Annual Mekong Flood Report 2010

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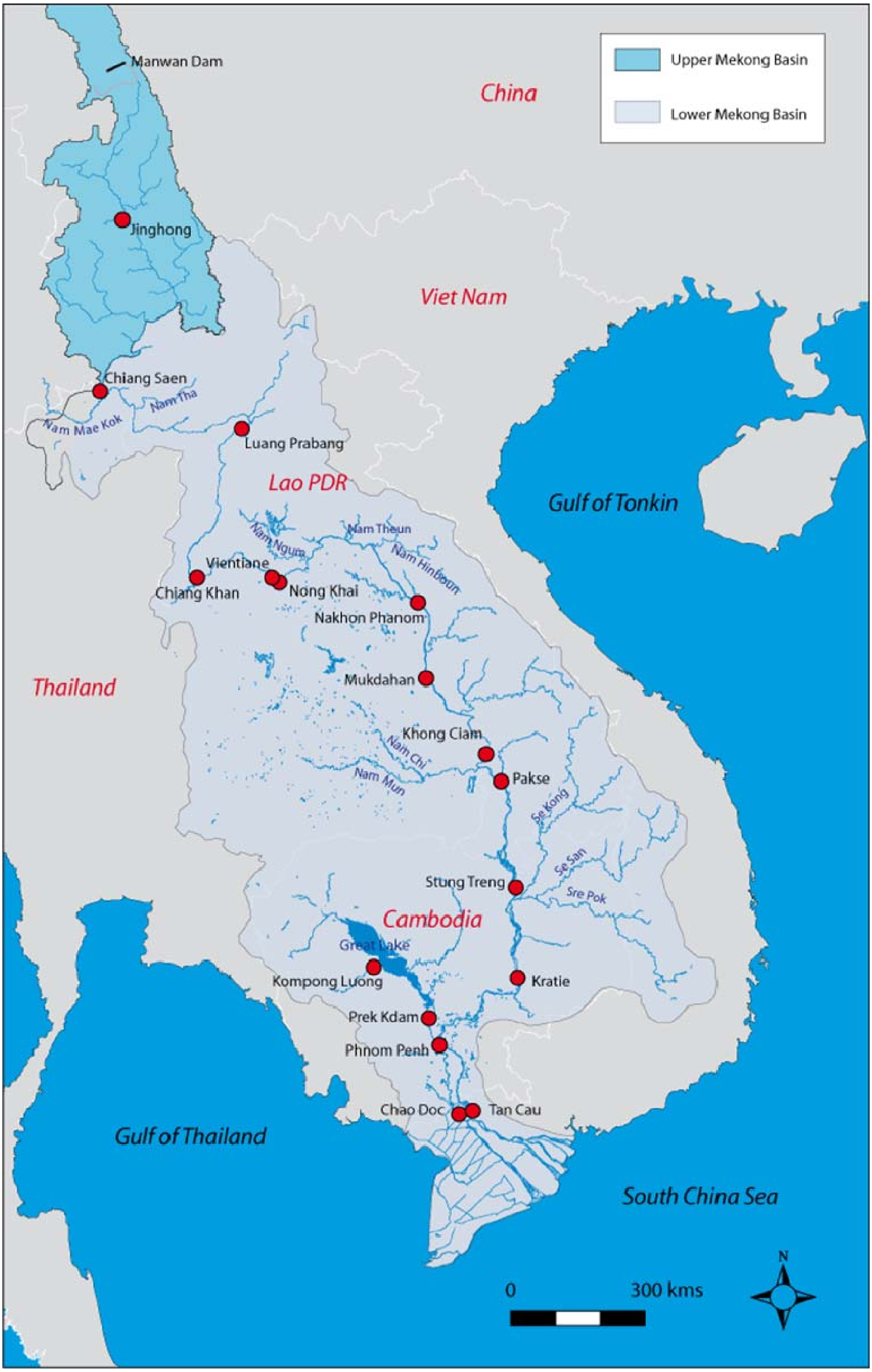

Figure 1: Regional context and places referred to in the text

1. Synopsis and Content

This report considers the general hydrological conditions in the Lower Mekong Basin during the 2010 flood season, which saw the lowest volume of flood season flow within the 87 year period of record on the Mekong mainstream at Kratie[1] in Cambodia. The flow deficit therefore exceeded that of 1992, which was regarded as the worst observed regional hydrological drought. Water levels across the Cambodian flood plain in the Viet Nam Delta were well below average with the inevitable consequences for natural flood plain irrigation and salt intrusion.

Geographically, the 2010 flood season deficit was less severe in the northern parts of the region, but downstream of Pakse and Kratie the situation was unprecedented both in terms of seasonal flow volumes and the duration of the season itself.

On average, the flood season lasts between four and five months in the Lower Mekong Basin. In 2010, it lasted for just three. The principal reason is that the onset of the annual flood was delayed by a month and more due to a lack of runoff producing storms during the early weeks of the SW Monsoon. In addition, total seasonal rainfall in Southern Lao PDR and over the Se Kong, Se San and Sre Pok Basin in Cambodia was 40% below average making it one of the weakest monsoon seasons on record in this part of the region. These conditions during 2010, when the annual flood volume was 40% below normal at Kratie, complete an eight year sequence of below average floods.

The theme of the Report considers the relationship between some aspects of the regional climate and the annual flood. Previous Annual Flood Reports have considered many of these linkages as a matter of course. The major subject area addressed here is based upon seminal studies of the long term structure and pattern of the Asian Monsoon over the last millennium, based on regional tree ring chronologies. The reconstructions reveal that drier and wetter phases can last for a decade or longer and significantly that the overall pattern has remained the same for the last 1,000 years.

A major revelation is how the historical ‘mega droughts’ that are revealed through the tree ring studies correspond with events referred to in historical chronicles, which for example in Viet Nam and Thailand go back as far as the 11th and 12th centuries. Such episodes led to famine, social unrest, rebellions and on occasion to regime change such as the end of the Ming Dynasty in China in the mid 17th Century. Such correspondence with the chronicles not only confirms the overall accuracy of the long term climate reconstructions but also emphasises the key role that the monsoon has played in the history of the region and the ongoing dependence of society upon it.

The report concludes with a summary of the four National Flood Reports, produced by the respective responsible Line Agencies of the MRC Member Countries. A major point to emerge here is that although regional conditions were generally dry, the passage of tropical storms across the region resulted in narrow belts of significant flooding, particularly in the Mun- Chi Basin in Thailand during October.

[1] The hydrological data at Kratie may be considered providing the benchmark for describing the overall regional hydrological situation in any given year.

2. Aspects of the Climate of the Mekong Basin and its Relationship with the Flood Report

2.1 Context

Many aspects of the climate and meteorology of the Mekong Basin and their relationship with the regional flood regime have been routinely considered in previous Annual Flood Reports. For example, the role of typhoons and severe tropical storms was considered in report 2009, while the relationship between intense storms and localized flash flooding in the tributary systems was examined in the 2007 Annual Flood Report.

In this report, two perspectives are taken:

- The first sets the climate of monsoonal Asia as a whole within its long term context by reporting important research results based on dendrochronology, or tree ring, histories. These chronologies of annual tree growth can be related to soil moisture availability, seasonal rainfall and therefore the strengths and weaknesses of the Asian monsoon. It emerges that these drier and wetter conditions have persisted over decadal and multi-decadal timescales and over the last millennium 'mega droughts' in particular are mentioned in the ancient chronicles since they have been linked to famines, social unrest and even dynastic change. Such droughts interspersed with extreme flood conditions occurred during the 14th and 15th Centuries in the Mekong region at the time of the decline of the Angkor Empire, and although not the primary cause of its demise were an additional stress. Many of the most extreme droughts were associated with very strong El Niño events or the periodic increase in sea surface temperatures across the eastern Pacific. Conversely, some wetter phases were associated with a period of cooler sea surface temperatures that were specify linked to the so called La Niña events. It seems entirely appropriate to examine this long term pattern and structure of the Asian monsoon given that hydrological conditions within the Mekong Basin during 2010 were the most deficient over the last 87 years, since records began and complete an eight year sequence of significantly below average flows from the Basin as a whole.

- The second aspect of the climate theme reports feature characteristics of tropical monsoonal rainfall climates that is, the high frequency of storm days in which intense downpours occur. It has been estimated that during 40% of these events rainfall intensities exceed 25mm / hour, a rate that is highly erosive. These extreme rainfall rates are compared to those in other climatic regimes and typical figures for those that occur during the passage of typhoons and tropical storms are illustrated, since such events have historically been associated with some of the most devastating flood episodes.

This section of the report begins with emphasizing the nature of the annual flood on rivers, such as the Mekong. Here the term 'flood' requires some redefinition from the more commonly held notions. In the wider world, a flood is generally perceived as a natural hazard when water levels cross some critical upper threshold. It is argued that on large tropical monsoonal rivers such concepts are inappropriate and do not apply.

2.2 The Flood Concept in Large Tropic Monsoonal Rivers

In a very large tropical river basin such as that of the Mekong in which the coherent annual flood 'pulse' lasts for several months and defines a distinct hydrological season in its own right, the concept of what is meant by a 'flood' requires some redefinition from the more commonly held notions. In the wider world, a flood is generally perceived as a natural hazard during which discharges and water levels cross some critical threshold, inundate riparian areas and beyond, causing loss and damage. Such episodes last for days, at the most weeks and are naturally perceived as negative hydrological events.

In 'flood pulsed' rivers such as the Mekong and, for example the Amazon, the annual flood is quite predictable in terms of its occurrence and timing and defines a transition from a terrestrial phase during the 'dry' season to an 'aquatic' phase during the wet, when huge areas are inundated naturally. This is an annual process which determines the ecological and environmental dynamics of the system.

Under these circumstances, the annual 'flood' as such is not a hazard but by and large a benefit. Only when the normal range of the annual flood volume and peak discharges are significantly exceeded or they fall well below expectations do negative impacts occur. This reality is illustrated in Figure 2.1.

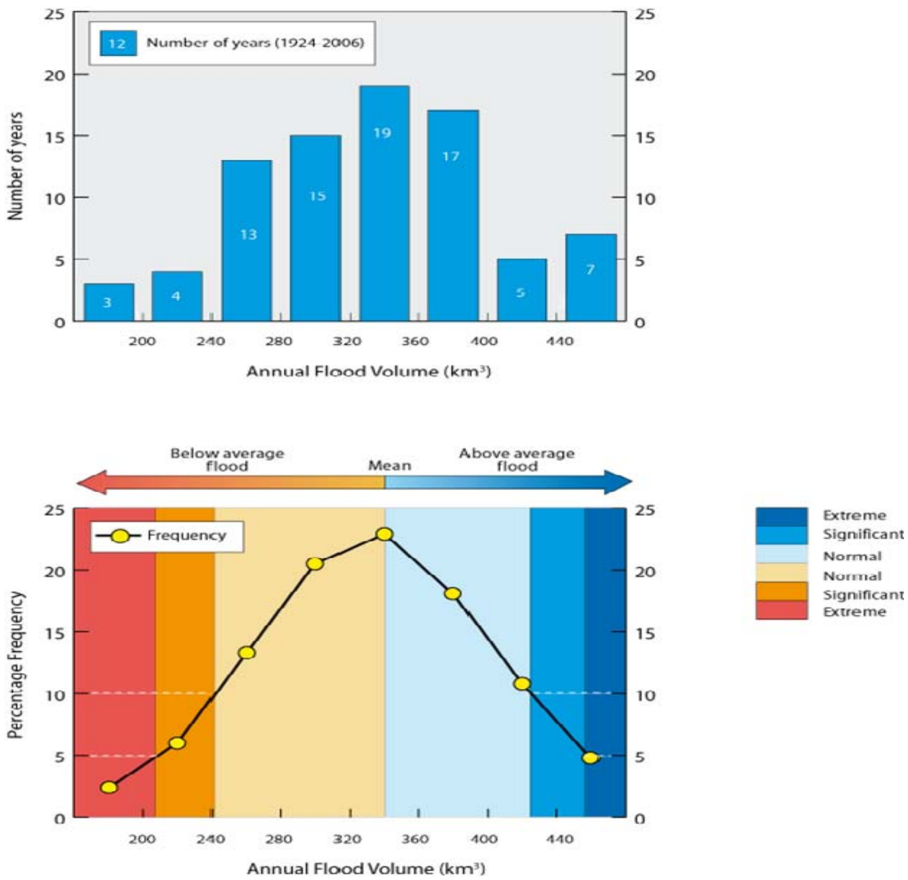

Figure 2. 1: Frequency histogrammes of the historical distribution of the annual flood volumes on the Mekong at Kratie which are normally distributed. The annual flood volumes are classified as 'significantly' and 'extremely' above or below their normal range. A significant year corresponds to a flood with a recurrence interval exceeding 1:10 years (10% annual probability) and an extreme year to a flood with a recurrence interval exceeding 1:20 years (5% annual probability)

In any year, the annual Mekong flood may be above or below ‘normal’ and this departure outside of the ‘normal’ range may be significant or even extreme. Interest does not lie only with the upper tail of the distribution of the flows as it does in smaller rivers and those that do not have a seasonal flood ‘pulse’. At Kratie, the mean annual flood volume between 1924 and 2006 is 333 km^3 and as the frequency histogramme shows, there has been a considerable historical variability on either side of this mean value.

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

‘Significant’, and to a much greater degree, ‘extreme’ flood season conditions expose the vulnerabilities of the regional ecology, environment and socio-economy to hydrological surplus and deficit beyond the ‘normal’ range. Such conditions have prevailed as recently as 2000 when the annual flood volume at Kratie was 45% above the annual average, the highest figure since records began in 1924. In comparison during the eight years from 2003 onwards the annual flood volume has never risen above average, typically being 20% less, while in 2010 it fell to 40% below normal, the smallest flood volume on record at Kratie[2].

These latter conditions could be described as a perennial hydrological ‘drought’, though the notion of drought as a meteorological hazard in tropical monsoon regions is not perhaps one that fits naturally with conventional perceptions. The term ‘monsoon’ is virtually synonymous with torrential rainfall, moisture surplus, floods and climatic predictability. Drought, on the other hand, is more generally associated with the marginal rainfall climates of arid and semi-arid regions, which show high variance and low reliability from year to year, such that rainfall deficits are common and often severe. The fact remains, however, that the Mekong and monsoonal SE Asia in general is a drought prone region (Source: Adamson and Bird, 2010).

The main climatic ‘driver’ of the magnitude of the Mekong flood in any given year is the strength or weakness of the SW Monsoon, though the incursion of typhoons and tropical storms from the South China Sea is an additional and significant factor. The long term annual pattern of monsoon intensity is therefore of considerable interest since monsoon failure, mega-droughts and extreme flooding events have repeatedly affected the agrarian peoples of Asia over the past millennium. It has also been a driving factor in the region’s socio-political history.

[2] The Regional Flood Hydrology, 2008 illustrated that conditions within the Lower Mekong Basin can be geographically quite variable. At Vientiane and further north one of the largest flood peaks observed in the last 90 years occurred. However, so low was the seasonal runoff further downstream that the flood at Kratie was still less than average.

2.3 The Asian Monsoon over the Last Millenium

The Asian Monsoon, a combination of the South West and East Asian monsoons. has in terms of its geographical and temporal variability, been ‘reconstructed’ over the last millennium using a network of tree ring chronologies drawn from India, China, Thailand, Viet Nam, Lao PDR, Indonesia, Malaysia and the Philippines (Cook et al, 2010). Tree rings provide a proxy source of information about the terrestrial climate from year to year. However, in the tropics, the most common tree species are not annular, that is they do not have annual growth rings. The species that do are relatively rare pines, teak and species such as *Fokienia Hodginsii*, native to south eastern China, northern and west central Viet Nam and western and northern Lao PDR. Relatively rare specimens of such species can be over 500 and up to 1,000 years old. Growth and therefore tree ring width are dependent on rainfall and soil moisture availability such that periods of reduced (narrower rings) or enhanced growth (wider rings) point to drier and wetter climate episodes.

Plate 2. 1: *Pinus Krempfii*, a rare endemic found only in the Central Highlands of Viet Nam, along with an example of its growth rings. ‘Coring’ a tree with a specially devised auger.

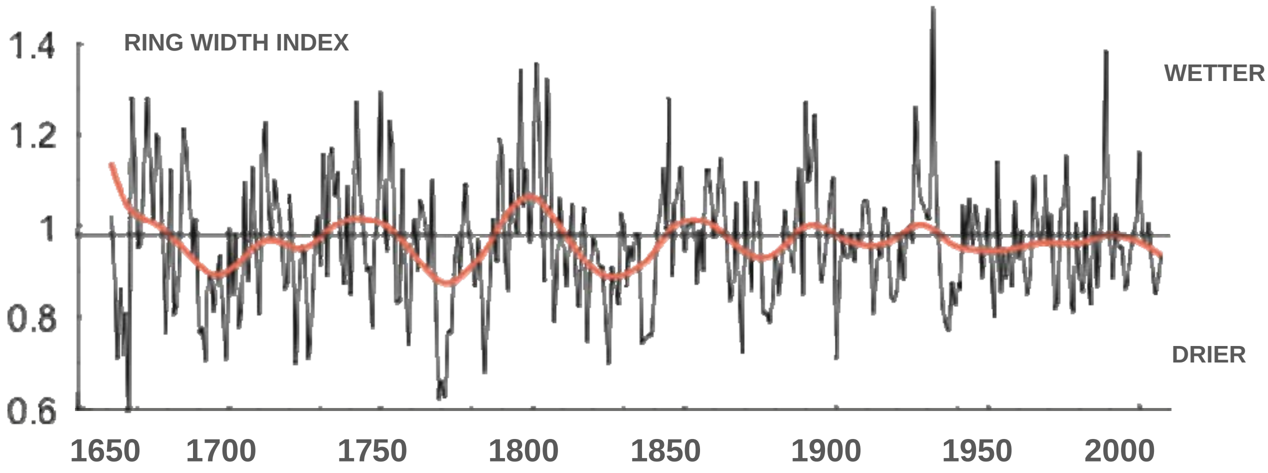

Figure 2. 2: *Pinus Krempfii* tree ring chronology from the Central Highlands of Viet Nam (1660 to 2003)

Figure 2.2 shows a ring chronology obtained from the *Pinus Krempfii* species in Viet Nam from 1660 to 2003. It indicates a wide variability in climate from year to year but with decadal and multi decadal periods of wetter and drier conditions. There is no evidence of any climatic change in terms of the structure and pattern of the data over the 344 year period.

Plate 2. 2: A very old specimen of *Pinus Krempfii* in the Central Highlands of Viet Nam

The climate reconstructions based on these dendrochronological studies do not emphasize the implied climatic deviations during individual years but the Asian Monsoon's repeated tendency towards extended extremely wet and dry episodes. The strategy in reconstructing the climate is to relate the pattern of tree rings to the observed instrumental data on rainfall and temperature. A robust integration of the two is the Palmer Drought Severity Index (PDSI), which is considered to be a proxy for soil moisture availability. Using fairly sophisticated statistical technology, the PDSI based on the observed climate data is related to the size and pattern of the annual ring widths and is then reconstructed backwards in time. Obviously the success of this procedure requires relatively long instrumental climate records. Regionally it is generally possible to obtain such data from the 1950's onwards, which offers almost 60 years for calibration.

Figure 2.3 shows a reconstruction of the PDSI for the last 1000 years based on a *Pinus Krempfii* chronology from Central Viet Nam. The multi decadal drought episodes are clear, from an epic sequence of drought years during the first half on the 13th century to a decadal sequence of dry years interspersed with flood episodes towards the end of the 19th century.

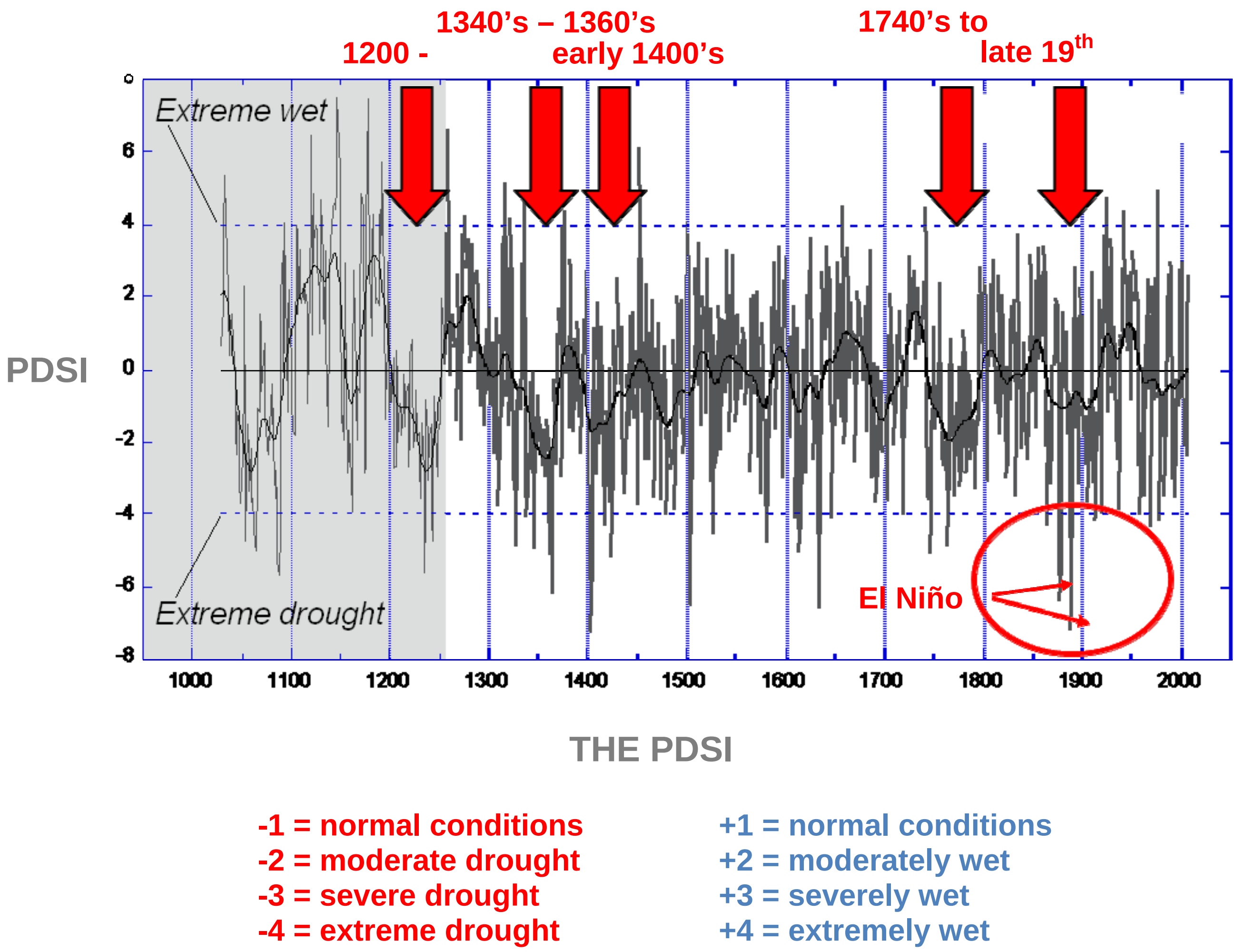

Figure 2. 3: A 1000 year reconstruction of the PDSI for Southern Viet Nam, indicating multi decadal periods of flood and drought (based on a specimen of Pinus Krempfii in the Central Highlands, the data kindly made available by the University of Columbia, NY).

These multi decadal droughts identified within the tree ring chronologies are independently confirmed by the contemporary chronicles which emphasize their social and political consequences. The Dai Viet Annals record the history of Viet Nam between the 10th and 18th Centuries and drought and its impacts are frequently mentioned:

- Monsoon failure during the early 1400s (Figure 2.3) led to years of severe drought, famine and social turmoil throughout Viet Nam. The Dai Viet kings are recorded as observing rituals to 'call rain from the heavens'.

- The decades of drought between the 1740s and 1780s also observed in the chronology culminated in years of famine between 1773 and 1778 and coincided with the Tay Son rebellion which began in 1771 and led to dynastic changes in the wake of war and natural disasters (see Barnes, 2000).

The "hydraulic city" of Angkor, the capitol of the Khmer Empire in Cambodia, experienced decades-long drought interspersed with intense monsoons in the fourteenth and fifteenth centuries that, in combination with other factors, contributed to its eventual demise. The Angkor droughts were of a duration and severity that would have impacted the sprawling city's water supply and agricultural productivity, while high-magnitude monsoon years damaged its water control infrastructure (Buckley et al, 2010). These droughts are also mentioned in the Thai Chao Praya chronicles.

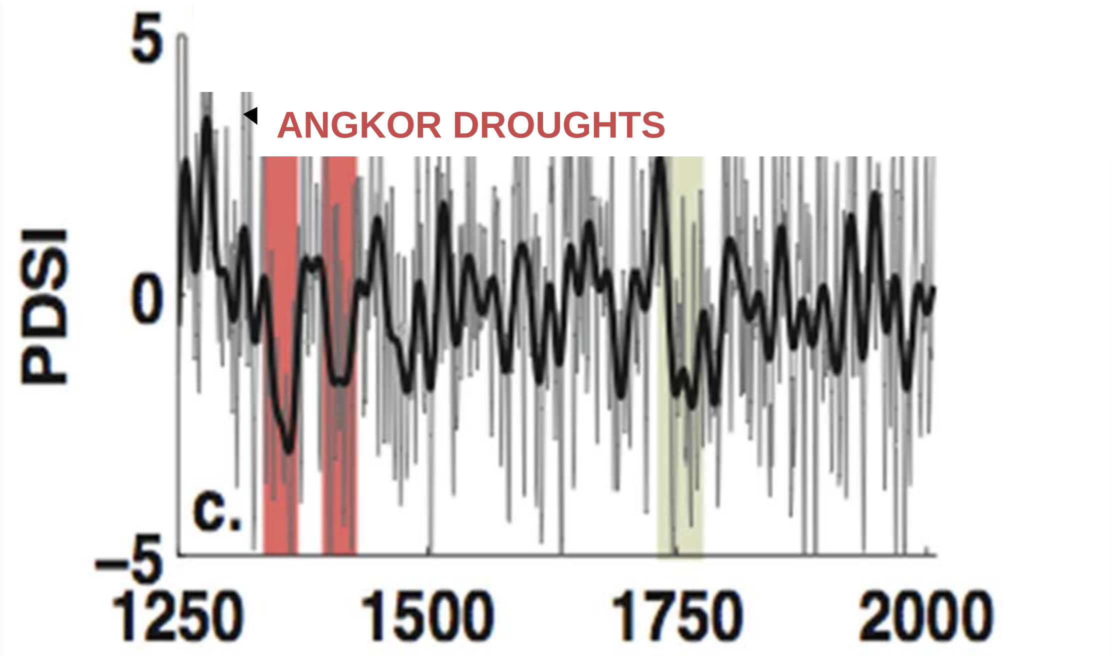

Figure 2. 4: The Angkor droughts of the 14th and 15th Centuries observed in a tree ring chronology (species *Fokienia hodginsii*) from Southern Viet Nam. These droughts were an additional 'stressor' at a time when the civilization was already in decline (Source: Buckley et al, 2010).

In order to better understand the historical spatial complexity of the Asian Monsoon Cook et al (2010) used 327 tree ring chronologies obtained from sites throughout Asia, estimated the summer monsoon PDSI for each year and projected the results onto 534 regularly spaced grid points, as indicted in Figure 2.5.

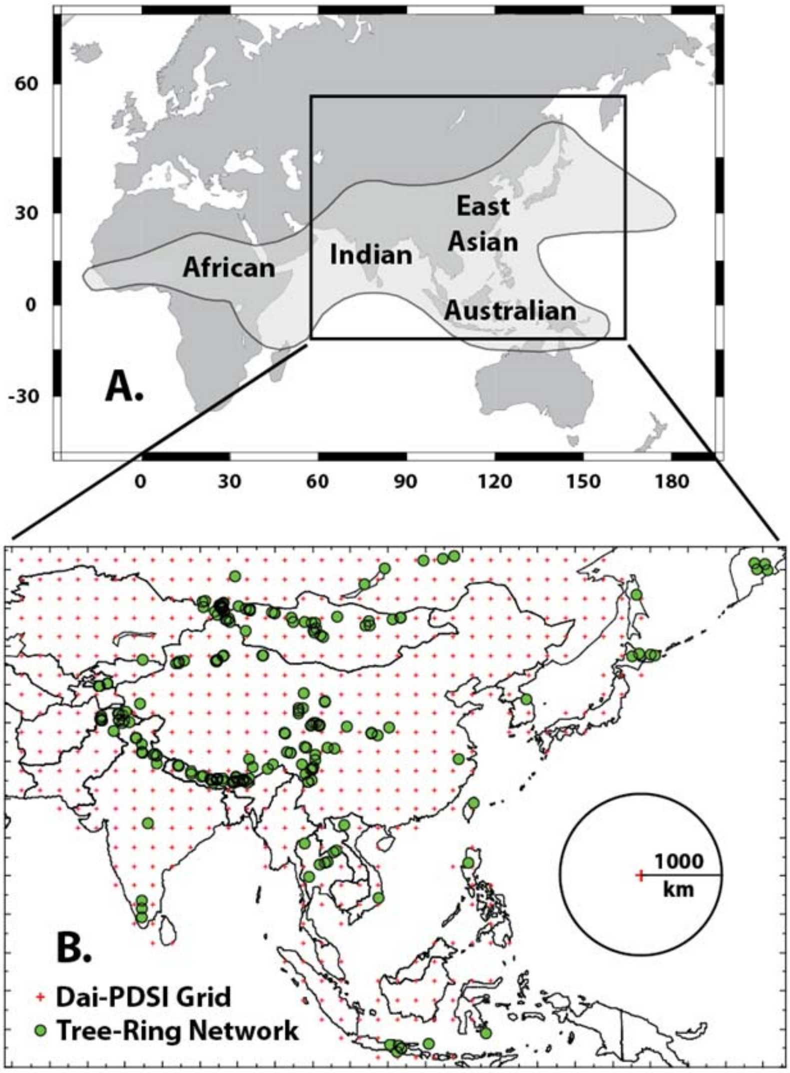

Figure 2. 5: The components of the Asian Monsoon and the regional tree ring network from 327 sites, along with the grid onto which the annual summer monsoon PDSI values were projected (Source: Cook et al, 2010).

The result is the Monsoon Asia Drought Atlas (MADA) which indicates the status of the summer monsoon over the last 1000 years. It confirms the tendency for extended dry and wet extremes which also have distinctive geographical characteristics. The MADA can be used to identify the spatial character and intensity of well documented historical droughts (and equally extremely wet multi year episodes) . Here four such drought events (Figure 2.6) are illustrated:

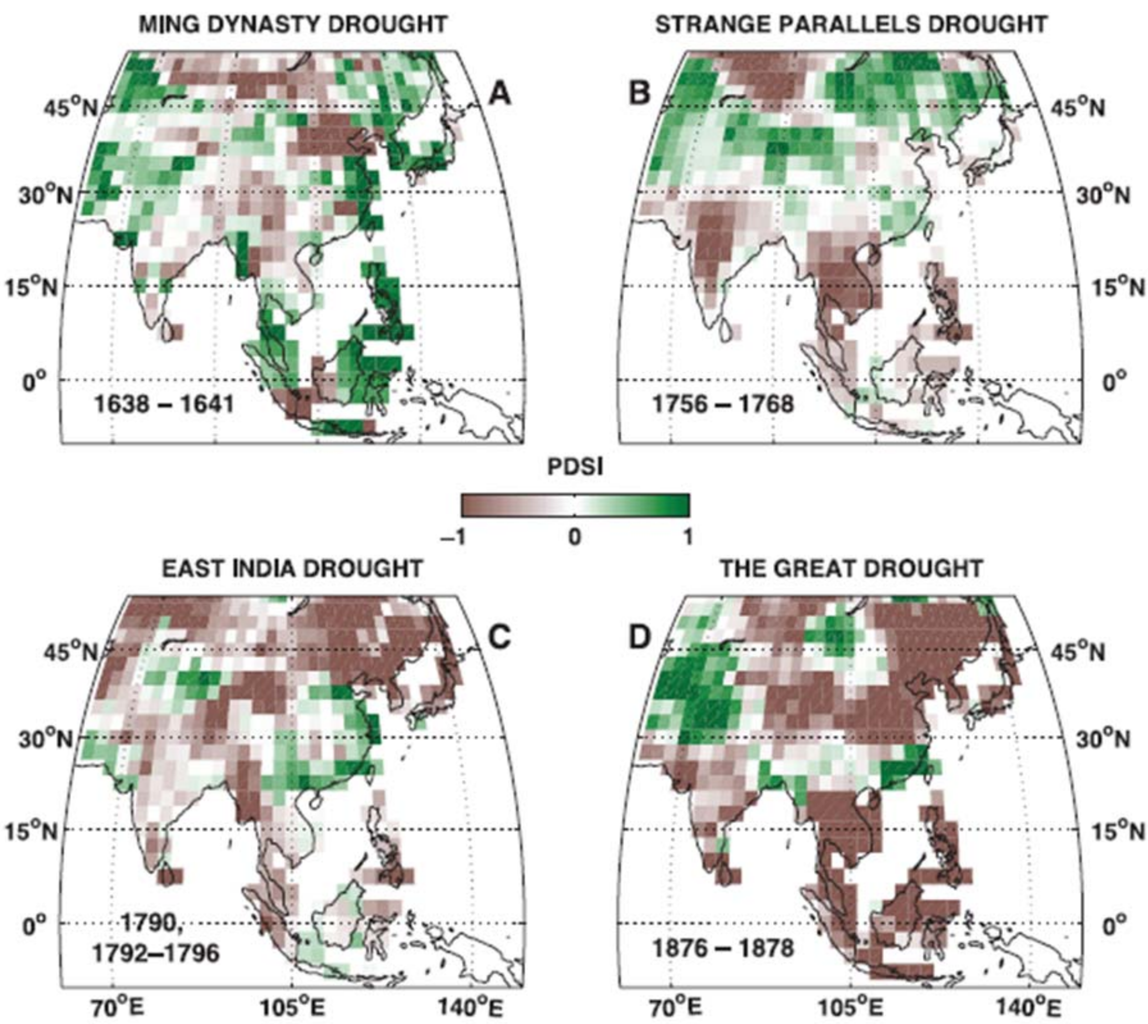

Figure 2. 6: Spatial drought patterns during four well documented historical Asian droughts. The Ming Dynasty Drought (1638 to 1641), the Strange Parallels Drought (1756 to 1768), the East India Drought (1792 to 1796) and the Great Victorian Drought (1876 to 1878). (Source: Cook et al, 2010)

- **The Ming Dynasty Drought (1638 to 1641)**[3]: The fall of the Ming Dynasty in 1644 was hastened by peasant rebellions during its final decades (Source: Parsons, 1970). Leading up to this dynastic collapse, a serious drought in the late 1630s and early 1640s appears from some historical records to have been the most severe over China for the past five centuries and may have contributed to the fall of the Ming Dynasty (Cook et al, 2010). The MADA map shows that this event was most severe in NE China near Beijing, with wetter conditions towards the SE.
- **The Strange Parallels Drought (1756 to 1768)**[4]: The mid–18th century Strange Parallels Drought over Southeast Asia coincided with a time of substantial societal upheaval and political reorganization across the region and simultaneously across the Siberian plains (Lieberman, 2003). This drought was first identified from a teak ring width record from NW Thailand (Buckley et al, 2007a, and Buckley, 2007b) and later corroborated in a Northern Vietnamese cypress chronology (Source, Sano

[3] Notice that on these maps the PDSI has been rescaled from -5 to +5, to -1 to +1.
[4] Named after the book by Lieberman, (2003).

et al, 2008).The map reveals that much of India, particularly western India, was also affected by this multidecadal drought. This spatially broad and persistent "megadrought" from India to Southeast Asia is one of the most important periods of monsoon failure found in the MADA (Cook et al, 2010). As can be seen it was particularly intense over the greater Mekong region.

- **The East India Drought (1792 to 1796):** The event occurred during the great El Niño of the late 18th century, which was felt worldwide and resulted in widespread civil unrest and socioeconomic turmoil around the globe. Much has been made of this drought's effect in India, with several references to severe famine there (Liberman, 2003). It also appears to have led to extremely dry conditions throughout NE China.

- **The Great Victorian Drought (1876 to 1878):** This 3 year drought occurred during one of the most severe El Niño events of the past 150 years . The effects of this devastating episode were felt across much of the tropics (Davis, 2001) and were particularly acute in India. A revolt against the French in Viet Nam also took place as a consequence of severe drought and famine at this time, and the drought was felt as far away as Jakarta, Borneo, and New Guinea (Davis, 2001). More than 30 million people are thought to have died from famine worldwide, and colonial-era imperialism left regional societies ill-equipped to deal with the effects of drought (Davis, 2001). This drought was severe across nearly all areas of monsoon Asia and ranks as the worst of the four historical droughts shown here. Similar to the Srange Paralells Drought, it was particularly severe within the Mekong region.

Figure 2.7 shows the severe El Niño (SST = Sea Surface Temperature) associated with the Great Victorian Drought as well as the between 1918 and 1919, which also saw an extremely weak monsoon over the Mekong region.

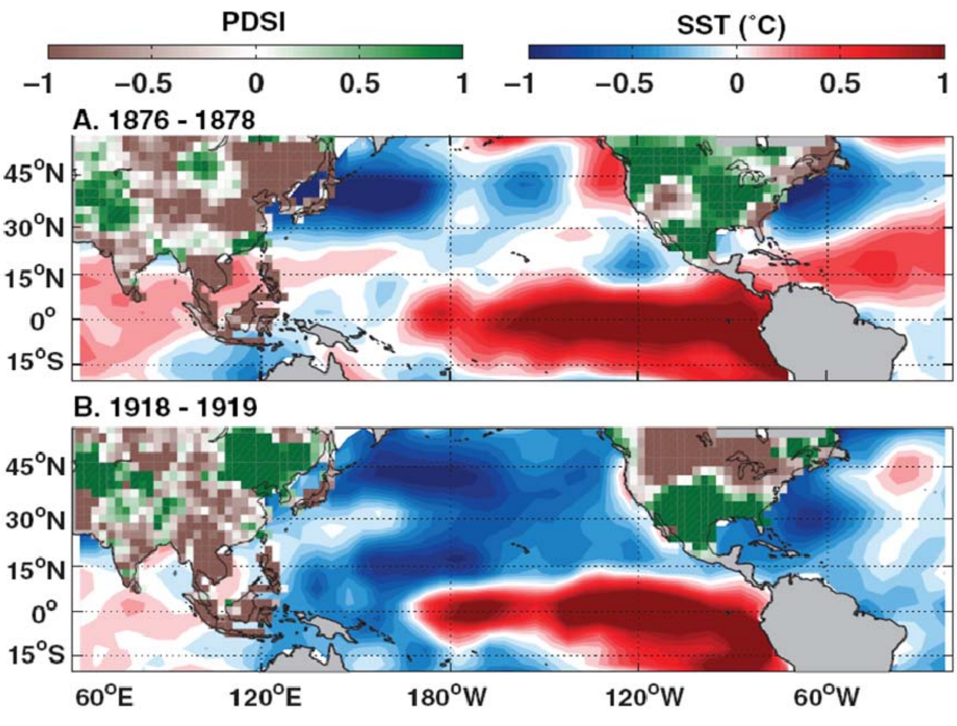

Figure 2. 7: The strong El Niños during the Great Victorian Drought (A) and the Indo China Drought of 1918 – 1919 (B). (Source: Cook et al, 2010).

Note that the geography of the drought pattern over Asia is quite different over NE China during these two events. During the Great Victorian Drought conditions were extremely dry, while during the later event, they were very wet.

Although there are clear historical linkages between tropical Pacific Ocean sea surface temperatures and the global atmosphere that affect the intensity of the Asian Monsoon these linkages should be perceived in probabilistic terms rather than as a deterministic relationship that might have implicit predictive value. This is also valid for the incidence and severity of Asian flood and drought episodes, which in turn predicate the annual flood hydrology of the Mekong.

Although the major drought episodes of 1992/3 and 1998 have been clearly linked to the El Niño phase, there have been warm phase years when flows have been above average. For example, strong El Niño conditions prevailed between 1940 and 1943, but flood volumes at Kratie were as much as 35% above average.

The major flood years are far less consistent with the onset of La Niña conditions, that is, the periodic cooling of the Eastern Pacific. During 1988 – 1989, when the cold phase was judged to be particularly strong, the annual flood was one of the smallest on record in terms of both peak and volume.

Figure 2.8 shows the joint distribution of the annual flood peak and volume observed at Kratie for the years 1924 to 2010, with the El Niño / La Niña years specified. The picture is not at all coherent, confirming that the relationship is neither straightforward nor consistent.

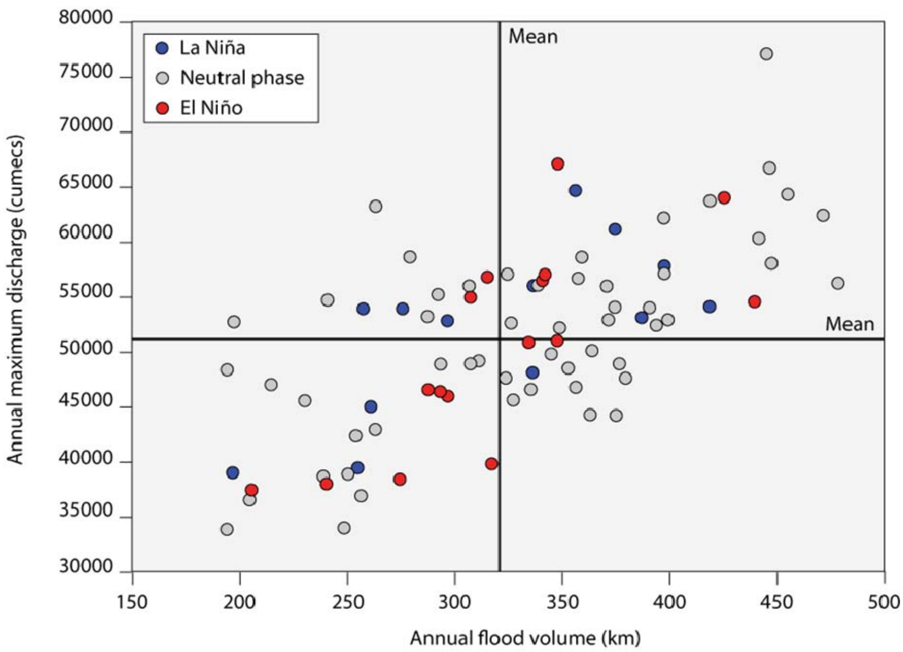

Figure 2. 8: This plot shows the joint sample distribution of the annual flood season volume and peak at Kratie (1924 to 2010). Although strong El Niños and La Niñas have historically brought extreme drought and flood conditions respectively to the Mekong, the relationship is not generally coherent for ENSO conditions as the result shows. If it was the ‘red dots’ would be concentrated in the lower left hand quadrant and the ‘blue dots’ concentrated in the upper right hand quadrant.

2.4 The Regional Rainfall Climate – Geography and Seasonality

Mean annual rainfall across the Lower Mekong Basin as a whole is in the range of 1,500 mm. However, the geographical range is significant, varying between more than 3,000 mm in the higher altitudes of Eastern and North-Central Lao PDR to less than 1,000.mm in parts of NE Thailand (Figure 2.9). In fact, according to some climatic classifications, the greater part of NE Thailand would be defined as semi-arid with rainfall marginally exceeding potential evaporation for just two months of the year.

The geography of regional rainfall clearly points to the dominant role of runoff from Lao PDR in determining the flood season hydrology of the Mekong. The left bank tributaries here and the Se Kong, Se San Sre Pok complex in Lao, Viet Nam and Cambodia together contribute 55% of the Mekong flow, whereas the right bank tributaries in Thailand provide just 20%. The balance is made up of the contribution from China (16%) and the Tonle Sap Basin (9%).

A major influence on the flood hydrology of the Mekong is the SW Monsoon. The strength of this monsoon has a considerable variability from year-to-year and a decadal and multi-decadal periodicity with respect to drier and wetter phases, as has already been demonstrated. These longer term influences on the statistical structure and pattern of the flood season flow regime combine with physical factors to produce an annual mono-modal flood season hydrograph that is highly predicatable in terms of its onset and duration, though not so in terms of its magnitude. One important feature of this tropical monsoonal hydrology is that during the early monsoon in June and July rainfall is usually, though not always, intense resulting in soil saturation, which maximises storm runoff response during the later weeks of the season. At Kratie, for example, on average, discharge starts rising at the beginning of June and has increased by a factor of five towards the end of July (roughly from 5,000 to 25,000 cumecs).

Average seasonal patterns can be misleading without reference to the variability of the process about the mean. In this regard, the regional seasonal and annual rainfall climate from year to year has a wide range (Figure 2.10). For example, at Phnom Penh the recorded annual rainfall has been as low as 650 mm and as high as 2,150 mm, equivalent to half and twice the long term mean. Similarly, seasonal amounts can vary substantially, by factors of four and more during the months of the monsoon.

The climatic factors that infuence tropical monsoonal flood runoff are complex and highly variable, with factors such as the waiting times between intense storm episodes. Their duration and intensity are key to the hydrological conditions in any given year. As the events of 2008 effectively demonstrated, such conditions can be quite localized giving rise to considerable spatial variation within the year.

As elsewhere in other climatic regions the storm rainfall observation network is sparse in the basin areas that generate the major proportion of the flood runoff, most critically in the case of the Mekong in the highlands of Lao PDR. Nontheless, the climatic linkages between the flood hydrology of the Mekong and the rainfall climate in particular are emerging as the need to understand and develop the ability to forecast flood and drought conditions receives the necessary research focus.

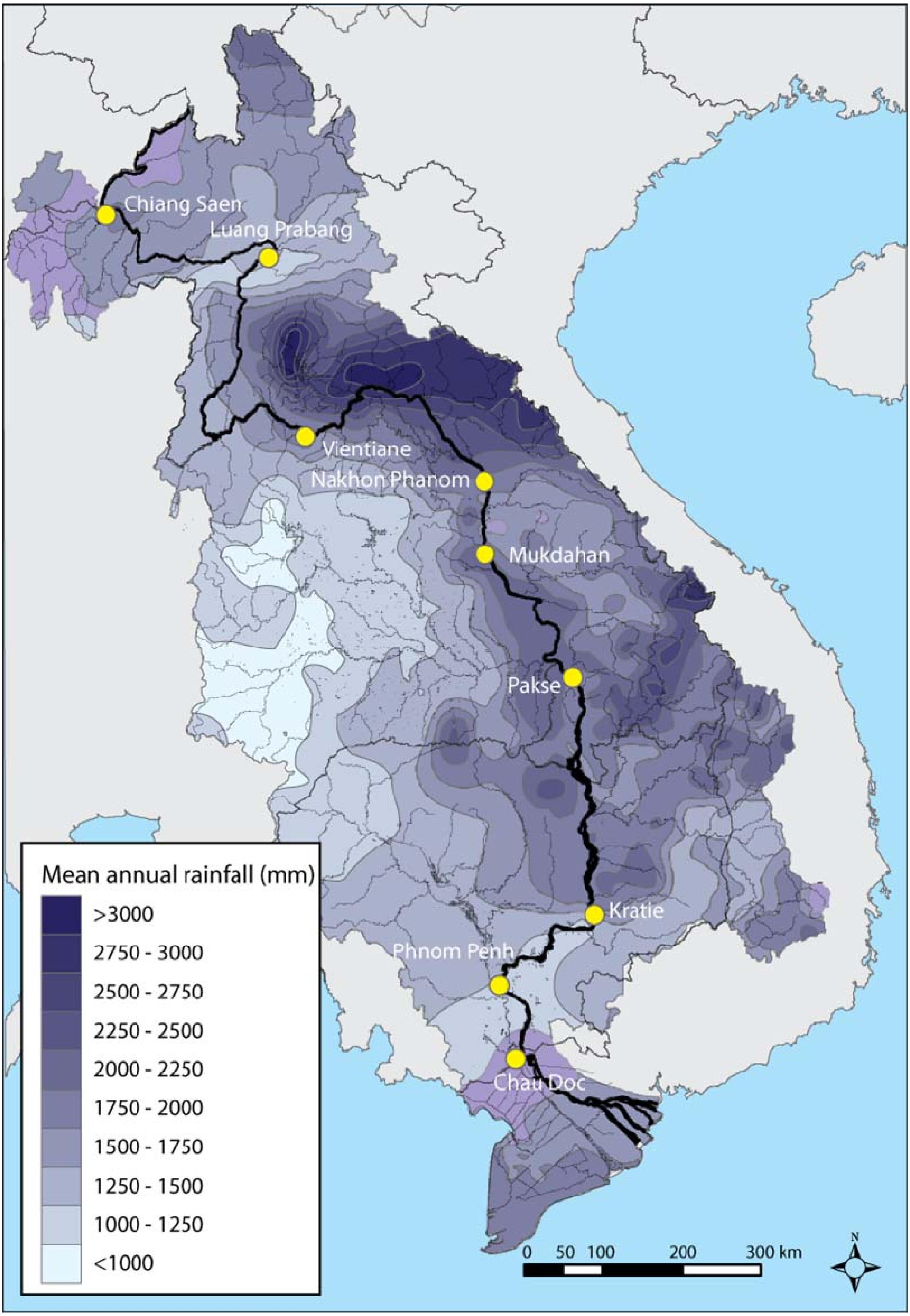

Figure 2. 9: The geography of the mean annual rainfall climate in the Lower Mekong Basin.

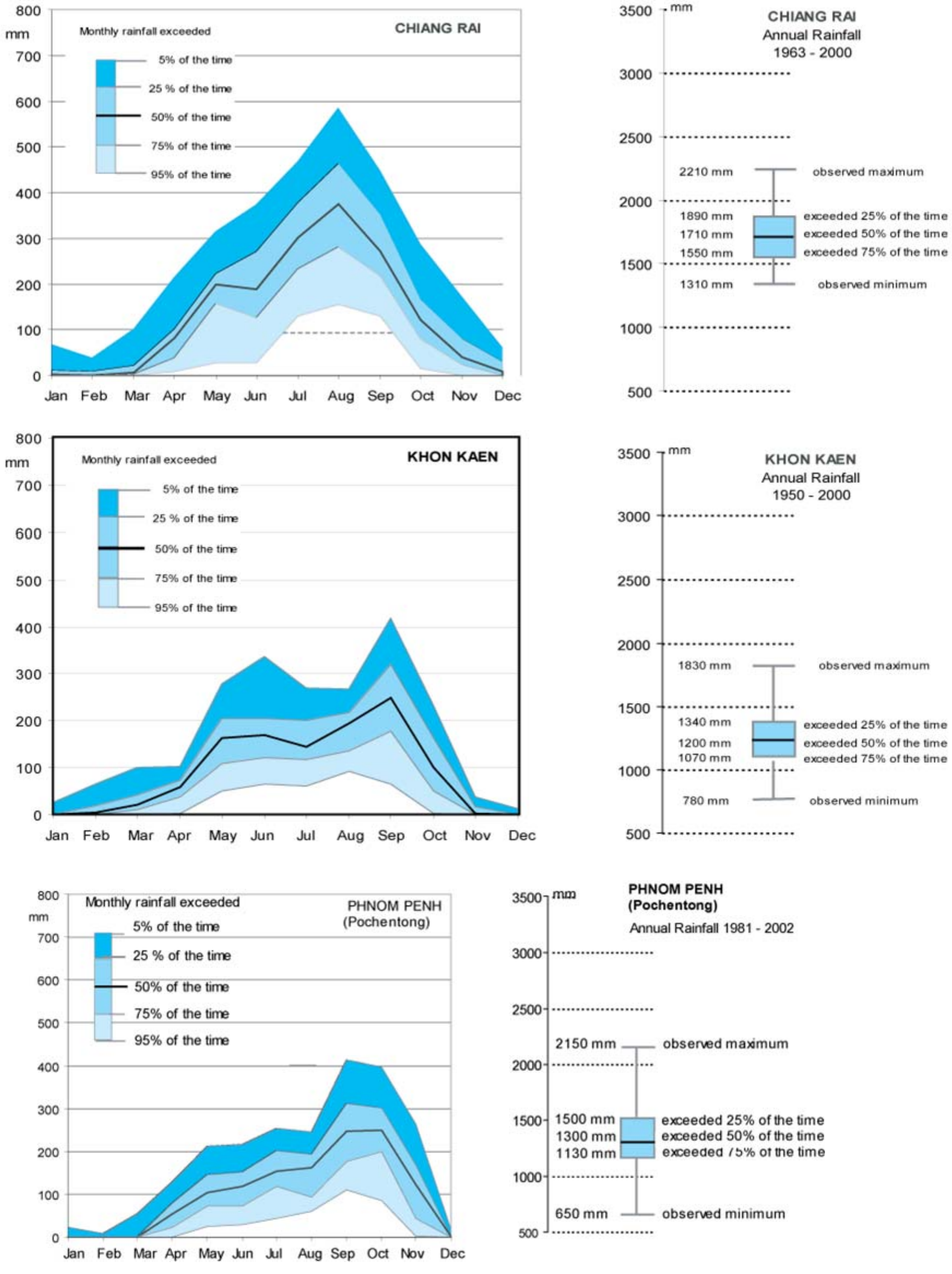

Figure 2. 10: The monthly and annual distribution of rainfall at three locations representative of the north, central and southern parts of the Lower Mekong Basin.

2.5 Regional Rainfall Extremes

A characteristic of tropical monsoonal rainfall climates is the high frequency of storm days on which intense downpours occur. It has been estimated that during 40% of these events rainfall intensities exceed 25mm / hour, a rate that is highly erosive (Goldsmith, 1998).

The figures for selected sites in the Lower Basin, presented in Table 2.1, suggest that between 12 and 19% of wet days fall into this category, the higher proportions occurring towards the north in line with the higher mean annual rainfalls. These figures may be compared to those typical of a temperate European climate such as those for London, where such intense rainfall events are far less common.

Site	Mean annual rainfall (mm)	Average proportion of wet days with	
		> 25 mm	> 50mm
Chiang Rai	1 740	18%	5%
Vientiane	1 650	19%	6%
Khon Kaen	1 230	17%	5%
Phnom Penh	1 270	15%	4%
Chau Doc	1 270	12%	3%
London (UK)	750	5%	<1%

Table 2. 1: Average annual proportion of wet days at selected sites in the Lower Mekong Basin upon which > 25mm and >50mm of rainfall occurs. These figures may be compared to those typical of temperate rainfall climates, here represented by the data for London.

Further evidence of the higher storm intensities in tropical monsoonal regions is shown in Figures 2.11 and 2.12. For example, at Phnom Penh the intensity of the annual maximum 60 minute 1:2 year (approximately equal to the average annual maximum event over an hour) is more than twice that typically observed in Mediterranean and Temperate European rainfall climates.

For longer storm durations total depth, versus rainfall intensity, is the more appropriate measure of severity. Figures compare the 1:2 year annual maximum one, two and three day storm rainfalls at Vientiane and Phnom Penh with those for two temperate climate regimes in Australasia. Other than indicating greater average storm depth, the Mekong data reveal a greater persistence of extreme rainfall over these longer durations, illustrated by the much greater relative increase between1 and 3 day totals.

Although tropical storms and typhoons are an integral feature of the regional storm rainfall climate and are generally associated with the most intense events, their incidence and severity is modest compared to such countries as the Philippines and specifically Northern Luzon. Here, at Baguio City (1 500 masl) the mean annual rainfall is 3,800 mm (more than twice that at Vientiane, for example), 60% of which is attributable to tropical cyclones. Tropical storm depths here are orders of magnitude greater than those in the Mekong Basin. (Figure 2.13).

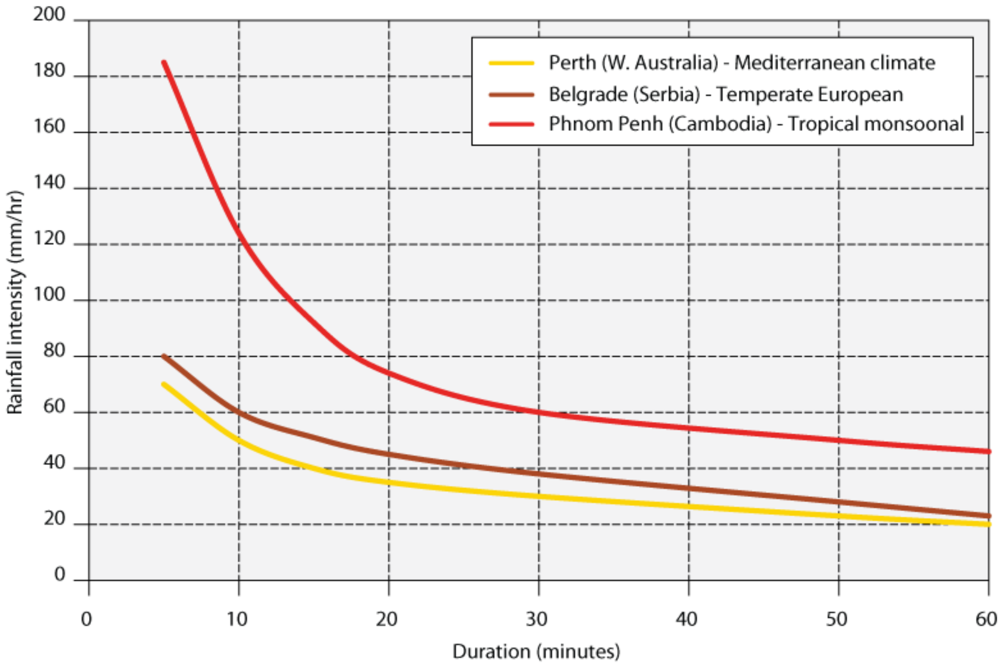

Figure 2. 11: One in two year comparative storm intensities for durations of 60 minutes and less, indicative of Mediterranean, temperate and tropical monsoonal climates (based in part on data in Maksimović et al. 1993).

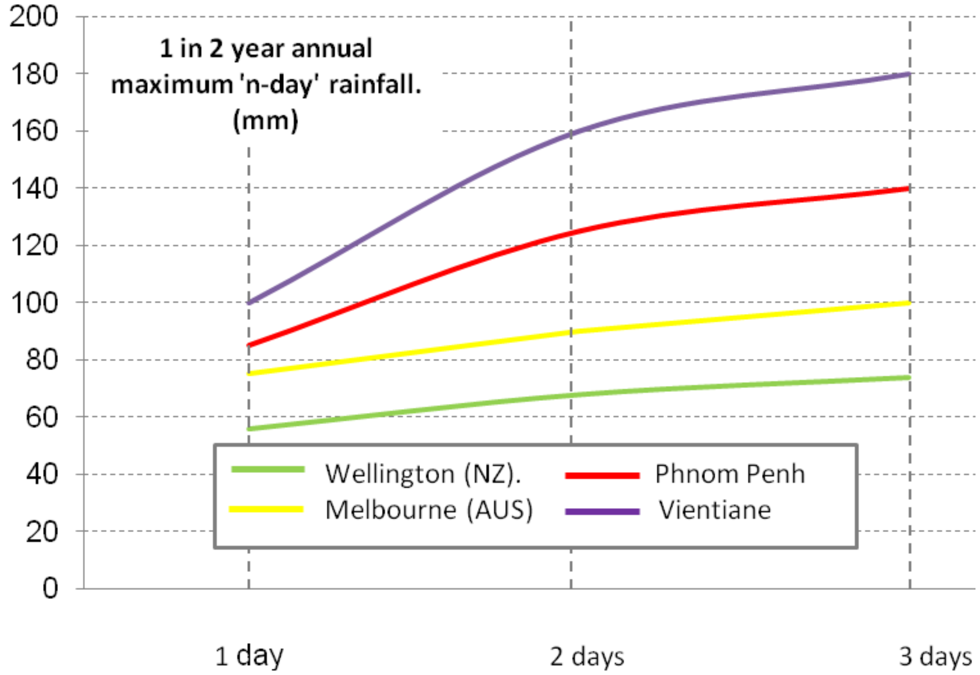

Figure 2. 12: One in two year comparative annual maximum storm rainfall depths for durations of 1 to 3 days for two representative sites in the Lower Mekong Basin and two in Australasia. The Mekong data indicate a greater persistence of extreme rainfall over these longer durations, indicated by the much greater relative increase between1 and 3 day totals (based in part on data in Daniell and Tabios, 2008).

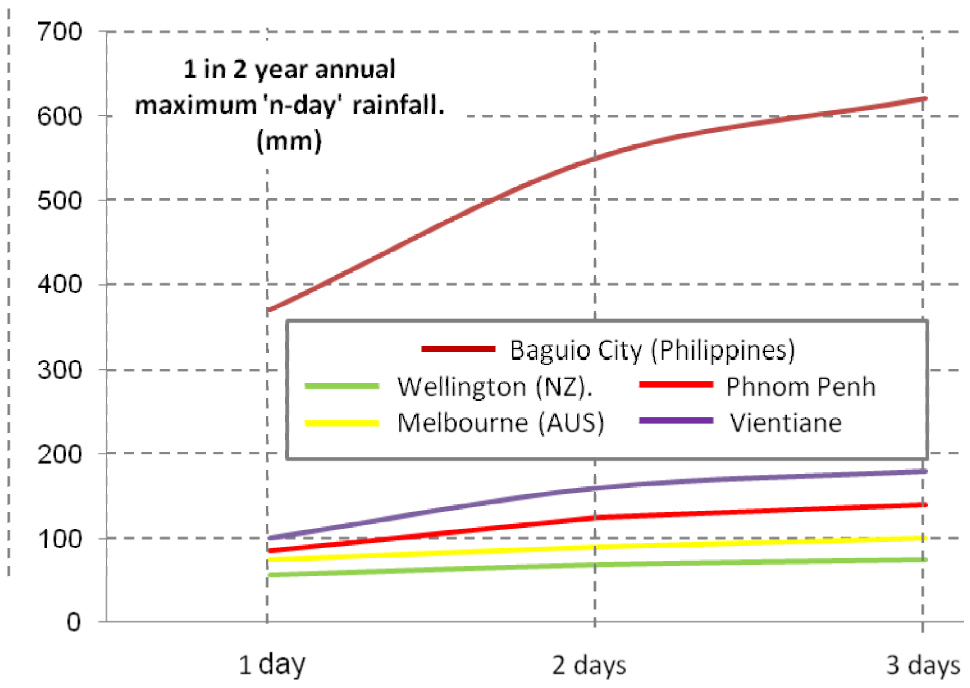

Figure 2. 13: The same data as those in Figure 2.13 with the addition of those for Baguio City in the Philippines which has one of the most globally extreme storm rainfall climates due to the high annual incidence of typhoons (based in part on data in Daniell and Tabios, 2008).

Table 2.2 indicates the distribution of 'n day' storm risk at Vientiane and Phnom Penh. At both locations the 100 year event has been approximated or exceeded, noting that the record lengths available for analysis are 80 and 34 years respectively.

T (years)	Vientiane			Phnom Penh		
	1day	2 day	3 day	1 day	2 day	3 day
2	95	160	180	85	125	140
5	120	200	230	110	165	185
10	140	230	260	125	195	215
20	160	260	290	140	220	245
50	190	290	330	160	255	280
100	210	320	360	180	280	310
Observed maxima	225	360	380	180	230	295

Table 2. 2: Estimated annual maximum 'n-day' storm risk for Vientiane (80 year record) and Phnom Penh (34 year record) with recurrence interval T years (units are mm). The figures for Vientiane are the greater, in line with a higher mean annual rainfall (see Table 2. 1).

Typically, 'n day' rainfalls during the course of typhoon incursions into the Basin can be extreme as the figures below illustrate, with over 400 mm in one day and as much as 700 mm over three being commonly observed.

Site	Location	Duration				
		1 day	2 days	3 days	5 days	10 days
Attopeu	Southern Lao PDR	400	640	710	900	1020
Nong Khai	NE Thailand	470	480	490	510	640
Nakhon Phanom	NE Thailand	460	520	540	555	810
Thakhek	Central Lao PDR	450	590	630	660	730

Table 2. 3: 'n day' rainfalls observed at selected sites in the Lower Mekong Basin during the course of severe tropical storm Wukong in September 1996 (units are mm).

There is no evidence to suggest that the incidence of such intense storm days is increasing in line with some of the projected impacts of global warming, as the representative regional plot for the data at Vientiane confirms (Figure 2.14).

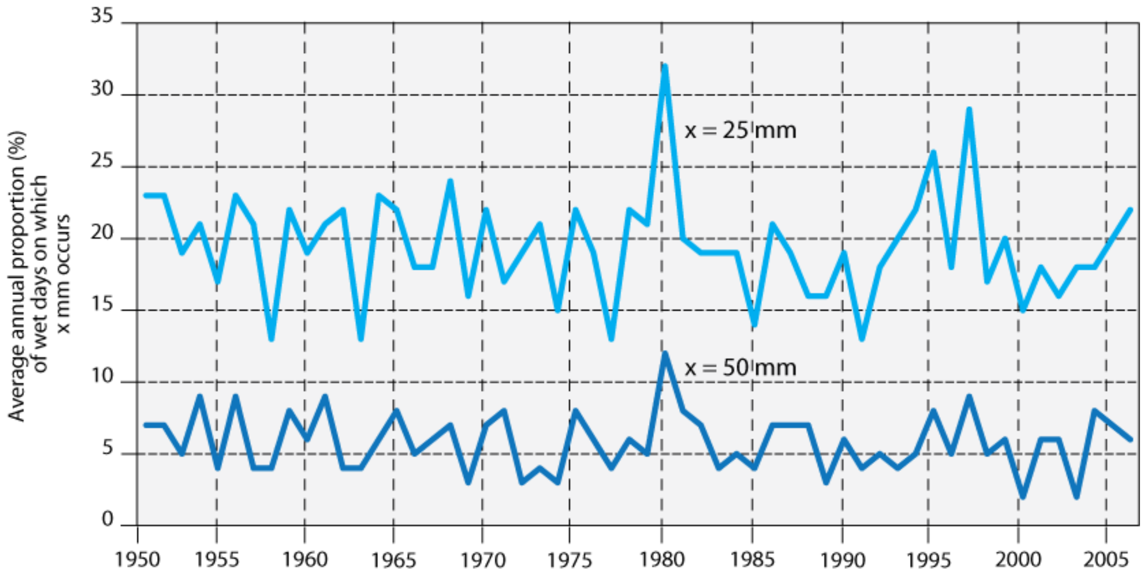

Figure 2. 14: Vientiane (1951 – 2006) – percentage of wet days on which more than 25 and 50 mm were observed.

3. The 2010 Flood Season

3.1 Overview

The hydrological data observed on the Mekong mainstream at Kratie may be considered to provide the benchmark for describing the overall regional hydrological situation in any given year. At this point, more than 90% of the total average flow of the Basin has entered the system such that conditions here can be regarded as the integral of those upstream parts of the Basin which generate virtually all of the runoff. Conditions at Kratie also define those further downstream across the Cambodian flood plain, within the Tonle Sap system and in the Delta in Viet Nam, since apart from the contribution of the Tonle Sap little further water is added to the mainstream.

Conditions at Kratie during 2010 represent the eighth year in succession that the annual flows there have failed to rise above average. In five of these eight years, flows have been between 10 and 20% below normal. However, in 2010 the total volume during the flood season set a historical precedent by falling to 40% below normal.

It would be quite wrong to invoke the climate change argument in the context of this recent perennial sequence of significantly below average flows within the Mekong region as a whole. Not only is there substantial geographical variation in hydrological conditions but such sequences have occurred before and are an integral feature of the temporal hydrological landscape. For example, the extreme flood conditions that occurred during September 2008 were confined to the northern parts of the Basin. Downstream of Vientiane flows during the same year were significantly below normal to the effect that overall basin conditions during the year, as indicated by the flows at Kratie, were below average. Comparable multi-year sequences of deficient flow conditions occurred throughout the 1950s at Kratie, underscoring the natural quasi periodic structure of the Mekong hydrological time-series between runs of years of above and below normal flows.

Though the annual flood volume observed at Kratie during 2010 was the lowest observed within the 87 year period of record, comparable “drought” conditions have occurred regularly in the past, for example in 1998, 1992, 1988 and 1977. The reasons for such extremely deficient flood season flows are related to a weak SW Monsoon and the lack of tropical storms.

Another factor in 2010 was the fact that the onset of the SW Monsoon was as much as three weeks later than expected which resulted in a flood season that was six weeks shorter than usual at Kratie. In addition, the early weeks of the monsoon up to the end of July did not produce the kind of intense and sustained storm rainfall that would have generated significant flood runoff.

While in some areas of the Basin rainfall conditions subsequently improved such that seasonal totals recovered to more or less average, in others this was not the case. At Pakse, for example, total seasonal rainfall was just 60% of the long term average. This serves to explain why soil moisture conditions in Southern Lao PDR and Northern Cambodia at the end of August were in deficit leading to considerable vegetative stress, which is clearly evident from satellite imagery. Inevitably, these features of the 2010 rainfall climate led to an uncharacteristically short flood season of just three months at Kratie, six weeks less than usual.

In short, 2010's drought conditions must be considered within its meteorological and hydrological context. This context completes an eight year sequence of below average annual floods when the overall conditions in the Basin are evaluated.

3.2 Rainfall and Soil Moisture

As indicated, the timing of the onset of the SW Monsoon during 2010 in many parts of the Basin was amongst the latest that has been observed historically. As the selected data in Table 3.1 indicate, the onset date has a remarkably low inter-annual variability of between one and two weeks. Even where the onset date lay within the typical May 'window', rainfall during the early weeks of the season fell well below average. Over the Northern (Vientiane) and Southern parts (Tan Chau) there was a recovery in the latter half of the season such that rainfall for the year finished close to average (Table 3.2). Crucially, however, rainfall in Southern Lao PDR and Northern Cambodia, as represented by the figures for Pakse, was just 60% of that to be expected in an average year.

Site	Monsoon onset				Monsoon end		
	Average Date	Standard Deviation	2010	Delay. (days)	Average Date	Standard Deviation	2010
Chiang Saen	7th May	9 days	3rd Jun	27	7th Nov	25 days	28th Oct
Luang Prabang	7th May	9 days	1st May	none	24th Oct	33 days	15th Dec
Vientiane	4th May	8 days	28th May	24	10th Oct	16 days	26th Oct
Mukdahan	6th May	8 days	7th May	1	8th Oct	16 days	19th Oct
Pakse	5th May	11 days	26th Apr	none	15th Oct	17 days	16th Oct
Tan Chau	18th May	12 days	6th Jun	30	18th Nov	13 days	17th Nov

Table 3. 1: The onset and end of the 2009 SW Monsoon at selected sites in the Lower Mekong Basin.

Rain gauge	Mean annual rainfall (mm)	2010 (mm)	2010 / average
Chiang Saen	1 750	1 550	88%
Luang Prabang	1 250	1 400	112%
Vientiane	1 650	1 600	97%
Mukdahan	1 500	1 600	106%
Pakse	2 100	1 300	62%
Tan Chau	1 250	1 300	104%

Table 3. 2: Lower Mekong Basin – 2010 rainfall compared to the long term annual mean at selected sites.

The seasonal patterns of rainfall accumulation at Vientiane and Pakse are illustrated in Figure 3.1.

At Vientiane, the monsoon got off to a late start towards the end of May, following rainfall which was sporadic, with two to three week periods of little if any in June and early-July. By the beginning of August, the accumulated total was more than 300mm less than average.

At Pakse, the 2010 seasonal rainfall pattern is quite different. At this location, the monsoon began at the end of April (Table 3.1). The total accumulated by the end of July and was crucially less than half of the mean expectation of 1,100 mm. The deficit continued throughout the season and resulted in a total shortfall of 800 mm (Table 3.2). There were no episodes of sustained heavy rainfall, rather a steady accumulation of modest daily totals. Under these conditions seasonal flood runoff would have been much reduced.

These two locations provide a basic summary of the rainfall climate across the Lower Mekong Basin during 2010. The data at Pakse are particularly significant since they indicate a wider and extreme sub-regional rainfall deficit which is confirmed in Figures 3.2 to 3.6.

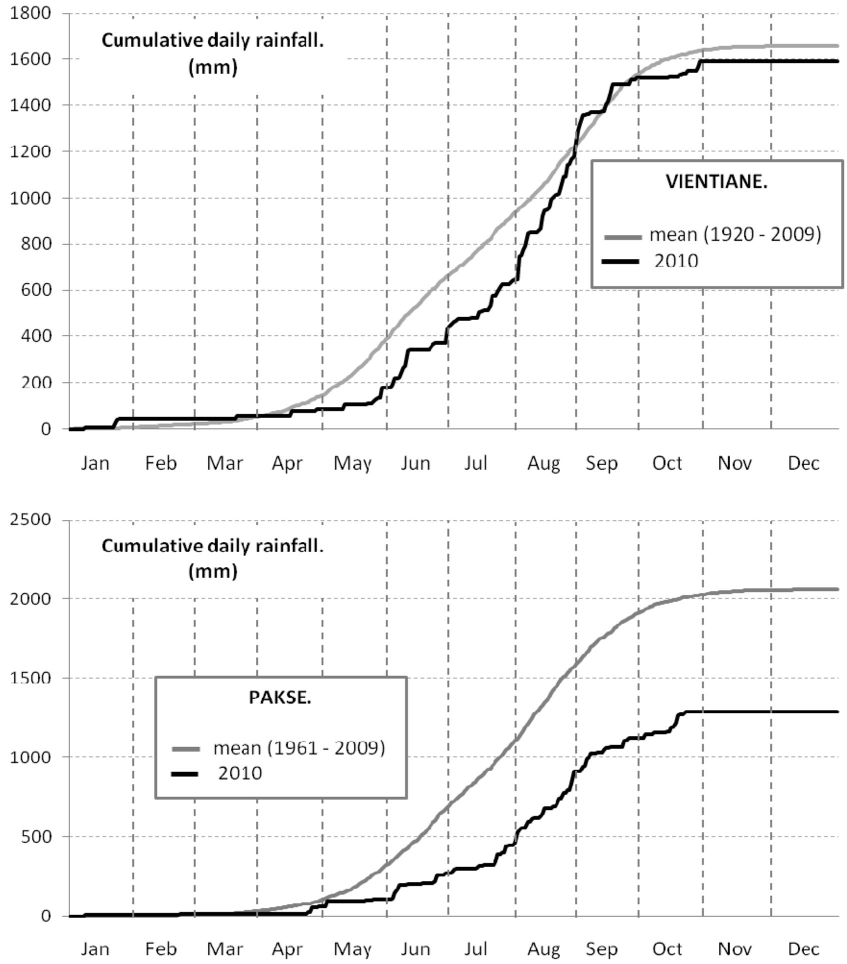

Figure 3. 1: Cumulative daily rainfall at Vientiane and at Pakse during 2010 compared to the long term pattern. At Vientiane the 2010 SW Monsoon began at the end of May but rainfall until late July was considerably below normal. Only during August and September did rainfall accumulate in any significant amounts, such that the final total for the year as a whole was close to average. At Pakse the whole Monsoon season saw rainfall at critically low levels - as much as 800 mm below normal at the end of August.

These five maps of rainfall during each month of the flood season (June to October) indicate that, with the exception of July, regional precipitation was below average over the greater part of the Lower Mekong Basin. Over most parts of the region, rainfall during each of these months would be expected to exceed 250 mm and, with the exception of NE Thailand, Central Cambodia and the Delta, to exceed 400 mm to 500 mm during July and August.

Only in the Central and Eastern highlands of Lao PDR was rainfall close to expectation throughout most of the flood season. The SW Monsoon, which should generally begin in June, was apparently delayed over large areas, with rainfall only reaching normal levels during July. After that the pattern is one of general deficit over large areas, particularly over Southern Lao PDR. In this area, the Se Kong, Se San and Sre Pok basin was particularly affected with very specific consequences for the flood season hydrology in these southern regions of the Basin at Kratie and further downstream, where as it turns out 2010 saw the lowest annual Mekong flood in terms of seasonal flow volume over the last 87 years (see below).

Figures 3.7 and 3.8 illustrate the 'condition' of the regional crops and natural vegetation as a function of the available soil moisture, which confirms the relatively severe and widespread seasonal rainfall deficit conditions. The maps are based on satellite imagary of the so called NDVI, which is a measure of crop stress and therefore the level of soil moisture availability.

- Figure 3.7 reveals that the normal situation during the middle of the monsoon season at the end of August is that soil moisture throughout the region would be expected to be saturated leading to no vegetative 'stress'.

- Figure 3.8, on the other hand, shows that at the end of August 2010 large areas of the Basin were under severe moisture stress, despite the apparently above average rainfall over most parts of the Basin during that month (Figure 3.4). The most extensive of the deficit areas lies within the Se Kong, Se San and Sre Pok Basin, which is the major tributary complex in terms of its average hydrological contribution to the mainstream (18%). Seasonal runoff from this system would have been very low with significant impacts upon downstream flows and water levels over the Cambodian floodplain, water levels in the Great Lake and in the Delta. Such levels of soil moisture deficit have probably not been seen since the 'great drought' of 1992 and suggest that similar shortfalls in seasonal rainfall to the 40% figure observed at Pakse (Table 3. 2) were widely evident throughout this part of the Basin.

- The central and eastern regions of Lao PDR indicate no crop or vegetation stress in keeping with the spatial distribution of rainfall already indicated in Figures 3.2 to 3.6. However, the far north of Lao PDR appears to have been extremely dry prior to the end of August, as were parts of the Isaan (northeastern) region of Thailand.

These regional rainfall deficits during the wet season of 2010, combined with what appears to have been the late onset of the Monsoon over large areas, are reflected in the flood season hydrology and conditions that were historically unprecedented in terms of the observed flow regime of the Mekong.

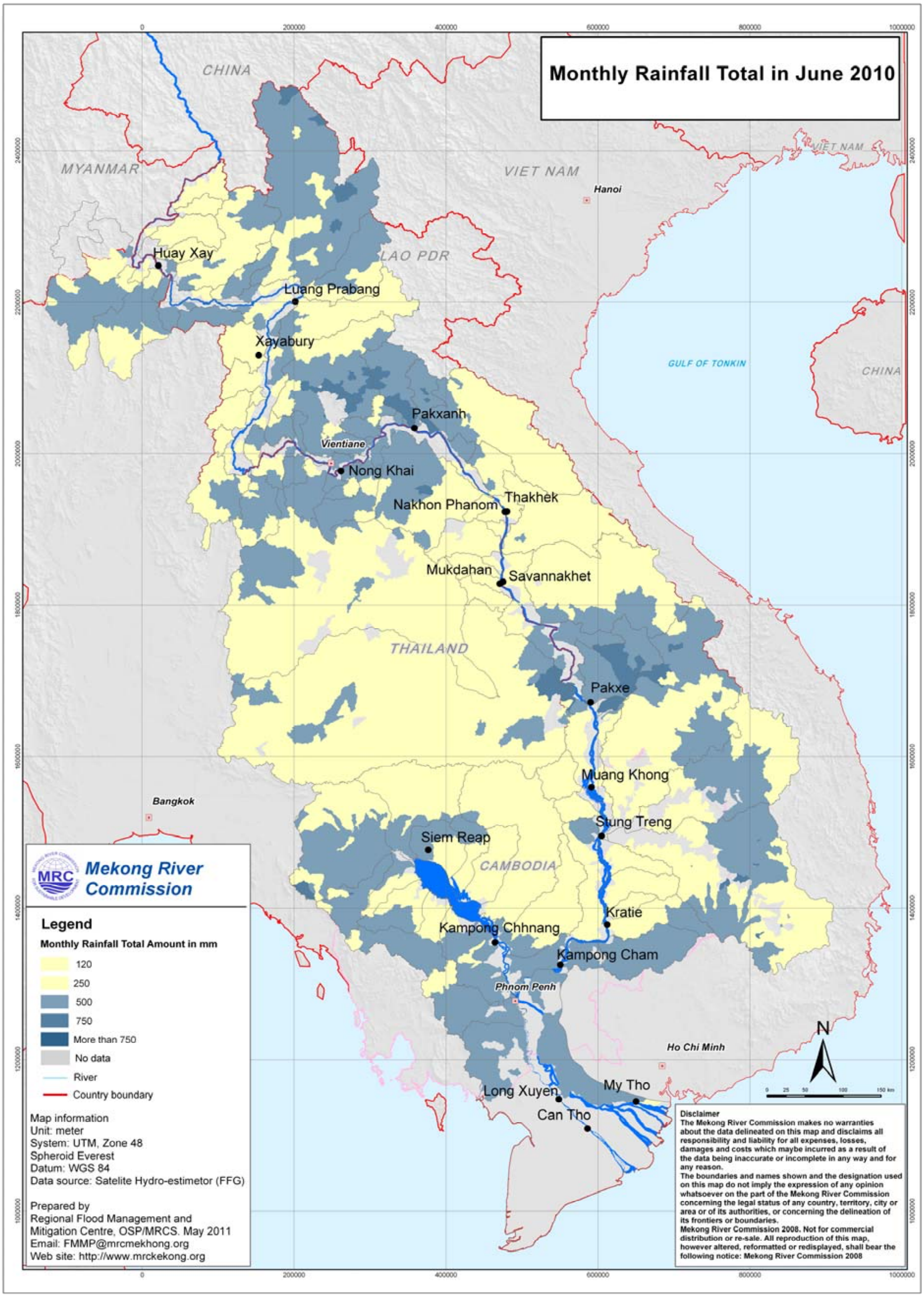

Figure 3. 2: Rainfall over the Lower Mekong Basin – June 2010.

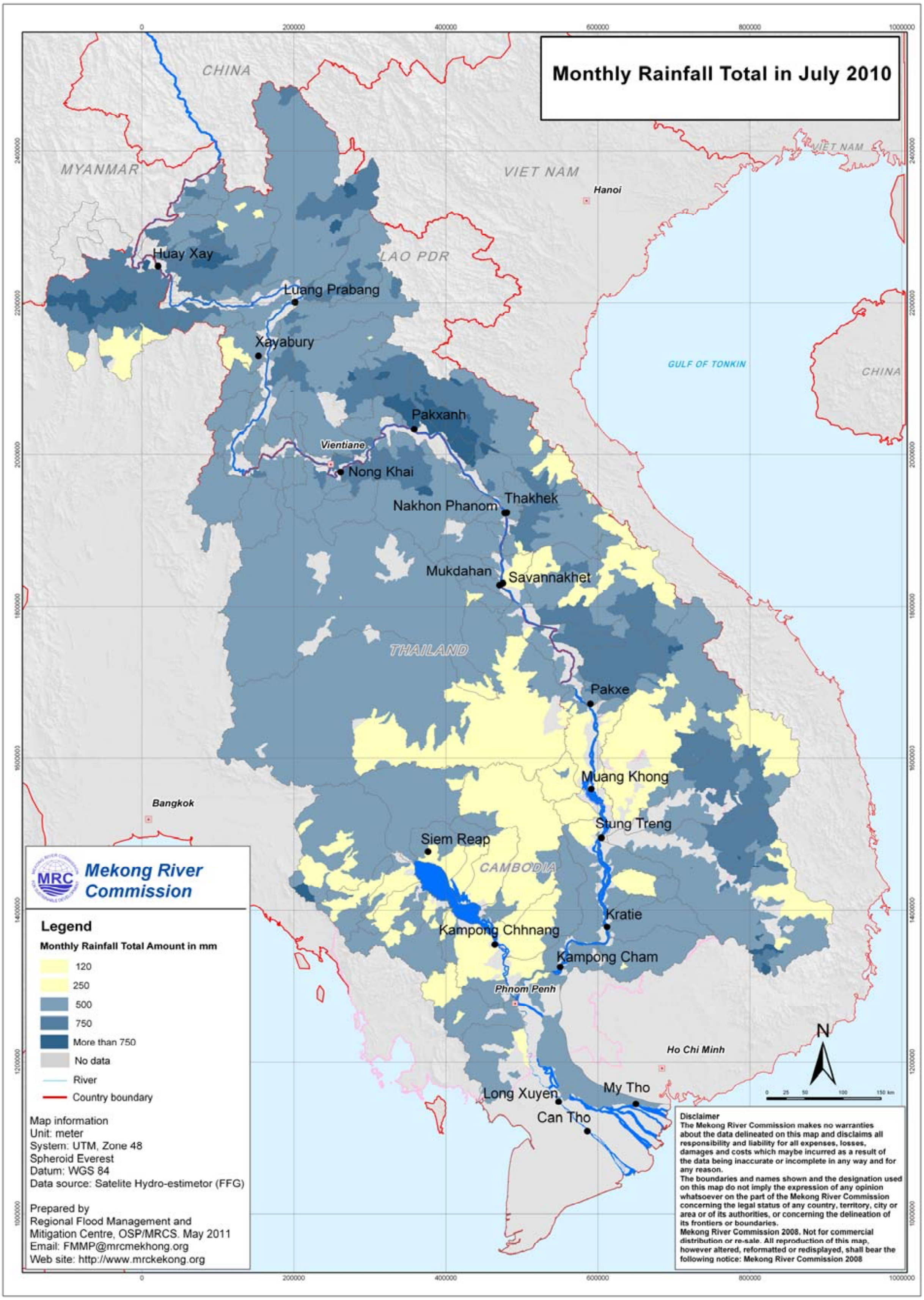

Figure 3. 3: Rainfall over the Lower Mekong Basin – July 2010.

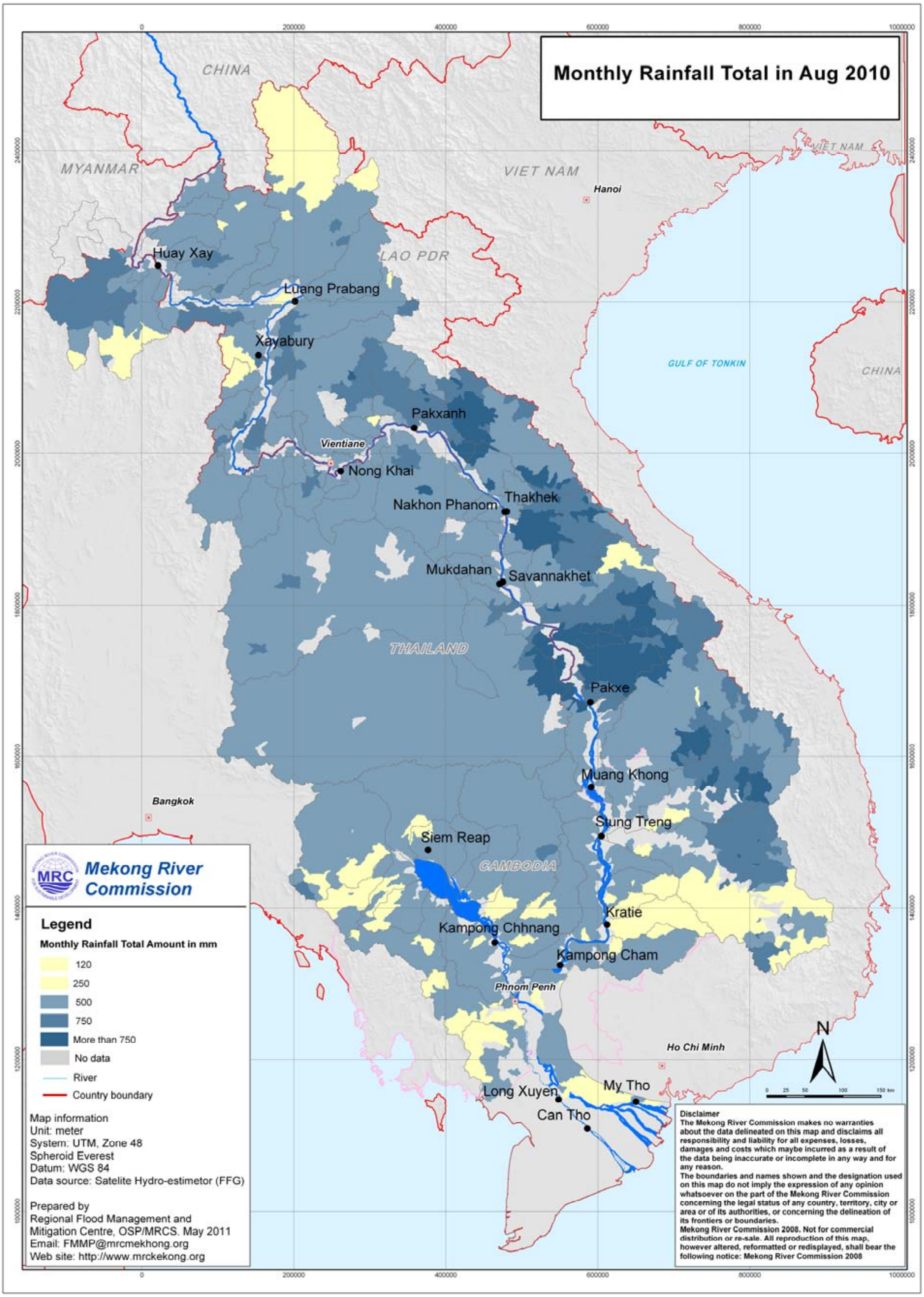

Figure 3. 4: Rainfall over the Lower Mekong Basin – August 2010.

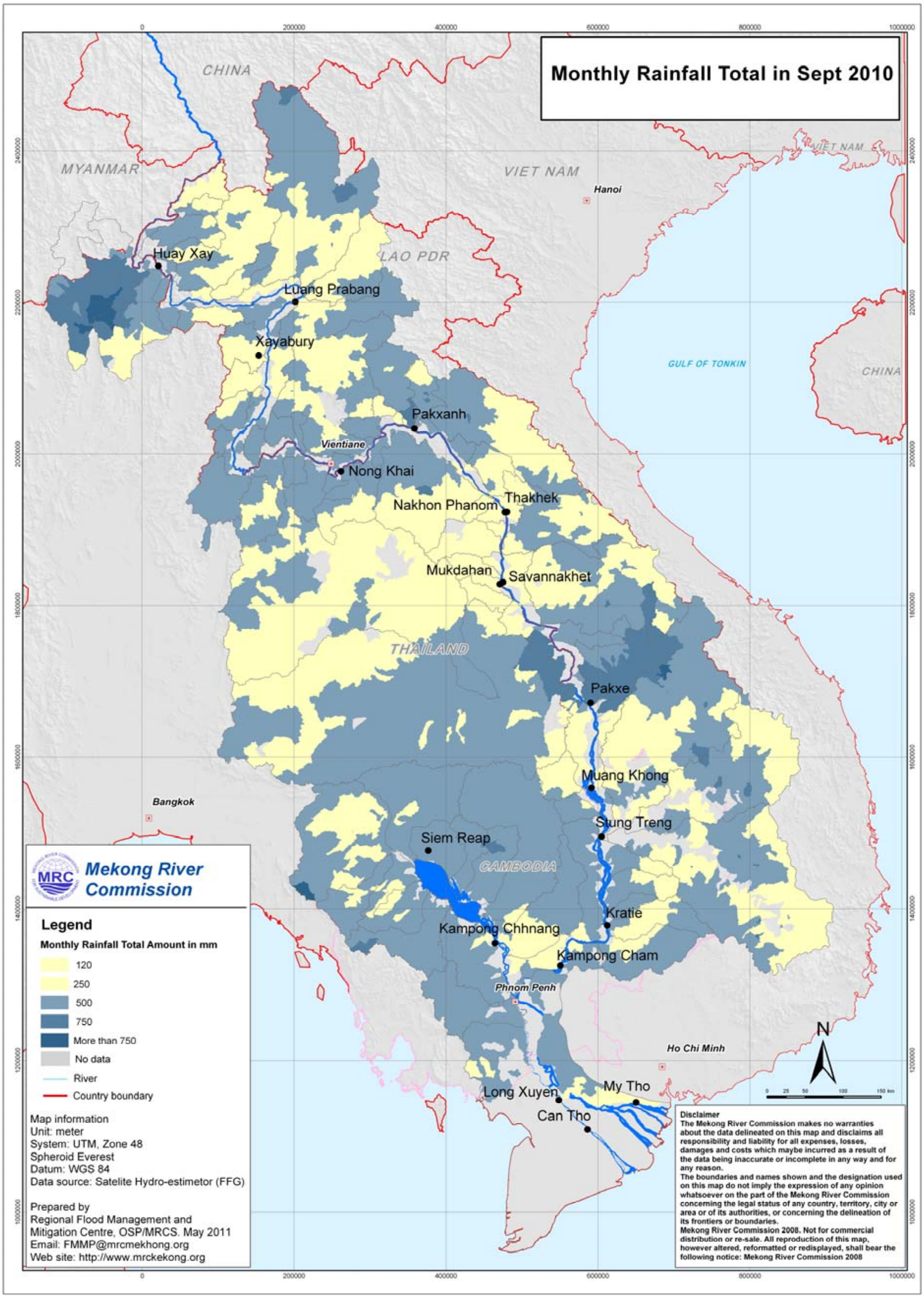

Figure 3. 5: Rainfall over the Lower Mekong Basin – September 2010.

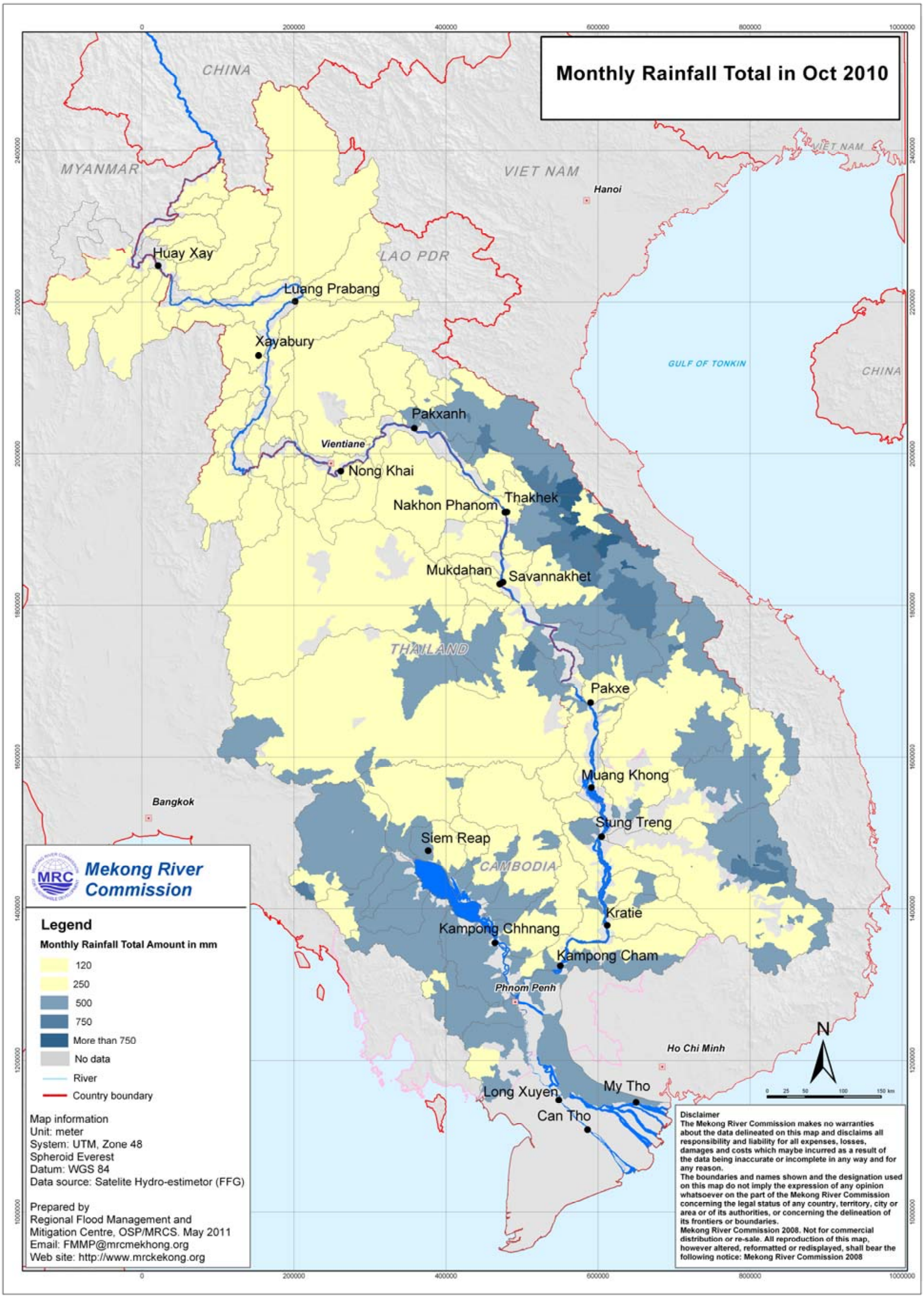

Figure 3. 6: Rainfall over the Lower Mekong Basin – October 2010.

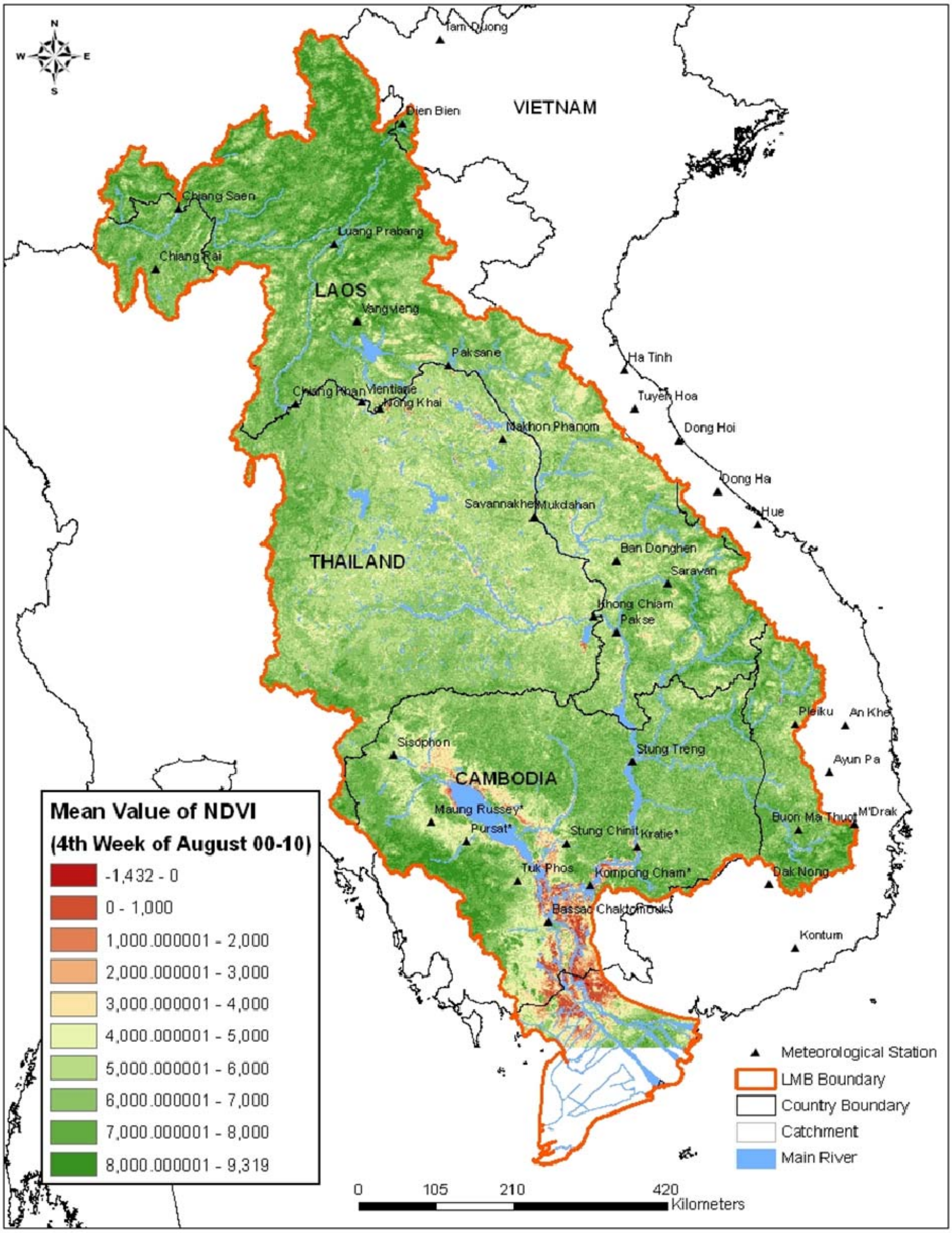

Figure 3. 7: The long term average value of the 'Normalised Difference Vegetation Index" (NDVI) for the 4th week of August. High values (green) indicate that crops and natural vegetation are under no 'stress' since there is sufficient soil moisture. Low values (red) indicate vegetative stress due to critically low levels of soil moisture. (Source: http:\\earthobservatorynasa.gov)

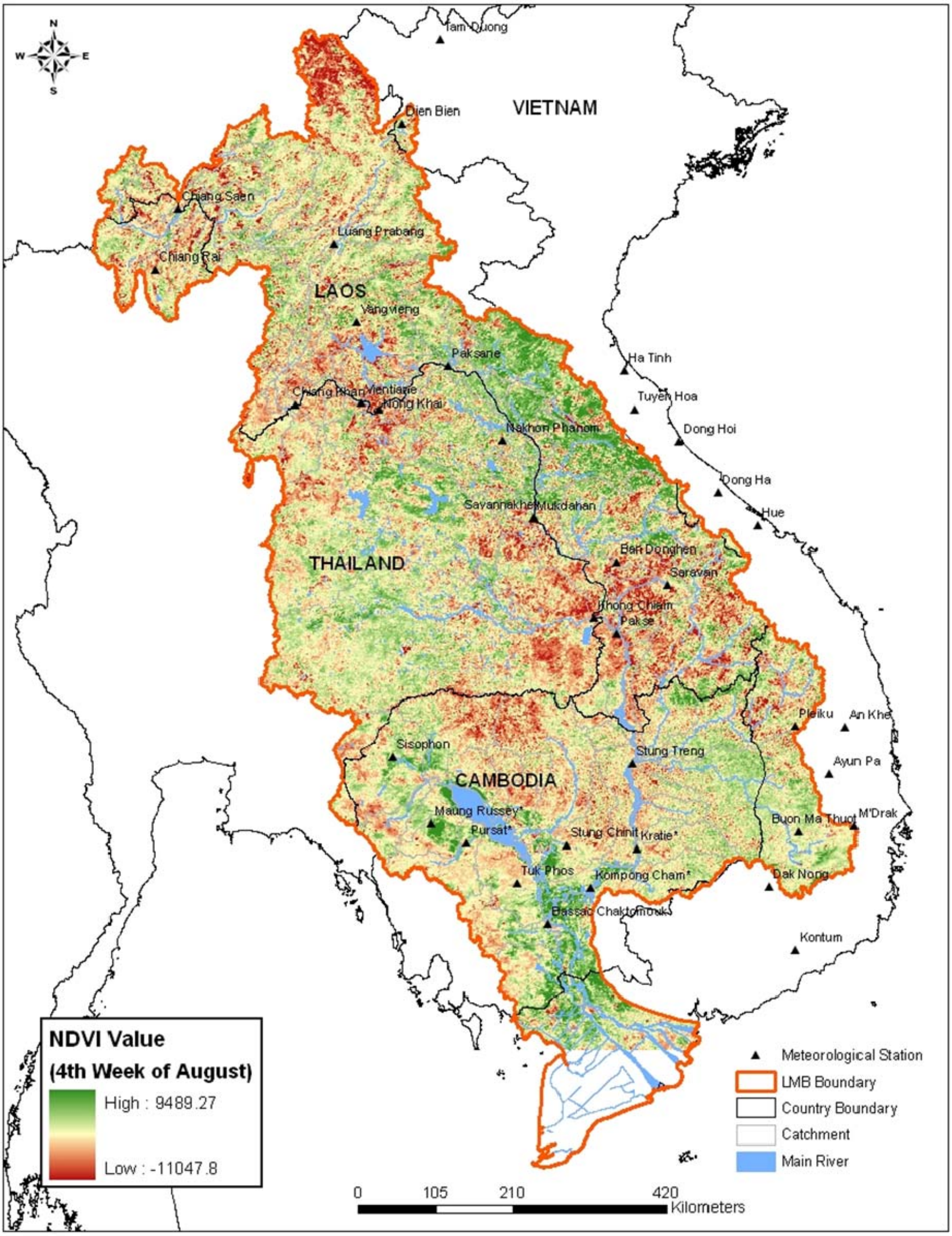

Figure 3. 8: The value of the 'Normalised Difference Vegetation Index" (NDVI) for the 4th week of August in 2010. Compared to the expected values as indicated in Figure 3.6 large areas of the Basin show crops and vegetation under high levels of moisture stress, most notably in southern Lao PDR and northern Cambodia. (Source: http:\\earthobservatorynasa.gov)

3.3 Stream Flow and Water Levels during the Flood Season of 2010

As expected, given the late onset of the SW Monsoon over large parts of the Basin in 2010 and the general lack of runoff inducing storm rainfall during the early part of the wet season, the onset of the flood season on the mainstream in terms of water level and discharge was delayed significantly. These onsets and end dates are defined in the usual way, as shown in Figure 3.9. On this basis, the two dates become random variables from year to year.

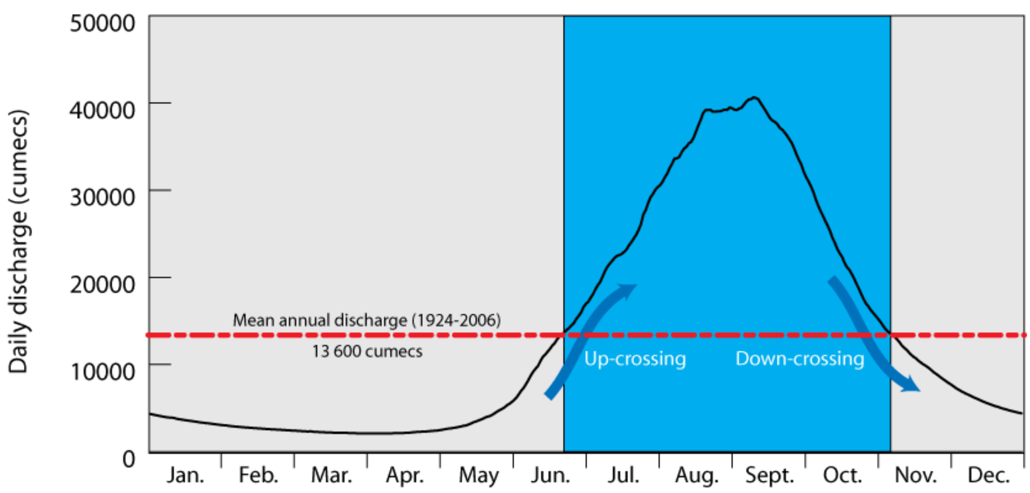

Figure 3. 9: The definition of the flood season, with the mean annual hydrograph at Kratie as the example. The onset is the date of the up-crossing of the long term mean annual discharge (or water level) and the end, the down-crossing. In a typical year, there is only one such crossing in each case.

As the results in Tables 3.3 and 3.4 illustrate, the delay in flood season onset increased downstream, from just a week at Chiang Saen to five weeks at Chau Doc. A delay of the latter order in the Delta would have had significant consequences with regard to saline intrusion and agricultural water supply. The flood season ended as usual during the first half of November at Kratie and further upstream and during December further downstream, where the natural regulating effect of the Tonle Sap sees higher water levels maintained for another month or so as the Great Lake drains into the Mekong mainstream.

Site	Onset of flood season			End of flood season		
	Historical average	Standard deviation	2010	Historical average	Standard deviation	2010
Chiang Saen	28th June	13 days	8th July	14th Nov	14 days	2nd Nov
Vientiane	3rd July	14 days	22nd July	11th Nov	15 days	6th Nov
Pakse	29th June	16 days	21st July	5th Nov	11 days	6th Nov
Kratie	1st July	16 days	29th July	7th Nov	12 days	2nd Nov

Table 3. 3: Start and end dates of the 2010 flood season compared to their historical mean and standard deviation at selected mainstream locations.

Site	Onset of flood season			End of flood season		
	Historical average	Standard deviation	2010	Historical average	Standard deviation	2010
Phnom Penh	10th July	14 days	10th Aug	15th Dec	14 days	8th Dec
Prek Kdam	11th July	16 days	11th Aug	20th Dec	17 days	15th Dec
Tan Chau	19th July	20 days	18th Aug	17th Dec	12 days	9th Dec
Chau Doc	23rd July	17 days	31st Aug	19th Dec	12 days	24th Dec

Table 3. 4: Cambodian floodplain and Mekong Delta – onset and end dates of the 2010 flood season compared to their historical mean and standard deviation.

At Chiang Saen, Luang Prabang, Vientiane and Kratie the maximum water levels achieved during the season were close to average (Table 3.5) but considerably below average further downstream (Table 3. 6). The latter is explained by the much reduced floodplain storage in Cambodia and the lower levels of storage in the Great Lake.

Site	Maximum water level		Date of maximum water level	
	average	2010	Average	2010
Chiang Saen	6.9 m	6.6 m	25th Aug	25th Jul
Luang Prabang	13.7 m	12.5 m	6th Aug	17th Sep
Vientiane	9.5 m	10.2 m	22nd Aug	1st Sep
Kratie	20.4 m	19.6 m	10th Sep	16th Sep

Table 3. 5: Average maximum water levels and their dates compared to those of 2010 at selected mainstream sites.

Site	Period of Record	Annual maximum water level. (masl)		
		Historical average	Standard deviation. (m)	2010
Phnom Penh Port	1960 -2010	9.02	0.67	7.6
Prek Kdam	1960 – 2010	9.08	0.73	7.6
Tan Chau	1980 – 2010	4.30	0.54	3.2
Chao Doc	1980 - 2010	3.82	0.58	2.7

Table 3. 6: Maximum water levels reached during 2010 in Cambodia and the Mekong Delta compared to their long term average.

Figures 3.10 to 3.12 compare the 2010 annual discharge and water level hydrographs at selected points on the Mekong mainstream with their long term average:

The feature common to all of them is the late onset of the flood season.

- At Kratie and further upstream discharges remained far below normal until there was some recovery towards average figures during September.
- Further downstream water levels remained much below average until the end of October.
- At all sites discharges and water levels during the flood recession months of November and December were very close to average.
- Nowhere was there a sustained period of above average hydrological conditions.

These very low discharges, sustained throughout most of the 2010 season, resulted in one of the lowest overall Mekong annual flood volumes observed over the last eighty to ninety years. The overall historical context can be appreciated by plotting the joint sample distribution of the annual flood volume and annual maximum discharge over the period of record, as illustrated in Figure 3.13 for Chiang Saen, Vientiane and Kratie. “Significant” and “extreme” flood years are defined in terms of the criteria included in the figure.

- According to these criteria, conditions at Chiang Saen and Vientiane would be defined as significantly “dry’ and at Kratie extremely “dry’.
- The key comparison is between the “drought” of 2010 and that of 1992, generally regarded as specifying the most critically deficient hydrological conditions throughout the Basin that have occurred probably over the last one hundred years. At Chiang Saen and Vientiane the annual flood of 1992 is more severe in terms of its hydrological deficit. This is not the case at Kratie where 2010 conditions contend with those of the earlier event. The hydrological drought of 2010 would appear to have become more severe downstream due to much reduced tributary contributions to the mainstream in the south of Lao PDR in general and from the Se Kong, Se San and Sre Pok in particular.
- In terms of their risk of occurrence deficient annual flood conditions comparable to those of 2010 are in fact not that rare. Figure 3.14 places the sample bi-variate distribution at of flood season peak and volume at Kratie in a probabilistic framework. Four comparable events occurred in 1988, 1992, 1998 and 2004, giving an estimated recurrence interval of such conditions lying between once in ten and twenty years according to this type of statistical analysis.

Table 3.7 presents the rank order of the five lowest annual flood volumes observed at Kratie. They are all quite similar and of the order of around 40% less than the long term average figure of 330 km^3. The feature common to all of them is that the flood season either started late – or ended early or both, resulting in a short season of below average flows. In 2010 the season was six weeks shorter than expected.

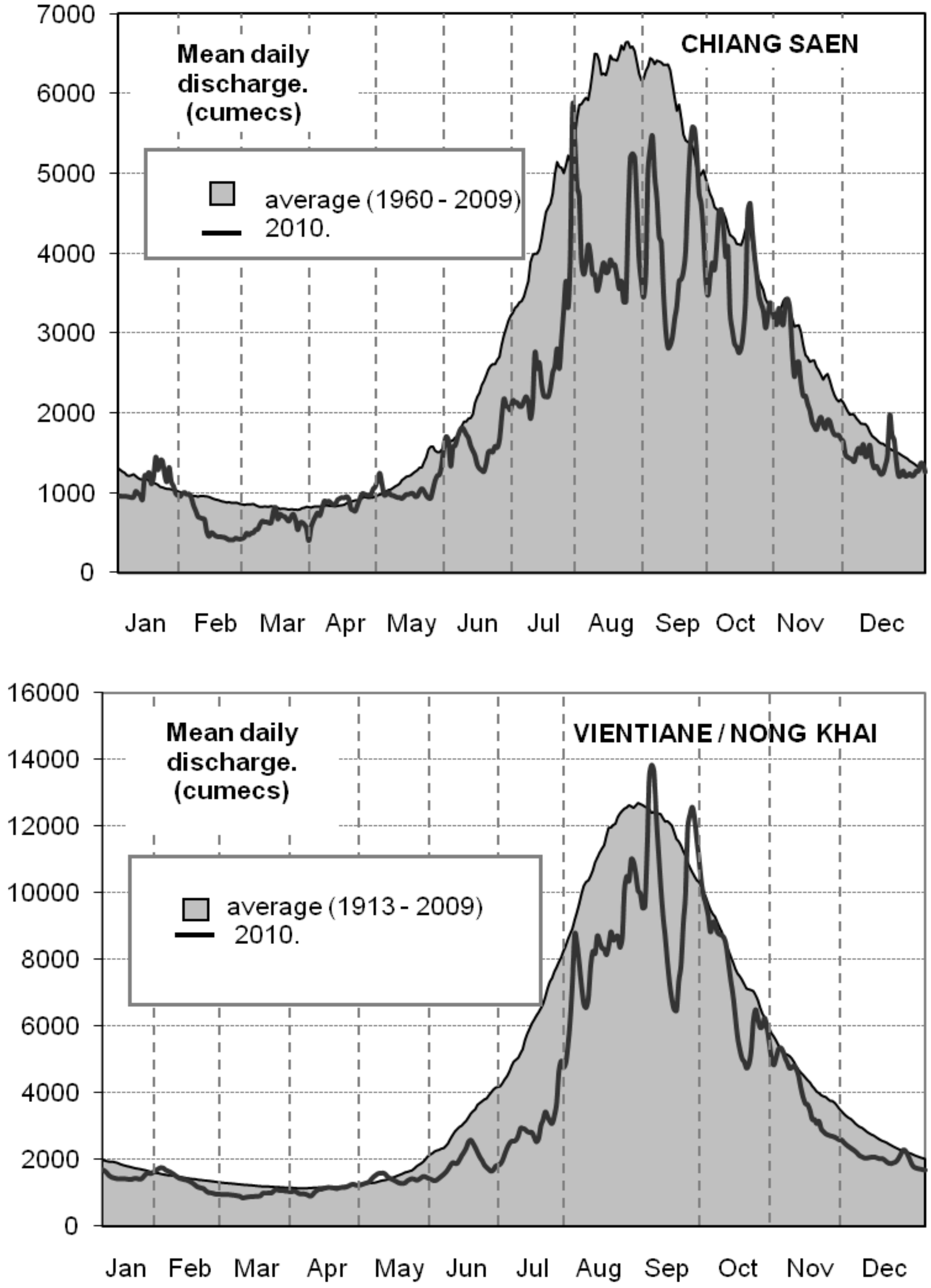

Figure 3. 10: The 2010 annual hydrographs at Chiang Saen and at Vientiane / Nong Khai, compared to their long term average.

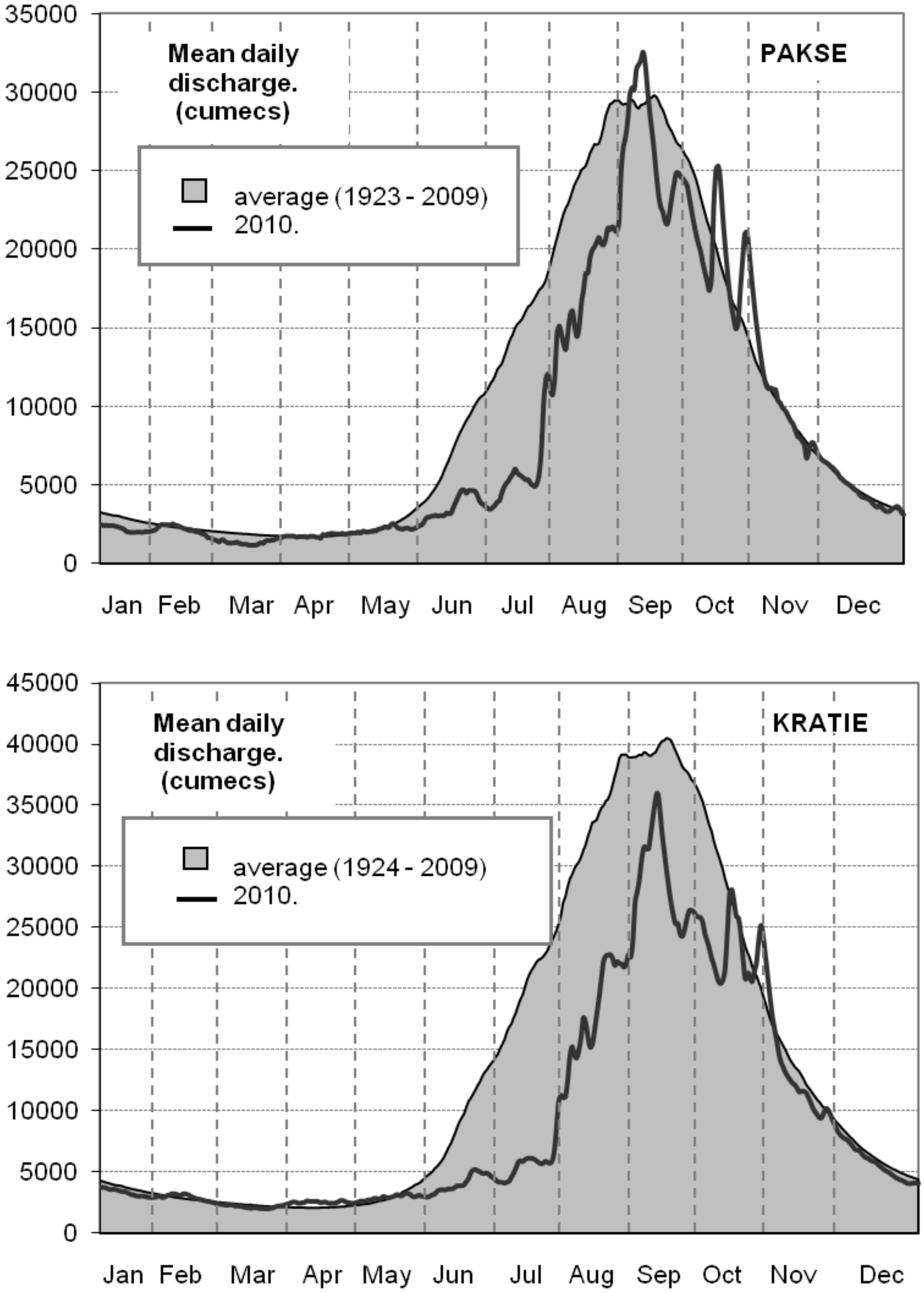

Figure 3. 11: The 2010 annual hydrograph at Pakse and at Kratie, compared to the long term average.

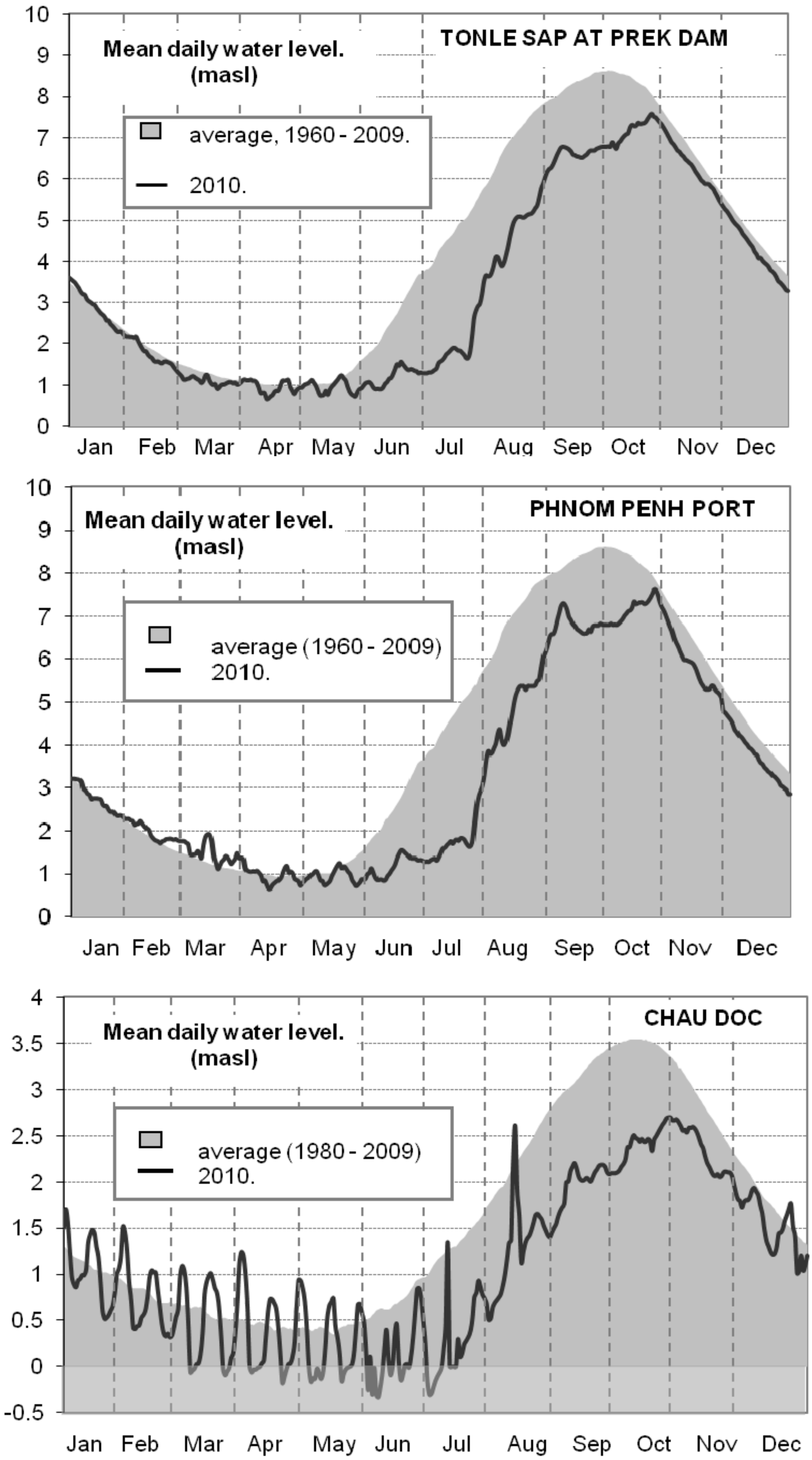

Figure 3. 12: The 2010 annual hydrograph at Prek Dam, Phnom Penh Port and at Chao Doc, compared to the long term average.

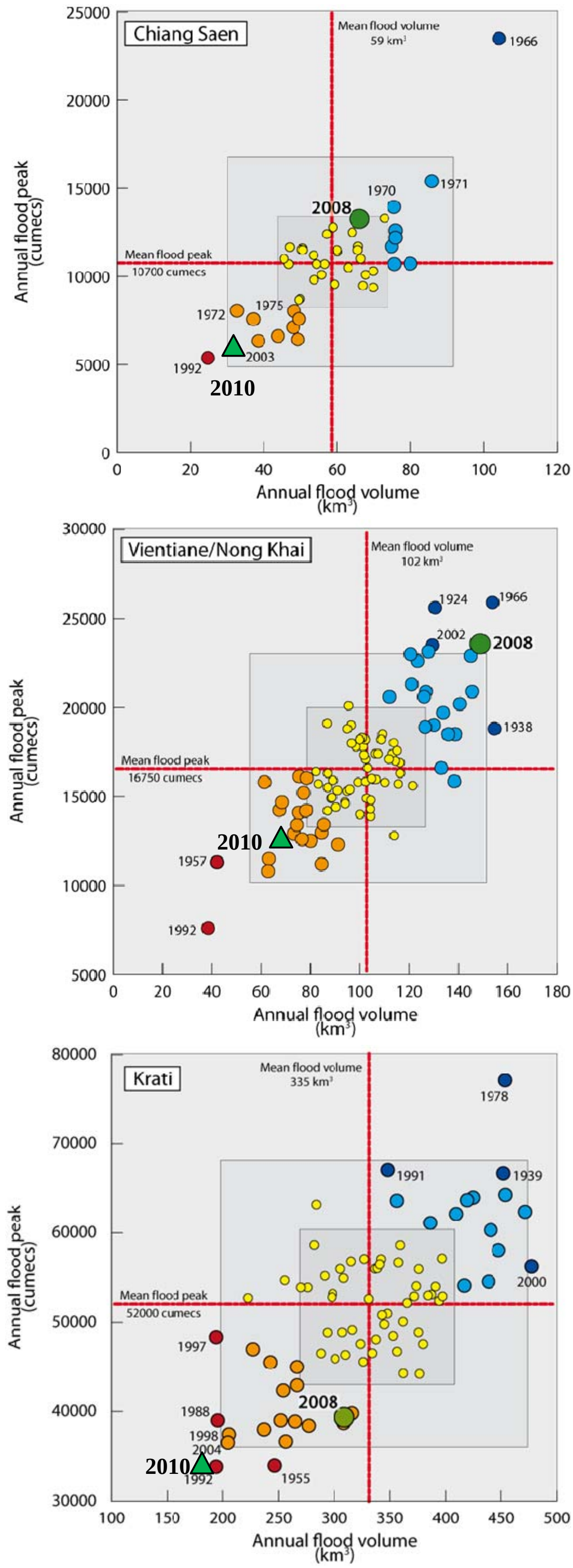

Figure 3. 13: Scatterplots of the joint distribution of the annual maximum flood discharge (cumecs) and the volume of the annual flood hydrograph (km^3) at selected sites on the Mekong mainstream. The 'boxes' indicate one (1δ) and two (2δ) standard deviations for each variable above and below their respective 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.

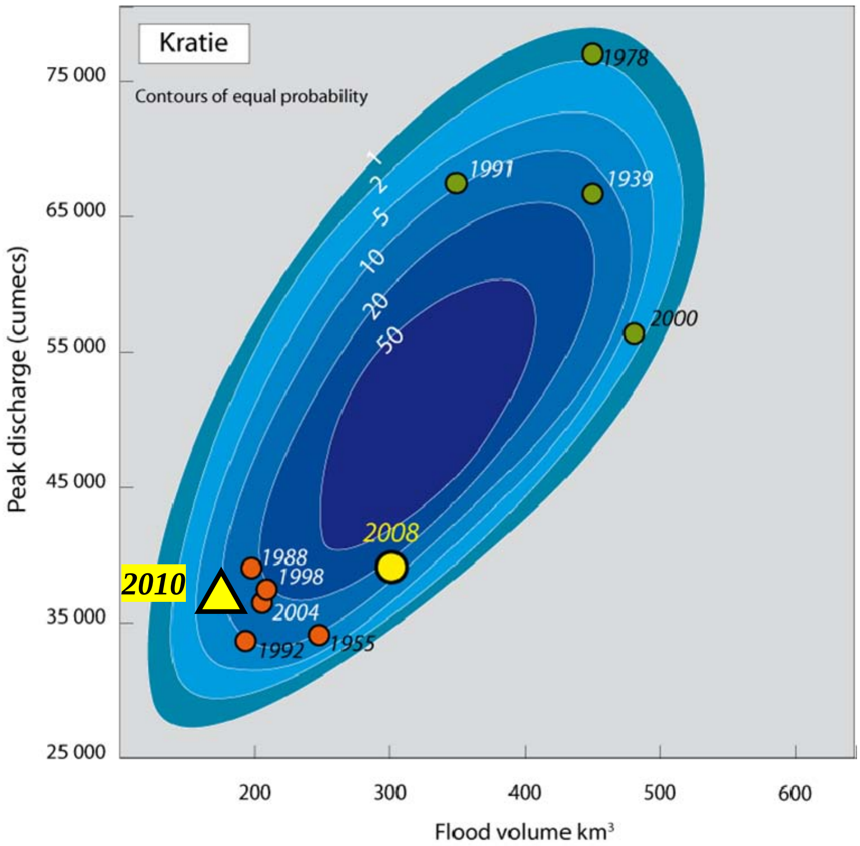

Figure 3. 14: Mekong at Kratie - the bi-variate distribution of annual flood peak and volume, 1924 to 2010. Four other events comparable to that of 2010 in terms of the joint magnitude of the two variables have previously been observed. The estimated recurrence interval of the 2010 deficient annual flood conditions lies between once in ten and once in twenty years.

Year	Annual flood volume km^3	Duration of flood season days
2010	193.1	97
1992	195.4	113
1977	196.6	104
1988	196.8	107
1998	205.6	93
Long term average	330.4	137

Table 3. 7: Mekong mainstream at Kratie – the five lowest ranked annual flood volumes that have been observed since records began in 1924. The flood volume of 2010 was even lower than that of 1992, widely regarded as the most severe regional drought of the last 87 years. The 2010 flood season was also one of the shortest on record, lasting just 97 days, 6 weeks shorter than the average duration of 137 days.

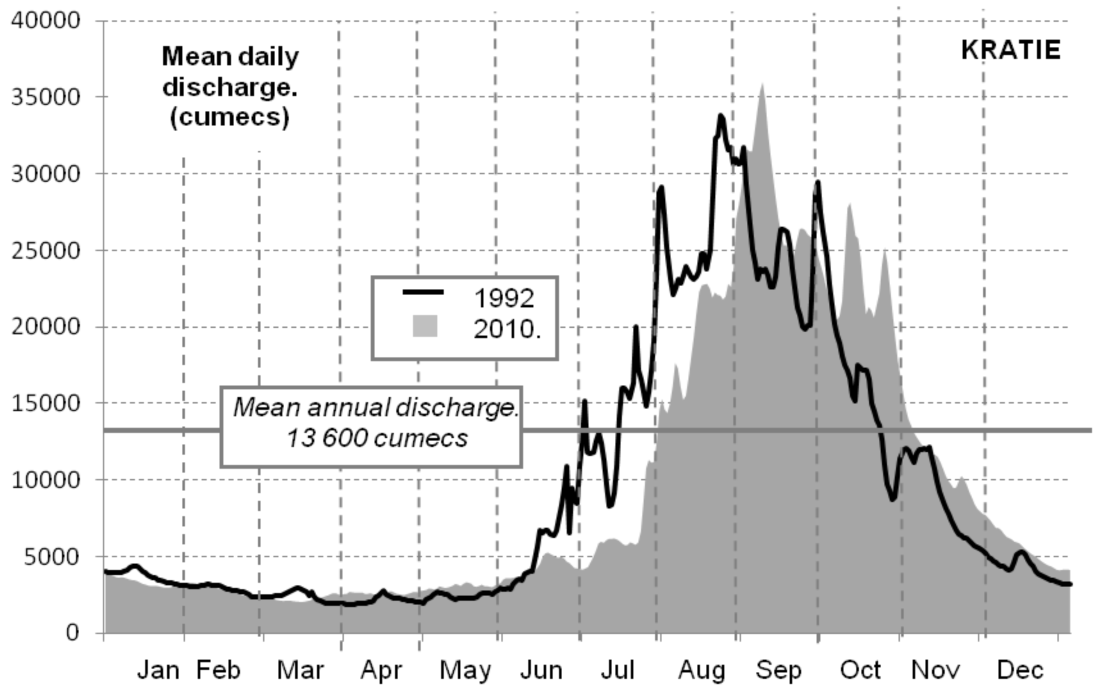

Figure 3. 15: Mekong at Kratie - the 1992 and 2010 annual hydrographs compared. In terms of their peak and volume the two years are quite similar. The distinction lies with the onset and end of the flood season which was a month earlier and 10 days earlier respectively in 1992 compared to 2010.

Figure 3.15 compares the annual hydrographs at Kratie for the ‘benchmark’ drought conditions of 1992 with those of 2010:

- Volumetrically, and in terms of the annual maximum discharge, the hydrographs are quite similar with regard to their overall pattern;
- However, the picture in 2010 is defined by the very late onset of the flood season. The delay directly relates to the order of one month.

Flood volumes and flood peaks have been consistently less than average since 2001 and 2002, in terms of the flood hydrology of the Basin as a whole. This is illustrated by the situation at Kratie as shown in Figure 3.16. At this location, the annual volumes of flow during the flood season are plotted in terms of their percentage deviation above and below the long term average. Such a ‘run’ of flood deficit years is not unprecedented as the data illustrates. In recent years, the departures below average have been typically around 20%, while in 2010 the flood volume was more than 40% below ‘normal’, the largest recorded.

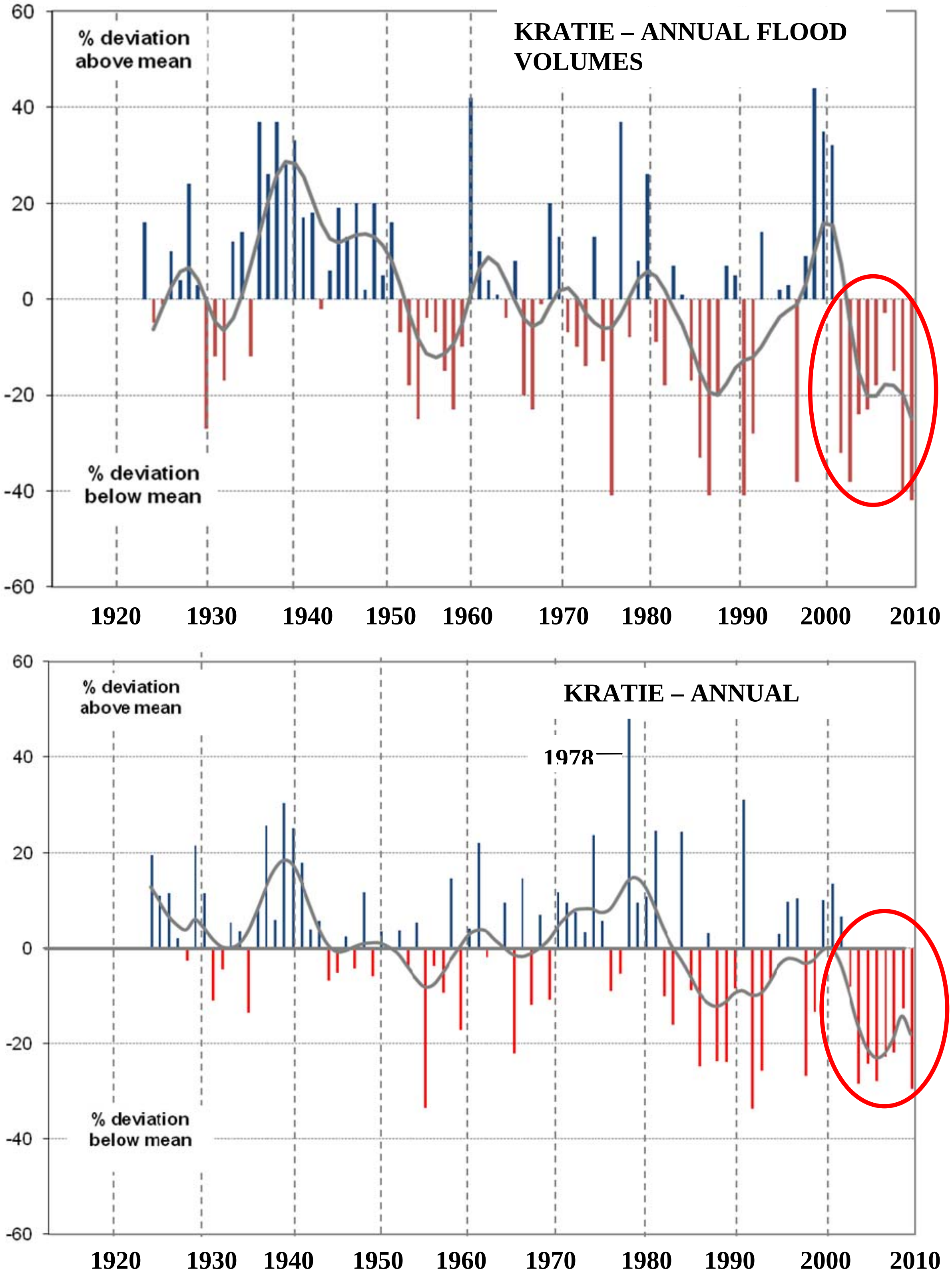

Figure 3. 16: Mekong at Kratie – modular annual flood volumes and maximum flood discharges as % deviation above the long term means (1924 to 2010).

3.4 The Continuing Impact of the Dams in China on Mainstream Hydrology

Being significantly below the long term average, the 2009 (Figure 3.17) and the 2010 (Figure 3.10) daily discharge hydrographs at Chiang Saen reveal considerable ‘noise’ in the data both during the low flow and flood seasons. In other words, there are a great number of short term fluctuations in discharge with a frequency and pattern that appears to be inconsistent with the hydrological response to rainfall that might be expected over the upstream drainage area which amounts to almost 200 000 km^2. At this scale, a much ‘smoother’ hydrograph would be the expectation. The oscillations also occur during the low flow season when, while most are quite small, there is little if any rainfall to explain them.

A simple definition of these fluctuations might be that they occur in the time series when the discharge on day ‘t-1’ and ‘t+1’ are both greater than (less than) that on day ‘t’ (t=1,365), or when $q(t-1) < q(t) > q(t+1)$ or $q(t-1) > q(t) < q(t+1)$. These fluctuations we might term ‘discharge reversals’.

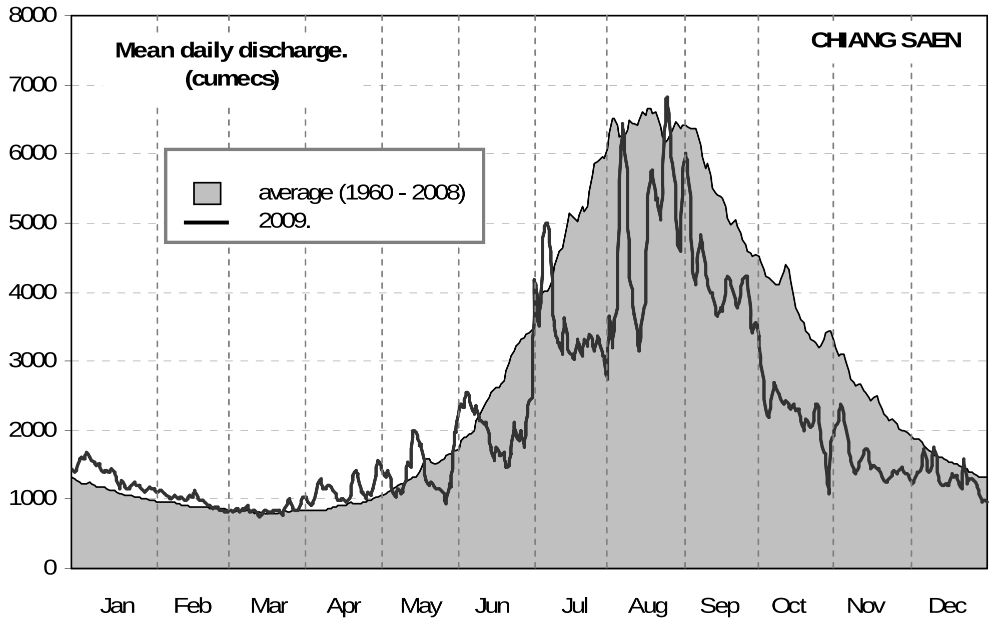

Figure 3. 17: Chiang Saen: the 2009 daily discharge hydrograph compared to the long term average showing the high frequency day to day fluctuations which continued into 2010.

Figure 3.18 below shows the annual count of these reversals over the 51 years between 1960 and 2010, the analysis being extended to include the Mekong daily discharge time series at Luang Prabang and Vientiane over the same time period.

There is a clear change point in their frequency around 1993 and the commissioning of Manwan hydropower dam, located in the middle reaches of the Lancang (Mekong) River in Yunnan Province in China. Post 1993; the mean annual rate doubles at Chiang Saen. At Luang Prabang the increased rate remains significant, while at Vientiane the change is much more modest. Clearly the short term hydrological impacts of reservoir operation are modulated downstream as tributary inflows exert an effect and ‘damp’ them out, but the picture that emerges from this simple analysis is that the operational impacts of the dams in China on the flow regime of the Mekong are already manifest upstream of Vientiane.

The impacts are not only detectable during the low flow season, as expected, but also during flood seasons such as those of 2009 and 2010 when discharges were considerably below average throughout. Also revealed is the effect of the basin scale on the short term variance of the annual flood hydrograph. Pre-1993 the river's hydrology may be considered to have been 'natural' and indicates that the mean annual frequency of discharge reversals decreases downstream as drainage area increases and the hydrograph becomes more coherent from day to day.

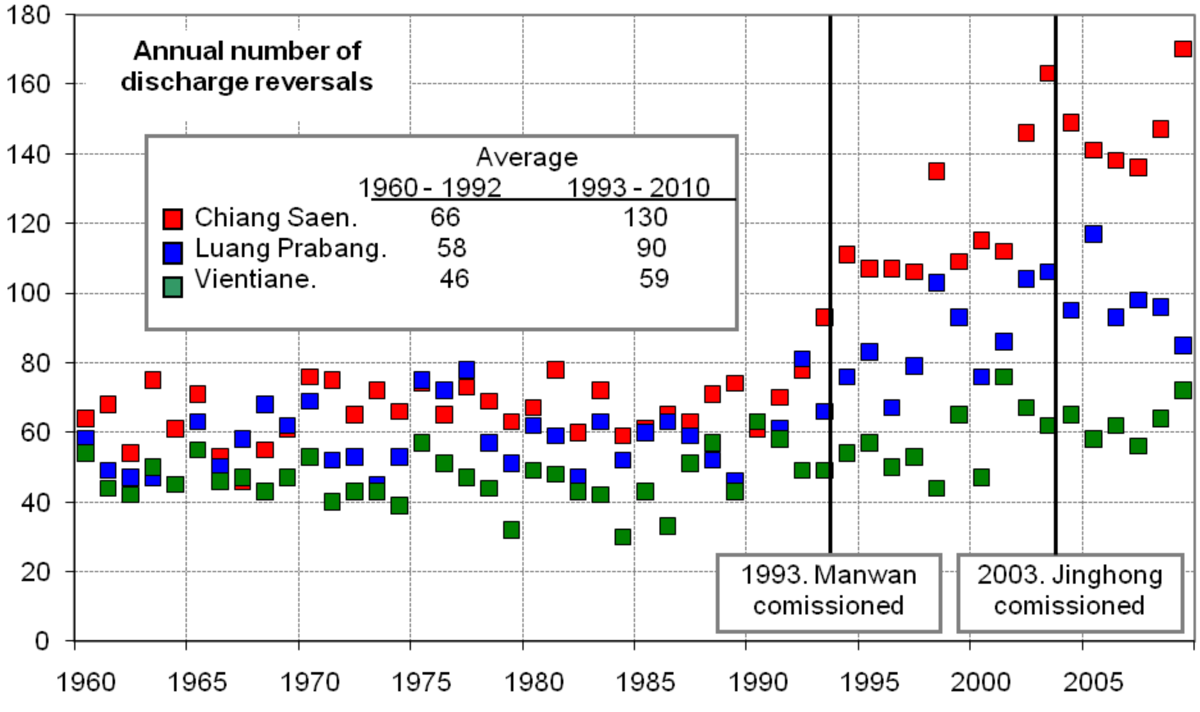

Figure 3. 18: The annual number of discharge reversals at Chiang Saen, Luang Prabang and Vientiane, 1960 – 2010.

4. Cambodia 2010 Country Report

4.1 General Situation

Meteorological and hydrological conditions during 2010 in Cambodia were well below the long-term average. The main cause was weak monsoonal rainfall which in some areas precipitated significant drought and agricultural losses. Mainstream water levels in the Mekong fell to the lowest on record, less than those of the 'benchmark' dry years of 1992 /1993. The 2010 low flow season follows conditions during 2009, which were amongst the lowest observed.

Accordingly, water levels never even approached flood alarm thresholds as they did not recede 2.5m below long term average at Kratie and almost 2m below at Prek Dam and Phnom Penh. Due to the late onset of the flood season within the Mekong mainstream the flow reversal, in which Mekong floodwater flows into the Tonle Sap Lake did not occur until late July, 6 weeks later than usual and amongst the latest ever recorded. This delay did have serious consequences for the regional fishery, which has suffered from eight years of low lake water levels. The maximum lake water level reached in late October 2010 was 1.5m lower than that achieved in 2009, which itself was considered to be low. The annual average maximum lake water level is 9 masl, compared to 7.1 masl in 2010, a critical deficit in terms of the consequent shortfalls in volume, depth and inundated area, the latter a critical influence on the yield of the fishery.

4.2 October Flash Floods and Urban Flooding

During October and November heavy rains, particularly during the second week of October, caused localized flash flooding in a number of provinces. The flash floods caused significant damage to infrastructures and agriculture in Takeo, Kandal, Pursat, Battambang, Batay Meanchey, Siem Reap, Kampog Speu and Phnom Penh. Rainfall in some of these areas exceeded 150mm per day and intense storms often continued for more than three days. At Siem Reap the rainfall observed on the 11^{th} October was 140mm. On the same day, 105mm of rainfall occurred in Takeo and 76mm in Kampong Cham.

Plate 4. 1: Urban flooding in Siem Riep, 11th October 2010.

October storms caused the damages provided in Table 4.1 below. These figures accounted for the only losses attributable to storm rainfall and flooding in 2010.

Province	Damage during October storms						
	Property		People		School	Agriculture	
	Affected	Damaged	Killed	Injured	Damage	Rice (ha)	Other crops (ha)
Takeo	1 628					428	
Kandal	10 494	5			24	1 022	312
Pursat	54				10	2 104	175
Battambang	801					117	
B. Meanchey	15 422	4	6		140	10 943	2 689
Siem Reap		53	1	5	982		10
Kpg Speu	62				11		176
Phnom Penh	4 573		1		12	551	
Total	**33 034**	**62**	**8**	**5**	**1 179**	**15 165**	**3 362**

Table 4. 1: Storm losses registered during the events of mid October. Source: Cambodian National Committee for Disaster Management.

4.3 Lessons Learned

The lessons learned from the 2000 and 2001 extreme flood conditions continue to be implemented by the various national line agencies responsible for flood management and mitigation. For instance, it is standard practice now that all public facilities will be constructed above the estimated 50-years return period flood level and will be provided with unimpeded drainage. Moreover, people and institutions are being encouraged and enabled, by means such as education and demonstration of technology, to adopt flood mitigation measures appropriated to their circumstances.

Notwithstanding this it is necessary to ensure that the last eight years of comparatively minimal damage does not ensure complacency. The policies regarding flood mitigation as set out in the National Water Resources Policy are steadily being implemented, which are:

- Phnom Penh and other localities with their high concentration of people and economic assets will be fully protected against flooding.

- Other urban and industrial centres with lesser concentration of people and assets will be provided with levels of protection that are economically justifiable.

- All people and institutions will be encouraged and enabled, by means such as education and demonstration of technology, to adopt flood mitigation measures appropriated to their needs.

- All public facilities will be constructed above the estimated 50-years flood level and will be provide with unimpeded drainage.

5. Lao PDR 2010 Country Report

5.1 General Situation and Localised Flash Flooding

As elsewhere in the region, loss and damage in 2010 focused on localised flash flooding since mainstream Mekong flood season conditions were at unprecedented low levels.

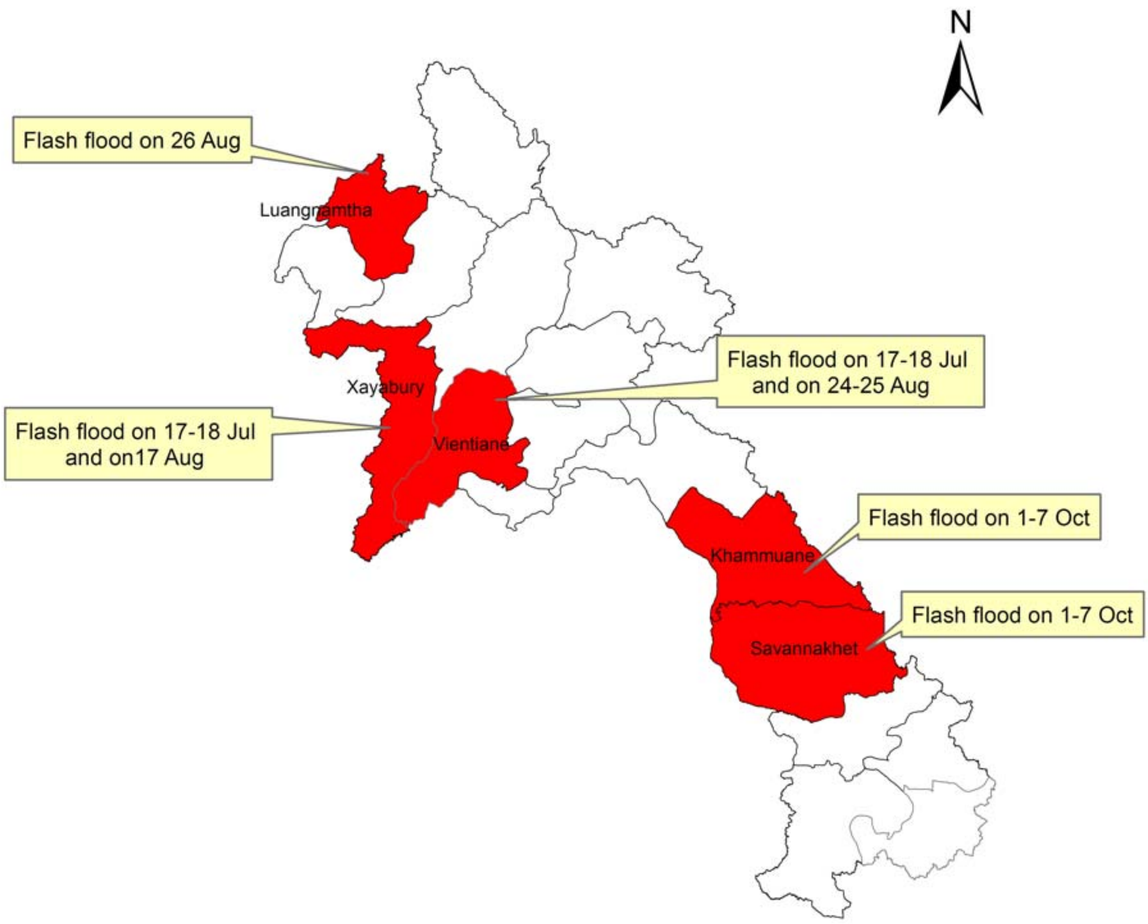

Figure 5. 1: Provinces of Lao PDR affected by flash flooding during 2010.

- In mid-July, tropical Storm CONSON No. 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 Xaignabouli Province. Flash flooding also occurred over Meuang Mat, Kasy and Vangvieng Districts in Vientiane Province with rainfall of 40mm recorded at Xaignabouli and 63mm at Phonhong stations in Vientiane Province on the 17th July.

- In the last week of August, extreme monsoonal rainfall up to 133mm 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 Viet Nam, downgrading to a tropical depression as it passed over northern Lao on 26th August, bringing local heavy rainfall of up to 80mm and more. These heavy rainfalls resulted in flash floods through Sing and Long Districts, Luangnamtha Province.

Plate 5. 1: Flash flood impacts in the Long District of Luangnamtha Province, last week of August

- During the first week of October an intense low pressure system moving across Viet Nam from the South China Sea into the south –central parts of the country caused local rainfall in excess of 115mm on the 3rd of the month, principally affecting flood conditions on the Se Bang Fai and Xeopon Rivers. Water levels rose 7m in 24 hours and 9m within 48 hours, causing flash flood conditions and widespread rapid inundation.

5.2 Flash Flood Damages

Losses due to flash flooding, although localized, were significant. In 2010, more than 80,000 persons were directly affected and 7 storm-related deaths were reported. The total reported damaged was estimated to be more than 20 million US dollars (Table 5.1).

Extent and Sector	Losses and damage
Provinces affected	5 provinces: Luang Namtha, Xaignabouli, Vientiane, Khammuane and Savannakhet
Districts affected	26
Villages affected	357
Household affected	16 080
People affected	86 097
People injured	2
People killed	7
Agriculture	
Hectares of Rice paddy fields affected	3,861.10
Hectares of upland rice and crop damaged	Rice field 42.39 ha; Crop field 18.87 ha
Farmer's houses rice stock affected	84 sites
Livestock	
Cattle	141 head lost
Poultry	6 622 head lost
Fish ponds, fishes and aquaculture	179 sites
Infrastructure	
House collapsed away	9
Houses affected	33
Water well and ground water affected	65 sites
Medical care centre affected	4 sites
School affected	20 sites
Estimated total damage US$ (Million)	**21**

Table 5. 1: Lao PDR - Estimated loss and damage due to localized flash flooding in 2010.

5.3 Lessons Learned

Although the modest flooding in 2010 may be considered to be inevitable, flood management, mitigation policies and investment require ongoing improvement in order to significantly reduce the annual loss and damage that occurs year-on-year. Progress is however, being made. For example, the forecasting and timely dissemination of flood warnings provided by the Department of Meteorology and Hydrology continue to improve response measures by the relevant Government Line Agencies and are steadily becoming more effective. Levels of investment, however, need reviewing by these Line Agencies.

6. Thailand 2010 Country Report

6.1 General Situation

In 2010, two major flood episodes occurred:

1) Tropical storm Mindulle tracked east across Lao PDR on 26 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. The depression partially damaged almost 120,000 properties in addition to as more than 4 million *rai* (equivalent to 640,000 ha) of agricultural land.

6.2 Rainfall

Over the monsoon season, between June and October, rainfall was below average across most of the Lower Mekong Basin, largely due to the late start of the monsoon and poor rainfall during June and July. Only during the last weeks of August was rainfall above average due to Tropical storm Mindulle.

Figure 6.1 shows the August, September and October monthly rainfall for Thailand as a whole.

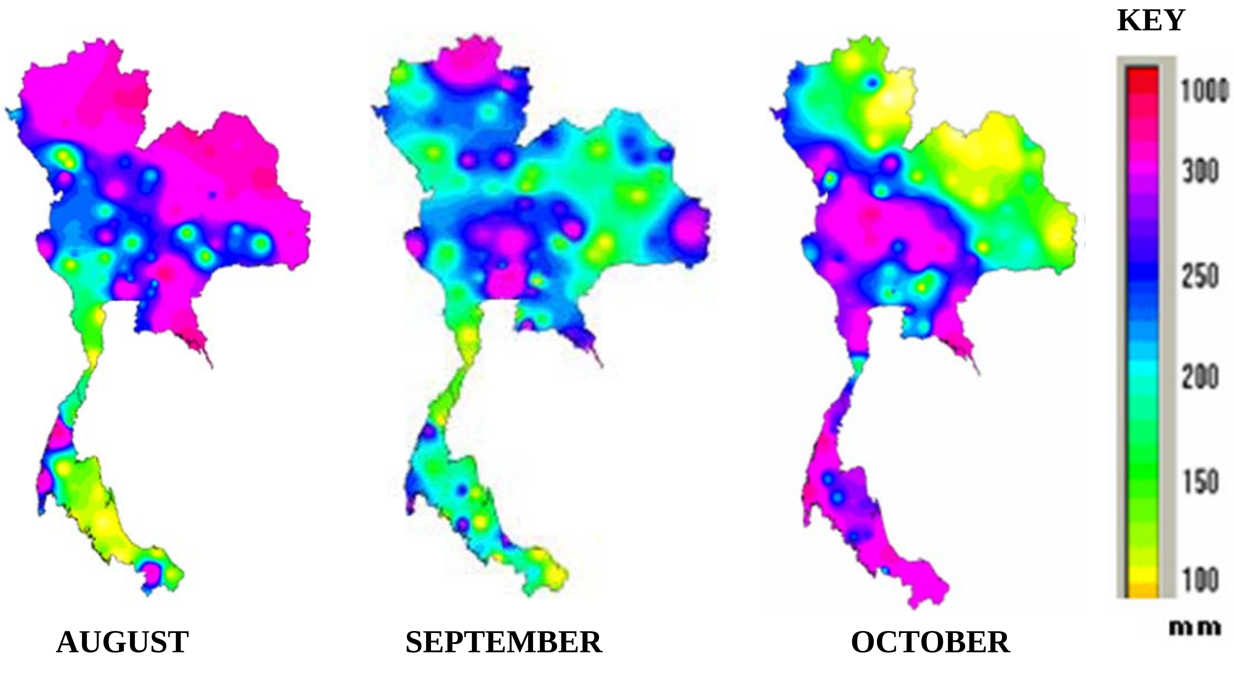

Figure 6. 1: Thailand – monthly rainfall: August, September and October, 2010 (Source: Thai Meteorology Department).

In the Mekong context, rainfall in the north and north-east of the country is most relevant. Mean monthly rainfall in the north-east is around 200mm at this time of the year. However due to tropical storm Mindulle some higher rainfall in the north occurred in August. See Figure 6.1. After recording the above average figure during August (the pink colour indicates roughly between 300 – 400mm) rainfall during the later months was either average or significantly below average.

6.3 The Events of August and October

In late August, tropical storm Mindulle affected Mae Hong Son, Chiang Mai, Lamphun, Lampang, Phrae, Nan, Uttaradit, Phetchabun, Phichit, Phitsanulok, Saraburi, Mukdahan, Nakhon Nayok Provinces. Almost 29,000 households and 82,000 people were affected and140 square kilometers of agricultural land was inundated.

Plate 6. 1: Flooding in Mukdahan on the 24 August during the course of Tropical Storm Mindulle.

The cause of the October flooding was due to heavy rainfall between the 11th and 19th of the month, mostly over the central regions of the country which resulted in high 'out of bank' water levels over large areas of the Chi - Mun Basin (Figure 6.2). Total damage was estimated at approximately US$ 47 million.

Figure 6. 2: The extent of flood inundation in the Mun – Chi Basin during October.

Plate 6. 2: Scenes from Nakorn Ratchasima Province during October.

Figure 6.3 indicates the Thai provinces affected by the August and October flood conditions and confirms that as far as the Mekong system was concerned the hydrological impacts were effectively confined to the Mun – Chi tributary system. This reflects the passage of tropical storm Mindulle in August and the intense tropical depressions during October over the eastern and central regions of the country.

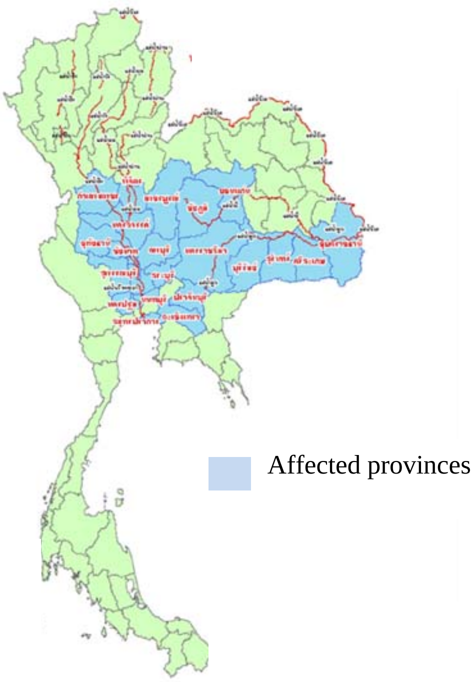

Figure 6. 3: Flood affected provinces in Thailand – 2010.

6.4 Overall Damage, Lessons and Recommendations

Regional flooding in 2010 illustrated that the extensive loss and damage caused by tropical storms is largely independent of the strength of the SW Monsoon. During the year, tropical storms were weak, which lead to drought conditions overall. However, two storms during August and Ocober caused severe damage across a relatively narrow belt of the Lower Mekong Basin.

In Thailand, the flooding caused by these two storm episodes directly affected approximately 5 million people, over 1 million families and resulted in the deaths of 79 people. More than 118,500 properties were damaged and 6,400 square kilometres) of agricultural land inundated. Total damages are reported to be in the region of US$1.2 billion.

There are many largely independent agencies responsible for flood emergency response and mitigation. There is a need for a single ‘overseeing’agency that takes overall responsibility for planning and coordination with a structure that extends throughout the community, basin and national levels.

7. Viet Nam 2010 Country Report

7.1 General Situation

Two tropical cyclones made landfall over Viet Nam during 2010 – Conson in July and Mindulle in August. Only tropical cyclone Mindulle had any significant flooding consequences in the Lower Mekong Basin. In the Delta, no flooding occurred and peak water levels remained well below average. In the Central highlands, specifically in the upper Sre Pok and Se San area, a tropical depression resulted in heavy rainfall of 100 to 300m between 30th October and 4th November. This rainfall caused some flooding, though the highest alarm Level III, was not exceeded on a wide scale. No flash floods were observed in these tributary basins during 2010.

7.2 Rainfall

The spatial variation of regional rainfall was very high. In the delta it was below average over the season, in the Central Highlands slightly higher than the long term average.

River Basin	Station	Total rainfall 30th Oct to 4th Nov
Dakbla	Mang Kanh	87 mm
Dakbla	Pleiku	49 mm
Se San	Dak Mot	52 mm
Se San	Kon Plong	80 mm
Sre Pok	Buon Mua That	160 mm
Sre Pok	Buon Ho	186 mm

Table 7. 1: Maximum cumulative rainfall observed in the Dakbla, Upper Se San and Upper Sre Pok Basins between 30th October and 4th November. The Upper Sre Pok saw the highest totals. These storms produced the only serious flooding during 2010 in those parts of the Central Highlands of Viet Nam that lie within the Mekong Basin.

7.3 Water Levels

In 2010, the maximum water level achieved at Tan Chau was only 3.20 masl, which is 30cm lower than the first alarm level of 3.50m. After just one week it fell back to 3.00m, while at Chau Doc on the Bassac the peak flood level was at 2.78 masl, which is historically very low. As a result, the seasonal flood volume was very small such that no flooding was observed across the delta during the year.

In the Central Highlands the magnitude and extent of flooding during 2010 were small compared to past extremes. Only one peak reached at alarm level III, while water levels at the most stations just reached alarm levels I or II. Flood levels in the Upper Sre Pok at the end of the season in November just reached alarm level III. For example, at Cau 42 station the peak water level was 456.5 masl, less than 6cm above alarm level III. At Bridge No.14 station, the water level was 301.9m, while at Ban Don station on the Srepok River the maximum water level achieved was 173.1 m, 0.39m lower than alarm level. Maximum water levels observed in the other tributaries were also lower than alarm level II.

7.4 Damages

During 2010 flood, damages in Viet Nam's part of the Mekong Basin were limited largely to the Upper Se San and were caused by the storm events which happened during the first week of November.

Item	Province	
	DakLak	DakNong
Number of people killed	1	3
Number of affected families	415	397
Number injured people		8
Agriculture damaged (ha)	5150	664
Assets	Some houses inundated	72
Fishery (ha) inundated	148	7
Water control structures	2180 m irrigation canal, 31 small control structures were damaged	
Transport	56.66 km road, 6 bridges, 29 sluices were damaged	
Total 'Cost' estimate US$	3 800	na

Table 7. 2: Flood damages and loss in the Upper Se San that resulted from the flooding during the first week of November.

Plate 7. 1: Bank erosion and subsidence continues to be a perennial problem in the Delta. National road 91Chau Phu district, An Giang province. March 2010.

7.5 Recommendations

Conditions during 2010 completed a sequence of years since 2002 when there has been no serious flooding in the Mekong Delta, while in the Central highlands only relatively minor flooding occurred in the Upper Se San. There is the need, however, to remain vigilant and continue to invest in flood warning, mitigation and emergency response. In particular, flash flood warnings in the Central Highlands need significant improvement.

8. Summary Conclusions and recommendations

The hydrological situation throughout the region during 2010 was defined by the very late onset of the SW Monsoon such that the start of the flood season was much delayed. Deficient rainfall during the early wet season intensified the hydrological drought conditions that eventually developed. Ultimately, the total volume of flow at Kratie during the 2010 flood season was even less than that of 1992 which is generally regarded as the most severe drought on record. Vegetative stress, due to a lack of soil moisture, was evident over large parts of the Basin at the end of August when the soil moisture storage is usually saturated. The 2010 flood season ended as usual at the end of October such that the low flows of early 2011 are close to, or just below, average. An early end to the flood season, as in 1992 and 2009, is the major cause of deficient dry season flows.

In order to further understand the development and impacts of hydrological drought in the region, a comprehensive technical study is required. The process and its causes and impacts need to be assessed in detail such that practical management and mitigation measures can be developed.

The ‘Country Reports’ each refer to the need to continue to strengthen capacity with regard to flood management and mitigation and ensure that investment levels are appropriate. They warn against complacency in the light of eight years of below normal conditions over the Basin as a whole, as measured in terms of the annual flood volume at Kratie.

The reconstruction of the Asian Monsoon climate over the last millennium through tree ring chronologies based on a recent seminal study is consistent with the timing and intensity of historical ‘mega droughts’ due to multi-year monsoon failure as revealed in the ancient chronicles. These droughts have been associated with famine and often with rebellion and social upheaval. This history effectively illustrates the historical and continuing dependence of society on the Asian Monsoon, a society that constitutes half of the global population.

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