rainfall in general provided the combination that has defined some of the lowest annual floods over the last two decades.

The theme of this 2012 Report is “Flash Floods”. The most common definition of flash floods is that they are localized events that occur with little, if any, warning. Within the general domain encompassing “the flood hazard”, flash floods are more often than not the most devastating and responsible directly for considerable loss of life. Riverine floods, that is those generated over longer periods of time over much larger areas tend, at least in tropical regions, to lead to what might be defined as “indirect” fatalities as the result of water borne diseases that develop during prolonged periods of inundation. In China some estimates suggest that approximately two thirds of flood related casualties arise from flash floods, landslides and mud flows (Li, 2006), while in Europe over the period from 1998 to 2008 it has been estimated that of the 1 000 flood related casualties, 40% arose from flash floods

In the Lower Mekong the flash flood hazard is widely recognized, and reflected in the development of flash flood guidance and waning systems both regionally and in Thailand. These are discussed in detail, as are the challenges to reducing the levels of fatality caused by the hazard.

6. REFERENCES

Anagnostou, E.N., Grecu, M., Anagnostou, M.N., (2006). *X-band polarimetric radar rainfall measurements in key area microphysics project*. Journal of Atmospheric Science. Vol 63, 187–203.

Barredo, J.I., (2007). *Major flood disasters in Europe: 1950–2005*. Natural Hazards. Vol 42. (1), 125–148. doi:10.1007/s11069-006-9065-2.

Beniston, M., (2009). *Trends in joint quantiles of temperature and precipitation in Europe since 1901 and projected for 2100*. Geophysical. Research. Letters. Vol36, L07707.

Beniston, M., Stoffel, M., Hill, M., (2011). *Impacts of climatic change on water and natural hazards in the Alps: Can current water governance cope with future challenges? Examples from the European ''ACQWA'' project.* Environmental . Science. Policy, doi:10.1016/j.envsci.2010.12.009.

Borga, M., Gaume, E., Creutin, J.D., Marchi, L.,(2008). *Surveying flash flood response: gauging the ungauged extremes*. Hydrological. Processes Vol 22 (18), 3883–3885, doi:10.1002/hyp.7111.

Borga M, Anagnostou. E. Blosch. N.G and J.D. Creutin. (2011). *Flash flood forecasting, warning and risk management: the HYDRATE project*. Environmental Science and Policy. Vol 14. pp 834 – 844.

Collier, C., Fox, N.J., (2003). *Assessing the flooding susceptibility of river catchments to extreme rainfall in the United Kingdom.* International Journal of River Basin Management Vol 1 (3), 1–11.

Davolio, S., Buzzi, A., Malguzzi, P., (2006). *Orographic influence on deep convention: case study and sensitivity experiments*. Meteorologische Zeitschrift. Vol 15 (2), 215– 223.

Collier, C., (2007). *Flash flood forecasting: what are the limits of predictability?* Quarterly Journal of the Royal. Meteorological. Society. Vol 133 (622A), pp 3–23.

CSIRO,(2008). *Mekong River Basin Water Resources Assessment: Impacts of Climate Change*'. CSIRO, Canberra. Water for a Healthy Country Flagship. Commonwealth Scientific and Research Organization, August.

Gordon H. B, Whetton, P. H, Pittock, A.B and M.R Haylock (1992). *Simulated changes in daily rainfall intensity due to the enhanced greenhouse effect: implications for extreme rainfall events*. Climate Dynamics. Vol 8 (2). pp 83 to 102.

Groisman, P.Y., Knight, R.W., Karl, T.R., Easterling, D.R., Sun, B., Lawrimore, J., (2004). *Contemporary changes of the hydrological cycle over the contiguous United States: trends*. J. Hydrometeorology. Vol 5 (1), pp 64–85.

Groisman, P.Y., Knight, R.W., Easterling, D.R., Karl, T.R., Hegerl, G.C., Razuvaev, V.N., (2005). *Trends in intense precipitation in the climate record*. J. Climate Vol 18 (9), 1326–1350.

Gruntfest E, and J, Handmer, (1999). *Coping with flash floods*. Proceedings of the NATO Advanced Study Institute on Coping with Flash Floods. Revello. Italy.

Herschy, R.W., (2002). *The world's maximum observed floods*. Flow Measurement and Instrumentation. Vol 13 (5–6), 231–235.

Huntington, T.G., (2006). *Evidence for intensification of the global water cycle: review and synthesis*. Journal of Hydrology. Vol 319, 83–95.

IPCC. (2007). *Climate Change 2007: The Physical Science Basis.* Cambridge University Press. Cambridge. UK.

Kleinen, T., Petschel-Held, G., (2007). *Integrated assessment of changes in flooding probabilities due to climate change*. Climate. Change Vol 81, 283–312.

Li, K. (2006) *A Critical Issue of Flood Management in China: Flash Flood, Landslide & Mudflow Disasters, Weakness in Defense, & Countermeasures*. World Environmental and Water Resource Congress 2006: pp. 1-10. doi: 10.1061/40856(200)238.

Marchi, L., Cavalli, M., Sangati, M., Borga, M., (2009). *Hydrometeorological controls and erosive response of an extreme alpine debris flow*. Hydrological. Processes 23 (19), 2714 – 2727, doi:10.1002/hyp.7362.

Marchi, L., Borga, M., Preciso, E., Gaume, E., (2010). *Characterisation of selected extreme flash floods in Europe and implications for flood risk management.* J. Hydrology. 394 (1–2), 118–133, doi:10.1016/j.jhydrol.2010.07.017.

MRC (2010). *Impacts of climate change and development on Mekong flow regimes, First assessment – 2009.* MRC Technical Paper No. 29. Mekong River Commission, Vientiane, Lao PDR June.

MRC (2012). *The impact and management of floods and droughts in the Lower Mekong Basin and the implications of possible climate change*. Working Paper. Flood Management and Mitigation Programme.

MRC – FMMP (2012). *Evaluation Report on Flash Flood Guidance System for Flood Season 2012 (May - October 2012)*. MRC. Regional Flood Management and Mitigation Centre. Phnom Penh. Cambodia.

MRC (2004), Flood Management and Mitigation 2004-2010 Programme Document, Main Report. Regional Flood Management And Mitigation Center, Phnom Penh, Cambodia.

MRC (2011), Flood Management and Mitigation 2011-2015 Programme Document, Volume 1 (Main Report) and Volume 2 (Annexes). Regional Flood Management and Mitigation Center, Phnom Penh, Cambodia.

Neuhold, C., Stanzel, P., Nachtnebel, H.P., (2009.) *Incorporation river morphological changes to flood risk assessment: uncertainties, methodology and application*. Natural Hazards Earth System. Science. Vol 9, 789–799.

Nguyen Van Tuong, and Bui Viet Hung. (2013). "*Vietnam 2012 Annual Flood Report*". Vietnam National Committee.

Ponput K. (2013). "*Thailand Country Flood Report with focus on the Mekong Basin*". Department of Water Resources Engineering, Kasetsart University, Thailand.

Samuels, P.G., Morris, M.W., Sayers, P.B., Kortenhaus, F., Klijn, F., Mosselman, E., van Os, A., Chanze, J., (2008). *Advances in flood risk management from the FLOOD site project*. In: FLOOD Risk Conference, Oxford, UK, 30th September – 2nd October.

Sene. K (2012). *Flash floods*. Springer. New York. 398 pp.

Smith, J.A., Baeck, M.L., Steiner, M., Miller, A.J., (1996). *Catastrophic rainfall from an upslope thunderstorm in the central Appalachians: the Rapidan storm of 27th June, 1995*. Water Resources Research. Vol 32 (10), 3099–3113.

Sok Bun Heng. (2013). "*Kingdom of Cambodia Annual Flood Report 2012*". Cambodia National Mekong Committee.

Vongphanchanh. S. (2013). "*Laos Country Flood Report 2012*". National Flood Unit. Lao National Mekong Committee. Water Resources Engineering Department. Faculty of Engineering. National University of Laos.

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