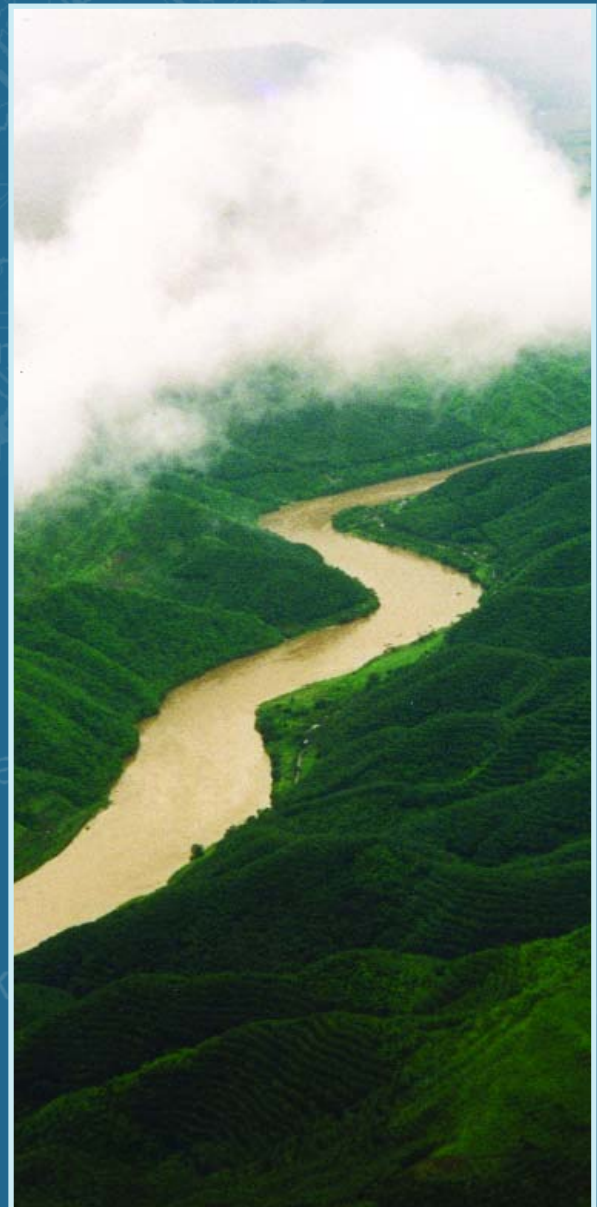
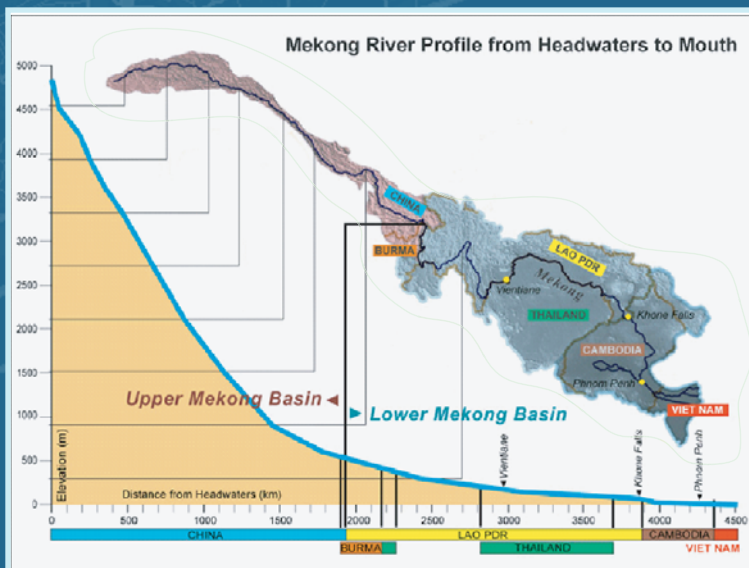
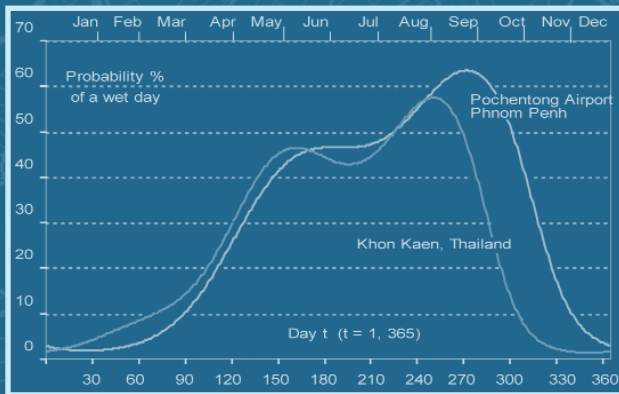




Mekong River Commission

Overview of the Hydrology of the Mekong Basin

November 2005





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Foreword

This Overview was prepared as part of the Start-up Project for the MRC's Water Utilisation Programme, financed by GEF through the World Bank. Intended as an intermediate technical introduction to the hydrology of the Mekong River, based on an analysis of the most recent observed data, it is aimed at a broad spectrum of applied scientists and engineers ranging from environmental analysts to water resources planners. A core objective has been to uncover and describe the key patterns and features of the Mekong Basin hydrology and synthesise the results in a way that provides some basic insights into the regime of this fascinating river system.

The Mekong is the common physical thread that defines the geographical region that is widely referred to as Indochina, drawing together Cambodia, Laos, Thailand and Vietnam into a single international water resources economy. These four countries have long recognised the need for joint cooperation and mutual consideration when planning and designing new water utilisation projects within a single transboundary river basin, this spirit of collaboration being embodied in the Mekong Agreement of 1995.

Within this spirit of international cooperation, the Mekong region, which also includes Yunnan Province in China and Myanmar, is in a process of accelerating economic development and the associated expansion of water use. The resources of the river basin are increasingly being used for hydropower generation, irrigated agriculture and industry and the number of schemes in the planning and implementation stages, including inter-catchment diversions, grows continually in response to the projected regional demands for water and energy. Inevitably, however, there are legitimate concerns about the possibility of long-term adverse impacts in one of the world's most diverse river ecosystems. These might arise as detrimental downstream effects from new upstream abstractions, from dam construction or inter-catchment water transfers. For example, at risk from any significant modification of the mainstream flood regime would be Cambodia's inland fishery, one of the world's largest and most diverse.


Of the economically active population of Cambodia, four out of five people depend on it in one way or another and therefore upon the annual flooding of the plains and wetlands around the Tonle Sap and Great Lake system where the fish feed and breed. Any upstream activities which might detrimentally affect the quantity and quality of the water reaching this aquatic habitat, specifically during the flood season, would jeopardise the long-term sustainability of the fishery.

During the dry season, the major hydrological hazard would be a decrease in average downstream low flows. The agricultural economy of the delta is vulnerable to any such change. It is the most important agricultural region of Vietnam, contributing more than 50 per cent of national primary sector output

and accounting for 20 per cent of national GDP. It is one of the world's major sources of rice. Reduced flows in the dry season would result in more extensive and severe marine saline intrusion, which in turn would lead to reduced areas available for planting, crop losses, reduced yields, severe local socio-economic and environmental impacts and major negative consequences for the national economy.

The links between hydrological regime, riverine ecology, the riparian environment and the degree to which a river's water resources can be sustainably and equitably developed are complex. The starting point to unravelling this complexity is an understanding of the hydrological regime and a consensus amongst policy makers of what represents the benchmark hydrology against which the magnitude of any change can be measured. One of the focal aspects of the MRC Water Utilisation Project is the identification of this benchmark hydrology, the drafting of procedures for water use to maintain the flows on the mainstream and the further development of notification procedures with regard to new resource development. The Project is a multilateral one, involving the active participation of senior representatives from each of the four downstream countries.

This hydrological overview has been prepared as part of this important process. It is recognised that its content would have broader appeal if the scope were widened to include aspects of the regional rainfall climate, material on the hydrometeorology of the Upper Mekong in Yunnan Province and a chapter on hydrological modelling in the lower part of the basin. With these additions it hopefully serves as a useful reference document that reflects the unique hydrological environment that is the Mekong River Basin.



Dr Olivier Cogels
Chief Executive Officer
Mekong River Commission

1 Introduction

The Yangtze, Salween, Irrawaddy, Red and Mekong rivers all begin their long journeys on the Tibetan Plateau at 4,500 or more metres above sea level. Here, this family of great rivers are separated by only a few hundred kilometres before moving off in different directions. The Yangtze flows across all of central China, the Red River runs through Viet Nam to the Gulf of Tonkin, and the Salween and Irrawaddy through Myanmar into the Indian Ocean. From its source, the Mekong continues south for approximately 4,800 km to the South China Sea, draining a total catchment area of 795,000 km² within the six countries of China, Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam (Table 1.1). The Mekong ranks 10th amongst the world's great rivers on the basis of mean annual flow at the mouth.

The Greater Mekong can be divided into two parts: the Upper Basin in Tibet and China (where the river is called the *Lancang Jiang*), and the Lower Mekong Basin from Yunnan downstream from China to the South China Sea (Figure 1.1).

The Upper Basin makes up 24 per cent of the total area and contributes 15 to 20 per cent of the water that flows into the Mekong River. The catchment here is steep and narrow. Soil erosion has been a major problem and approximately 50 per cent of the sediment in the river comes from the Upper Basin. It is now prohibited to plant crops on land that exceeds a 25 per cent slope. Therefore, any future development must come from hydropower generated on the mainstream because there are no major tributary systems flowing into this reach of the river.

Major tributary systems develop in the Lower Basin (Figure 1.2). These systems can be separated into two groups: tributaries that contribute to the major wet season flows, and tributaries that drain low relief regions of lower rainfall. The first group are left bank tributaries that drain the high-rainfall areas of Lao PDR. The second group are those on the right bank, mainly the Mun and Chi rivers, that drain a large part of Northeast Thailand. These two groups of tributaries are also marked by different levels of resource development. For example, in Thailand there is little room for further expansion of irrigation development. In Lao PDR, there is a lot of potential for water resources development of all kinds.

Table 1.1 Territory of the six Mekong River Basin countries within the catchment

Description	China	Myanmar	Lao PDR	Thailand	Cambodia	Vietnam	Total MRB
	Area (km ²)	165,000	24,000	202,000	184,000	155,000	65,000
Catchment as % of MRB	21	3	25	23	20	8	100
Flow as % of MRB	16	2	35	18	18	11	100

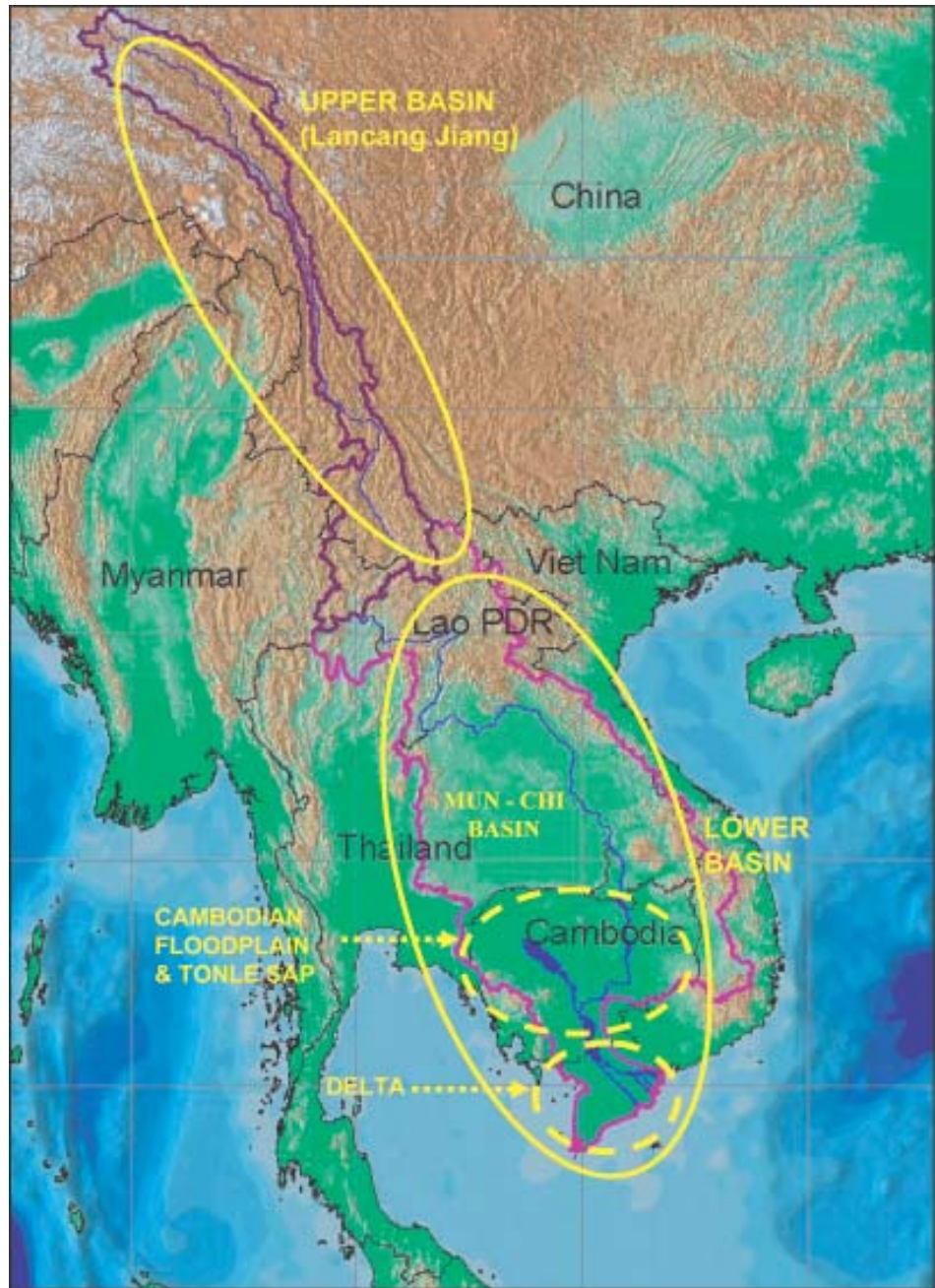


Figure 1.1 Mekong River Basin broad geographical regions

As the Mekong enters Cambodia over 95% of the flows have already joined the river. From here on downstream the terrain is flat and water levels rather than flow volumes determine the movement of water across the landscape. The seasonal cycle of changing water levels at Phnom Penh results in the unique “flow reversal” of water into and out of the Great Lake via the Tonle Sap River.

Phnom Penh also marks the beginning of the delta system of the Mekong River. Here the mainstream begins to break up into an increasing number of branches. Agriculture is most developed in the delta and the population density is the



Figure 1.2 Lower Mekong Basin topography, relief and principal sites of hydrological measurement along the mainstream

highest in the entire Greater Basin. The growing influence of tides from the South China Sea and the effects of saltwater intrusion on the water in the river show up more strongly as you move downstream.

Chapter 2

Catchment Geography



2 Catchment Geography

2.1 *General Background*

The Mekong flows for almost 2,200 km from its source and decreases in altitude by nearly 4,500 metres before it enters the Lower Basin where the borders of Thailand, Lao PDR, China and Burma come together in the Golden Triangle. Downstream from the Golden Triangle, the river flows for a further 2,600 km through Lao PDR, Thailand and Cambodia before entering the South China Sea via a complex delta system in Viet Nam (Figure 2.1).

In Yunnan province in China (where the river is called the Lancang Jiang), the river and its tributaries are confined by narrow, deep gorges. The tributary river systems in this part of the basin are small. Only 14 have catchment areas that exceed 1,000 km². In the south of Yunnan, in Simao and Xishuangbanna Prefectures, the river changes as the valley opens out, the floodplain becomes wider, and the river becomes wider and slower. The major concern here is soil erosion. As recently as 1998, up to 28 per cent of the Mekong Basin in Yunnan was classified as “erosion prone”. Cultivation is now restricted in favour of reforestation.

Lao PDR lies almost entirely within the Lower Mekong Basin. Its climate, landscape and land use are the major factors shaping the hydrology of the river. The mountainous landscape means that only 16 per cent of the country is farmed under lowland terrace or upland shifting cultivation. With upland shifting agriculture (slash and burn), soils recover within 10 to 20 years but the vegetation does not. Shifting cultivation is common in the uplands of Northern Lao PDR and is reported to account for as much as 27 per cent of the total land under rice cultivation (Lao Agricultural Census, 1998-9, 2000). As elsewhere in the basin, forest cover has been steadily reduced during the last three decades by shifting agriculture and permanent agriculture. The cumulative impacts of these activities on the river regime have not yet been measured.

Loss of forest cover in the Thai areas of the Lower Basin has been the highest in all the Lower Mekong countries over the past 50 years. On the Korat Plateau, which includes the Mun and Chi tributary systems, forest cover was reduced from 42 per cent in 1961 to 13 per cent in 1993. Although this part of Northeast Thailand has an annual rainfall of more than 1,000 mm, a high evaporation rate means it is classified as a semi arid region. Consequently, although the Mun and Chi Basins drain 15 per cent of the entire Mekong Basin, they only contribute 6 per cent of the average annual flow. Sandy and saline soils are the most common soil types, which makes much of the land unsuitable for wet rice cultivation. However, in spite of poor fertility, agriculture is intensive. Glutinous rice, maize and cassava are the principal crops. Drought is by far the major hydrological hazard in this region.

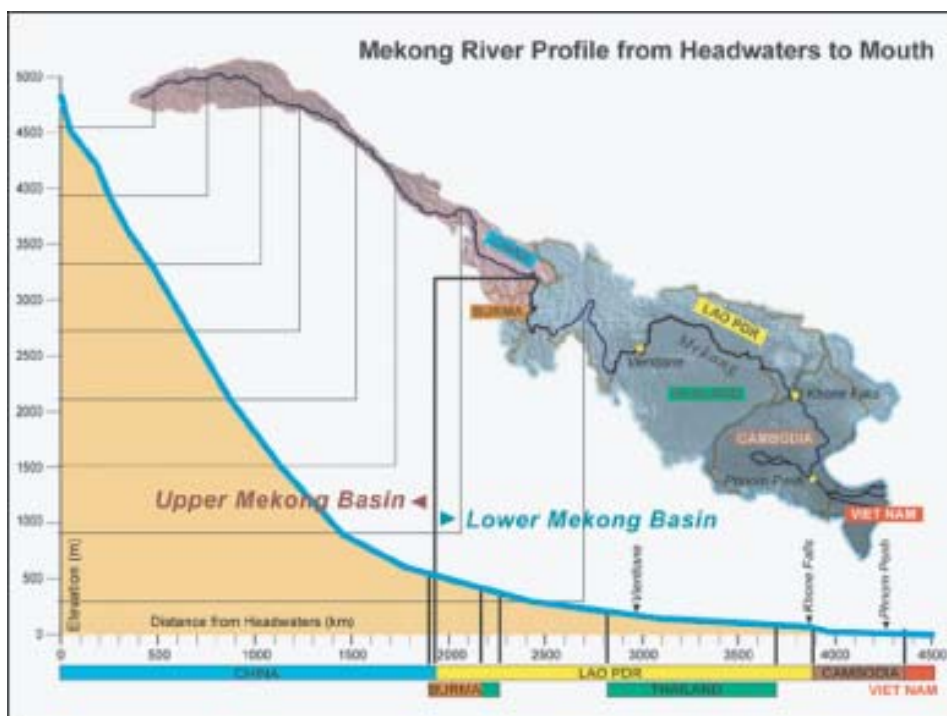


Figure 2.1 Longitudinal river profile of the Mekong River from source to delta

In Cambodia the agriculture sector accounts for half of the GDP and employs 80 to 85 per cent of the labour force. Wet rice is the main crop and is grown on the flood plains of the Tonle Sap, Mekong and Bassac rivers. More than half of Cambodia remains covered with mixed evergreen and deciduous broadleaf forest, but forest cover has decreased from 73 per cent in 1973 to 63 per cent in 1993. Here the river landscape is flat. Small changes in water level determine the direction of water movement, including the large-scale reversal of flow into and out of the Tonle Sap basin from the Mekong River.

The Mekong Delta in Viet Nam is farmed intensively and has little natural vegetation left. Forest cover is less than 10 per cent. In the Central Highlands of Viet Nam, forest cover was reduced from over 95 per cent in the 1950s to around 50 per cent in the mid 1990s. Agricultural expansion and population pressure are the major reasons for land use and landscape change. Both drought and flood are common hazards in the Delta, which many people believe is the most sensitive to upstream hydrological change.

It is still unclear, however, how much impact land use changes have had on the hydrological regime of the Mekong. The removal of so much forest cover would be expected to result in changes in the rainfall-runoff relationship. Less catchment storage of water would result in less water flowing into the river during the dry season from December to April. Less catchment storage capacity would also tend to increase the rate of rainfall runoff during the wet season and this would result in an increase in flood volumes.

There is a lot of hydrological data, at least for the mainstream, but linking rainfall to stream flow is difficult, even on an annual timescale. However, no one has yet found any conclusive evidence in the 90 years of historical data for any significant changes in rainfall-runoff relationships.

2.2 Hydrological Reaches and Reaches of the Mekong Mainstream

The Mekong mainstream can be divided into six main “reaches” (Figure 2.2).

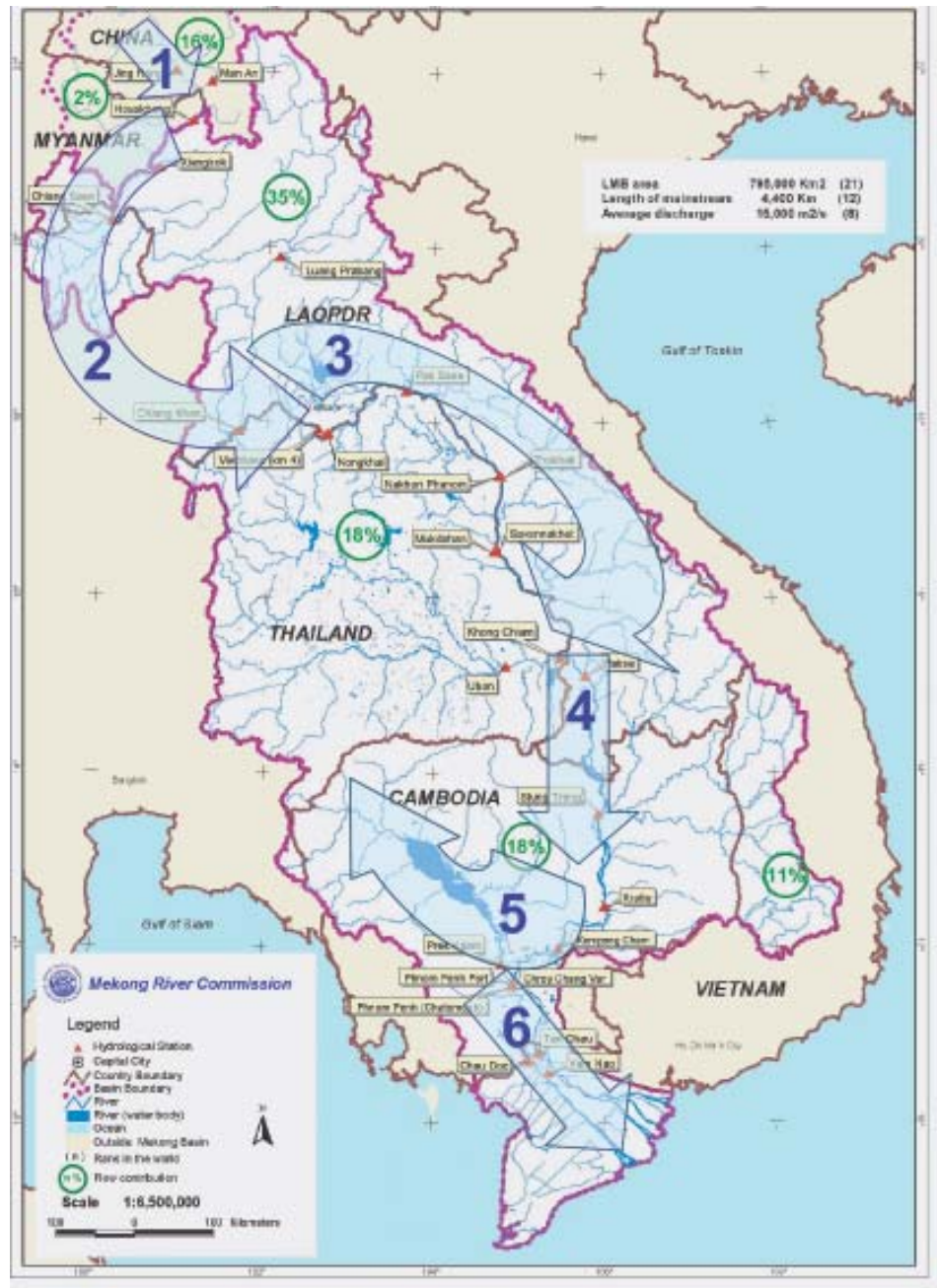


Figure 2.2 Major geographical river zones in the Lower Mekong Basin

In dividing the river this way, geographers take into account a number of considerations including:

- hydrological regime
- physiography
- land use
- existing, planned and potential resource developments

Reach 1: Lancang Jiang or Upper Mekong River in China. In this part of the river, the major source of water flowing into the river comes from melting snow on the Tibetan Plateau. This volume of water is sometimes called the “Yunnan Component” and plays an important role in the low-flow hydrology of the lower mainstream. Even as far downstream as Kratie, the Yunnan Component makes up almost 30 per cent of the average dry season flow. A major concern is that the on-going and planned expansion of dams and reservoirs on the Mekong mainstream in Yunnan could have a significant effect on the low-flow regime of the Lower Mekong Basin system.

Reach 2: Chiang Saen to Vientiane and Nongkhai. This reach is almost entirely mountainous and covered with natural forest, although there has been widespread slash and burn agriculture. There is little scope for wide scale permanent agricultural development and there are no plans for any major water resources developments. Pre-feasibility and feasibility studies of the hydropower potential here have focused on small run-of-river schemes for local needs. This may change, however, with recent interest in schemes in the Upper Nam Ou, the major tributary system, which could be developed to export power to China. On the Thai side, there are schemes to divert water out of the Mekong Basin to south-flowing basins. Although this reach could hardly be described as “unspoiled”, the hydrological response is perhaps the most natural and undisturbed in all the Lower Basin. Many hydrological aspects of the Lower Basin start to change rapidly at the downstream boundary of this reach.

Reach 3: Vientiane and Nongkhai to Pakse. The boundary between Reach 2 and 3 is where the Mekong hydrology starts to change. Reach 2 is dominated in both wet and dry seasons by the Yunnan Component. Reach 3 is increasingly influenced by contributions from the large left bank tributaries in Lao PDR, namely the Nam Ngum, Nam Theun, Nam Hinboun, Se Bang Fai, Se Bang Hieng and Se Done rivers. The Mun - Chi river system from the right bank in Thailand also enters the mainstream within this reach.

It would be easier to measure impacts on mainstream hydrology from changes to the major left and right bank tributary systems by further dividing the river into subreaches upstream and downstream of where the Mun and Chi rivers meet the Mekong (the confluence). The hydrologies of these subreaches are distinct, as are the present status and future direction of their water resources development potential. The Mun and Chi rivers are highly developed low-relief, agricultural

basins with low runoff potential and significant reservoir storage for dry season irrigation. The left bank Lao tributaries are in an accelerating phase of development in terms of water demand for agriculture and hydropower.

Reach 4: Pakse to Kratie. The main hydrological contributions to the mainstream in this reach come from the Se Kong, Se San and Sre Pok catchments. Together, these rivers make up the largest hydrological subcomponent of the Lower Basin. Over 25 per cent of the mean annual flow volume to the mainstream at Kratie comes from these three river basins. They are the key element in the hydrology of this part of the system, especially to the Tonle Sap flow reversal. One of the major issues here is the potential impacts on flow regimes that would result from hydropower regulation on the upper Se San in Viet Nam.

Reach 5: Kratie to Phnom Penh. This reach includes the hydraulic complexities of the Cambodian floodplain, the Tonle Sap and the Great Lake. By this stage, over 95 per cent of the total flow has entered the Mekong system. The focus turns from hydrology and water discharge to the assessment of water level, over-bank storage and flooding and the hydrodynamics that determine the timing, duration and volume of the seasonal flow reversal into and out of the Great Lake.

Reach 6: Phnom Penh to the South China Sea. Here the mainstream divides into a complex and increasingly controlled and artificial system of branches and canals. Key features of flow behaviour are tidal influences and salt water intrusion. Every year, 35 to 50 per cent of this reach is flooded during the rainy season. The impact of road embankments and similar infrastructure developments on the movement of this flood water is an increasingly important consequence of development.

2.3 *The Tonle Sap System*

The Tonle Sap Lake in Cambodia is the largest body of freshwater in Southeast Asia and a key part of the Mekong hydrological system. Its mean surface area changes from 3,500 km² during the dry months (January to April - May), to a maximum of up to 14,500 km² during the wet season. Maximum depths of 6 to 9 metres can be measured in late September to early October and minimum of around 0.5 metres in late April. The seasonal changes in the amount of water stored in the lake are from as low as 1 - 2 cubic kilometres (km³) in the dry season, rising to 50 to 80 km³ in the flood season.

Differences between the water level in the lake and the water level in the mainstream Mekong cause the unique flow reversal in the Tonle Sap River. During the flood months, water flows up the Tonle Sap from the Mekong mainstream into the Lake. As the water level in the mainstream falls in late September, water flows out of the lake down the Tonle Sap back into the Mekong mainstream. Nowhere else in the world is there a flow reversal this large. The lake retains about 80 per

cent of the sediment and nutrients carried into it by the flow reversal. This annual natural fertilisation of the floodplains in Cambodia has been a key factor in thousands of years of successful wet rice cultivation. The flooding of huge areas of forest provides an abundant food source for fish. Fishing or fishing related activities are the major economic activity for up to 80 per cent of the labour force in Cambodia and the fishery depends directly on this seasonal flooding.

The seasonal storage of water in the Great Lake also acts as a huge natural regulator for water flows downstream of the Tonle Sap - Mekong confluence at Phnom Penh. This has some significant advantages in terms of the seasonal distribution of flows in the Vietnamese delta. As stored water flows out of the lake back to the mainstream during the dry season, the low flows in the Mekong are increased and are therefore higher downstream of Phnom Penh than they would be otherwise. The benefit is more water for irrigation and a reduction in the amount of saltwater intrusion in the delta.

Chapter 3

The Climate of the Mekong Basin



3 The Climate of the Mekong Basin

3.1 Background

The climate of the Mekong Basin is dominated by the Southwest Monsoon, which generates wet and dry seasons of more or less equal length (Table 3.1). The monsoon season usually lasts from May until late September or early October. There is usually heavy rainfall (> 5 mm) on one day in two over most of the region. Later in the season, tropical cyclones occur over much of the area so that August and September and even October (in the delta) are the wettest months of the year.

Table 3.1 Generalised climate seasons in the Mekong River Basin

Cool / Cold		Hot / Dry		Wet							Cool / Cold	
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
NE Monsoon		Transition		SW Monsoon							NE Monsoon	

The Northeast Monsoon, which sets in towards late October, brings lower temperatures. Rainfall during the months of the NE Monsoon is generally confined to Viet Nam since the rest of the Lower Mekong region lies in the lee of the Annamite Mountains or the Central Highlands.

In the Upper Basin, Yunnan province has a similar monsoon climate, although there is considerable variation with local topography. The climate varies from tropical and subtropical monsoons in the south of Yunnan, to temperate monsoons in the north as the land rises from a mean elevation of 2,500 metres above sea level (masl) to 4,000 masl on the Plateau of Tibet.

3.2 Temperature and Evaporation

The seasonal range of mean temperatures in the lowlands and river valleys of the Lower Basin is not large. There are, however, significant changes, both season to season and from day to night at increasing altitudes and in the more temperate climates to the north. Sample mean monthly temperature data for both the Upper and Lower Mekong are in Table 3.2.

Mean summer temperatures during the period from March to October are similar within the Lower Basin from Phnom Penh, Cambodia to as far north as Luang Prabang in Lao PDR and Chiang Rai in Thailand. At altitudes above 500 masl, summer temperatures are lower, though not by much. At almost 2,500 masl in the Upper Se San subbasin in Viet Nam, Pleiku has mean summer temperatures that are only 2° to 3° C lower than those typical of the Mekong lowlands. Winter mean temperatures decrease significantly from south to north, from 26° - 27° C in Phnom Penh to 21° - 23° C in Chiang Rai.

Table 3.2 Mekong Basin Mean monthly temperature data (°C) at selected sites

Site	Altitude masl	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deqen ¹	4,000	-4	-2	2	5	10	13	13	13	11	11	6	-3
Pleiku	2,460	18	20	23	24	24	23	22	22	22	22	21	19
Dali ²	1,900	8	10	13	16	19	20	20	18	18	15	12	9
Jinhong ³	540	15	18	21	24	26	26	25	25	24	23	18	16
Chiang Rai	382	21	22	26	30	29	27	28	27	27	27	23	21
Luang Prabang	305	22	23	26	28	28	28	28	28	27	27	24	21
Vientiane	170	24	25	28	29	29	29	28	28	28	28	25	23
Khon Kaen	166	24	25	28	29	28	28	27	27	26	26	25	23
Pakse	102	26	27	30	30	29	29	28	28	28	28	26	25
Phnom Penh	10	27	28	30	31	30	29	28	28	28	28	27	26

1. North Yunnan-Tibet border 2. Central Yunnan 3. South Yunnan

Winter temperatures are much cooler within the Upper Basin in Yunnan province. At Jinhong, which is 340 km upstream of the hydrological boundary of the Lower Basin, average summer temperatures are only 2° to 3° C lower, but in winter they are 5° to 6° C below temperatures at Chiang Rai. However, these differences are generally far less than the changes from day to night. On the Tibetan Plateau at Deqen in the far north of Yunnan, the seasonal temperature pattern becomes truly high-altitude continental. Winter temperatures here fall below zero and summer averages may only reach 13° C.

Annual rates of evapotranspiration range between 1 and 2 metres, with little variability from year to year, and high relative humidity resulting in fairly constant annual values. The Korat Plateau in Northeast Thailand, mainly the Mun and Chi Basins, is one of the driest areas in Southeast Asia. In many climate classification systems this region is defined as semi-arid. At Khon Kaen, for example, mean annual rainfall is 1,200 mm, compared to a mean annual rate of evaporation of 1,900 mm. Lack of soil moisture in the area becomes critical during the late dry season from February to April. Further south in the Cambodian and Vietnamese parts of the Basin, annual evaporation rates are somewhat lower at 1,500 to 1,700 mm. To the north at Chiang Rai, the rate is around 1,400 mm. Within the Lower Basin anywhere below an altitude of 500 masl, annual rates of evapotranspiration generally do not fall below 1,000 mm. In the Upper Basin in Yunnan, evaporation rates are more complex due to rapid changes in altitude and slope orientation. Data for many climate variables are only useful within local areas.

3.3 *The Rainfall Climate*

The distribution of mean annual rainfall over the Lower Basin is mapped in Figure 3.2. This figure shows a range from less than 1,500 mm in most of the Thai subbasins, to over twice this figure in the Central Highlands of Lao PDR. The map clearly shows that the left bank tributaries of Lao PDR generate most of the flows to the mainstream.



Figure 3.1 Greater Mekong Basin and locations referred to in text regarding rainfall climate

The Lower Basin is divided into six subregions to compare annual and monthly rainfall and changes in space and time. Table 3.3 compares long-term averages. Annual average rainfalls over the Cambodian floodplain and the Vietnamese delta are equally low and less than 1,500 mm. Elsewhere, the highest rainfalls are as expected – in the Central Highlands and within the mainstream valley at Pakse. Rainfall is lower in the more temperate northern regions around Chiang Rai. July, August and September are generally the months of highest rainfall, although there is evidence of a shift to later in the season in Cambodia and on the delta where more rain falls in September and October.

Table 3.3 Lower Mekong Basin annual and seasonal average rainfall (mm) for representative subregions (see Figure 3.1 for station locations)

Month	Northern Region	Central Region	Korat Plateau	Central Highlands	Cambodian Floodplain	Vietnam Delta
	Chiang Rai	Pakse	Khon Kaen	Pleiku	Phnom Penh	Chau Doc
Jan	13	2	5	6	8	8
Feb	10	7	15	6	3	3
Mar	20	20	35	25	15	15
Apr	85	70	60	85	65	75
May	190	220	170	225	115	165
Jun	210	380	180	350	125	110
Jul	310	390	160	360	160	140
Aug	390	500	185	460	160	170
Sep	280	320	260	360	265	160
Oct	140	100	120	220	255	250
Nov	60	20	10	75	130	160
Dec	20	3	3	20	20	40
ANNUAL	1,730	2,050	1,210	2,200	1,320	1,300

This seasonal shift in the distribution of subregional monthly rainfall patterns can be seen in more detail in the plots shown in Figures 3.3 and 3.4. These plots also indicate the range of monthly and annual totals from year to year:

- In the north at Chiang Rai, the seasonal pattern has a single-peak rainfall month in August. The range, however, is considerable. The August average is 390 mm, but in some years it can be as high as almost 600 mm and as low as 150 mm. Annual rainfalls here have a typical range of between 1,500 and 2,000 mm, with an average figure of around 1,700 mm.
- For Pakse in the Mekong Lowlands and Pleiku in the Central Highlands of Viet Nam the amounts and between-year ranges are similar. The annual average exceeds 2,000 mm and the inter-annual variability is quite wide, from lows of 1,200 - 1,300 mm to highs of 3,000 mm and more. At both locations there is evidence of two rainfall peaks in wet years.

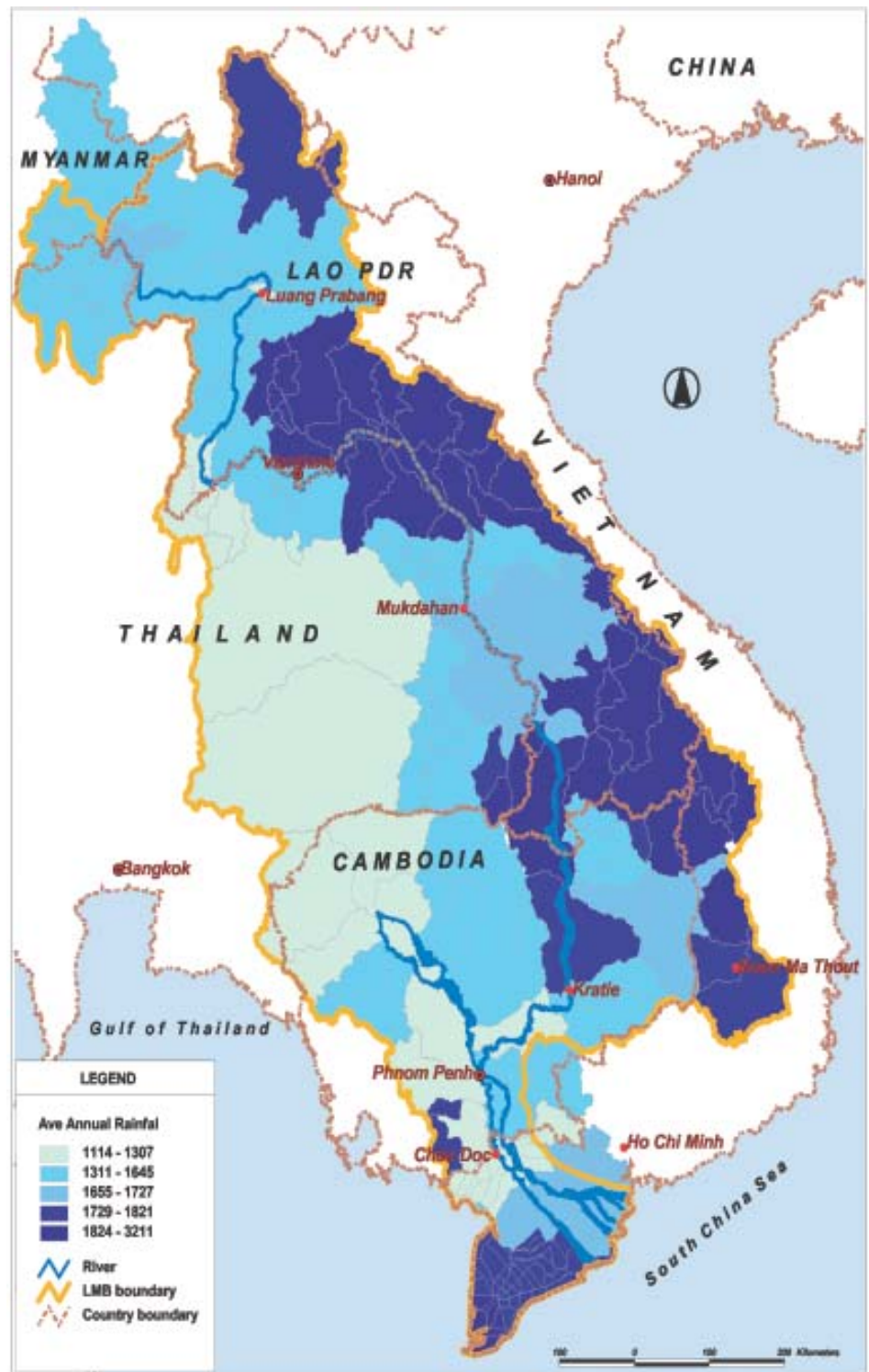


Figure 3.2 Distribution of mean annual rainfall (mm) over the Lower Mekong Basin

This characteristic of “twin peaks” in rainfall in wet years is also evident at Khon Kaen on the Korat Plateau. Here the mean annual rainfall is only 1,200 mm, although it has been as low as 780 mm.

In Phnom Penh on the Cambodian floodplain and at Chau Doc in the delta, the seasonal distribution has a very different pattern. Here the rain comes during the final quarter of the year. Annual totals generally range between 1,000 and 1,500 mm, with a long-term average of 1,200 to 1,300 mm. During drought years the figures can be much less and have been as low as 650 mm at Phnom Penh.

Tropical storms and cyclones have a strong affect on the rainfall climate of the Basin. This effect shows up as a double peak in rainfall distribution over most of the Lower Basin during wet years and the concentration of maximum rainfalls during the last quarter of the year in Cambodia and Viet Nam. The influence of cyclones is not widely recognised but becomes clear from the results in Table 3.4 and on Figure 3.3. Data on the wider regional occurrence of tropical cyclones shows that over Central and Southern Viet Nam they are most frequent between September and November and are largely responsible for the higher rainfalls occurring in these later months.

Table 3.4 Monthly frequency of occurrence of the 128 tropical cyclones observed in central and southern Vietnam for 38 years between 1954 and 1991 (Source: Asian Disaster Preparedness Centre, May 2000)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Occurrence Frequency (%)	0	0	2	2	2	6	0	11	20	32	20	5

In years of above average cyclone activity and intensity, there are wider impacts on the rainfall climate in those parts of the Basin to the north of Viet Nam and Cambodia. In Thailand and Lao PDR, such years are much wetter than normal due to a late wet season rainfall peak linked to cyclone disturbances. During this tropical cyclone period, the probability that any given day will be wet (> 1 mm) reaches a maximum over most of the Lower Basin. This happens even in the relatively dry parts of Northeast Thailand, represented by the result for Khon Kaen in Figure 3.4.

The Southwest Monsoon, combined with severe tropical storms, has been the cause of flood disasters in the Lower Mekong, particularly in Cambodia and the delta. But the major impacts of such weather systems are not confined to the southern part of the Basin. In 1966, Typhoon Phyllis was responsible for the most extreme flood recorded at Vientiane since 1913.

Figure 3.5 presents the annual rainfall histories at six representative locations. The plots show the percentage of rainfall in each year above and below the long-term averages calculated for a common 25-year period from 1980 to 2004. This

statistical technique helps identify “drier” and “wetter” periods and highlights years that were exceptional. In an “exceptional” year, rainfall will be above or below average by more than 25 per cent.

The first thing to note from these data is that correspondence between the above and below average periods and their intensity from station to station are not as high as might be expected. Rainfall during the early 1990s was generally below average, and during the last half of the 1990s generally above average (except at Chiang Rai), but there is little consistency from site to site or subregion to subregion. This indicates that rainfall in the Lower Basin is subject to large changes over short distances.

Therefore, the use of annual data from one station to represent large geographical areas or short durations is not valid.

3.4 *The Rainfall Climate of the Upper Basin in Yunnan*

The rainfall climate of the Upper Basin in China is also determined by global monsoon systems, although in Yunnan Province there is a much wider variation in the date of the onset of the Southwest Monsoon from year to year. The seasonal distribution of rainfall is the same as in the Lower Basin, although annual amounts decrease towards the north to as little as 600 mm on the Tibetan Plateau. Snow is rare in the valleys but is significant at higher altitudes and is the major source of water for the dry season and spring flows (April, May) in the upper mainstream.

Precipitation is a function of elevation, which goes from 900 to 1,100 mm on the valley floor to 1,600 to 1,700 mm in the mountains. The data for Jinhong, Dali and Deqen given in Table 3.5 show the rainfall climate along the mainstream at lower elevations. As altitude increases towards the Tibetan Plateau, rainfall decreases and snow becomes the major source of river runoff. At Deqen in the far north of Yunnan, mean annual rainfall is only 600 mm.

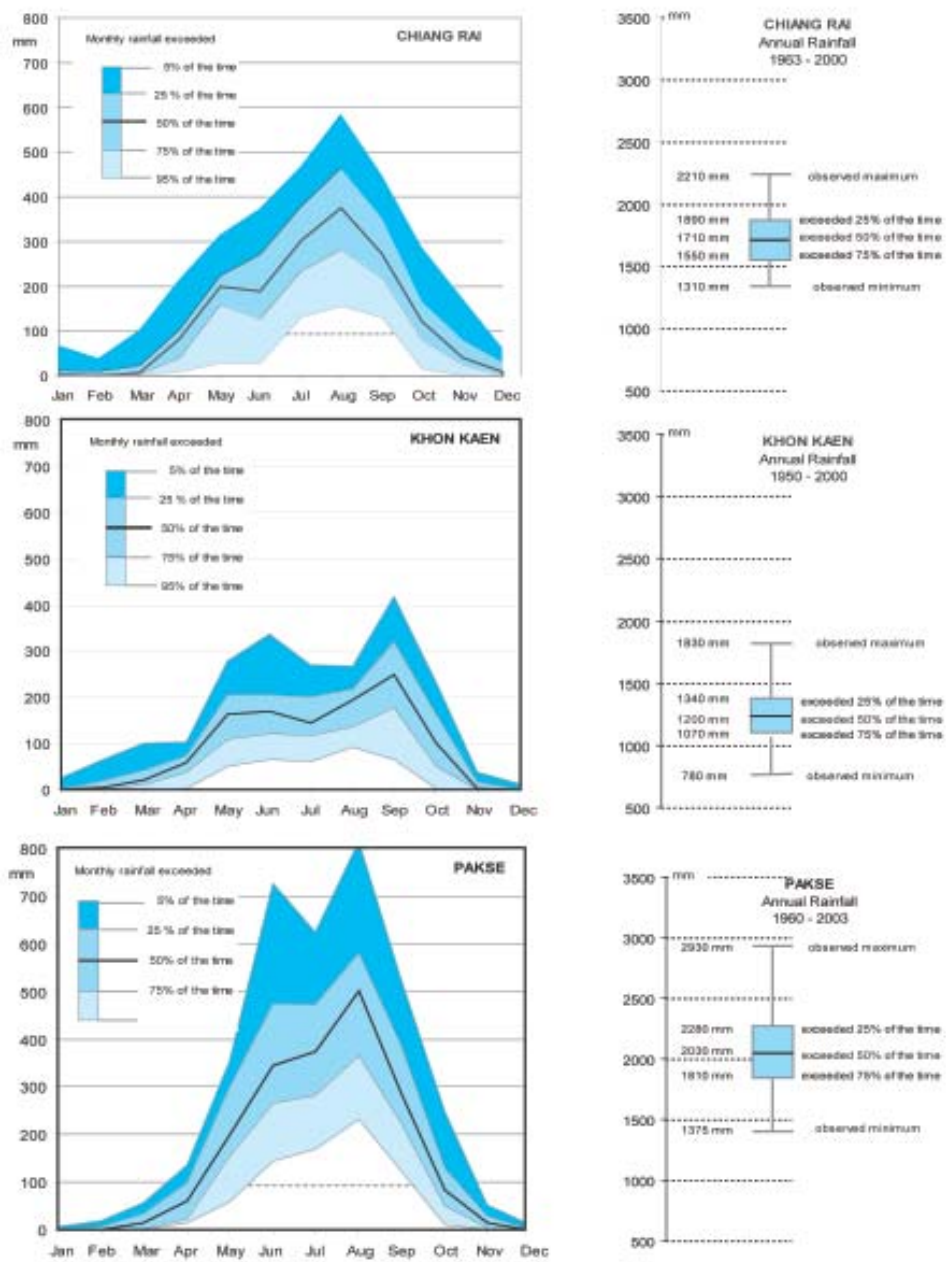


Figure 3.3 Lower Mekong Basin, distribution and range of annual and monthly rainfall at selected locations

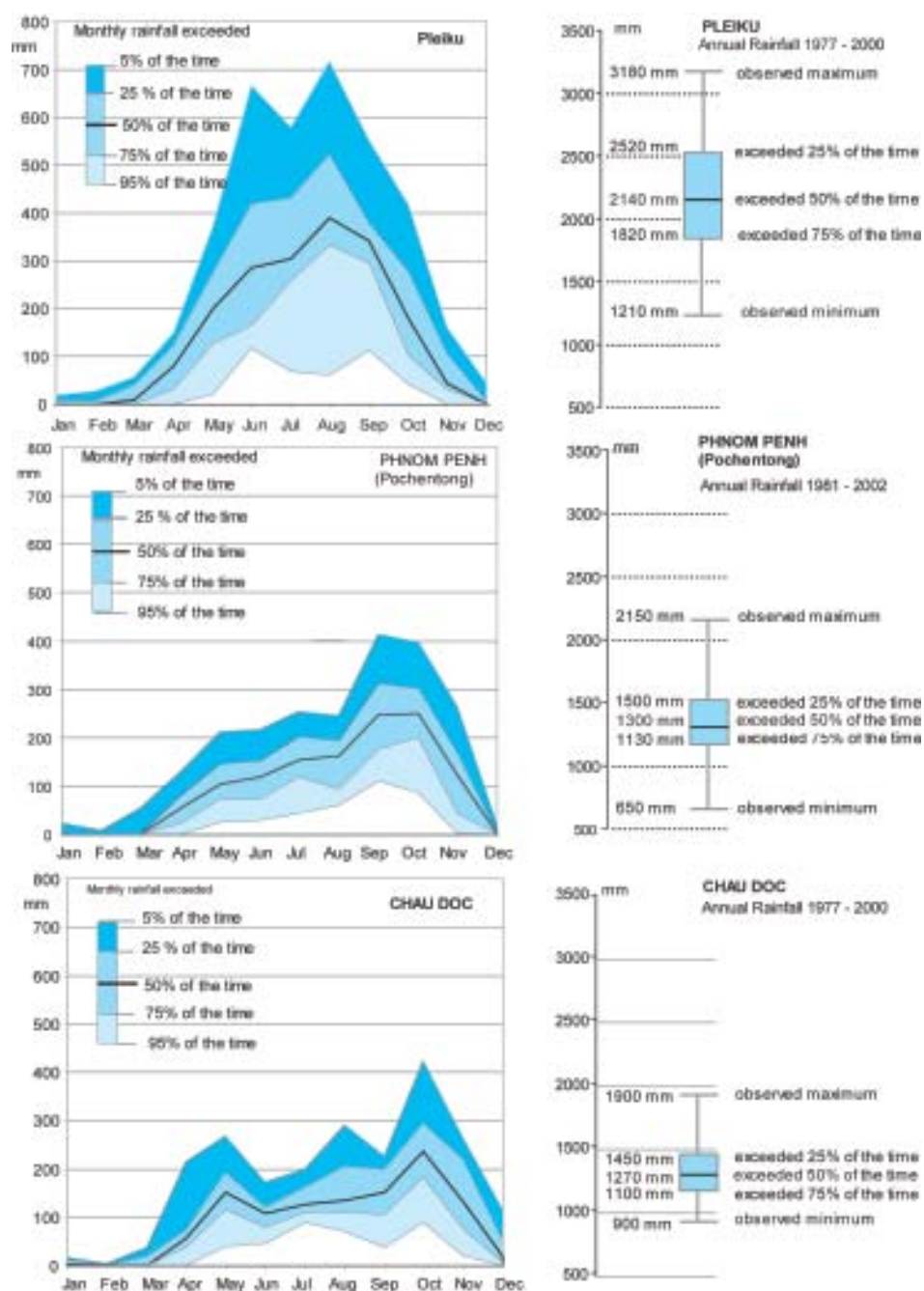


Figure 3.3 Continued

Lower Mekong Basin, distribution and range of annual and monthly rainfall at selected locations

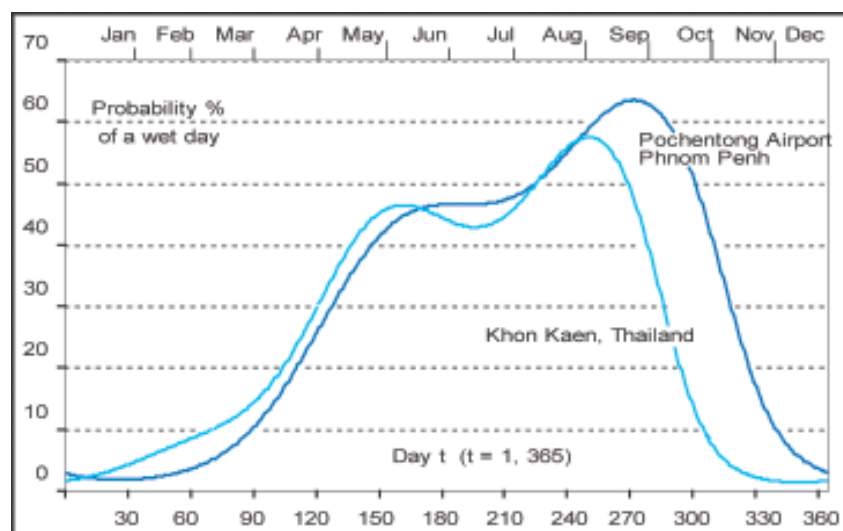


Figure 3.4 Percentage probability that a given day will be wet (> 1 mm) at Phnom Penh and at Khon Kaen based on observations made from 1960 to 2004

3.5 *Climate Change Scenarios*

Two researchers, Arora and Boer (2001), investigated possible changes in the volume of stream flow and river regime caused by climate warming on a selection of some of the world's largest rivers. They used a general global climate circulation model. Their analysis predicted:

- changes in mean annual discharge at river mouths
- changes to the seasonal distribution of flows in rivers
- changes to the flood regime and annual maximum discharges

The study results predicted that over land, precipitation would decrease by 2 per cent and evaporation would increase by 2 per cent. These two effects would combine to reduce freshwater supply to the oceans by 14 per cent. Over the oceans, precipitation and evaporation would increase by 5 and 3 per cent respectively. According to the model, runoff and river discharge decrease in a warmer world.

Results for the Mekong predict lower mean annual flows and floods but the seasonal distribution of water remains the same. Flood season volumes would decrease by 15 per cent.

Climate research tells us that a number of climate, ocean and geographic systems are likely to change rapidly and drastically as a result of global warming. The Tibetan Plateau is one such system. Permafrost on the Tibetan Plateau begins at an average altitude of about 5,000 m. This area is one of several that are not yet significantly affected by direct human activity. Because the heat and moisture conditions in this area are on the edge of the ecological limit for vegetation, it is

Table 3.5 Mean monthly and annual rainfalls (mm) representative of the Upper Mekong Basin in Southern, Central and Northern Yunnan

	Jinhong S. Yunnan	Dali Central Yunnan	Deqen N. Yunnan Tibetan Plateau
Jan	18	14	5
Feb	10	22	15
Mar	20	33	20
Apr	50	21	27
May	130	67	30
Jun	190	210	90
Jul	220	180	160
Aug	250	240	160
Sep	140	165	72
Oct	100	100	38
Nov	50	33	8
Dec	25	15	5
Year	1200	1100	630

believed to be highly sensitive to global warming. The boundary between intermittent or seasonal permafrost areas on the Tibetan Plateau are likely to shift toward the centre of the Plateau and the whole region will become much warmer. If this occurs it will have a significant impact on the hydrology of the Upper Mekong and runoff volumes during both the flood and low flow seasons would fall considerably.

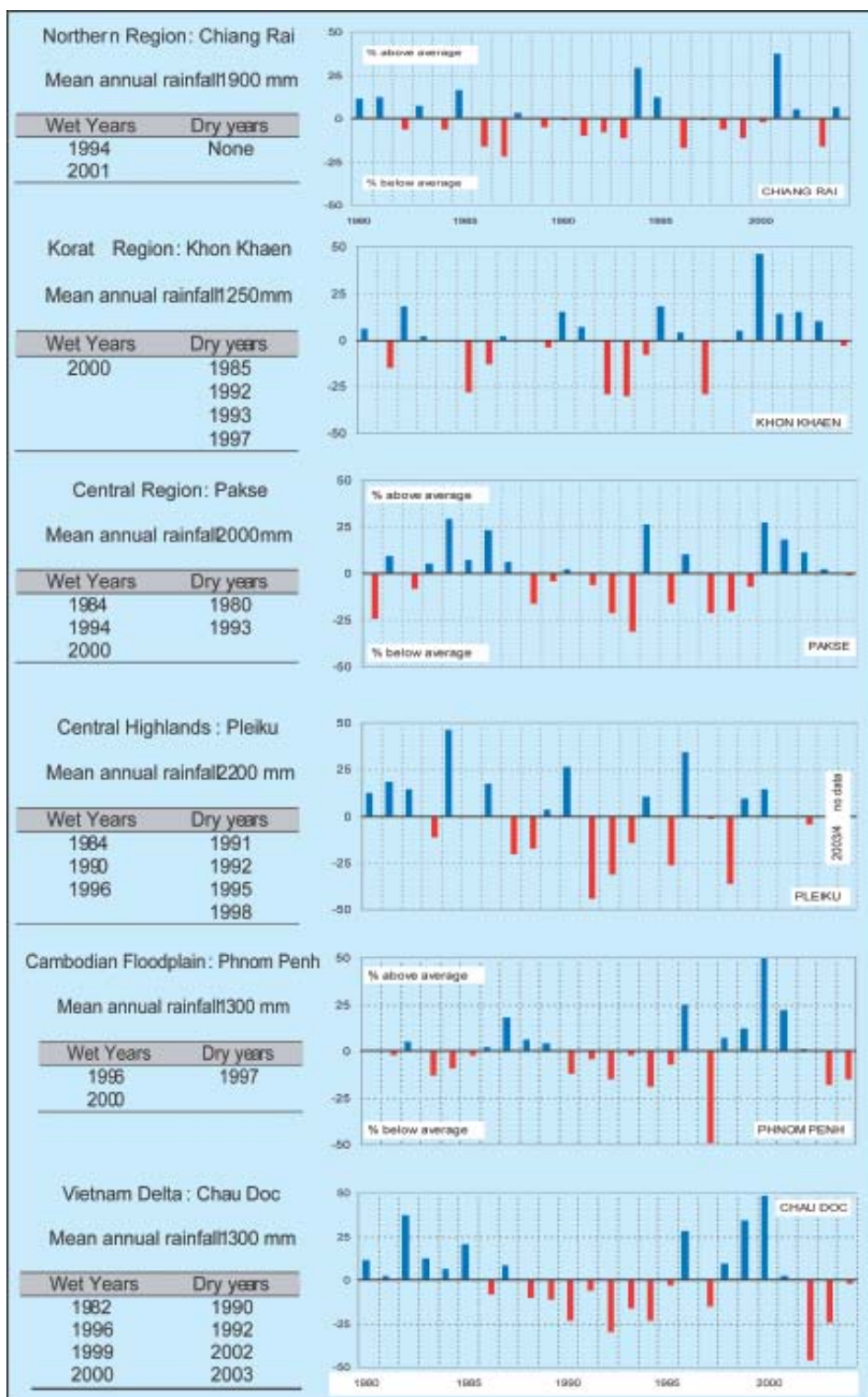
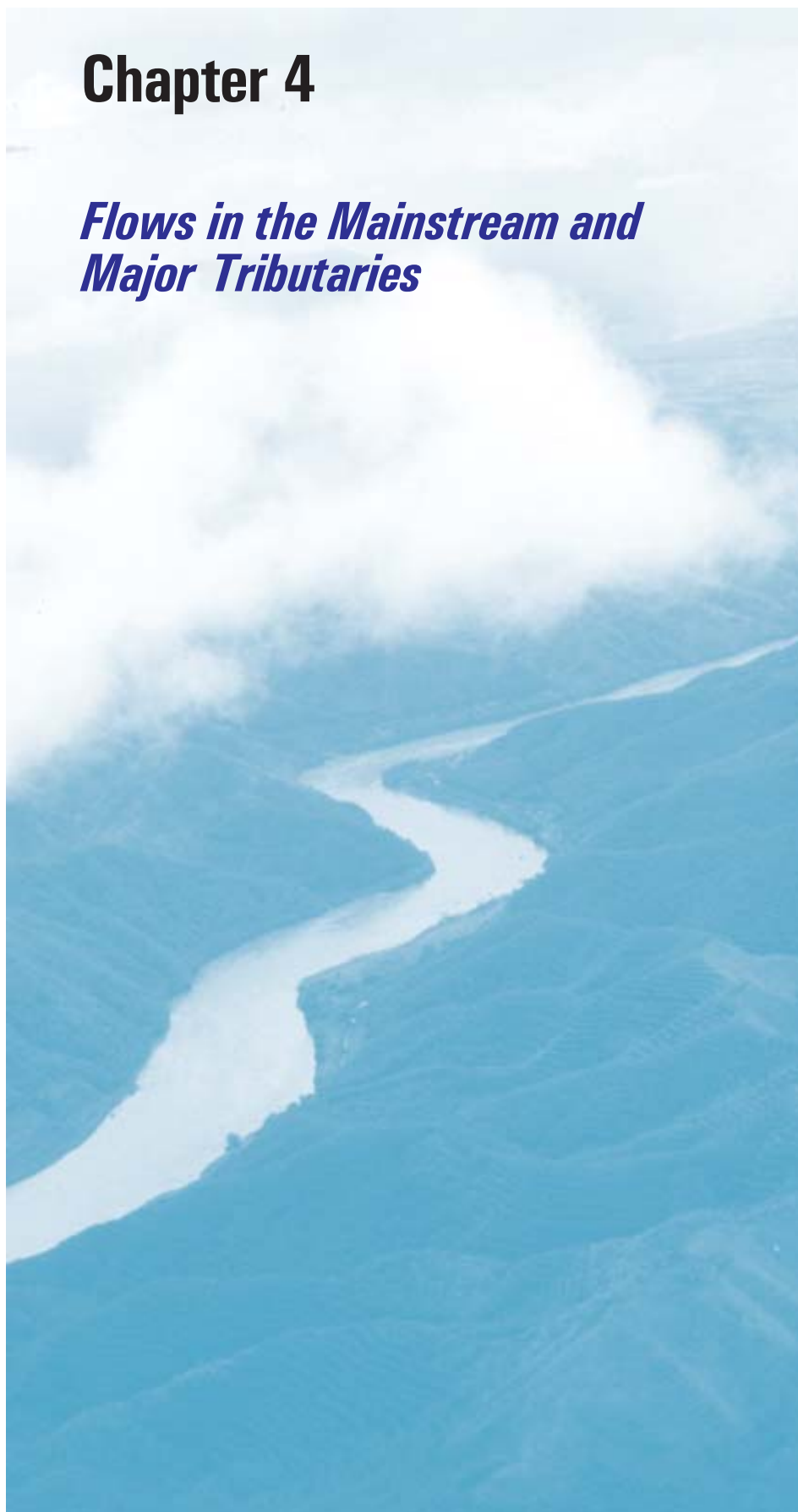


Figure 3.5 Lower Mekong Basin: Annual rainfall timeseries for the period from 1980 to 2004 representative of various sub regions. The plots show the percent deviation of annual rainfall above and below the average for the same 25 years. Notably wet and dry years are defined as when the deviation from average exceeds 25 per cent.

Chapter 4

Flows in the Mainstream and Major Tributaries



4 Flows in the Mainstream and Major Tributaries

The mean annual discharge of the Mekong is approximately 475 cubic kilometres (km³). Of this amount, about 16 per cent comes from China and only 2 per cent from Myanmar. Most of the remainder comes from Lao PDR and the major left bank tributaries, particularly the tributaries that enter downstream of Vientiane-Nongkhai (Table 4.1).

Table 4.1 Flow contributions for mainstream reaches

River reach	Left Bank %	Right Bank %	Total %
China	16		16
China - Chiang Saen	1	4	5
Chiang Saen - Luang Prabang	6	3	9
Luang Prabang - Chiang Khan	1	2	3
Chiang Khan - Vientiane	0	0	0
Vientiane - Nongkhai	0	1	1
Nongkhai - Nakhon Phanom	19	4	24
Nakhon Phanom - Mukdahan	3	1	4
Mukdahan - Pakse	5	6	11
Pakse - Stung Treng	23	3	26
Stung Treng - Kratie	1	0	1
Totals:	60	16	24
			100

Figure 4.1 shows the seasonal distribution of mean discharge along the mainstream and the major tributary rivers in each reach.

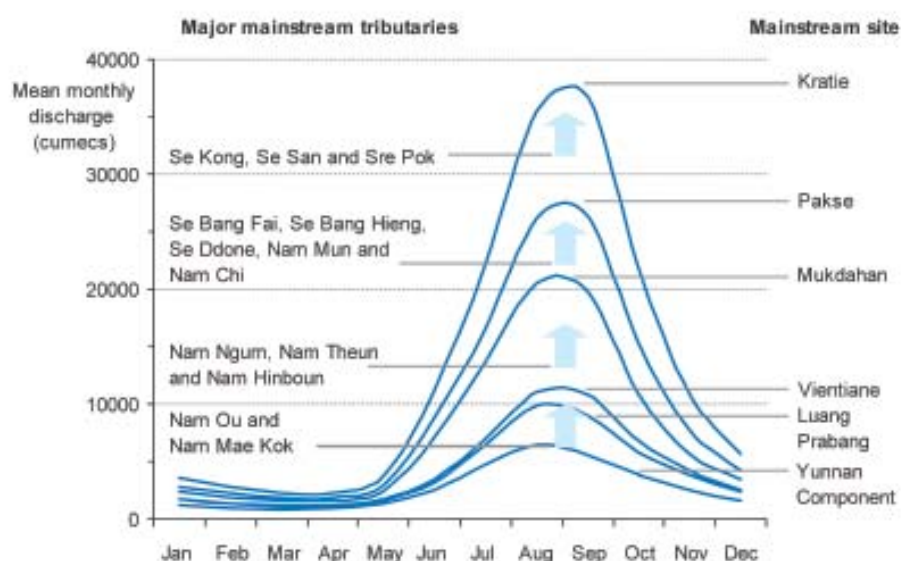


Figure 4.1 Mean monthly discharges at various sites on the mainstream and the major tributary sources in each reach

The geography of the runoff in the Basin is shown in Figure 4.2. The figure shows the major flow contributions from the left bank tributary systems in Lao PDR and the Se Kong and Se San Rivers, which enter the mainstream between Pakse and Kratie.

Table 4.2 summarises the mean annual flows along the mainstream. Figure 4.3 shows the step-by-step increase in mainstream runoff as the major left bank tributaries enter the system. The mean annual flow entering the lower Mekong from China is equivalent to a relatively modest 450 mm depth of runoff. Downstream of Vientiane this increases to over 600 mm as the principal left bank tributaries enter the mainstream, mainly the Nam Ngum and Nam Theun. The flow level falls again, even with the right bank entry of the Mun-Chi system from Thailand. Although the Mun - Chi basin drains 20 per cent of the lower system, average annual runoff is only 250 mm. Runoff in the mainstream increases again with the entry from the left bank of the Se Kong from southern Lao PDR and Se San and Sre Pok from Viet Nam and Cambodia.

Flows at Chiang Saen entering the Lower Basin from Yunnan make up about 15 per cent of the wet season flow at Kratie. This rises to 40 per cent during the dry season, even this far downstream. This key seasonal feature of the mainstream hydrology is illustrated in Figure 4.4 for the length of the lower Mekong. The concern is that large-scale reservoir regulation on the mainstream in Yunnan would have a significant impact on the dry season hydrology of the lower system. During the wet season, most of the flow comes from the large tributaries in Lao PDR, so any regulation effects coming from China will be less noticeable in the wet season.

Table 4.2 Lower Mekong Mainstream mean annual flow (1960 to 2004) at selected sites

Mainstream Site	Catchment area km ²	Mean annual flow as			as % total Mekong
		discharge cumecs	volume km ³	runoff mm	
Chiang Saen	189,000	2,700	85	450	19
Luang Prabang	268,000	3,900	123	460	27
Chiang Khan	292,000	4,200	133	460	29
Vientiane	299,000	4,400	139	460	30
Nongkhai	302,000	4,500	142	470	31
Nakhon Phanom	373,000	7,100	224	600	49
Mukdahan	39,1000	7,600	240	610	52
Pakse	545,000	9,700	306	560	67
Stung Treng	635,000	13,100	413	650	90
Kratie	646,000	13,200	416	640	91
BASIN TOTAL	760,000	14,500	457	600	100

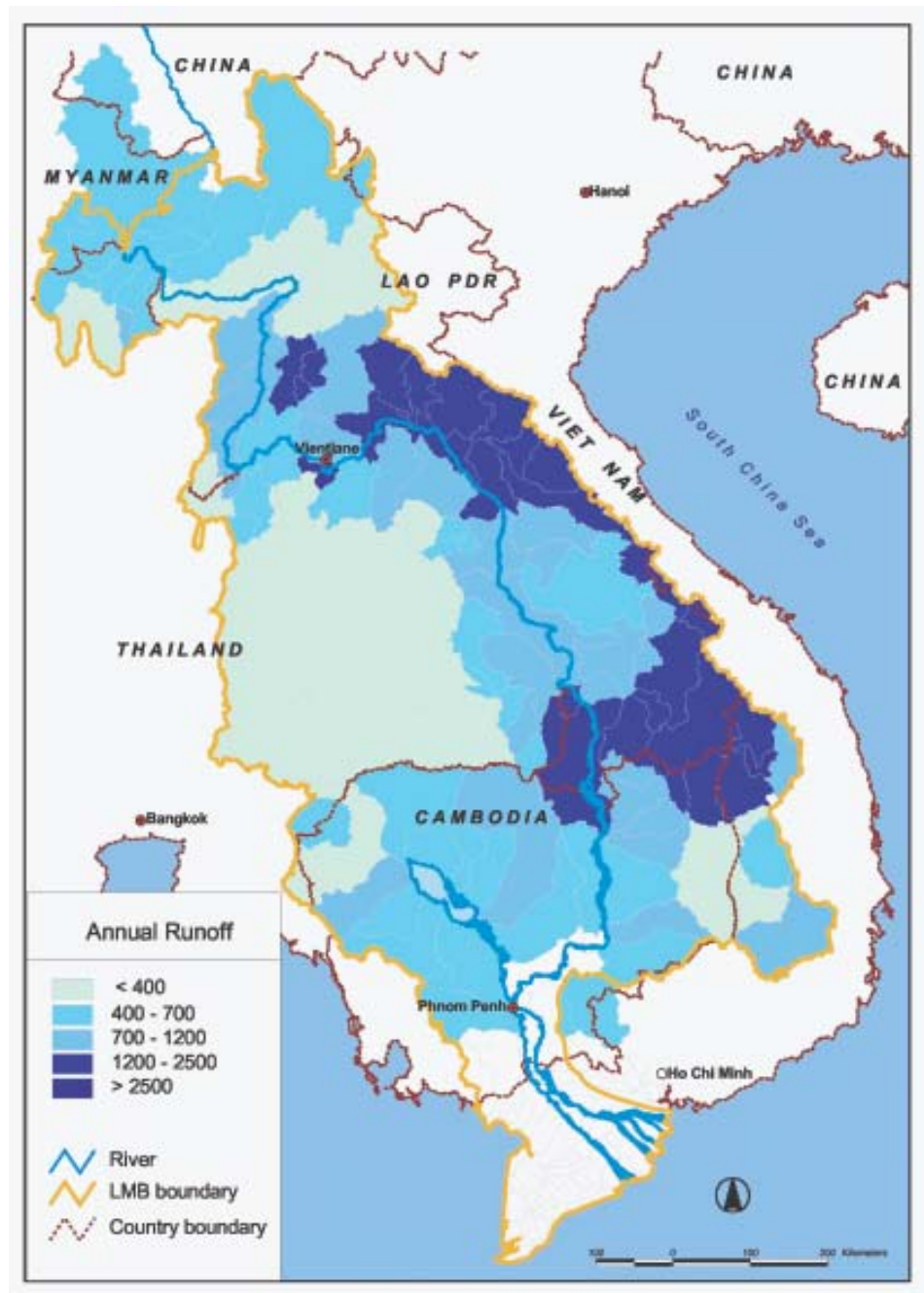


Figure 4.2 Lower Mekong Basin mean annual depth of runoff (mm)

Sources of flow in the wet season (June to November) and dry season (December to May) months are summarised in Figure 4.5. During the wet season, the proportion of average flow coming from Yunnan rapidly decreases downstream of Chiang Saen, from 70 per cent to less than 20 per cent at Kratie. The dry season contribution from Yunnan is much more significant. The major portion of the balance comes from Lao PDR, which points to a major distinction in the low-flow hydrology of the river. One fraction comes from melting snow in China and Tibet and the rest from over-season catchment storage in the Lower Basin. This has implications for the occurrence of drought conditions. For example, if runoff from melting snow in any given year is very low, then flows upstream of Vientiane-Nongkhai would be lower.

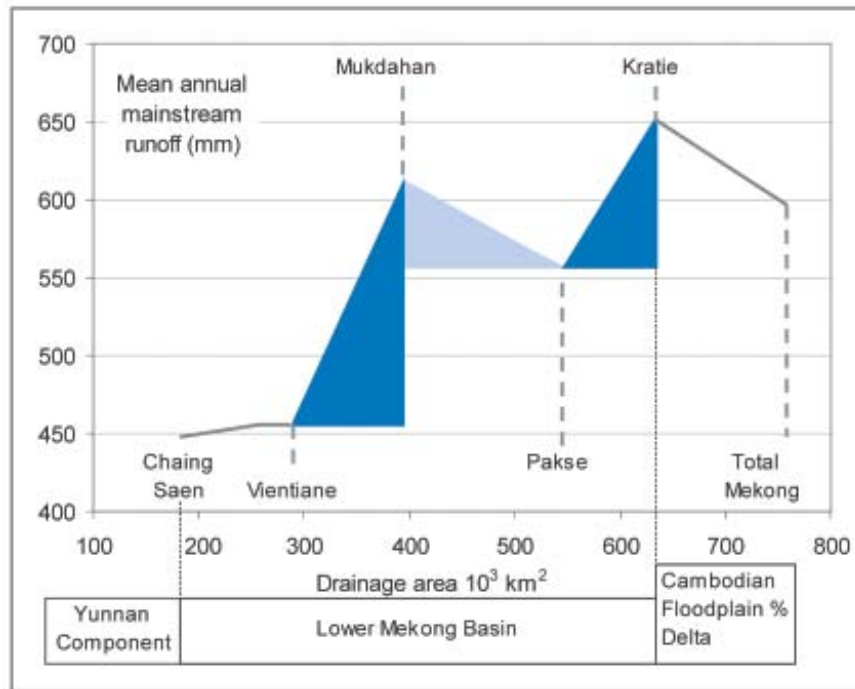


Figure 4.3 Accretion of mean annual depth of runoff (mm) at selected locations on the Lower Mekong mainstream indicating the rapid rise in basin runoff depth once the major left bank tributaries from Laos enter the mainstream and the temporary fall caused by the entry of the Mun-Chi system (average annual runoff 250 mm compared to the basin average of over 600 mm)

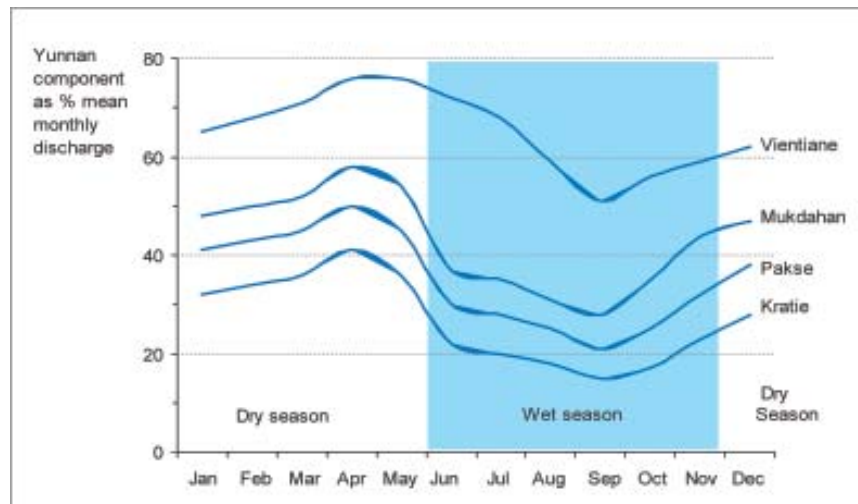


Figure 4.4 Mekong mainstream percentage contribution of the Yunnan Component to mean monthly flow at selected sites. The graph indicates how the Yunnan component dominates dry season hydrology of the Mekong as far downstream as Pakse.

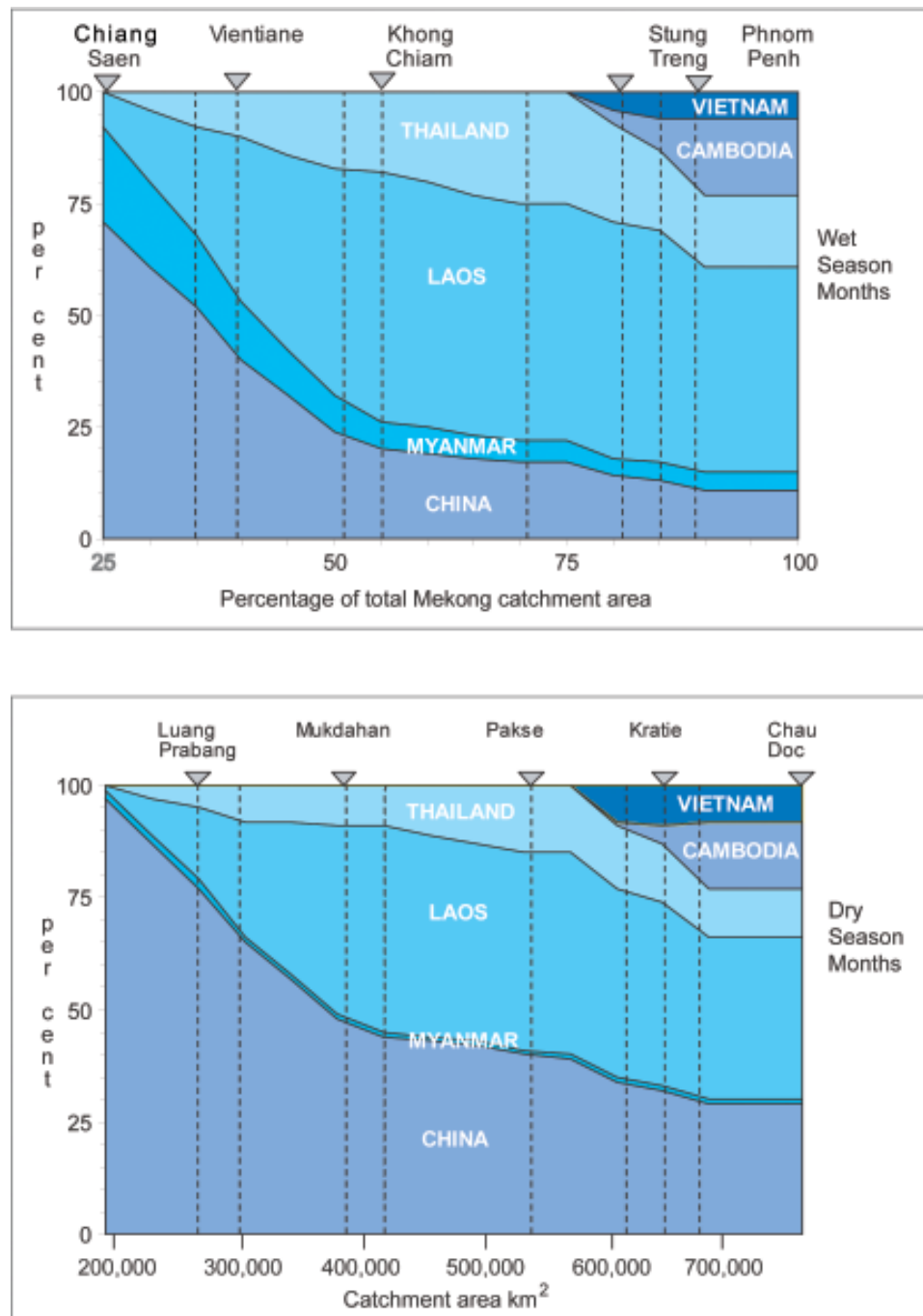


Figure 4.5 Percentage of average flow during the wet (June to November) and dry (December to May) season months originating in each country at selected sites on the mainstream

In a large river system like the Mekong, seasonal flows can be quite variable from year to year. Although the pattern of the annual hydrograph is fairly predictable, its magnitude is not. The average monthly flows along the mainstream are listed in Table 4.3. An indication of their range and variability from year to year is presented in Figure 4.6. At Pakse, for example, flood season flows during August would exceed 20,000 cubic metres per second (cumecs) 9 years out of 10, but exceed 34,000 cumecs only 1 year in ten.

Table 4.3 Mekong Mainstream mean monthly discharge 1960 to 2004 (cumecs)

Month	Mainstream Site						
	Chiang Saen	Luang Prabang	Vientiane	Nakhon Phanom	Mukdahan	Pakse	Kratie
Jan	1,150	1,690	1,760	2,380	2,370	2,800	3,620
Feb	930	1,280	1,370	1,860	1,880	2,170	2,730
Mar	830	1,060	1,170	1,560	1,600	1,840	2,290
Apr	910	1,110	1,190	1,530	1,560	1,800	2,220
May	1,300	1,570	1,720	2,410	2,430	2,920	3,640
Jun	2,460	3,110	3,410	6,610	7,090	8,810	11,200
Jul	4,720	6,400	6,920	12,800	13,600	16,600	22,200
Aug	6,480	9,920	11,000	19,100	20,600	26,200	35,500
Sep	5,510	8,990	10,800	18,500	19,800	26,300	36,700
Oct	3,840	5,750	6,800	10,200	10,900	15,400	22,000
Nov	2,510	3,790	4,230	5,410	5,710	7,780	10,900
Dec	1,590	2,400	2,560	3,340	3,410	4,190	5,710

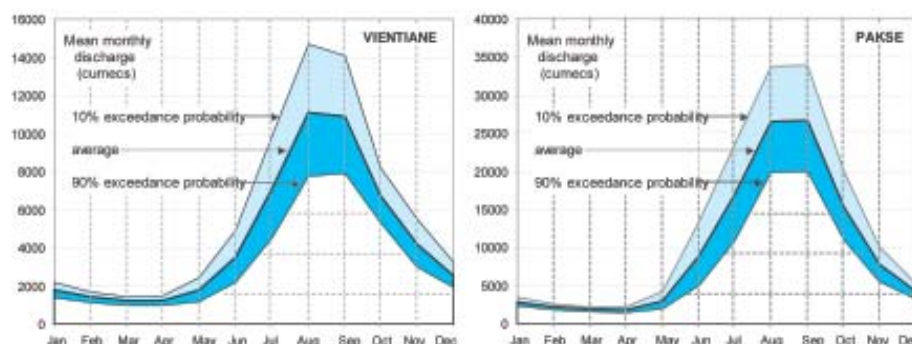


Figure 4.6 Monthly flows at Vientiane and Pakse indicating the pattern and range of the seasonal regime of the Lower Mekong from year to year

There is little evidence from the last 45 years of data of any systematic changes in the hydrological regime of the Mekong. Figure 4.7 shows two timeseries plots taken at Vientiane and Kratie showing the percentage deviations in the annual discharge above and below long-term averages for these two points. The data show that:

- There is no evidence of any upward or downward shift in the average magnitude of the flow in the years from 1960 to 2004.
- Although the overall time patterns of the flows at the two sites are consistent, as indicated by the 3 year running average, the magnitude of the deviations differs, often significantly. For example, the 1966 flood in Vientiane, which remains the highest observed since records began in 1913, becomes a minor feature of the timeseries in the downstream reaches represented by the Kratie data. Here the high flood years of 1961, 1978 and 2000 stand out.
- Although the distinction is not quite as strong for the below average years, there are still some major differences. The drought of 1977 at Kratie, when flows were 25 per cent below normal, corresponds to a more or less average year at Vientiane. In 2004, flows at Vientiane were above average at a time when the annual flows were very low at Kratie.

There has been a lot of debate about the dry season hydrology of the mainstream and there is a widespread belief that there has been significant change due to upstream reservoir storage in China. Figure 4.8 shows the minimum daily discharge averaged over a sequence of 90-days in each year from 1960 to 2004 for Vientiane and Kratie. Such a “long duration” statistic can be regarded as an effective measure of dry season flow conditions from year to year. The data show that:

- There is no evidence of any systematic change in the low-flow hydrology, either in terms of a long-term increase or decrease in dry season discharge.
- The plot includes a range of ± 2 standard deviations either side of the long-term average 90-day annual low flow. Years when the flows lie outside of this range may be considered exceptional, the most recent of these being 1999 (or the dry season following the poor flood season of 1998).
- Current claims that the low-flow hydrology of 2004 was exceptional and far below “normal” appear unfounded and are probably linked to the fact that the previous years from 2000 onwards had above average flows during the dry season.

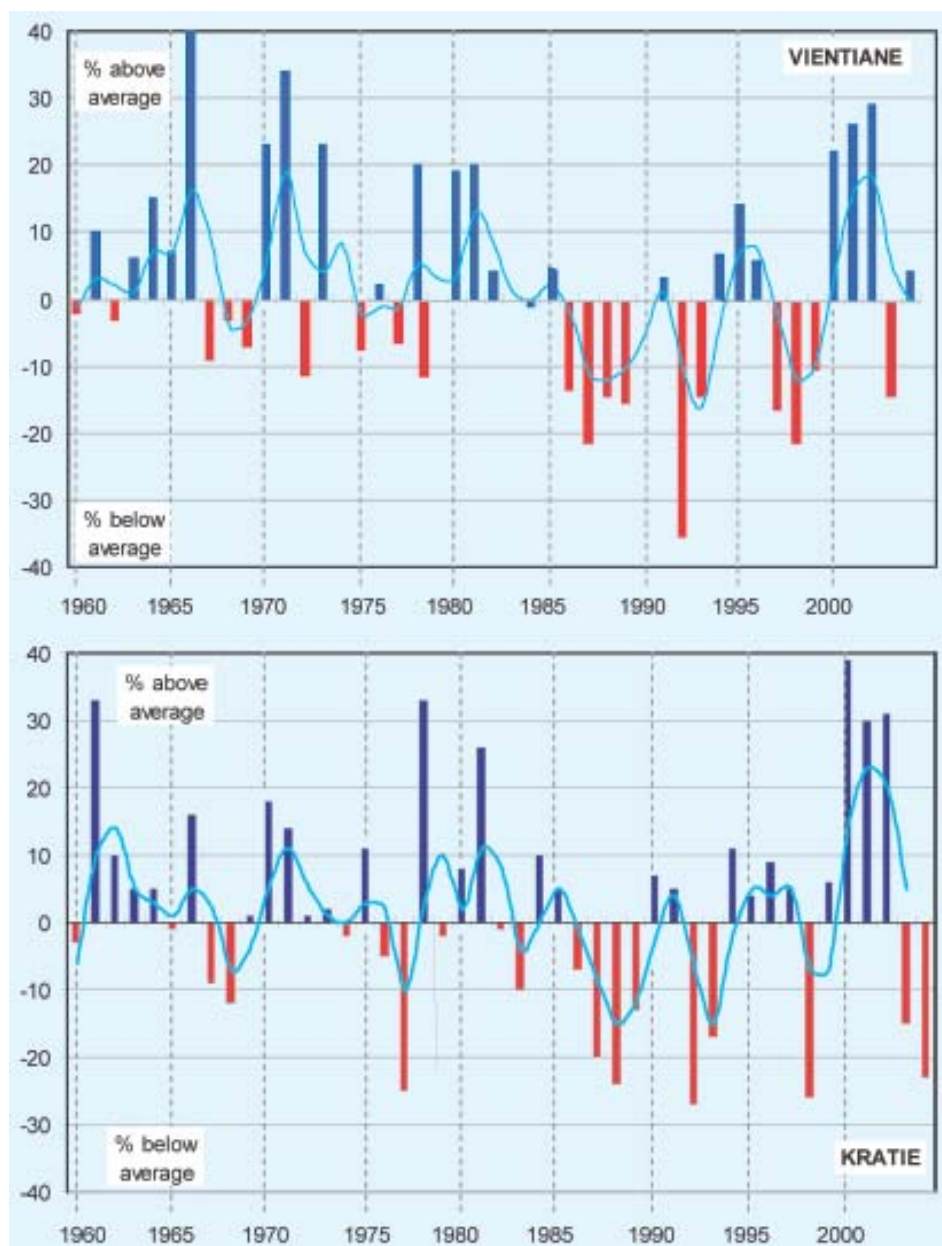


Figure 4.7 Mekong mainstream at Vientiane and Kratie: Percentage deviations above and below long-term average annual discharge between 1960 and 2004 (line plot indicates the 3-year running average of the deviations)

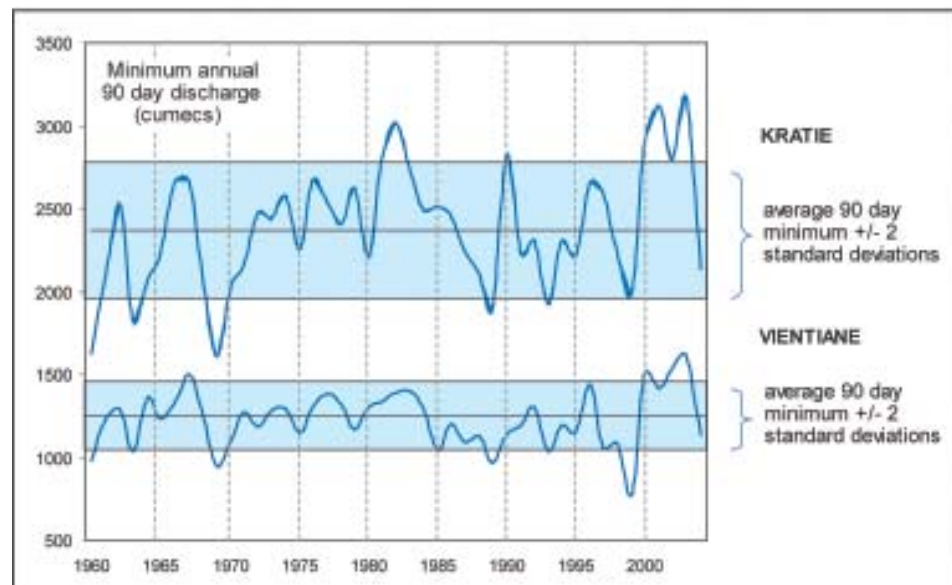


Figure 4.8 Mekong mainstream annual minimum 90-day mean discharges observed at Vientiane and Kratie between 1960 and 2004. The shaded bands indicate a range of ± 2 standard deviations either side of the average 90-day low flow. Years when the minima fell outside this range would be considered exceptionally above or below normal dry season conditions.

Chapter 5

Floods and Droughts



5 Floods and Droughts

5.1 Flood Hydrology

Floods are most often measured in terms of maximum or peak discharge. On large rivers such as the Mekong, this is not a good enough measure since there are other aspects of a flood that are often as important or more important. For example, the duration of the flow above a critically high threshold can cause long periods of inundation and cause the collapse of protection dykes. Rice paddies can be submerged in water for 8 to 10 days but longer than that and the crop begins to die. Flood volume is also an important indicator of the extent and length of time that natural wetlands are flooded and the degree to which a flood event can be modified by natural over-bank storage.

All these aspects need to be brought together for a complete description and analysis of flood incidence and severity on a river such as the Mekong, where the seasonal distribution of flow is dominated by a single annual flood hydrograph which lasts for several months. However, if a single measure of the annual flood magnitude is required, then probably the most useful statistic is the total volume of flow during the six flood season months between June and November.

A statistical analysis of the annual flood volumes allows us to see the historical incidence of exceptional flood seasons along the Lower Mekong mainstream. First, at each of the 10 flow gauging sites between Chiang Saen and Kratie, the annual flood season volumes were collected for the years from 1960 to 2004. The 'flood volume' for each year is determined from the daily discharge data from 1 June to 30 November. Second, the average recurrence interval of flow volumes was determined at each site. Table 5.1 shows results for Vientiane and Kratie. At Vientiane, the two-year average recurrence interval flood volume is 120 km³, which means a flood having a volume of this size or larger will occur on average once every two years.

Finally, each annual volume at each mainstream site was then classified according to the criteria indicated in Figure 5.1, with the range from below normal (less than the 1:2 year volume) to severe (above the 1:20 year flood volume).

Table 5.1 Annual flood season (June to November) volumes of flow estimated for Vientiane and Kratie for selected annual recurrence intervals (km³)

Mainstream Site	Annual Recurrence Interval				
	2 years	5 years	10 years	20 years	50 years
Vientiane	120	135	145	150	160
Kratie	380	430	455	475	500

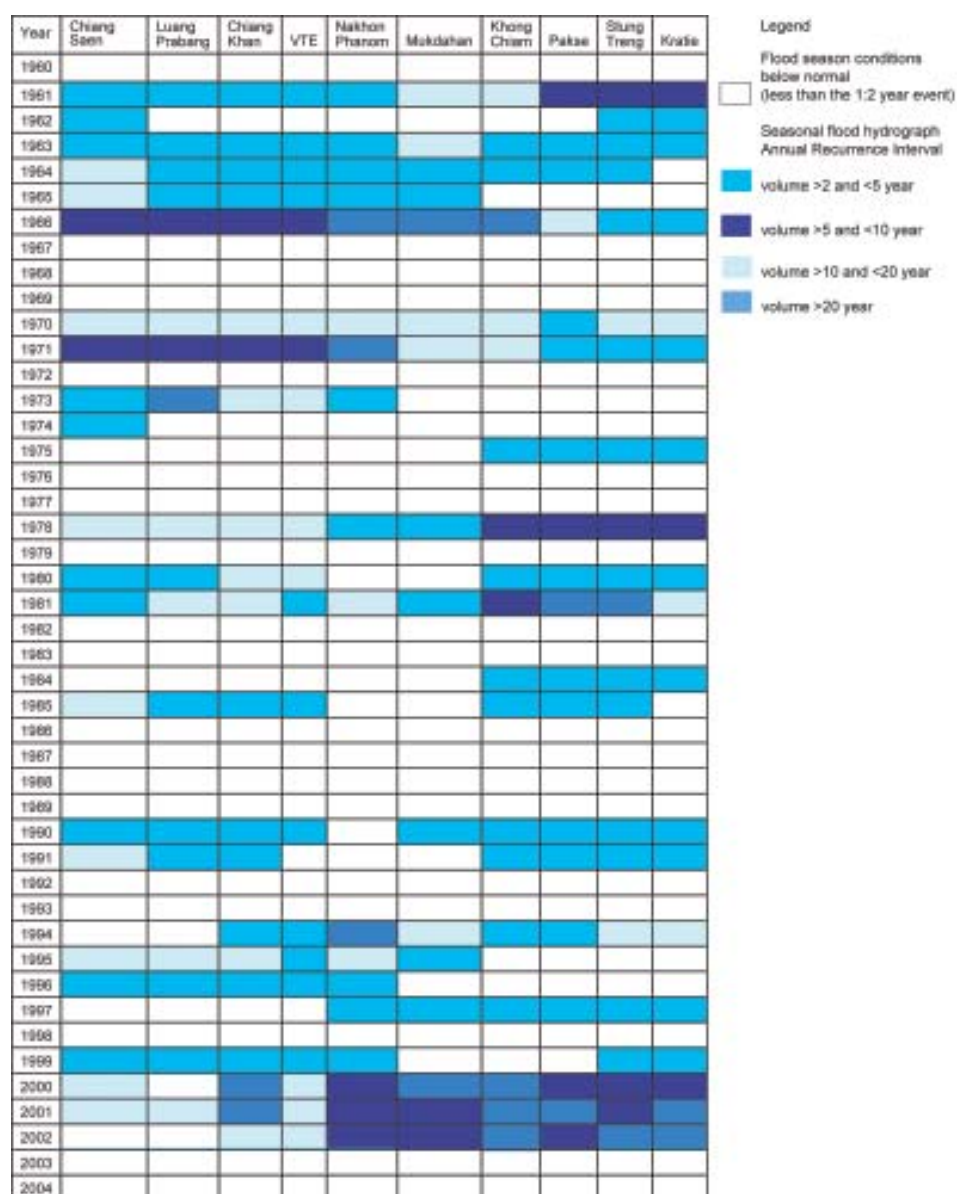


Figure 5.1 The flood history of the Lower Mekong Basin from 1960 to 2004 based on a statistical analysis of the annual volumes of flow during the six flood months (June to November).

The main features of this Mekong flood history are:

- A geographical split in the flood regime of the lower mainstream at Vientiane-Nongkhai. Downstream from Nongkhai, the flood hydrology is dominated by wet season runoff from the large left bank tributaries in Lao PDR. Upstream, the Yunnan Component dominates (refer to Figure 4.5).
- This upstream-downstream flood pattern is further characterised by floods in 1961, 1978 and 1981 that affected only the reaches downstream of Kong Chiam and Pakse, further evidence of extreme flows originating in the lower Lao tributaries, the Mun-Chi in Thailand and the Se Kong-Se San-Sre Pok system.
- The dominant feature of the mainstream flood history after 1960 is the extreme three-year sequence of events from 2000 onwards in the downstream zones of the Basin. Otherwise, during the 18-year period from 1982 to 1999, there were no years at all with exceptional floods.

Some features of the 1966 flood and the conditions observed at the time in Vientiane are presented in Figures 5.2 and 5.3. The peak discharge was about 25,000 cumecs in late July, which is about twice the normal level for this time of the year. Table 5.2 indicates a recurrence interval for such an annual maximum flow of about 1:100 years.

Table 5.2 Mekong at Vientiane. Estimated annual recurrence intervals of annual maximum discharge in cumecs (Generalised Extreme Value Model using the 1960 to 2003 data)

Annual Recurrence Interval						
2 years	5 years	10 years	20 years	50 years	100 years	200 years
16,000	18,500	20,000	22,000	24,000	25,500	27,000

Daily discharge data are available for Vientiane from 1913 and this much longer timeseries was used to extend the statistical modelling of flood risk to a multivariate extreme value analysis of peak, volume and duration. This involves the use of more complex statistical models, but the results are interesting. Figure 5.3 shows the joint distribution of peak flood discharge and seasonal (June to November) hydrograph volume with their recurrence intervals shown as a series of elliptical functions. A key feature of the plot is that the relationship between peak and volume shows a wide scatter, such that one is not usefully predictable from the other.

The principal features of the plot are:

- The 1966 event is, in terms of peak and volume, slightly in excess of a 100-year flood hydrograph. Flood conditions at Vientiane during 1924 and 1938 had a similar probability of occurrence, but with different combinations of hydrograph peak and volume.
- The conditions in 1957 were also exceptional but for entirely different reasons. In this case the peak discharge was extremely low at around 11,000 cumecs, the average being 16,000. This was combined with the lowest hydrograph volume ever observed. 1954 would therefore classify as a year of extreme drought.

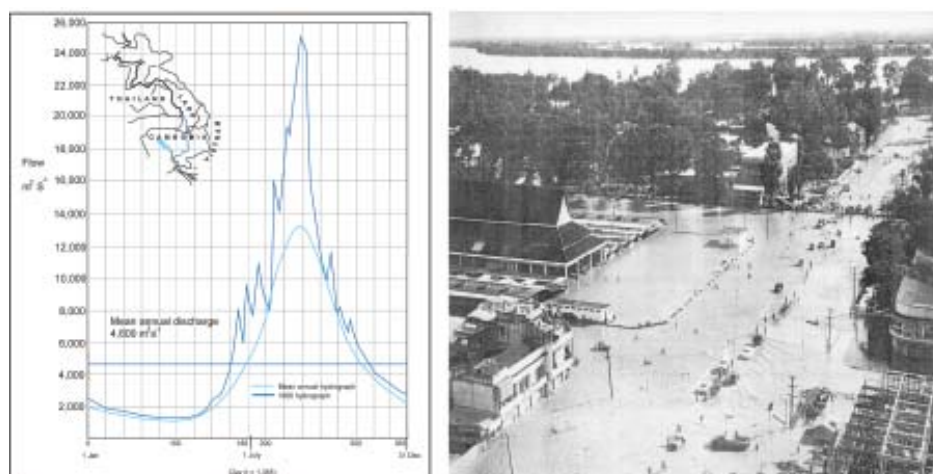


Figure 5.2 The September 1966 flood in Vientiane when peak discharge reached 26,000 cumecs and the city centre was flooded for several weeks

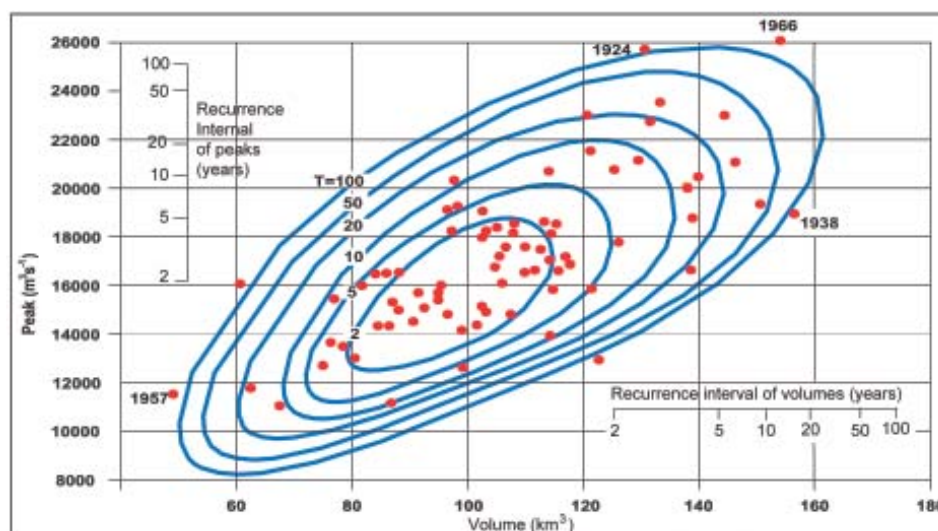


Figure 5.3 The joint statistical distribution of the peak and volume of the annual flood hydrograph on the Mekong River at Vientiane, Lao PDR (Source: Adamson et al., 1999)

The flood conditions in the downstream reaches of the Lower Mekong that occurred during 2000 were of an entirely different character. In this case, the peak discharge was average. The extreme nature of the 2000 flood was entirely the result of the unprecedented flood volume and the fact that the seasonal flood hydrograph began a month to six weeks early, causing natural wetlands to fill up long before they usually do. Floodwaters arriving later had nowhere to go except into areas that usually do not flood. The early rise of the flood hydrograph and the later arrival of large volumes of floodwater during September can be clearly seen in Figure 5.4.

The observed peak discharge and the volume of water that accumulated between 1 June and 30 November 2000 are compared with their estimated distributions in terms of annual recurrence intervals in Table 5.3.

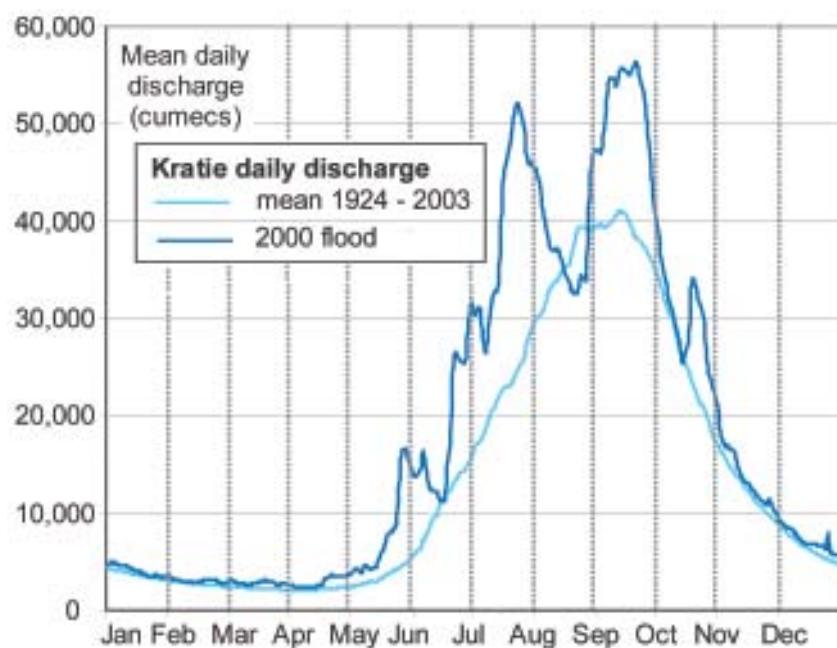


Figure 5.4 The 2000 flood hydrograph recorded at Kratie compared to mean daily discharges for the period 1924 to 2003

The peak discharge of 56,000 cumecs is not significantly above a typical annual maximum or the 1:2 year figure. Historically, such a figure has been exceeded at least twice in each decade since 1927. What made the 2000 conditions the most severe in over 70 years was the volume of flow – almost 500 km³. This is consistent with a recurrence interval for this component of the flood hydrograph of 1:50 years.

Table 5.3 Kratie peak discharge (cumecs) and seasonal flood hydrograph volume (km³ accumulated between 1 June and 30 November) observed in 2000 and compared to estimated risk of occurrence

Statistic	Observed	Recurrence Interval (years)						
	2000	2	5	10	20	50	100	200
Peak flow	56,000 cumecs	51,000	59,500	63,000	66,500	70,000	72,500	75,000
Flood volume	500 (km ³)	380	430	455	475	500	510	520

These events were caused by unusually early and heavy rainfall in Northwest Lao PDR and Southwest China in July, which added to rain from tropical storms from the South China Sea affecting southern Lao PDR and Cambodia. This led to a major discharge of the Mekong across the Lao PDR-Cambodia border and the filling of the Tonle Sap in Cambodia six weeks earlier than usual. Then, heavy rainfall in Southern Lao PDR in August and September resulted in high Mekong discharge downstream and severe flooding around Phnom Penh at a time when the Tonle Sap was already full. This explains the second rise in the flood hydrograph. More tropical storms from the South China Sea resulted in high August-September-October rainfall in Viet Nam. The areas flooded were usually safe and hundreds of people lost their lives in this flood.

The impact of these 2000 flood conditions on the flow reversal in the Tonle Sap and the filling of the Great Lake was simulated using the computer models described in Chapter 7. An analysis of the outputs is shown in Figure 5.5. The timing and volumes of flow that entered the Great Lake via the reversal of the Tonle Sap are historically unique.

This overview of the flood hydrology of the Mekong shows the complexity of the flood regime of large river systems and the need for assessments of flood risk and severity that go beyond routine statistical descriptions.

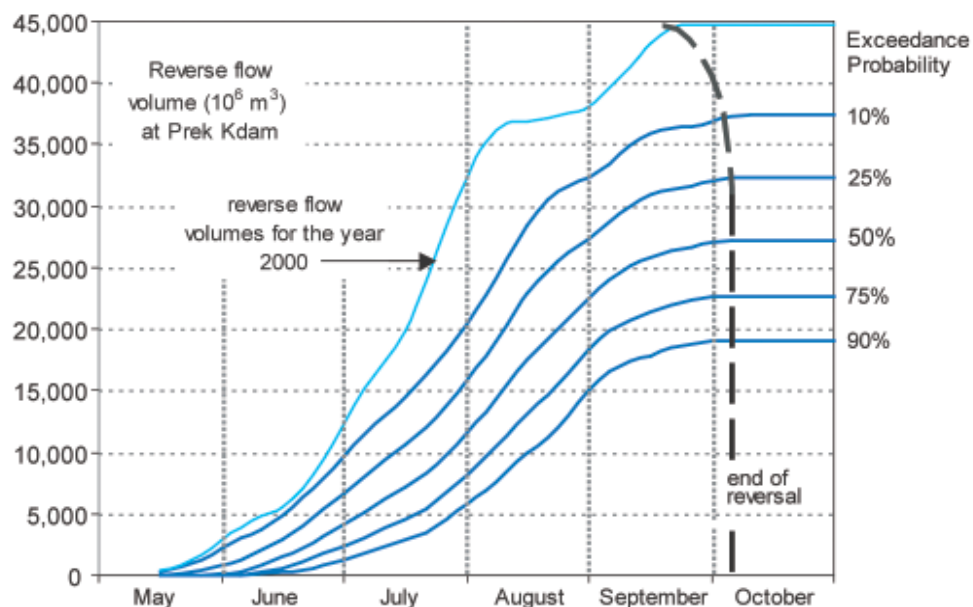


Figure 5.5 Probability distribution of cumulative reverse flow volumes at Prek Kdam from May to October. For example, by the end of the season there is only a 10% probability of an accumulated reversal volume in excess of 37,000 x 10⁶ m³. This underscores the severity of the conditions by the end of the 2000 season, when almost 45,000 x 10⁶ m³ had entered the Great Lake. The graph was prepared using simulated data obtained from DSF outputs.

5.2 Drought Hydrology

Compared to floods, droughts are more complex geophysical and climatological phenomena. Droughts are much more difficult to define since shortages in water affect different processes and activities in different ways. A hydrological drought as an extremely low river flow condition is different from an agricultural drought, which is different from a meteorological drought. The impacts of rainfall shortfalls on hydrology, agriculture and economic activity can depend on the climate, the time of year, crop water demands, soil type, resistance of vegetation to moisture stress, and the infrastructure available for water storage.

A defining feature of a drought is “the accumulation of a water and moisture deficit”. This may be measured in terms of rainfall, stream flow or soil moisture. The severity of an event is a function of the critical levels that the deficit reaches and the timing of the critical levels of moisture shortfall. If these critical levels

coincide with the grain-filling stage of crop development, then the severity of the event from an agricultural point of view is maximised.

In the Mekong Basin, hydrological drought can be assessed in terms of the flows in the mainstream and the degree to which they fall below some measure of what is normal or expected in any year. These flows are determined by rainfall surplus and deficit, the strength of the annual Southwest Monsoon and the response of the landscape to the recent rainfall climate. In a large river like the Mekong, drought flows can be considered in two ways:

- Below average cumulative hydrological conditions over the year as a whole, which would focus on whether or not the flood season flows between June and November were deficient.
- The minimum flow during the year over some duration of interest (weeks or months). This would emphasise the dry season hydrology as the basis for classifying drought incidence and severity from year to year.

The link between wet and dry season hydrology in the Mekong is complex. The dry season hydrology is a key indicator of drought conditions because in the dry season the competition for water resources becomes critical if there is any shortage. Water is needed for irrigation and other domestic and industrial uses and for minimum acceptable environmental flows, for navigation of ships and adequate water delivery to the delta to minimise the risk of salt water intrusion. Figure 5.6 presents a history of dry season flow conditions on the mainstream from Chiang Saen to Kratie between the years 1960 and 2004.

Figure 5.6 was prepared by measuring, for each year at each site, the minimum 90-day mean discharge. At most locations and during most years this occurred between early February and mid-May. These annual 90-day minimum measures were then statistically analysed to estimate the 1:2 to 1:20 year minimum 90-day discharge. Finally, the figures for each year were classified according to the scheme described in Figure 5.6 and plotted accordingly. In this way, a “time and space pattern” of low flow conditions along the Mekong over a 45 year period can be seen. The plot shows:

- A geographical split in the low-flow regime of the lower mainstream at Vientiane-Nongkhai similar to the one described for the flood hydrology. The magnitude of the low flows are dominated by runoff from the large left bank tributaries. Upstream, the Yunnan Component dominates the dry season hydrology.
- In the downstream reach, 1960 and 1969 appear to have seen critical low flow conditions during the dry season months. Conditions were also well below normal during 1969 upstream of Vientiane, although 1999 deficits were even more severe.

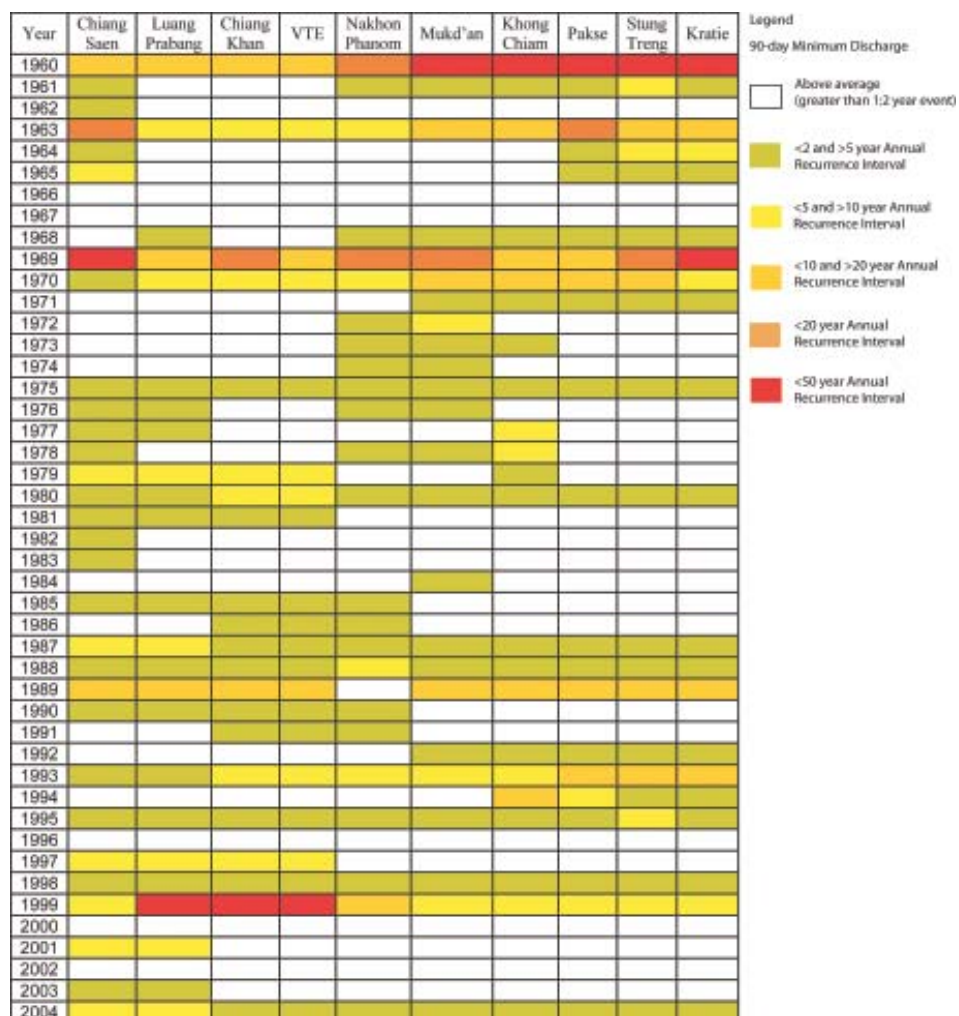


Figure 5.6 The low-flow history of the Lower Mekong Basin 1960 to 2004 based on a statistical analysis of the minimum 90-day mean discharge in each year.

Only during the early and late 1960s and during 1999 have the dry season flows been critically low along the full length of the lower mainstream from Chiang Saen downwards. At other times, the severity of drought conditions has varied from reach to reach in response to the volume of water flowing into the mainstream from tributary systems.

Drought years defined in terms of total annual flow tend to mask this pattern in the dry season. Figures 5.7 and 5.8 confirm that the magnitude of an annual drought on the Mekong amounts almost entirely to a shortfall in the volumes of flow associated with the seasonal flood hydrograph. These results indicate that a 1:50 year annual drought on the Lower Mainstream amounts to a ± 30 per cent shortfall in mean annual flow, compared to a 1:10 year event, which represents a 20 per cent deficit.

This order of shortfall in annual flow volumes at Kratie has a significant impact on the Tonle Sap flow reversal and therefore on the maximum levels in the Great Lake in Cambodia. Figure 5.9 shows the annual maximum lake levels observed at

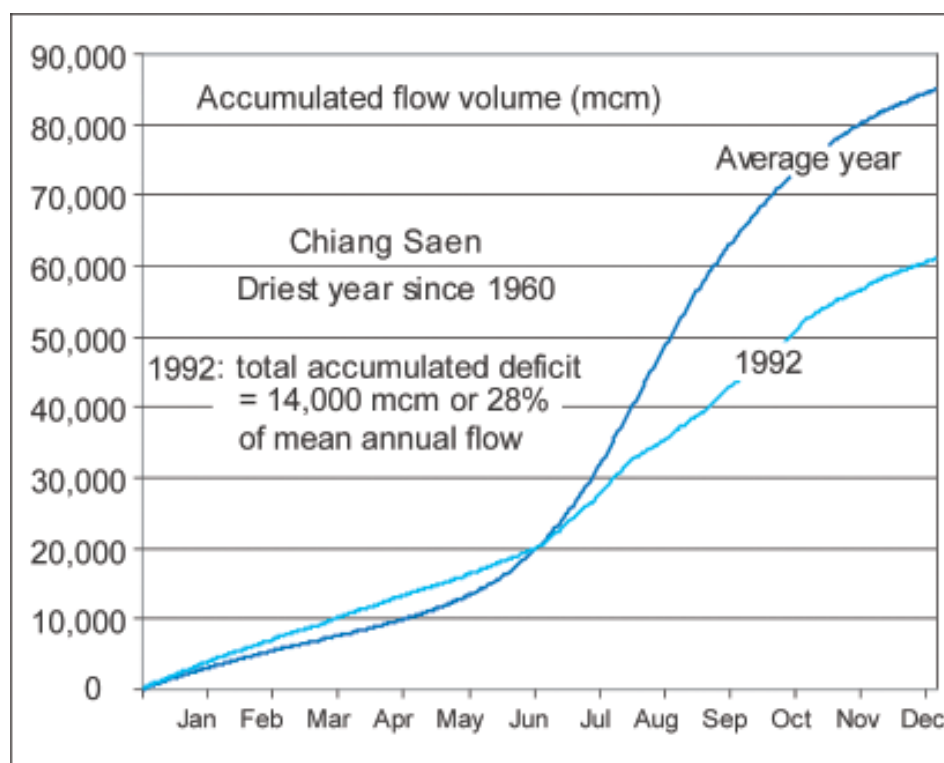


Figure 5.7 Chiang Saen average annual accumulation of total flow volume compared to 1992, the driest year observed since 1960

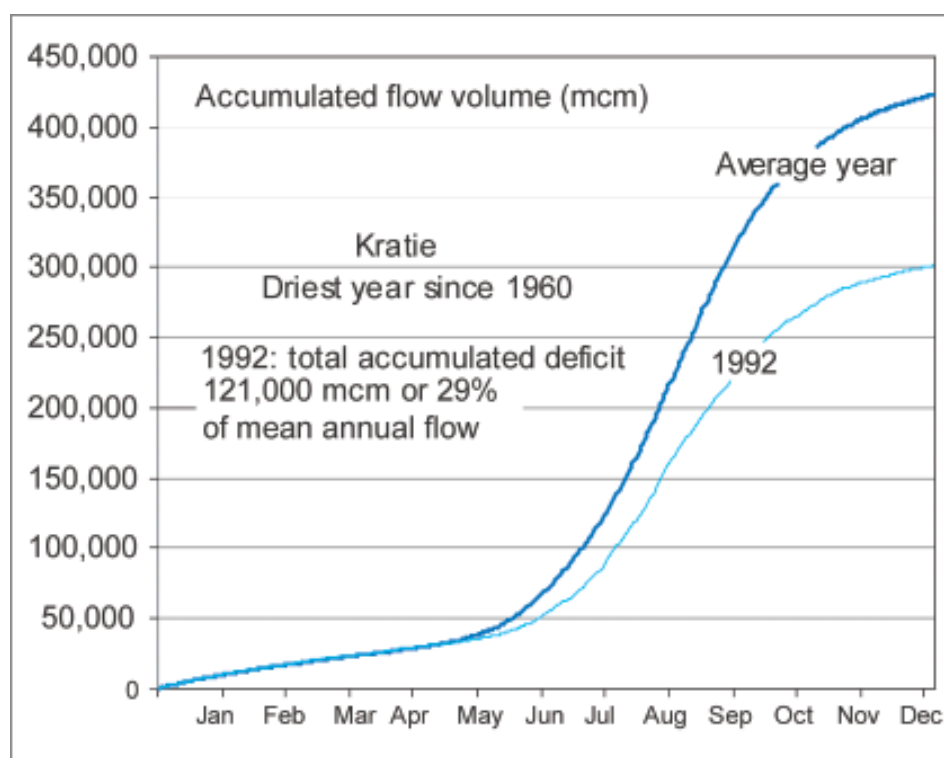


Figure 5.8 Kratie average annual accumulation of total flow volume compared to 1992, the driest year observed since 1960

Kampong Chhnang and Prek Kdam for the years between 1960 and 2003. The impact of the three most severe mainstream drought years based on the observations at Kratie are clear (Table 5.4). The maximum levels at Prek Kdam during 1988, 1992 and 1998 were as much as 2.4 m less than the long-term mean maximum of 9.1 masl. Changes in lake levels so far below normal have a critical impact on the fish breeding cycle and the annual fish catch, both within the Great Lake system and on the wider Cambodian floodplain.

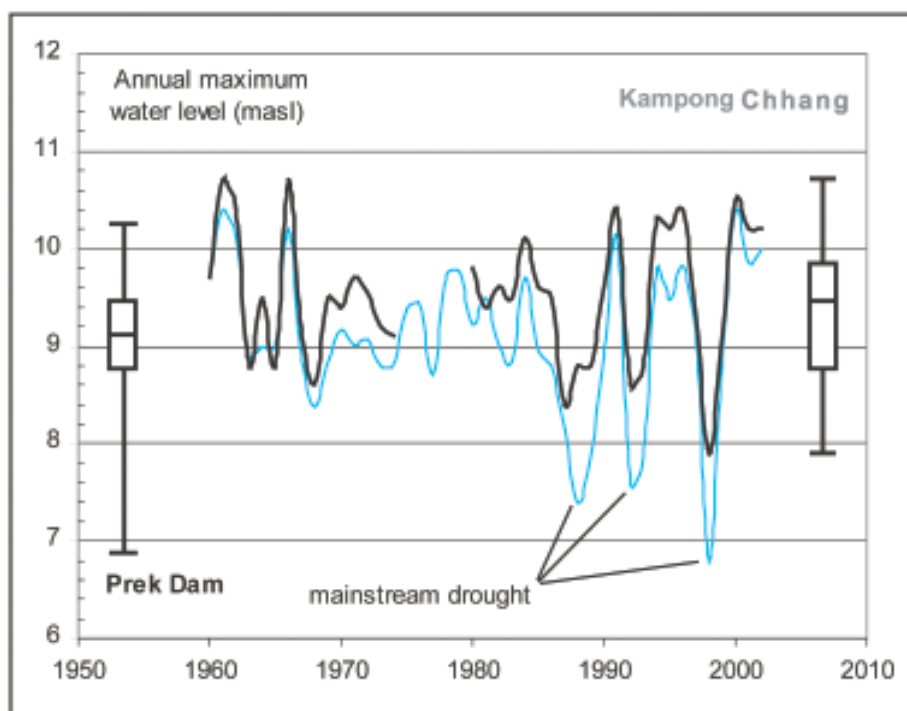


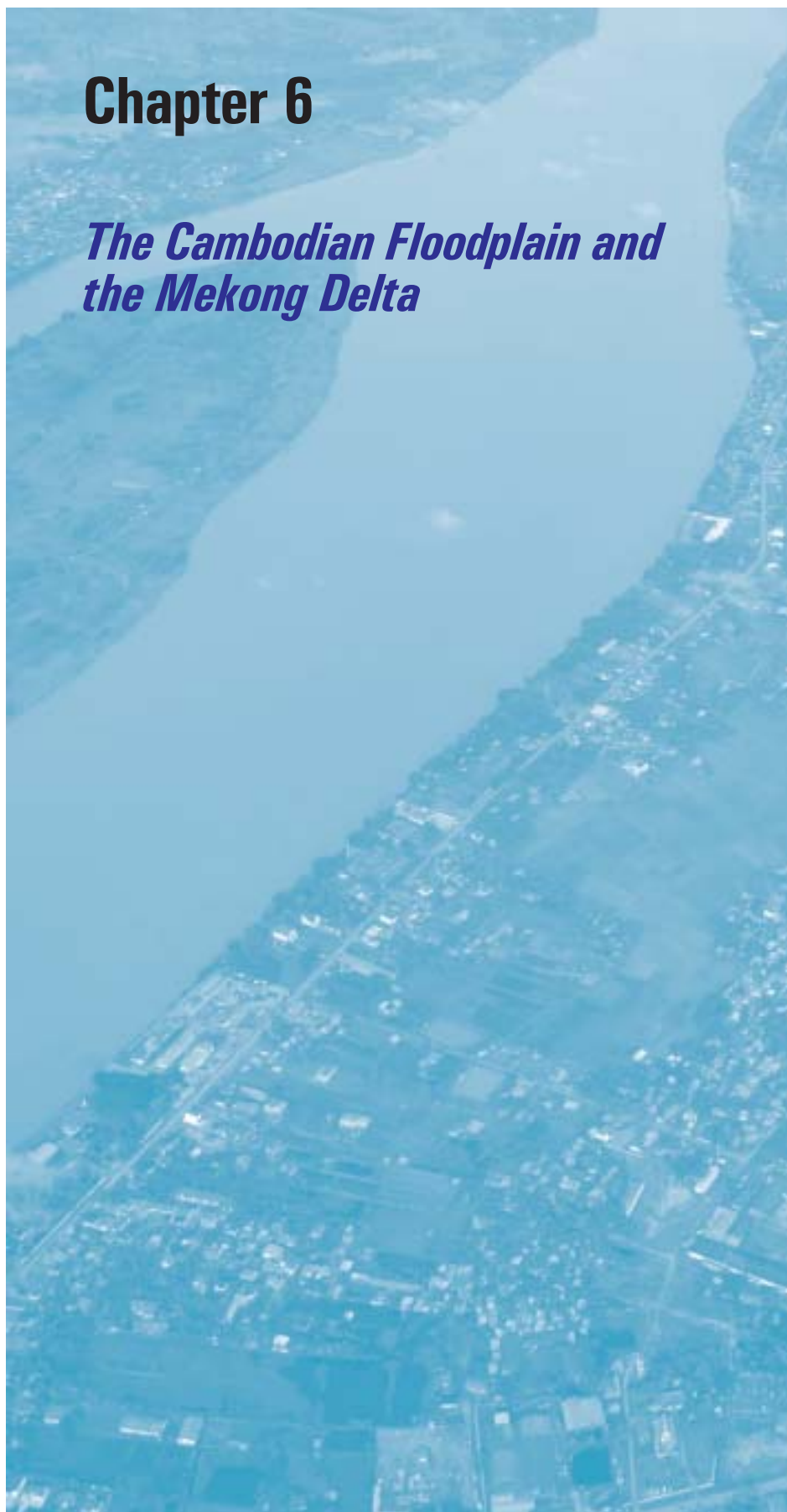
Figure 5.9 Annual maximum levels (masl) observed for the Great Lake in Cambodia observed at Prek Kdam (on the Tonle Sap) and at Khamppang Chhnang (on the Lake itself) indicating the significant impact of drought conditions on the mainstream in 1998, for example.

Table 5.4 Lowest observed annual flows since 1960 observed at Chiang Saen and Kratie and their estimated risk of occurrence

Site	Year	Annual Flow km ³	% of average	Recurrence Interval
Chiang Saen	1992	61.0	72 %	+/- 50 years
	2003	63.5	75 %	+/- 30 years
	1972	67.0	79 %	+/- 15 years
Kratie	1992	301.5	72 %	>> 50 years
	1998	306.0	74 %	+/- 50 years
	1988	313.5	75 %	+/- 30 years

Chapter 6

The Cambodian Floodplain and the Mekong Delta



6 The Cambodian Floodplain and the Mekong Delta

6.1 *Background*

Kratie is generally regarded as the point in the Mekong system where the hydrology and hydrodynamics of the river change significantly. Upstream from this point, the river generally flows within a clearly identifiable mainstream channel. In all but the most extreme flood years, this channel contains the full discharge with only local over-bank natural storage. Downstream from Kratie, seasonal floodplain storage dominates the annual regime and there is significant movement of water between channels over flooded areas, the seasonal refilling of the Great Lake and the flow reversal in the Tonle Sap. There is extreme hydrodynamic complexity in both time and space and it becomes impossible to measure channel discharge. Water levels, not flow rates and volumes, determine the movement of water across the landscape.

The extent of this annual floodplain inundation in this part of the Basin is shown in Figure 6.1. The figure indicates that even in a year when mainstream flows were among the lowest recorded in recent times (1998), the flooded area is vast, amounting to almost 26,000 km². This figure rose to 45,000 km² during 2000 when some of the worst flood conditions recorded caused over 800 deaths in Cambodia and Viet Nam. Nonetheless, the floods are essential to the environmental, social and economic fabric of this region, which supports in excess of 25 million people.

6.2 *The Cambodian Floodplain and the Tonle Sap*

The Tonle Sap River and Great Lake System represent one of the world's most productive ecosystems. This river-lake system supports the world's largest freshwater fishery and directly or indirectly provides a livelihood for most of the population of Cambodia. This high biological productivity depends on the transfer of floodwater from the Mekong during the wet season, when increased water levels in the mainstream at the confluence with the Tonle Sap River cause the water in the river to flow upstream and back into the Great Lake:

- The area of the lake increases from a dry season average of 2,500 km² to a typical flood season area of 15,000 km².
- Typically mean depth increases from 1 m to 6 - 9 m.
- During the wet season the lake volume rises to between 60 and 70 km³ from a dry season figure of less than 1.5 km³.

The lake functions as a natural storage reservoir for Mekong floodwater. When the water in the lake is slowly released from October onwards, it becomes a crucial source of water supply to the delta during the dry season.

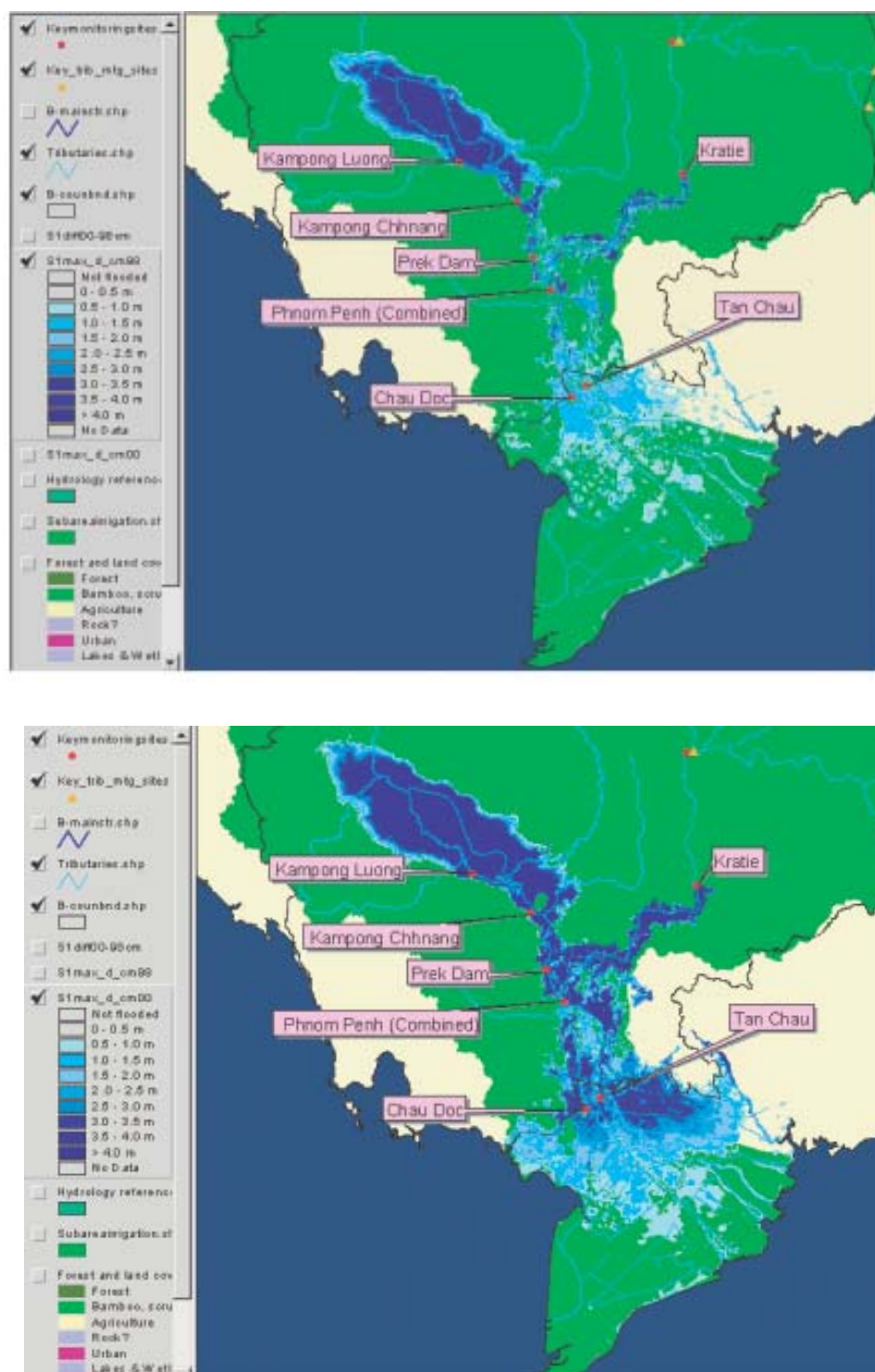


Figure 6.1 Flood inundation: Extent of depths in excess of 0.5 m and maximum depth compared for 1998, a dry year (top) and 2000, a flood year (bottom)

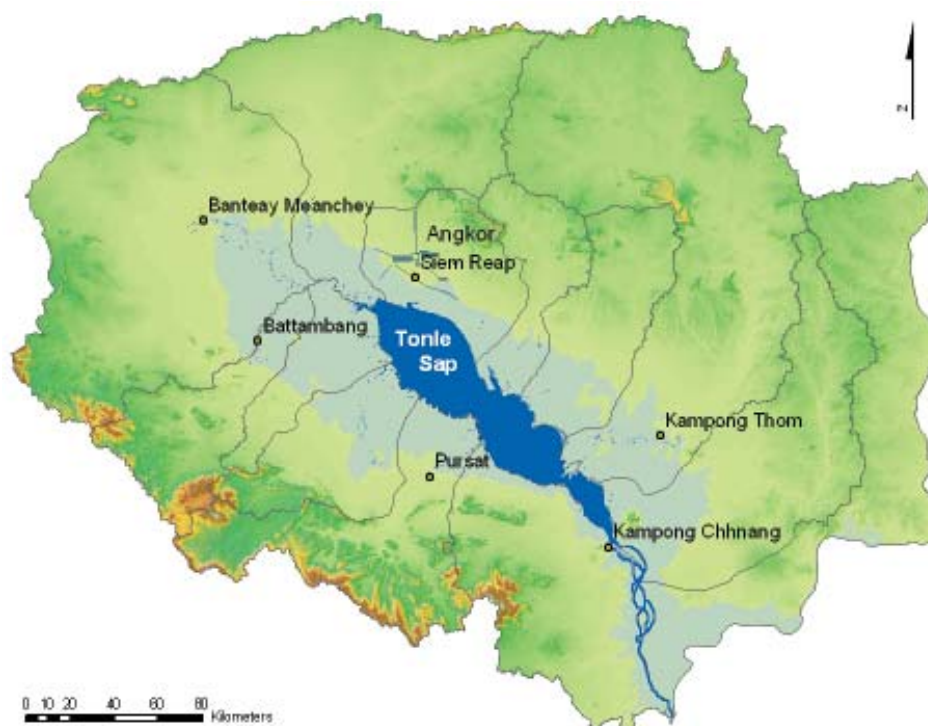


Figure 6.2 Catchment area of the Tonle Sap- Great Lake system showing the dry season extent of the Lake and the area of inundation during a typical flood season

The mean annual reverse flow volume in the Tonle Sap is 30 km^3 , or about half of the maximum lake volume. A further 10 per cent is estimated to enter the system by overland flow from the Mekong. The lake's own natural catchment drains most of western and northwestern Cambodia, in all amounting to about 25 per cent of the total area of the country. Typically, this drainage would supply between 40 and 50 per cent of the flood volume of the lake. Therefore, interventions upstream of the lake could have impacts on the system and its ecological productivity equal to any in the wider Mekong system. In all, the Tonle Sap System covers an area of $85,000 \text{ km}^2$ and contributes about 6 per cent of the mean annual flow of the Mekong Basin.

The unique flow reversal is possible because of the low, flat landscape throughout Central Cambodia. The seasonal timing and discharge rates associated with the movement of water into and out of the Tonle Sap system are indicated in Figure 6.3. Inflow generally starts in late May, with maximum rates of flow of around 10,000 cumecs by late August. This is over 25 per cent of the average mainstream discharge at that time of the year. Outflow normally starts in late September and reaches the same discharge volumes in the opposite direction in a matter of only a few weeks.

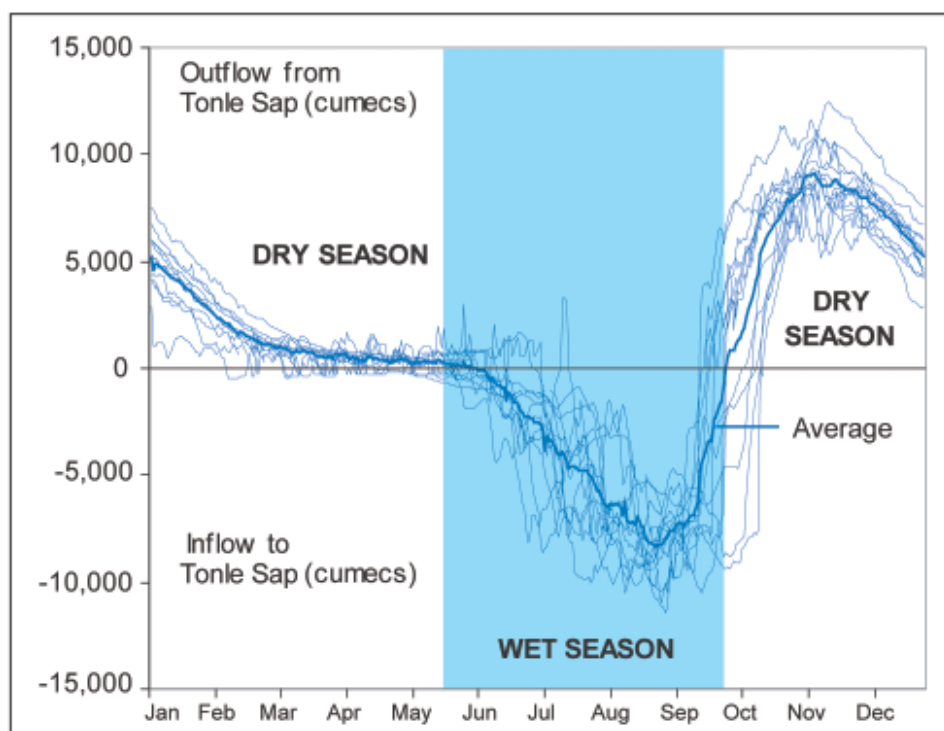


Figure 6.3 Annual inflow and outflow hydrographs to and from the Tonle Sap based on data observed at Prek Dam between July 1960 and June 1973

Storing mainstream floodwater in this natural reservoir complex of lake and floodplains has important positive consequences downstream, particularly in the delta. The extended season of floodwater drainage from the lake and vast areas of inundated floodplain means that:

- Peak rates of flood discharge in the Mekong mainstream are modified, reducing the severity and extent of flooding in the delta.
- More water becomes available during the dry season months, increasing the volume and reliability of water that can be diverted for irrigation in Viet Nam.
- Increased dry season flows also mean that salt water from the South China Sea does not intrude as far upstream into the rivers and channels of the delta.

This natural reallocation of floodwater from the wet to the dry season is known as “hydrological regulation” and the extent to which it occurs in this part of the Mekong is shown in Figure 6.4:

- In an average year, August is the month of maximum flow at Phnom Penh, with a mean discharge of around 30,000 cumecs. Downstream of the Tonle Sap confluence, however, flows at this time are reduced by 5,000 cumecs so that the month of maximum mean discharge is delayed until September.
- Flows in the dry season between November and February are increased substantially, doubling from 5,000 to 10,000 cumecs in December alone.

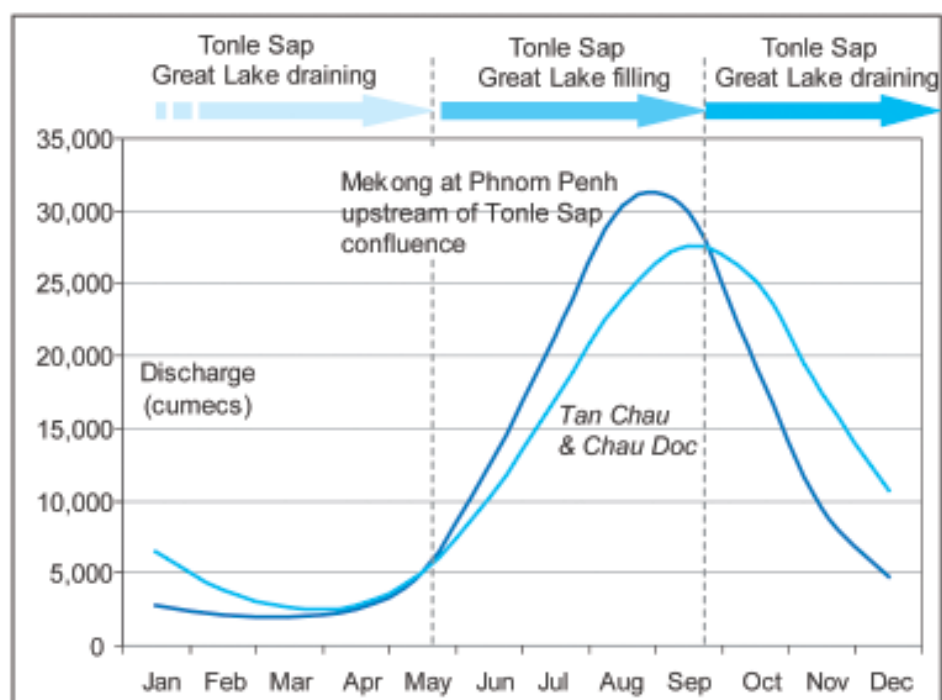


Figure 6.4 Comparison of mean monthly discharges based on simulated data upstream and downstream of the Mekong-Tonle Sap confluence

Immediately downstream of its confluence with the Tonle Sap at Phnom Penh, the Mekong splits up, at first into two channels, as it enters the delta before finally flowing into the South China Sea.

6.3 *The Mekong Delta*

The Mekong Delta begins at Phnom Penh, where the river divides into its two main distributaries, the Mekong and the Bassac. The Mekong then divides into six main channels and the Bassac into three to form the “Nine Dragons” of the outer delta in Viet Nam. The main delta is made up of a vast triangular plain of approximately 55,000 km². Most of this plain is lower than 5 metres above sea level.

The movement of water within this complex channel network (Figure 6.5) cannot be regarded as natural due to the long history of modification. Levees were built hundreds of years ago along some of the main natural channels. These were regularly over-topped and lower areas far from the main river system were permanently submerged as they retained water. These “ponded water” zones are biologically rich and play a key hydrological and environmental role in the system. The need to conserve the areas that remain is widely recognised. In addition to their role in maintaining ecological diversity, they have a key hydrological benefit by functioning as floodwater retention areas and as natural water purification systems.

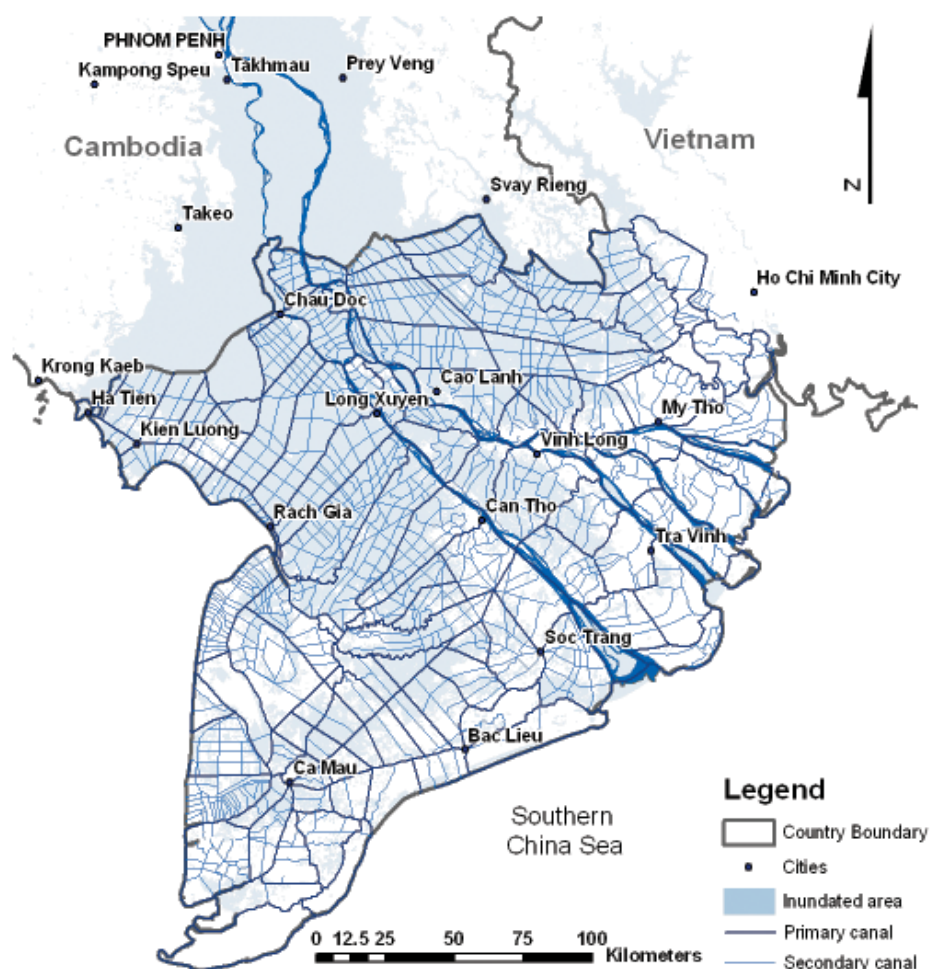


Figure 6.5 Map of the Mekong Delta in Vietnam indicating the density and extent of the excavated canal system (inundated area shows the flood of 2000)

The historical, social and agricultural development of the delta has been dominated by paddy rice cultivation. Access to the extensive wetlands was difficult until huge areas were drained between 1890 and 1925. The area under rice cultivation has continually expanded, particularly after 1975, such that by the 1990’s agricultural land covered 85 per cent of the land area and now supports 70 per cent of the population. Excavated canals are now the major irrigation and drainage systems and provide the principal transport routes..

Up to three crops of rice can be grown in a year, two irrigated and one rain-fed. Rainfed is the traditional cropping system practised in the tidal coastal regions where dry season salt water intrusion makes irrigation impossible. Now, with new faster-growing varieties of rice, it is possible to obtain two rain-fed crops in saline risk areas and in areas where irrigation water is not available.

The delta has become one of the world’s largest rice production regions as a result of this expansion of area drained and on the basis of the ability to harvest three crops annually (Table 6.1). Farmers can get yields of up to 5 tonnes per hectare (irrigated) compared to an average of 3.9 tonnes for the Asia Pacific region as a

System	Season	Planting	Harvesting	Note
Dong Xuan	Winter - Spring	Nov / Dec	Feb / Mar	Irrigated
He Thu	Summer - Autumn	May / Jun	Aug / Sep	Irrigated / Rainfed
Mua	Wet Season	Jul / Aug	Dec / Jan	Single Rainfed

Table 6.1 Rice cultivation seasons in the Mekong Delta

whole. Hydrology plays its part by delivering mineral and nutrient rich alluvial sediments during the flood season that help to sustain this exceptional agricultural productivity.

This intensely cultivated and densely settled low-lying landscape is vulnerable to floods and droughts and from changes to normal water levels in terms of the start or duration of the wet season. Cyclones moving in from the South China Sea are an additional hazard. The events of 2000 caused severe damage in the region due to the unusually large volumes of floodwater in the Mekong and their long duration. The flood hydrology of the delta can generally be classified as low peak, high volume. This means that the huge upstream seasonal floodplain storage and the natural modification effects from drainage into and then out of the Tonle Sap reduces the intensity of the flood hydrograph and distributes the volume over a much longer period of time. The most severe events are associated with extended periods of discharge above critical thresholds, leading to long periods of inundation, bank and levee erosion and to infrastructure damage. The hydrology of the dry season is equally important in controlling the natural, social and economic environment of the region.

The greater part of the delta is tidal. Tidal influence is highest in the low-flow months and less in the flood season. The tidal amplitude from the South China Sea is between 3 and 3.5 m, which translates into a typical dry season day-night water level change at Can Tho (90 km from the sea) of 1.5 to 2 m and at Tan Chau and Chao Doc (190 km from the coast) of 1 m.

High tides combined with deep channels and low hydraulic slope and bed gradients result in extensive salt water intrusion, particularly during the middle and later months of the low-flow season (March and April). During a normal dry season, the maximum extent of salt water intrusion covers somewhere between 15,000 km² and 20,000 km². However, model simulations reported by Cross and Beecham (2005) for the critical drought year of 1998 indicate that during critical events the figure increases to as much as 28,500 km². This is equal to roughly half of the total area of the delta (Figure 6.6).

The brackish water conditions caused by extensive saline intrusion make the water unsuitable for rice irrigation and the late dry season planting is abandoned in affected areas, reducing the number of potential crops from three to two (Table 6.1).

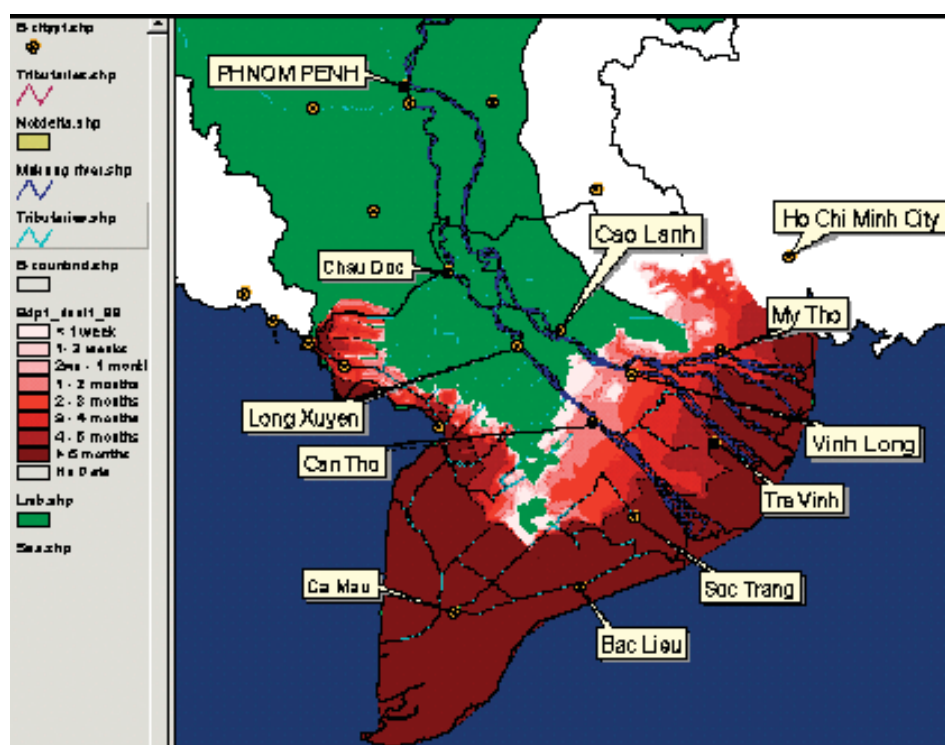


Figure 6.6 Mekong Delta: Simulation of saline intrusion during the dry season drought conditions of 1998. The map shows the duration of salinity levels greater than 1 gram per litre. The area affected exceeds half of the total 55,000 km² that defines the main delta

Farmers in these areas have adapted to the changing freshwater-salt water environment by evolving a rotating rice-shrimp system to maximise income through both rice and high value, intensive or semi-intensive shrimp production.

Acid sulphate soils cover 40 per cent of the delta. Generally, as long as the sulphides in the sediments remain below the water table they are not harmful. When the water table falls, however, as it does during prolonged drought, the sulphides oxidise to sulphuric acid and produce low Ph and acid soil water conditions which are toxic to crops and vegetation. Severely affected areas can become “scalded” and barren for decades. If early wet season rainfall washes this sulphuric acid soil into the drainage systems and canals, it can kill aquatic organisms, cause an increase in fish diseases, change estuary ecosystems and corrode the steel and concrete of engineering structures.

Further upstream, the environment and economic productivity of the delta is highly sensitive to the amount of water that flows downstream during the dry season months. Even small shortfalls in the amount and mean rates of discharge between January and April can cause secondary impacts, such as more extensive

salt water intrusion. Any changes to the dry season hydrology of the Mekong mainstream, either in terms of its pattern or amount, would be viewed with concern by Viet Nam. For example, increases in water use for dry season irrigation upstream in the Lower Basin would lead to some reduction in flows reaching the delta during these critical months. These impacts could be offset by the significant increases in average discharge between December and April that would result from the proposed scale of reservoir storage to be developed on the mainstream in the Upper Basin. Hydropower schemes in Yunnan will store flood season water for release via the turbines during the low-flow months to maximise total annual power output. This is a reallocation of water from the flood season to the dry season. Depending on the degree of regulation that these schemes achieve, dry season flow entering the delta could be increased by between 10 and 20 per cent. Additional dry season water supply on this scale, combined with the increase in year-to-year reliability that regulation brings, would be of considerable benefit during the dry season.

Chapter 7

Hydrological Modelling



7 Hydrological Modelling

Engineers use mathematical equations to “model” real-world behaviour. An equation will have one or more input variables and one or more outputs. The equation can then be used to “simulate” or model what would happen to the real-world outputs if one or more inputs are changed. An equation is a model. A set of related equations is often referred to as a “modelling package”. Most models make one or more assumptions to simplify real world conditions so the mathematics don’t become too complex and difficult to calculate. Computers have made it possible to increase both the speed of calculation and the complexity of mathematical models. The benefit of models is that engineers can predict with some accuracy what will happen to a system if the inputs are changed. These “what-if” predictions are often referred to as “scenarios”, for example, “in Scenario 1, if we do A, B and C, the most likely result will be D”. Modelling a river system as complex as the Mekong required considerable time, effort and skill.

Many computer-based models have been developed over the years to describe the hydrology and hydraulics of the flows in the Mekong Basin. The most recent modelling activity conducted through the MRCS was the development of three modelling packages:

1. The Mekong River Commission Decision Support Framework (DSF). This modelling package was developed during the period 2001-2004 under the Start-up Project for the MRC Water Utilisation Programme, financed by GEF through the World Bank.
2. The MIKE11¹ modelling work carried out under the WUP-JICA² and TSLVP³ during the period 2000-2004 with financing from the Government of Japan.
3. Phase 1 of the WUP-FIN modelling of the flow regime and water quality of the Tonle Sap project carried out during the period 2001-2003 and financed by the Government of Finland.

Only the DSF was developed using a participatory approach involving consultation with the four Lower Mekong Basin countries and included a careful process for “calibrating” the model. The DSF is the only modelling package agreed on by all members of the MRC to be applied to planning and water resources management.

The MIKE11 and WUP-FIN models were developed for specific purposes and more limited areas within the floodplain only. They will be used to complement DSF analyses in the areas for which they have been developed.

The MRCS Modelling Team within the Technical Support Division has been involved in the development and training of the models and they can operate and support all these modelling packages.

¹ MIKE11 is a software modelling package by DHI Water and Environment, Denmark. ² WUP-JICA are activities financed by the Government of Japan in support of MRC’s WUP. ³ TSLVP is the Tonle Sap and Vicinities Project, funded by the Government of Japan.

The following sections present an overview of these modelling packages and discuss potential “scenarios” that can be modelled.

7.1 *MRC Decision Support Framework*

7.1.1 Purpose of the DSF

The MRC Decision Support Framework (DSF) makes it possible to investigate the environmental and socio-economic impacts of changes in the quantity and the quality of flows in the Lower Mekong river system brought about by changing circumstances within the river basin. The DSF offers a powerful analytical tool for understanding the behaviour of the river basin and for making planning decisions on how best to manage its water and related natural resources.

The DSF has been set up to help planners assess both the magnitude of changes brought about through natural and human interventions in the water resource

Box 1: Examples of interventions that can be investigated with the DSF

- Land use/ land coverage changes
- Climate and sea level changes
- Water supply demands
- Aquaculture development
- Irrigation abstractions
- Revised crop patterns
- Changes in existing dam operation
- New dams and reservoirs in LMB
- China dam cascade
- In-stream regulation
- Inter-basin diversions
- River improvement works
- Flood works in floodplain/tributaries
- Salinity intrusion barriers

system, as well as the impacts that these changes will have on the natural environment and on people’s livelihoods. The models are set up to run simulations over a number of years (hydrological data for 1985-2000 are available throughout the LMB) or for a single year or season (Box 1).

Multi-year analysis makes it possible to do statistical comparisons of impacts to see what happens on average, or for risk assessment over a sequence of wet or dry periods.

Simulation of a single year or season helps planners look at what would happen in typical or extreme years. Potentially, a wide range of socio-economic and environmental indicators can be assessed. The DSF has been developed in a general format that allows analyses to be done with data already loaded into the database and on new data as they become available in the future.

Typical socio-economic issues are illustrated with the model (Box 2). The final choice depends on how planners wish to structure their analyses. This will depend to a large extent on the data they are able to assemble. For example, environmental indicators have been identified in relation to the transboundary issues of concern to the four MRC member countries.

The DSF is a PC-based system suitable for use on local area networks (LANs). The system is set up in each of the four countries with a master copy at the MRC Secretariat. It is configured in a manner that allows local users to do their own analyses and to share these analyses with colleagues for discussion, review or verification. For the present, sending results to other locations will be done by CD or DVD. The DSF can be modified to make use of the Internet when line capacity and speeds are improved.

The immediate purpose of the DSF is to support the on-going MRC programmes concerned with establishing procedures for water use and the Basin Development Plan. The system is also useful to other MRC core and sector programmes, which are directly or indirectly concerned with development of appropriate subsector strategies.

<p>Box 2: Possible Socio-economic Indicators</p> <p>Economic production</p> <ul style="list-style-type: none"> • Hydropower energy production * • Fresh and brackish water fisheries production • Agricultural production on flood plains • Irrigated agricultural production * <p>Social & livelihoods</p> <ul style="list-style-type: none"> • Health <ul style="list-style-type: none"> Access to water supply Food security • Employment <ul style="list-style-type: none"> Jobs in agriculture Jobs in freshwater fisheries Jobs in brackish water fisheries • Poverty alleviation <p>* Production is directly measured by the simulation</p>

The DSF is a “toolbox” that supports planning assessments and is fully complementary with the wider planning process. The basic use of the DSF is as a tool to make assessments of possible future circumstances and interventions referred to as “scenarios”. In the context of the DSF, a scenario is defined by a specific combination of hydrological conditions, demands on the system and interventions (dams, water diversions, irrigation systems, increases in water use by industry or population centres, etc.).

The full process of scenario assessment requires the collaboration of both planners in the BDP and Integrated

Basin Flow Management teams and DSF operators and modellers in the Technical Support Division.

7.1.2 DSF components

The system is made up of three main elements accessed through a single user-interface (Figure 7.1):

- a Knowledge Base containing information on the historical and existing resources and, when fully loaded, socio-economic and environmental conditions, as well as predictions of how these may change in the future
- a package of Simulation Models for predicting the possible impacts of changes within the Basin on the river system, and
- a set of Impact Analysis Tools for predicting environmental and socio-economic impacts in response to changes in the condition of the river system.

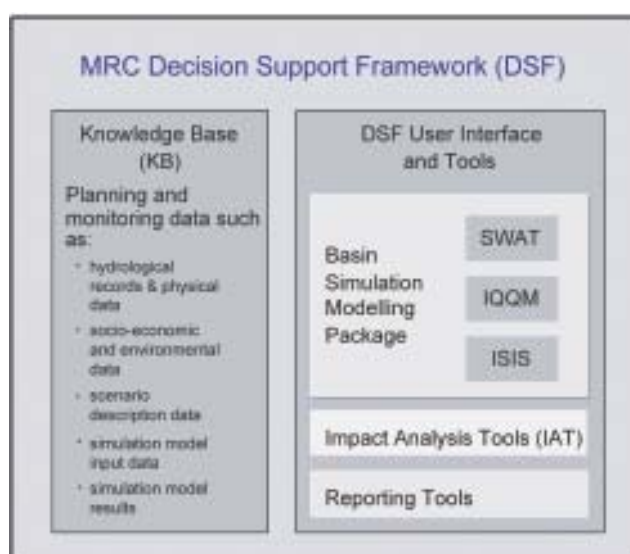


Figure 7.1 MRC Decision Support Framework (DSF)

7.1.3 User interface

The DSF main interface offers menus to guide the user through the entire system. A Help function is provided with direct links to a set of User Guides. The main user interface can be easily customised to provide user-defined views.

7.1.4 Knowledge base

The Knowledge Base contains the core data and pre-defined models. New model configurations can be set up by the Specialist Modellers and loaded into the Knowledge Base). The Knowledge Base also contains selected outputs from the model simulations and the results of analyses conducted with the Impact Analysis Tools. The Knowledge Base allows new information to be added. Data held in the Knowledge Base are listed in the on-line data catalogue. The core data have been drawn mainly from the MRCS Databases, with some directly from individual country sources.

7.1.5 Hydrological models

Three basic types of model have been developed for the DSF. The first is a series of hydrological models based on the SWAT software from the US Department of Agriculture. These have been set up to simulate catchment runoff based on estimates of daily rainfall and the topography, soils and land cover of each subbasin. The SWAT software allows users to investigate nutrient and sediment flows also, but there are insufficient data to set up calibrated models for these at present.

7.1.6 Basin simulation models



The hydrological models provide inputs to a series of basin simulation models (Figure 7.2) that are based on IQM software originally developed for the Murray-Darling Basin in Australia. The simulation models route catchment flows through the river system, making allowance for control structures such as dams and irrigation systems. Information on daily discharges is calculated throughout the system and particularly at the primary outfalls of Kratie on the mainstream and the Great Lake in the Tonle Sap Basin. The IQM software also draws from data in the Knowledge Base to estimate irrigation demand.

Figure 7.2 Basin simulation models

7.1.7 Hydrodynamic models

A hydrodynamic model, based on ISIS software developed by HR Wallingford and Halcrow, is used to simulate the river system downstream of Kratie, including the Tonle Sap and the East Vaico in Vietnam, where wet season flooding extends beyond the Lower Basin boundary. The hydrodynamic model represents the complex interactions caused by tidal influences, flow reversal in the Tonle Sap River and over-bank flow in the flood season with the varying inflows from upstream. The model generates hourly data for water levels and discharges throughout the main channels and distributaries in the delta. A salt water intrusion model has also been set up with the ISIS software drawing on the results of the hydrodynamic model. ISIS also makes it possible to simulate other water quality parameters, including sedimentation, but at present there are insufficient data to set up these models.

Each model is run from the DSF interface with data automatically transferred from one to another through the Knowledge Base. A number of adjustments that do not involve reconfiguring the model are also possible through the DSF interface (such as varying demands and climate). Results from the model

simulations are stored in the Knowledge Base for further investigation using the Impact Analysis Tools.

7.1.8 Impact Analysis Tools

Guidance on when and which impact analyses tool to select is provided in the DSF Final Report. Each tool has been developed so that the full range of environmental and socio-economic indicators can be investigated. In the case of the spatial analyses, information from the mapping tools can be overlaid on any range of appropriately formatted spatial data using ArcView (provided with the DSF) to make direct assessments of affected populations, land areas or sites of specific interest.

7.2 *WUP-JICA - MIKE11 Model*

7.2.1 Purpose of the MIKE11 Model

A computer-based mathematical model (MIKE11 by DHI - Water and Environment, Denmark) of the rivers and land uses of Cambodia was developed under several programs and project activities within the MRC in the period 2000-2004. The model was first introduced for the Chaktomouk project in year 2000 to provide boundary conditions for a detailed two-dimensional morphological river model set up for the Chaktomouk junction. This version was developed further in the WUP-JICA study during the period 2001-2003, during which extensive modifications and additions were made to meet the specific purposes of the study. The model improvements took place continuously through the WUP-JICA study as additional data and information became available. The overall aims of the modelling component of the WUP-JICA study were:

1. data gap filling
2. flow regime analysis
3. water balance study
4. downstream flow prediction
5. support to the MRC water sharing rules

The model was further improved through the Tonle Sap Lake and Vicinities Project (TSLVP), also funded by JICA in the period 2002-2004. The main purpose of the TSLVP was to collect information and analyse land use areas in Cambodia. The dynamics of filling and releasing floodwater on land use, the exchange of flow between river and floodplain, as well as between floodplain compartments, was described quantitatively. A complete and detailed water balance for components of the river-floodplain system was provided.

The TSLVP goals were achieved by a combination of data collection and analysis and hydraulic modelling. A comprehensive data collection campaign was part of the study. Water levels were continuously monitored on the floodplains and discharge measurements were conducted on tributaries located in the floodplain area. In addition, nine satellite images of the Lower Mekong Basin were taken. The satellite images were taken from July 2002 to January 2003 at 3-4 weeks interval, and show the gradual process of flooding and draining on the use of land. Together with the data collected for the WUP-JICA project, the work formed the basis for a unique quantitative understanding and description of the hydrological functions of the river and land use system of Cambodia.

7.2.2 Key features and capability of the model

The MIKE11 model consist of two submodules, a rainfall-runoff model and a river-lake-floodplain model. The rainfall-runoff model describes on a daily basis the runoff from all subcatchments in the Great Lake area as well as the subcatchments in the Cambodian part of the delta. The rainfall-runoff model provides inflow to the dynamic model of the river and land use system (Figure 7.3).

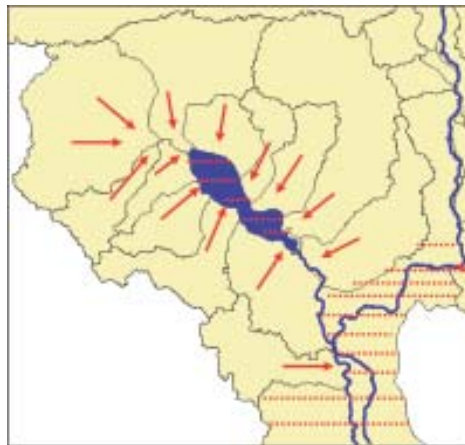


Figure 7.3 MIKE11 modelling inputs from the catchment and floodplain

The model has been set up to continuously simulate the period 1998-2003 using both hourly and daily data. The model system is well calibrated against water levels and flows obtained for this period. The model can simulate entire hydrological years including both wet and dry seasons. The system can simulate the flow and water level conditions in the main rivers quite accurately, including the unique features of Tonle Sap flow reversal and land use flows. Dry season flows and tidal dynamics are accurately described with the model.

7.2.3 Present use of the MIKE11 model within MRC

Besides the projects for which the MIKE11 model was developed, it has been used for additional activities at MRC. The model was applied in 2003 for daily and forecasted flood mapping at MRC. The model simulation and flood map production was carried out automatically on a daily basis by MRC staff using a stand-alone Flood Mapping Tool. The tool integrated the daily information on water levels with the MIKE11 model and GIS. The output was published on the MRC Flood Monitoring web page.

Recently, MIKE11 was used as a tool for a study on Tonle Sap Flow Reversal. This study was part of the Phase 1 Integrated Basin Flow Management (IBFM)

activities at MRC. The purpose was to understand the reverse flow mechanisms and to provide guidance to MRC on the formulation of water sharing procedures related to Tonle Sap flow reversal (Article 6B in the Mekong Agreement). The model system and associated data has been transferred to MRC and staff from the Technical Support Division at MRCS and from the Department of Hydrology and River Works (DHRW) in Cambodia have been trained to use it.

7.2.4 Future use of the model

The MIKE 11 model is suitable for studies related to flow and water level conditions in the Mekong-Bassac-Tonle Sap River and Great Lake system including associated floodplains. It has potential use within existing and future activities at MRC. The model can provide support to IBFM activities at MRC, as well as selected studies under the BDP, Environment, and Fisheries programmes. The model has potential use as a tool for Flood Management and Mitigation Programme at MRC, where it could be used for overall and detailed flood analysis studies. The system can easily be expanded to include the MIKE11 Flood Forecasting module. Operational MIKE11 flood forecasting systems already exist in Thailand and are under way in Vietnam.

The model system is confined to Cambodian territory for now. However, the model can be expanded to the northern part of Thailand and Lao PDR and the delta. Donor funded activities in Vietnam outside the MRC have supported the establishment of a MIKE11 model, which describes part of the delta. Besides this, DHI has established conversion tools which can convert ISIS models to MIKE11 model setups. From a technical point of view, expansion of the model is a task which can be completed in a relatively short time.

7.3 *WUP-FIN Modelling of the Flow Regime and Water Quality of the Tonle Sap*

7.3.1 Model purpose

The activities of the WUP-FIN Phase 1 Project (2001-2003) included gathering and evaluating existing data as well as collecting the additional data needed for the creation of the Tonle Sap model system. This system includes two main modelling elements:

1. Conceptual HBV-model and Distributed Vmod Model for the Tonle Sap watershed, and
2. Three-dimensional Flow and Water Quality Model for the Tonle Sap Lake and Floodplain.

The database for the models consists of standard GIS data and meteorological, hydrological, hydrodynamic and water quality measurements. The database and the models are accessed through a common user interface.

The project objectives guided the model selection and data demands by underlining the importance of improved understanding of the Tonle Sap Lake and surrounding wetlands. This led to a number of conclusions:

- The Great Lake model must be three-dimensional because significant gradients appear in the Lake, both in horizontal and vertical directions. As a result of these gradients, there is a distinct separation of habitats.
- A distributed watershed model should be used to predict impacts of land use changes to provide a basis for water resources management and to give estimates on material loads (sediments, nutrients) for the lake model.

7.3.2 Model application

Model parameters relevant to assessments for the Tonle Sap include:

- flood related parameters (e.g. flood arrival time, flood duration, average and maximum water depth, drying time, flow speed)
- water quality (e.g. dissolved oxygen, nutrients, harmful substances, municipal wastes, coliforms; Figure 7.4)
- sediment related parameters (e.g. transport, fluxes, erosion, sedimentation; Figure 7.5)
- fish spawn and larvae
- oil and chemical spills

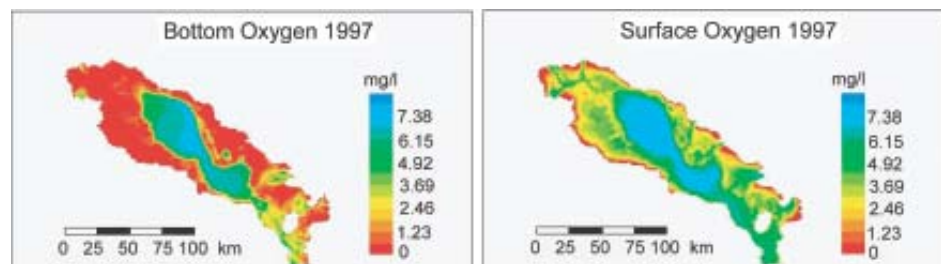


Figure 7.4 Simulated Tonle Sap dissolved oxygen concentrations for bottom and surface in year 1997

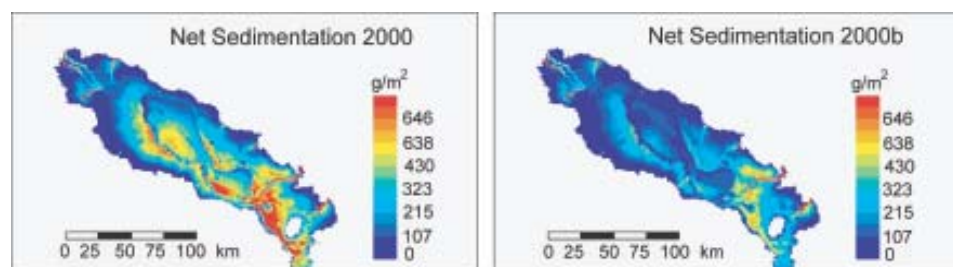


Figure 7.5 Comparison between 2000 calculated net sedimentation and dam trapping scenario (2000b)

Below is a general list of potential uses of the WUP-FIN modelling system. The system has been used in over 230 case studies:

- flood modules for flood prediction, dam and dyke breaks, detention area simulation, flooding of floodplains etc.
- reservoir models for managing reservoir hydrodynamics, sedimentation and water quality
- water resources management (power production, land use management, groundwater uptake and recharge, irrigation, urban water use etc.)
- hydropower production optimisation in river and lake networks
- watershed, river and coastal sedimentation and erosion
- dredging and navigation channel and harbour maintenance
- oil and chemical accidents
- agricultural, industrial and municipal waste water management
- anoxia, eutrophication, algal blooms, filamentous algae, shore vegetation etc.
- benthic processes
- lake restoration
- fisheries management
- sea rescue
- monitoring support

Typically, the modelling system is used to understand the function of the system being studied, to integrate and visualise data from various sources, to study different management options, and to estimate impacts from development scenarios.

In Phase 2 of the WUP-FIN project (2004-2006), the models will be extended to cover the Cambodian floodplains and the delta in Vietnam. Other areas include upstream “hotspots” in Thailand and Lao PDR. The system will be based on a combination of watershed, river, channel, lake, floodplain and coastal models.

7.4 Potential applications for all models

The models described above are available and supported by the Technical Support Division of the MRCS and, to varying degrees, by the NMCs and some line agencies in each member country. Each has been developed with specific applications in mind. However, for some cases, the use of more than one model may be appropriate in the analysis of particular water management problems.

The DSF was developed under the WUP as a basin-wide model and knowledge base in support of Basin Development Plan activities. It is also useful for providing technical support for flow assessments for the procedures for maintenance of flows on the mainstream (Article 6 of the 1995 Agreement).

The DSF is the only modelling package developed in a fully participatory manner with representatives of all MRC member states taking part in a process of quality control and calibration. It is also the only modelling package that has been accepted by all MRC member states. The DSF has been pre-loaded with demonstration scenarios to illustrate the range of analyses that can be undertaken. These include:

1. A nominal baseline scenario (2000 year development conditions), and six additional scenarios assessing:
 - 1.1 Impact of climate change
 - 1.2 Impact of catchment cover changes
 - 1.3 Impact of a high irrigation demand
 - 1.4 Impact of Chinese dams
 - 1.5 Impact of Lower Mekong Basin dams
 - 1.6 Impact of flood embankments

2. The MIKE11 model developed under the WUP-JICA activities was designed to assess the flow regime and water balance of the Cambodian floodplain, specifically the Chaktomouk Junction and the Tonle Sap Lake Basin.

3. The WUP-FIN models provide the only available three-dimensional modelling capabilities designed to support flow and development impact assessments related to the Tonle Sap Lake and floodplain.

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