Working Paper 2011-2015:

The Impact & Management of Floods & Droughts in the Lower Mekong Basin & The Implications of Possible Climate Change

Flood Management and Mitigation Programme

Mekong River Commission

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

Mekong River Commission
Flood Management and Mitigation Programme

The Impact & Management of Floods & Droughts in the Lower Mekong Basin & the Implications of Possible Climate Change

Working Paper (2011-2015)

March 2012

Note:

This document has been developed in the framework of FMMP's contribution to the MRC State of Basin Report, 2009. The document has been written by Dr. Christopher Joy of Water Matters International, in close cooperation with the FMMP and the Environment Programme (EP), and will serve as a Working Paper to guide the FMMP 2011-2015 implementation.

Summary of Findings

Weather Disasters in the LMB

The Lower Mekong Basin (LMB) is subject to the risk of various natural disasters, including the three 'weather' disasters of flood, drought and storm. The following Table shows the ranking of these disasters in the four riparian countries in terms of relative frequency of occurrence in the LMB[1]. It is seen that flood ranks first in three of the four countries and second in the fourth and that drought ranks second or third in all countries.

Ranking of Occurrence of Weather Disasters, Lower Mekong Basin

Disasters	Lao PDR	Thailand	Cambodia	Viet Nam[ma]
Flood	1	1	1	2
Drought	2	3	2	3
Storm	2	2	3	1

[A] For the whole country

In terms of average number of people affected per weather disaster, drought is the primary weather disaster in Cambodia, Thailand and Viet Nam, whereas in Lao PDR it is storm. In terms of the average number of people killed per weather disaster, flood is the primary disaster in Cambodia and Thailand (87 and 44 persons per event respectively), whereas in Lao PDR and Viet Nam, the primary disaster is storm 146 and 14 persons per event respectively).

In terms of the average economic costs of weather disasters, floods and droughts are the primary disasters and cost about the same in Cambodia and Thailand (USD 25-27 M per event and about USD 70 M per event respectively), whilst in Lao PDR the primary disaster is storms (about USD 75 M per event), and in Viet Nam it is droughts (about 130 M per event).

Floods in the Lower Mekong Basin

Floods can be classified into the following three categories: Rainfall floods, Dam related floods, and Maritime floods.

Rainfall Floods are caused by excessive rainfall and comprise:

- *Mainstream floods* in the LMB occur when the Mekong River overflows its banks, typically in the wet season from June to November. In the Upper and Middle Reaches of Lao PDR and Thailand, mainstream floods typically inundate a narrow floodplain for several weeks; in the flatter reaches of the Cambodian Lowlands and Cuu Long Delta, mainstream floods inundate vast areas for several months. The Great Lake modifies flooding in downstream areas, reducing the flood peak but extending flood duration.
- *Tributary floods* occur in the LMB when Mekong tributaries overflow their banks. Three types of tributary floods can be distinguished: flash floods, combined floods and landslips. *Flash floods* refer to sudden and unexpected flooding that occurs within 6

[1] In the following analysis, results for Cambodia and Lao PDR pertain to the LMB, but results for Viet Nam and Thailand pertain to the whole country. This will bias the results for Thailand and Viet Nam to some extent. For example, Storm is the Rank 1 disaster in terms of frequency of occurrence in Viet Nam. This arises because of the long storm-prone coast of the country. It is thought that floods and droughts may be more frequent than storms in the Cuu Long Delta of the LMB.

hours of the onset of the flood-producing rains. They typically occur in the steep, narrow Upper Reaches of tributaries. The Lower Reaches of tributaries are susceptible to *combined flooding*: the interaction of mainstream and tributary flood flows raises tributary flood levels higher than otherwise would be the case. *Landslips* occur because of slope instability and happen abruptly and with little warning. Although not floods per se, they are often in tributary catchments and in concert with tributary floods and can be more deadly than the latter.

- *Local floods* occur when heavy rainfalls overwhelm the capacity of local drainage systems (typically in urban areas).
- *Dam related floods* are caused by the operation or failure of dams and dikes and comprise:
- *Dam release floods* occur when releases from a dam overtop the banks of the receiving waterway. Sudden and large releases may have to be made to cater for an incoming flood. Dam release floods can results in sudden and unexpected rises in downstream water levels.
- *Dam break floods* occur when a dam embankment fails because of overtopping, structural failure or the undermining of its foundations. Dam break floods are extremely hazardous, being characterized by rapid (instantaneous) increases in water level, high velocities and rapid progress downstream.
- *Dike breach floods* occur when a dike breaches because of overtopping, structural failure or undermining of its foundations. A dike breach flood is similar to a small dam break flood, but not as hazardous or destructive because of the generally low nature of dikes.

Finally, *Maritime floods* refer to the inundation of coastal and estuarine lands by seawater and comprise storm surge floods and tsunami floods:

- *Storm surge flooding* occurs when a storms typically a tropical weather system, raises coastal and estuarine water levels through the action of low atmospheric pressures and storm driven waves. In the LMB, only the coastal and estuarine areas of the Cuu Long Delta are exposed to storm surge flooding.
- *Tsunami floods* are caused when the ocean floor is thrust up or down by tectonic plate movements or undersea landslides occur. Again, in the LMB, only the coastal areas of the Cuu Long Delta and its estuaries are subject to tsunami risk, which is considered to be small to very small because of the small size of locally generated tsunamis (less than 0.5 m high) and protection from larger tsunamis generated in the Philippines provided by the favourable orientation of the coastline of the Cuu Long Delta.

In terms of flood risk, which embraces the population at risk, together with the frequency, severity and hazard of flooding, the greatest flood risk in Cambodia and Viet Nam is mainstream flooding (a very high risk), whereas in Lao PDR it is tributary flooding (a high risk), and in Thailand it is inferred that mainstream and tributary floods have about the same risk (medium).

The economic cost of floods varies significantly from country to country. The following Table shows the estimated average annual cost of flooding in the LMB.

Estimated Average Annual Flood Damage, Lower Mekong Basin

Country	Average Annual Flood Cost (USD M)
Lao PDR	11
Thailand	7
Cambodia	18
Viet Nam	25
Total	**61**

Floods also provide significant benefits to the LMB, including sustaining the annual fish catch, especially in the Great Lake, sustaining the 5.24 M ha of flooded wetlands in the LMB with associated socio-economic benefits, providing water supply for dry season irrigation, fertilizing the floodplains with an annual deposit of silt, etc. The average annual benefit of flooding in the LMB has been estimated at between USD 8 and 10 B, i.e. ***over 100 times*** the average annual cost of flooding.

Droughts in the Lower Mekong Basin

Droughts, like floods can occur anywhere in the LMB. We can distinguish three different types of drought:

- *Meteorological drought* occurs when rainfalls over some prescribed period are significantly less than the long-term average. The most meteorologically drought-prone locations of the LMB are the western area of the Khorat Plateau in Thailand and the South-eastern area of Cambodia.
- *Hydrological drought* occurs when water resources are significantly depleted because of meteorological drought, e.g. stream flows over some prescribed period are significantly less than the long-term average.
- *Agricultural drought* occurs when meteorological and hydrological droughts reduce crop yields and livestock and fisheries production. As far as agriculture is concerned, an agricultural drought occurs when soil moisture is insufficient to meet crop water requirements. (The actual reduction in crop yield depends on the type of crop, its growth stage and the water holding properties of the soil). As far as fisheries and livestock production is concerned, an agricultural drought occurs when the supply of water and/or the condition of the water are inadequate to maintain fodder supplies and normal growth.

Drought severity depends upon drought intensity, i.e. the magnitude of the rainfall, water or soil moisture deficits, along with the extent, timing and duration of the deficits, and its socio-economic impacts. Typically, a drought is deemed to be *severe* if the rainfall, stream flow or soil moisture deficit is greater than 20 percent of the average annual value.

The likelihood of an annual meteorological drought is greatest in Lao PDR and Thailand (about 0.40 to 0.45 per year) and is least in Cambodia and Viet Nam (0.30 to 0.35 per year).

Definitive data for the cost of drought in the LMB are lacking. However, it is apparent that meteorological drought will have a major impact of rainfed rice production (which accounts for over 75 percent of total LMB rice production in Lao PDR, Thailand and Cambodia). A recent study estimated the average annual drought loss of rice production in northeast Thailand (the western area of the Khorat Plateau) at 78,000 T/pa valued at USD 10 M pa. Drought also has a significant impact on fishery production in the Great Lake, with an estimated average annual loss of around USD 15 M pa. Figures available at the time of writing this report do not lend themselves to a definitive estimate of annual drought costs in the LMB. However, given the relatively high frequency of droughts (2 years in 5 in Lao PDR and northeast Thailand, and one year in three in Cambodia and Viet Nam), coupled with the high costs of individual droughts (the 2004-05 drought cost some USD 45 M in the Cuu Long Delta and significant amounts in the other riparian countries), it is expected that the average annual cost of drought in the LMB is greater than the average annual cost of flood damage, perhaps markedly so.

Unlike floods, there are no benefits associated with the occurrence of droughts, and droughts have only a limited impact (if any) on public infrastructure.

The Management of Flood and Drought Risk in the Lower Mekong Basin

We do not manage floods and droughts *per se*. Rather, we attempt to manage flood and drought risk. Both flood and drought risks are dependent on the likelihood of occurrence of the flood or drought event under consideration, i.e. its 'intensity' or 'severity', and the socio-economic impact of the event on the population at risk. This can be expressed as follows:

$$\text{Risk} = \text{Function}\{P * \text{SEI}\}, \quad \text{and} \qquad (1)$$

$$\text{SEI} = \text{Function}\{N * LU * SEV\} \qquad (2)$$

Where: P refers to the likelihood (probability) of a specific flood or drought event occurring,

- SEI is the socio-economic impact of that flood or drought event,
- N refers to the nature of flooding at the location of interest (depth, velocity, rate of rise, duration, etc); or the nature of the drought (time of onset, duration, etc),
- LU refers to land-use (impacts are greater for flood or drought-sensitive land-uses), and
- SEV refers to the socio-economic vulnerability of the community to 'flood shock' or 'drought-shock'.

Flood risk can be reduced (managed) by:

(i) Reducing the likelihood of flooding (flood protection embankments, dams),

(ii) Making land-use, infrastructure and assets less damage-prone (flood-proofing), and

(iii) Reducing community vulnerability (i.e. increasing community resilience).

Similarly, drought risk can be reduced by:

(i) Reducing the likelihood of drought occurrence[2] (through the provision of water supply for domestic, commercial, industrial and agricultural purposes),

(ii) Making land-use and assets less drought-prone (drought-proofing), and

(iii) Reducing community vulnerability (i.e. increasing community resilience).

Both flood-prone and drought-prone communities are exposed to three types of flood risk:

- *Controlled Risk:* Reflects current community land-use and the effectiveness of any structural risk reduction measures in place (e.g. flood embankments and flood control

[2] We cannot prevent the occurrence of meteorological drought (attempts elsewhere have been made to do so through cloud seeding), but we can offset the impacts of hydrological and agricultural drought through the provision of water supplies held in upstream dams.

dams in the case of flood risk, and supplementary water supplies and water conservation measures in the case of drought risk);

- *Residual Risk:* The risk to the community over and above the 'managed risk', i.e. the current risk exposure; and
- *Future Risk:* The risk at some nominated time in the future, reflecting changes to population and land-use, and possibly additional risk reduction through the provision of additional structural risk management works. The future risk is generally always greater than the current residual risk: populations grow, land-use will also change with time, often to more risk-sensitive types.

Five primary and *four supplementary measures* are available *to manage flood risk*. The four primary measures are (i) land-use zoning (keep people away from the water), (ii) structural works (keep water away from the people), (iii) development and building controls (recognize that people will get flooded and attempt to limit the damage to buildings and infrastructure through 'flood proofing' measures), (iv) regional flood emergency planning, and (v) community-based flood emergency planning. The last two measures also recognize that flooding will occur (the residual risk), but the socio-economic impact can be reduced through the preparation of or prevention, response, relief and recovery plans (PRRR plans) at the regional and community levels to increase community flood resilience. The four supplementary measures are land-use planning, flood simulation modelling, flood forecasting and flood warning. These nine flood risk management measures interact in a complex way. Their usefulness and effectiveness, both separately and together, needs to be considered when developing an 'integrated flood risk management plan' for a particular area.

There are *three primary* and *three supplementary measures* available *to manage drought risk*. The three primary measures are (i) structural works (supplementary water supplies or water conservation works), (ii) regional drought emergency planning, and (iii) community-based drought risk management. Again, the last two measures recognize that droughts cannot be wholly prevented (residual risk), and that the socio-economic impacts of droughts can be reduced by preparation of prevention, response, relief and recovery plans at regional and community levels to increase community drought resilience. The three supplementary measures are drought monitoring, drought forecasting and drought warning. The usefulness and effectiveness of these six drought risk management measures needs to be considered when developing a 'drought risk management plan' for a particular area. These six drought risk management measures also interact, but not in so complex a fashion as the flood risk management measures. Their usefulness and effectiveness, both separately and together, needs to be considered when developing an 'integrated drought risk management plan' for a particular area.

Thus, there are a number of similarities in the management of flood and drought risk.

Finally, the concept of Integrated Flood Risk Management (IFRM) needs to be appreciated as the most effective way of reducing flood risk and as a fundamental component of integrated water resources management. The concept was briefly introduced above, but is wider than simply integrating flood risk management measures. A number of agencies and groups, both private and public, can influence flood risk by developments on the floodplain or their developments can be adversely affected by changes to flood risk. If a flood risk management plan is to be effective, it is essential to identify all stakeholders influencing or affected by flood risk, and integrate their activities, roles and responsibilities into the plan.

Similar, but lesser, considerations hold in the development of integrated drought management plans.

Climate Change in the Lower Mekong Basin

An obvious starting point for any discussion on climate change and its ramifications for the LMB is the finding that too date, *there is little if any statistical evidence* in the hydrometerorological record over the period 1925-2005 of climate change in the LMB (Adamson 2006). This finding pertains to 90-day low flow behaviour at Kratie and Vientiane, the dates of onset and cessation of the Northwest monsoon, and the amount of monsoonal rainfall.

The IPCC (2007) has developed a number of projected climate change scenarios for the LMB. These scenarios are *theoretical constructs* driven by an assumed relationship between CO_2 levels and temperature that contain a number of *identifiable uncertainties, simplifications and limitations* that influence findings regarding the projected climate change. A major simplification/error in this approach has been the omission, not to say understanding, of the 'natural weather cycles' that are generally apparent in any period of hydrometeorological data of reasonable length (cycles of up to 70 years have been identified).

Notwithstanding the uncertainties and limitations of the IPCC results, projected climate change scenarios have been used to assess likely impacts on flood and drought behaviour in the LMB (CSIRO 2008 and MRC 2010a). CSIRO 2008 predicts significant changes to flooding and drought behaviour in the LMB. However, this study contains a number of obvious flaws. MRC 2010a undertakes a much more workmanlike investigation into the likely effects of climate change in the LMB. In particular, care is taken to calibrate predicted rainfall and stream flow behaviour to observed behaviour over a baseline period. The findings of this study indicate much more modest changes to flood and drought behaviour.

Adaptation is the obvious approach to adopt when the nature, direction and cause of likely climate change are all uncertain. One thing that is certain, however, is that the climate is changing: it always has and it always will. An adaptation approach, if properly designed and implemented on an iterative basis, will 'work' irrespective of the degree or direction of climate change and at a modest cost. It is noted that MRC has recently introduced a Climate Change Adaptation Initiative (CCAI) into its armoury of basin programmes.

There is an important role for FMMP in climate change studies in the LMB. FMMP is the repository of historical flood information and also has flood simulation models to evaluate the impact of any changes to flood behaviour on populations at risk. Further, as noted above, FMMP has a potential role to play in drought management in the monitoring and possibly forecasting of drought behaviour. Thus, under the recently approved extension of MRC's FMMP, the best use of resources will be achieved by FMMP liaising with CCAI and DMP to provide an integrated approach to common issues across the three programmes.

Table of Contents

List of Tables

List of Figures

List of Boxes

List of Acronyms

3S	The Se San, Sre Pok and Se Kong Rivers in the Eastern Highlands region of Southern Lao PDR, North-eastern Cambodia and Viet Nam.
ADB	Asian Development Bank.
AOGCM	Atmosphere Ocean Global Climate Model.
AR4	Assessment Review No. 4 (of IPCC).
ARI	Average Recurrence Interval.
ARR	Average Annual Rainfall.
ASEAN	Association of South-East Asian Nations.
DMP	Drought Management Programme (of MRC).
ENSO	El Nino-Southern Oscillation.
FMMP	Flood Management and Mitigation Programme (of MRC).
GCM	Global Climate Model
GWP	Global Water Partnership.
IPCC	Intergovernmental Panel on Climate Change.
LMB	Lower Mekong Basin (the basin area in Lao PDR, Thailand, Cambodia and Viet Nam).
M	Million.
MB	Mekong Basin.
MMD	Multi-Model Dataset.
MT	Million Tonnes.
NGO	Non-Government Organization.
pa	Per annum.
PCC	Pattern Correlation Coefficient.
RFMMC	Regional Flood Management and Mitigation Centre (in Phnom Penh).
RMS	Root mean Square.
T	Tonne.
TC	Tropical Cyclone.
TD	Tropical Depression.
TS	Tropical Storm.
TWS	Tropical Weather System (Includes Tropical Depressions, Storms and Cyclones).
UN	United Nations.
UNISDR	United Nations International Strategy for Disaster Reduction.
WB	The World Bank.

1 Introduction

Floods and droughts can occur anywhere in the Lower Mekong Basin. A flood is a highly visible natural disaster that clamours for attention and better management. In contrast, drought is a ‘quiet’ and largely invisible disaster that develops and intensifies over time; an Act of God, something to be endured rather than managed. Both disasters impose large economic and social costs on the peoples of the LMB. However, the economic benefits of floods far outweigh their economic costs: the average annual cost of flooding in the Lower Mekong Basin is USD 60-70 M/year; the average annual cost of flood benefits is USD 8-10 B/year, i.e. some 100 times greater. The challenge for better flood risk management is to reduce the costs and impact of flooding whilst preserving the benefits. The average annual cost of drought in the Lower Mekong Basin is at least as large as the flood cost and possibly considerably bigger.

Droughts in the Mekong Basin can occur at any time during the year. Meteorological droughts are defined by low rainfalls over the wet season (May to November) and reduce the yield of rain-fed rice and other crops. (Over 90 percent of rice production in Lao PDR, Thailand and Cambodia is rice-fed). Hydrological drought is defined by a reduction in surface and groundwater resources. The agricultural impact of a hydrological drought is most severe during the dry season, when less than normal stream flows reduce irrigation opportunity and the yield of dry season crops. Hydrological droughts also occur during the wet season, when less than normal stream flows reduce the volume and extent of floodwaters stored in the Great Lake and the yield of its fishery.

The annual flood in the Mekong River is the most pervasive physical event in the Lower Basin. It has shaped the environment and ecology of the basin, especially across the Cambodian Lowlands and the Cuu Long Delta, including the nature, culture, welfare and economy of riparian societies, and the vegetation, animals and land-use of flood-prone areas. Between July and October, a massive flood wave moves down the Mekong River pass Lao PDR and Thailand, growing in volume on its downstream journey. At Kratie in North-eastern Cambodia, with a volume of some 300 km^3 (average conditions), the flood wave moves out onto the Cambodian Lowlands, where some 30 km^3 flows upstream along the Tonle Sap River into the Great Lake, and the remainder flows down the Mekong and Bassac Rivers and into the Cuu Long Delta of Viet Nam before entering the South China Sea. From October onwards, the Great Lake drains back into the Mekong and Bassac Rivers, sustaining the recession limb of the flood at downstream locations. In total, an average of some 460 km^3 of water flows out into the South China Sea each year. The Mekong flood is a regular annual event, driven by the southwest monsoon and supplemented by tropical weather systems generated in the Northwest Pacific and the South China Sea.

Mainstream flooding across the Cambodian Lowlands and Cuu Long Delta persists for some two-four-months each year and affects several million people. Flooding also occurs in the various tributaries of the Mekong River, but is of a more sporadic nature and with a typical duration of several days to one week.

Droughts can occur at any location in the Mekong Basin. Meteorological droughts (characterized by rainfall deficits) are especially devastating for rainfed agriculture. Two areas of the LMB particularly prone to meteorological droughts are the Western region of the Khorat Plateau in North-eastern Thailand and the South-eastern area of Cambodia. Hydrological droughts (characterized by stream flow deficits) allow ocean salinity to penetrate further up the waterways of the Cuu Long Delta, thereby limiting irrigation use of these waters during the low flow season.

Climate change has the potential to worsen both flooding behaviour and drought impacts. This report examines and identifies shortcomings in several studies of climate change in the LMB. A more considered approach to deal with climate change impacts in the basin is outlined.

2 Background

2.1 Natural Disasters in the Lower Mekong Basin

Information concerning the occurrence, impacts and costs of natural disasters in the LMB is plentiful, but is scattered, often incomplete, inconsistent and inaccurate. Further, official statistics are often wanting in detail and availability. There are a number of reasons for this: the four riparian countries of the LMB do not have consistent disaster reporting procedures; there are many stakeholders in the disaster risk management process, each with their own individual wants and needs.

One consistent set of data, as far as presentation is concerned, is available on the ‘Prevention Web’ website, which is operated by the United Nations to foster the United Nations International Strategy for Disaster Reduction (UNISDR). Results form this website are given below to provide an overview of the significance of various natural disasters in the LMB, especially floods and droughts. No details are available regarding the origin of the source data or its accuracy. However, it does provide a useful basis for the inter-comparison of the various disasters across the four riparian countries of the LMB.

2.1a **Occurrence of Natural Disasters**

Table 2.1 presents details of the occurrence of four types of natural disasters (flood, drought, storm and epidemics) over the general period 1980-2008 in the four riparian countries. Note that the results for Thailand and Viet Nam are whole of country results and thus may be somewhat misleading to the occurrence and nature of disasters in Northeast Thailand and in the Cuu Long Delta, the principal areas of these countries included in the LMB. The Rank 1 disaster in each country, in terms of frequency of occurrence, is shaded dark-grey. The following observations are made concerning the occurrence of natural disasters:

- In terms of the frequency of occurrence of total disasters over the reporting period, the most disaster-prone country is Viet Nam, which had an average of 4.8 disasters/year, most of which were ‘storms’ (the Rank 1 disaster type for Viet Nam). Thailand is the next most disaster-prone country, with an average of 3.4 disasters/year over the reporting period. Cambodia and Lao PDR experienced an average of 1–1.5 disasters/year over the reporting period.

Table 2.1 Occurrence of Natural Disasters, Lower Mekong Basin

Disaster Details		**Cambodia**	**Lao PDR**	**Thailand**	**Viet Nam**
		1987-2007	**1981-2008**	**1980-2008**	**1980-2008**
Total No. Disasters		28	28	98	140
Average Disasters per Year		1.3	1.0	3.4	4.8
No. Disasters and Rank	Flood	13 (1)	12 (1)	53 (1)	50 (2)
	Drought	5 (3)	4 (3)	6 (3)	5 (4)
	Storm	1 (4)	4 (3)	29 (2)	70 (1)
	Epidemic	9 (2)	8 (2)	4 (4)	9 (3)
Probability of Occurrence	Flood	0.62	0.43	1.83	1.72
	Drought	0.24	0.14	0.21	0.17
	Storm	0.05	0.14	1.00	2.41
	Epidemic	0.43	0.29	0.14	0.31

- In terms of frequency of occurrence of individual disasters, flood is the Rank 1 disaster type in Cambodia, Lao PDR and Thailand, and the Rank 2 disaster type in Viet Nam. Drought is the Rank 3 disaster type in Cambodia, Lao PDR and Thailand, and the Rank 4 disaster type in Viet Nam. Epidemics are the Rank 2 disaster type in Cambodia and Lao PDR, and the Rank 3 disaster type in Viet Nam.
- In terms of frequency of occurrence of individual disasters, flood is the Rank 1 disaster type in Cambodia, Lao PDR and Thailand, and the Rank 2 disaster type in Viet Nam. Drought is the Rank 3 disaster type in Cambodia, Lao PDR and Thailand, and the Rank 4 disaster type in Viet Nam. Epidemics are the Rank 2 disaster type in Cambodia and Lao PDR, and the Rank 3 disaster type in Viet Nam.
- In terms of the annual probability of occurrence of floods, Thailand and Viet Nam are the most flood-prone riparian countries, suffering an average of about 1.7-1.8 flood events per year. Cambodia and Lao PDR experience only around 0.4-0.6 flood events/year on average, i.e. a flood every 1.5-2.5 years.
- In terms of the annual probability of occurrence of droughts, the four countries are similar (0.14-0.24) and experience a drought once every 4-7 years on average, with Cambodia and Thailand suffering drought more frequently than Lao PDR and Viet Nam[3].
- In terms of the annual probabilities of occurrence of storms, Viet Nam is the most storm-prone country (2.41 events/year on average), followed by Lao PDR and Thailand (1.0 storm events/year). Storm disasters are rare in Cambodia (0.05 events/year).
- In terms of the annual probability of epidemics, Cambodia is worst (0.43 events/year), followed by Lao PDR and Viet Nam (about 0.3 events/year), with Thailand being least exposed to epidemics (0.14 events/year on average).

2.1b Average Impacts per Disaster Event

Table 2.2 shows the average impact per disaster for three different types of disasters - floods, droughts and storms – in terms of number of people affected, number of people killed and economic cost. The following observations regarding average disaster impacts are made:

- In terms of the average number of people affected per event, droughts are the pre-eminent disaster in Cambodia, Thailand and Viet Nam (1.31 M, 3.92 M and 1.22 M people/event respectively), whereas storm is the pre-eminent disaster in Lao PDR (0.32 M).

Table 2.2 Average Impacts per Disaster, Lower Mekong basin

IMPACT	DISASTER	CAMBODIA	LAO PDR	THAILAND	VIET NAM
		1987-2007	**1981-2008**	**1980-2008**	**1980-2008**
No. People Affected (M)	Flood	0.73	0.23	0.50	0.41
	Drought	1.31	0.19	3.92	1.22
	Storm	0	0.32	0.11	0.59
No. People Killed	Flood	87	6.4	44	84
	Drought	0	0	0	0
	Storm	25	14	30	146
Economic Cost (USD M)	Flood	25.2	1.90	69.5	45.5
	Drought	27.6	0.25	70.7	129.8
	Storm	10.0	76.5	30.8	46.1

Source: UN, 2010.

[3] It is expected that drought might be under-reported because of difficulties in defining when unfavourable weather conditions become a 'drought' (agricultural yields are reduced in both situations). Severe droughts are relatively easy to define, e.g. when the rainfall deficit over a prescribed period becomes greater than 20 percent of the long-term average rainfall over that period. Are 'mild droughts' included in the drought events? For example, when the rainfall deficit is only 15 percent of the long-term average. Further, what is the minimum area affected that constitutes a 'drought'. Widespread droughts are easy to classify, what about smaller areas?

- In terms of the average number of people killed per disaster, floods are most hazardous in Cambodia and Thailand (87 and 44 people/event respectively), whereas storms are the most hazardous disaster in Lao PDR and Viet Nam (14 and 146 people/event respectively).
- In terms of average economic costs per event, floods and droughts are closely equal and preeminent in both Cambodia and Thailand (about USD 26 M and USD 70 M per event respectively). The pre-eminent event in Lao PDR is storm[4] (USD 76.5 M per event), whereas in Viet Nam it is drought (USD 129.8/event). It is noted that average flood and drought costs/event in Lao PDR are at more than an order of magnitude less than in the other three countries.

2.1c Average Annual Impacts of Disasters

By combining the probability of occurrence of disasters in each country (Table 2.1) with the average impact of disasters in each country (Table 2.2), the average annual value of disaster impacts (in terms of numbers of people affected, numbers of people killed and economic costs) can be estimated. These results are shown in Table 2.3. The following observations regarding average annual impacts are made:

- In terms of the average annual value of the number of people affected by disasters, floods affect the greatest number of people in Cambodia, Lao PDR and Thailand (an average of 0.45 M, 0.44 M and 0.92 M people pa respectively), whereas storms affect the greatest number in Viet Nam (1.42 M people pa). Floods also affect a significant number of people in Viet Nam (an average of 0.71 M people pa). Droughts affect large numbers of people in Thailand, Cambodia and Viet Nam (an average of 0.82 M, 0.31 M and 0.21 M people pa respectively). The average number of people affected by drought each year in Lao PDR is comparatively low (0.03 M pa).
- In terms of the average annual number of people killed in disasters, floods are the most deadly in Cambodia, Lao PDR and Thailand (an average of 54, 12 and 46 people pa respectively). In Viet Nam, an average of some 350 people pa are killed each year by storms and a further 144 people pa are killed by floods.
- In terms of the average annual economic cost of disasters, floods are the most expensive in Cambodia and Thailand (an average of USD 15.6 M and USD 127 M pa respectively). In Lao PDR, storms are the most expensive disaster (an average of USD 10.7 M pa), but as discussed above economic disaster impacts in Lao PDR are biased high by one large storm event (1993). The average annual value of economic cost of floods in Lao PDR is USD 0.82 M pa. In Viet Nam, the highest economic cost is associated with storm (an average value of USD 111 M pa). Flood costs in Viet Nam are also high (an average of USD 78.3 M pa)

Table 2.3 Average Annual Impacts per Disaster, Lower Mekong Basin

IMPACT	DISASTER	CAMBODIA	LAO PDR	THAILAND	VIET NAM
		1987-2007	1981-2008	1980-2008	1980-2008
No. People Affected (M)	Flood	0.45	0.44	0.92	0.71
	Drought	0.31	.03	0.82	0.21
	Storm	0	.33	0.11	1.42
No. People Killed	Flood	54	12	46	144
	Drought	0	0	0	0
	Storm	1.2	0.15	30	350

4 Disaster costs in Lao PDR are biased by (apparently) two major storm events in 1993 and 1995. The 1995 event affected the most number of people (1.0 M); the 1993 event caused the greatest economic loss in the reporting period (USD 302 M). The veracity of this information has not been checked.

IMPACT	DISASTER	CAMBODIA	LAO PDR	THAILAND	VIET NAM
		1987-2007	1981-2008	1980-2008	1980-2008
Economic Cost (USD M)	Flood	15.6	0.82	127	78.3
	Drought	6.62	0.04	14.9	22.1
	Storm	0.50	10.7	30.8	111

Source: UN, 2010.

2.2 Rice Growing in the Lower Mekong Basin

2.2a Rice Production

Rice is the main agricultural crop of the LMB; it is essential for the livelihoods and sustenance of tens of millions of people, many of whom eke out a rice-based subsistence living. An understanding of rice production practices is essential to discussing the impact of floods and droughts on rice cultivation. Up to three rice crops can be grown a year in the LMB, but this is only realized to a significant degree in the Cuu Long Delta, where water management is more widespread and effective than in the other three riparian countries (60 percent of the lowland rice crop area of the Cuu Long Delta is irrigated compared to around 10 percent or less in the other three riparian countries).

Table 2.4 shows the rice production details in the four countries of the LMB over the decade 2000-09. Note that the figures for Thailand and Viet Nam are whole of country figures. Regarding the LMB, the Cuu Long Delta of Viet Nam produces some 52 percent of the country's total rice output (Maclean et al, 2002); North-eastern Thailand `accounts for some 56 percent of the country's rice growing area and produces some 46 percent of Thailand's rice, (Yoshino, 2001; Naklang, 2005). Thailand and Viet Nam are major rice exporters, exporting 9.0 MT and 5.2 MT respectively in 2008. These figures amount to respectively 32 percent and 15 percent of each country's total annual production for 2008. Nearly all of the rice exported from Viet Nam comes from the Cuu Long Delta. In contrast, Cambodia has only recently commenced the export of rice (0.4 MT in 2008 or six percent of total production), and Lao PDR PDR, where most rice farming is subsistence-based, has never exported rice in significant quantities.

Table 2.4 Rice Production Details, Lower Mekong Basin, 2000-09

COUNTRY	YEAR	PLANTED AREA (1000 HA)	PRODUCTION (1000 TONNES)	YIELD (TONNES/HA)
Cambodia	2000	1,903	4,026	2.12
	2005	2,414	5,986	2.48
	2009	2,650	7,349	2.77
Lao PDR	2000	719	2,201	3.06
	2005	736	2,568	3.49
	2009	875	3,167	3.62
Thailand	2000	9,891	25,844	2.61
	2005	10,224	30,291	2.70
	2009	10,720	30,303	2.83
Viet Nam	2000	7,666	32,529	4.14
	2005	7,329	35,790	4.72
	2009	7,290	36,053	4.95

Source: IRRI, 2003a.

2.2b Rice Growing

Rice is grown in a number of different ways across the LMB, depending on crop location (*Lowland* or *Upland*) and the method of watering (*Rainfed*, *Deepwater* or *Irrigated*). In fact, there are variations on these three watering systems: in flood-prone areas, rice will be planted on the rising limb of the flood wave to be watered initially by rainfall and then by rising flood waters (it is being hoped that the waters do not rise too high and kill the crop or reduce yield (a 'bad' flood). Rice will also be planted on the recession limb of the flood wave to be watered by locally trapped floodwaters or rainfall. These rice productions systems are lumped under 'rainfed systems'. Table 2.5 shows the details of the rice growing systems in the four countries of the LMB[5]:

- In *Cambodia*, rainfed lowland rice accounts for three quarters of the total production, followed by irrigated rice (16 percent). Cambodia has the greatest proportion (eight percent) of deepwater rice, which is grown around the Great Lake and in the area where the Mekong and Bassac Rivers cross the Viet Nam border.
- *Lao PDR* has the highest proportion (15.3 percent) of rainfed upland rice production, which together with rainfed lowland rice (74.7 percent), accounts for 90 percent of the total rice production. Some 10 percent of Lao's production is from irrigated rice. This proportion has been increasing in recent years as the Government fosters increasing numbers of small scale irrigation schemes.
- In *Northeast Thailand*, rainfed production is again the dominant system, with lowland systems (82 percent) and upland systems (10 percent) again accounting for over 90 percent of total production. The remaining eight percent of production in Northeast Thailand is from irrigated rice.
- In the *Cuu Long Delta*, the dominant production systems are irrigated rice (52 percent) and rainfed lowland rice (45 percent). The amount of deepwater rice now grown in the Delta is negligible, but in 1983 there was some 300,000 ha that have been progressively replaced with irrigated rice.

Thus, in Lao PDR, Northeast Thailand and Cambodia, rice production is overwhelmingly by rainfed systems, predominately lowland. In the Cuu Long Delta, production is about evenly split between irrigation and rainfed rice, again predominately lowland rainfed rice. A significant proportion of rice in Cambodia is produced by irrigation, but irrigated rice production in both Northeast Thailand and Lao PDR is 10 percent or less.

Table 2.5 Rice Growing Systems in the Lower Mekong Basin, 2000-2004

COUNTRY	UPLAND RICE	LOWLAND RICE			TOTAL RICE AREA (1000 HA)
	RAINFED	RAINFED	DEEPWATER	IRRIGATED	
Cambodia[a]	1%	75%	8%	16%	2,347
Lao PDR[a]	15.3%	74.7%	0%	10%	691
Thailand[a]	1.7%	72.8%	0.5%	25%	10,097
NE Thailand	10%	82%	0%	8%	5,930
Viet Nam[a]	5%	39%	3%	53%	7,366
Cuu Long Delta	2.5%	45.5%	~ 0%	52%	4,121

Source: IRRI 2003b, IRRI 2003c, IRRI 2003d, IRRI 2003e, Bell and Seng 2004, MRC 2003e, Bestari et al, 2006, Pandey et al, 2007.
[a] Whole of Country

[5] There are differences, significant at times, between the estimates contained in the various references. The figures in Table 3.4 are value judgements based on this information.

2.2c Cropping Calendars

Finally, Table 2.6 shows the rice cropping calendars for the four riparian countries of the LMB (IRRI, 2003e), i.e. when rice is planted, grown and harvested. Note that three rice crops are grown in the Cuu Long Delta, but only two crops in Cambodia, Northeast Thailand and Lao PDR[6]. Three crops[7] are possible in the Cuu Long Delta because of more extensive and effective water management. Local conditions determine differences in planting and harvesting times between the four countries.

Table 2.6 Rice Cropping Calendars, Lower Mekong Basin

Country	Crop	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
			Summer			Autumn			Winter			Spring			Summer			Autumn			
Cambodia	1			■	■	■	■	■	■	■	■										
	2									■	■	■	■								
Lao PDR	1			■	■	■	■	■	■	■											
	2									■	■	■	■	■	■						
Northeast Thailand	1			■	■	■	■	■	■	■	■										
	2										■	■	■	■	■	■	■				
Cuu Long Delta	1		■	■	■	■	■	■	■	■	■	■									
	2									■	■	■	■	■	■						
	3													■	■	■	■	■	■	■	

Source: IRRI, 2003f, Bestari et al, 2006

6 According to IRRI, 2003f, only one crop is grown in Lao PDR per year, but this appears inconsistent with the situation in Northeast Thailand, where two crops are grown. Irrigation will allow production of a dry season crop in Lao PDR, as stated by Bestari et al, 2006.

7 Crop No.1, the Winter Crop, is sown to 0.6 M ha; Crop No. 2, the Spring Crop, is sown to 1.45 M ha; and Crop No. 3, the Autumn Crop is sown to 1.95 M ha (IRRI, 2003c.

3 Floods and Flooding in the Lower Mekong Basin

3.1 Background

To facilitate the discussion of floods and flooding, the Mekong Basin (MB) has been divided into four river reaches, two floodplain reaches and adjacent tributary areas, as shown in Table 3.1 and Figure 1.

- The first river reach covers the Upper Basin or Lancang Basin (as it is called in China) and is not discussed further.
- The remaining three river reaches, the *Upper*, *Middle* and *Lower Reaches* of the LMB, span the 1,750 km length of the Mekong from Chiang Saen on the Lao PDR-China border to Kratie in Cambodia. The Upper Reach (x km) runs from Chiang Saen to Vientiane/Nong Khai; the Middle Reach runs from Vientiane/Nong Khai to Mukdahan; and the Lower Reach runs from Pakse to Kratie.
- The river reaches are followed by the two floodplain reaches, the *Cambodian Lowlands* and the *Cuu Long Delta* of Viet Nam.
- The tributaries of the Upper Reach rise in the Northern Highlands of Lao PDR and Myanmar.
- The Eastern tributaries of the Middle and Lower River Reaches rise in the Eastern Highlands of Lao PDR, North-eastern Cambodia and Viet Nam, and include the 3S catchments (Se Kong, Se San and Sre Pok). The western tributaries of the Middle and Lower River Reaches principally drain the relatively flat Khorat Plateau of Northeast Thailand (the Khong and Mun Chi Basins).
- The tributaries draining the Cambodian Lowlands are minor, except for Tonle Sap River, which connects the Bassac River to the Great Lake.
- There are no tributaries of significance in the Cuu Long Delta of Viet Nam, which is criss-crossed by a network of irrigation and drainage channels.

Table 3.1 River Reaches and Tributary Areas of the Mekong River Basin

RIVER REACH	WESTERN TRIBUTARIES	MEKONG RIVER	EASTERN TRIBUTARIES
1. Lancang Basin (Upper Basin)	Medium Size.	Headwaters in China to Chiang Saen	Medium Size.
2. Upper Reaches	Small Size. Rise in Northern Highlands of Lao PDR and Myanmar.	Chiang Saen to Vientiane/Nong Khai	Large Size. Rise in Lao PDR (Northern Highlands).
3. Middle Reaches	Medium Size. Khong Basin of Khorat Plateau, Thailand.	Vientiane/Nong Khai to Mukhadan	Medium Size. Rise in Lao PDR (Eastern Highlands).
4. Lower Reaches	Large Size, but flat. Chi and Mun Basins of Khorat Plateau, Thailand.	Mukhadan to Kratie	Large. Rise in Lao PDR and Viet Nam (Eastern Highlands). Includes 3S catchments
5. Cambodian Lowlands	Minor Size. Rise in Kravanh Range, Cambodia. Includes Ton le Sap.	Kratie to Cambodian-Viet Nam Border	Minor Size. Rise in low hills around the Cambodian-Viet Nam border.
6. Cuu Long Delta	No defined tributaries; only floodplain and built channels.	Cambodian-Viet Nam Border to South China Sea	No defined tributaries; only floodplain and built channels.

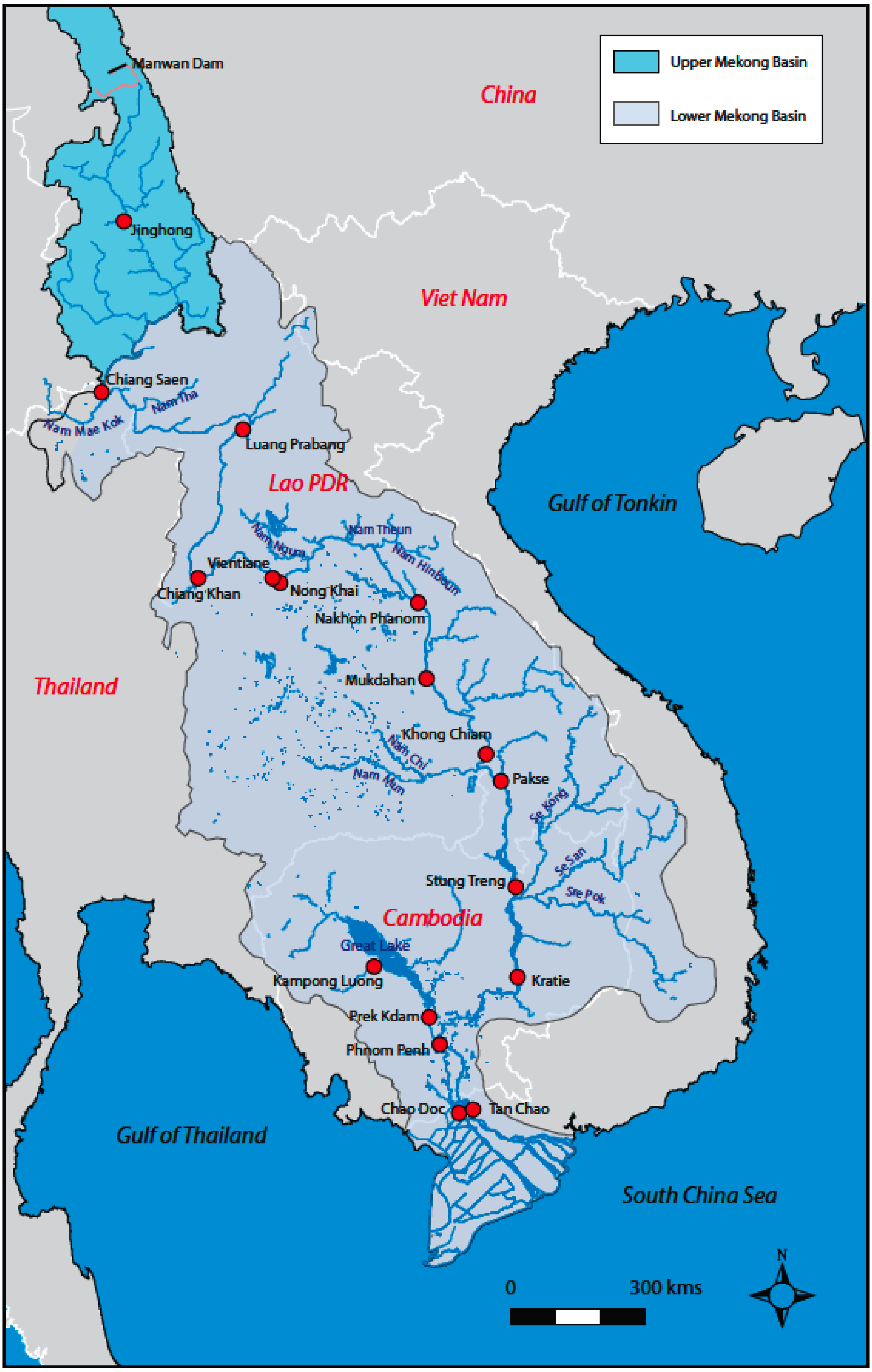


Figure 3.1 *The Mekong Basin*

3.2 Causes of Floods

Floods in the LMB are driven principally by rainfalls associated with two major weather phenomena: the widespread and extended rains of the Southwest monsoon, and shorter, more localized rainfalls generated by the remnants of tropical weather systems (TWSs) moving westwards into the LMB after land-falling principally on the Northern and Central coasts of Viet Nam[8].

3.2a **Southwest Monsoon**

The annual wet season winds of the Southwest Monsoon, passing over the Andaman Sea and Myanmar, deliver moisture from the Bay of Bengal to the LMB, causing widespread, heavy and extended rainfalls, typically from May to October.

3.2b **Tropical Weather Systems**

Westward-tracking tropical depressions, storms and cyclones (collectively called TWSs), generated in the western Pacific Ocean, the South China Sea and occasionally in the Andaman Sea, are annual synoptic phenomena. Typically, four-six TWSs landfall on the Vietnamese coast each year, most commonly during the period August to November, migrating southwards from the Northern to the Central coast as the cyclone season develops (see Figure 3.1). After land-falling, TWSs continue westward to enter the LMB, where they can deliver regional high intensity rains to all parts of the LMB, but especially the Northern Highlands and the catchments of the Se Kong, Se San and Sre Pok (3S) rivers, which drain the area of the Eastern Highlands around Southern Lao PDR, Northwest Cambodia and Viet Nam.

TWSs initially cause flooding in Mekong tributaries, especially those draining the Northern Highlands, the 3S basins of the Eastern Highlands and the Khorat Plateau of Thailand (see Figure 3.1). On entering the Mekong, these tributary floods travel downstream as separate flood crests, piggy-backing on the underlying southwest monsoonal flood wave, where they amplify the peak water level, discharge and volume of the mainstream flood wave and sustain flood duration. (This behaviour is readily apparent in the flood hydrographs Boxes 1, 2 and 3).

3.3 Types of Floods

A flood can be defined as

> *"relatively high water levels caused by excessive rainfall, storm surge, dam break or tsunami that overtop the natural or artificial banks in any part of a stream, river, estuary, lake or dam; and/or local overland flooding before surface runoff enters a watercourse; and/or inundation resulting from super-elevated sea levels and/or waves overtopping the coastline or the banks of an estuary[9]".*

The LMB is exposed to eight different types of floods, as shown in Table 3.2, each with its own characteristic behaviour and degree of hazard. Rainfall-induced floods have been briefly described in Section 1, but floods can also be of a dam-related and maritime origin. In the LMB,

---

8 Occasionally TWSs skirt or landfall on the Cuu Long Delta or enter the northern areas of the LMB after land falling in Southern China, where they can cause heavy regional flooding.

9 This definition is a combination of the definitions of 'flood' presented in 'Floodplain Management in Australia' (SCARM, 2000) and 'Floodplain Development Manual: The Management of Flood Liable Land' (DIPNR, 2005).

maritime floods are limited to the coastal and estuarine areas of the Cuu Long Delta of Viet Nam.

3.3a Rainfall Floods

Mainstream Floods

Mainstream floods occur when excessive rainfall causes the Mekong River to overflow its banks. Typically, the mainstream flood season is from June to November, with flood levels peaking in August-September (Boxes 1, 2 and 3). In the Middle and Lower River Reaches of Lao PDR and Thailand, mainstream floods inundate the relatively narrow Mekong floodplains for 1-2 weeks or thereabouts and cause backwater flooding along the Lower Reaches of tributaries. In Cambodia and Viet Nam, mainstream floods inundate vast areas of the Cambodian Lowlands and the Cuu Long Delta to depths of 3 m and more for periods of 2-4 months or longer. In 1998, when the mainstream flows and flood levels were amongst the lowest recorded in recent times (see Figure 3.3), some 26,000 km^2 of Cambodia and Viet Nam were flooded; in 2000, when flooding across the Cambodian Floodplain and Cuu Long Delta was the most severe in the last 20-50 years (see Figure 3.3), some 45,000 km^2 were inundated (MRC, 2005a).

Mainstream floods passing through Cambodia and into Viet Nam are moderated by 'the Great Lake' of Cambodia, which reduces downstream flood levels and extends the duration of the flood season by storing an average of 30 km^3 of water on the rising limb of the mainstream flood wave and returning this water, plus local wet season inflows, on the recession limb of the flood. During this process, the surface area of the Great Lake swells from a dry season average of 2,500 km^2 to a wet season average of 15,000 km^2 (MRC, 2005a).

Table 3.2 Floods of the Lower Mekong Basin

FLOOD		CAUSE	CHARACTERISTICS
CATEGORY	NAME		
Rainfall	Mainstream	Excessive RF over Mekong Basin catchment.	Generally slow onset and slow moving. Average annual flood volume flowing into South China Sea is 460 km^3. Duration can last for 2-4 months.
	Tributary	Excessive RF over Tributary catchments.	Rapid onset and fast moving because of small, steep catchments. Duration typically several days to one-week.
	Local	Excessive RF over Local Catchments.	Rapid onset. More of a nuisance and less hazardous than Mainstream and Tributary floods. Duration typically hours to one-day.
Dam-Related	Dam release	Excessive Release of Water from Dams.	Onset can be rapid and unexpected, especially for emergency releases. Hazard levels can be high.
	Dam break	Structural Failure of Dams.	Immediate onset and rapid increase in water levels. Destructive velocities and extreme hazard.
	Dike breach	Structural Failure of Dikes.	Similar to a Dam break flood, but water levels and hazard tempered somewhat by generally low height of dikes.
Maritime	Storm Surge	Tropical Cyclones, Depressions & Storms.	Slow onset. High water levels and flood, wind and saltwater damage can occur. Can be very hazardous.
	Tsunami	Undersea Earthquakes.	Immediate onset. Extreme and immediate increase in water levels. Very destructive and extremely hazardous.

Tributary Floods

Tributary floods occur when excessive rainfall causes Mekong tributaries to overflow their banks. Three types of tributary floods can be distinguished: '*flash floods*', '*combined floods*' and '*landslips*'. A flash flood can be defined as

> "*Sudden and unexpected flooding caused by local heavy rainfall or rainfall in another area of the catchment often defined as flooding that occurs within six hours of the onset of the flood-generating rainfalls*". (DIPNR, 2005)

In the LMB, all floods in steeper Upper and Middle Reaches of tributaries can be considered to be 'flash floods'[10]. Significant floodplains have developed around the confluence of the Mekong and its tributaries. These areas are subject to combined flooding from both mainstream and tributary floods and to backwater flooding from mainstream floods. 'Landslips' are rainfall-induced landslides or mudslides that occur in the relatively steep upland areas of the LMB and often accompany tributary floods. Landslips occur because of slope instability and happen abruptly and with little warning. Although not floods per se, they are treated as 'floods' because they generally occur in concert with tributary floods. Landslips are frequently more hazardous and destructive than any accompanying tributary flood. In 2001, landslips in Phetchabun province of Thailand, which is adjacent to the Western edge of the Khorat Plateau, caused about 100 deaths.

Local Floods

Local floods occur when runoff from heavy rainfalls overwhelms the local (typically urban) drainage system. Local floods are generally of a 'nuisance' nature: they affect relatively small areas and are generally characterised by shallow flood depths, low flood velocities and low hazard.

3.3b Dam-Related Floods

Dam Release Floods

Dam release floods occur when released water from a dam overtops the banks of the receiving stream. Day to day dam releases, for hydroelectricity generation and other purposes generally do not constitute a 'flood'. However, to cater for an incoming flood in an emergency situation, it can be necessary to release high discharges, which can flood downstream communities and imperil lives. In recent years there have been several instances of serious dam release flooding in the LMB; lives have been lost, as have riverside gardens and possessions. Dam release floods are largely controllable; their frequency, size and impact should be assessed during the investigation phase of a new dam. Appropriate inflow forecasting and dam operations minimize the need for emergency releases. If necessary, warning systems can be installed to alert downstream communities of unexpected releases.

Dam break Floods

Dam break floods occur when a dam wall breaches because of overtopping, structural failure or the undermining of its foundations. Because of its high water velocities and a rapid and extreme rises in water levels, a dam break flood wave can cause catastrophic damage and extreme flood risk as it races downstream. To date, no dam failures have occurred in the LMB, but proposed dam building programs in China, Lao PDR, Cambodia and Viet Nam will increase the number of dams. The risk of dam failure can be controlled (i.e. reduced to an acceptably small level) by ensuring that dams are built to strict design, construction and maintenance standards and are

[10] In the LMB, 'flash flooding' is synonymous with tributary flooding, even when tributary flooding is not strictly 'flash' in nature.

appropriately monitored during their life. Spillway capacities should be regularly checked and enlarged if found wanting. These days, it is usual to undertake a ‘dam break analysis’ of both new and existing dams to assess the hazard of the resulting flood wave to downstream communities should the dam fail, and to put in place emergency management measures if necessary.

Dike Breach Floods

Dike breach floods occur when flood protection dikes fail or breach in a similar way as described for dams. The dikes that protect flood-prone areas of the LMB are typically 2-5 m high, and whilst much lower than dams, dike breach floods can impose significant risks to people and assets within ‘protected’ areas. The likelihood of dike breach floods can be minimized by appropriate design, construction, maintenance, and monitoring.

3.3c **Maritime Floods**

Storm Surge Floods

Storm surge floods occur when storm-induced increases in coastal water levels inundate coastal and estuarine areas. Such storms include the tropical weather systems (TWSs) described in Section 3.2b. Coastal water levels are raised by the effects of reduced atmospheric pressure of the storm and by the action of onshore winds and storm-driven waves pushing water against the coast (see MRC, 2007b). In the LMB, only the coastal waters of the Cuu Long Delta and the Lower Reaches of its waterways are exposed to storm surge flooding. The northern and central coastal regions of Viet Nam are considerably more prone to storm surge effects of TWSs than the Cuu Long Delta. Over the 49-year period, 1945-98, the coastal provinces of the Delta were affected by TWSs on only 5 occasions, predominately in October and November (DMU, 2005). Notwithstanding their rarity, even a modest storm surge will increase flood levels in the delta reaches of the Mekong and Bassac rivers, perhaps substantially if it coincides with mainstream flooding.

Tsunami Floods

Tsunami floods are caused when the ocean floor is thrust up or down by an undersea earthquake, the greater the movement of the ocean floor, the higher the resultant tsunami waves. In the LMB, Tsunami Flooding is limited to the coastline of the Cuu Long Delta and the Lower Reaches of the Mekong and Bassac Rivers. The risk of significant tsunami flooding around the coast of the delta is small to very small: locally generated tsunamis would be less than 0.5 m high; substantial tsunamis generated around the Philippines would be moderated by the favourable orientation (approximately East-west) of the coastline of the delta (MRC, 2007b).

3.4 Extent of Flooding in the Lower Mekong Basin

As noted earlier, floods can occur anywhere in the LMB if conditions re correct. Figure 3.2 shows indicative areas of the LMB affected by the various types of floods described above.

3.5 Factors Exacerbating Flooding

3.5a **Tides in the South China Sea**

Flooding in the Cuu long Delta is worsened by tides in the South China Sea, which have a tidal range of 2.5 - 3.0 m. During the flood season, flood levels at Tan Chau and Chau Doc, close to the border of Cambodia and Viet Nam and some 190 km upstream from the coast, are raised by ocean tides. Whilst this may be of little significance during a major mainstream flood, high astronomical tides by themselves can cause flooding in certain low-lying areas of the Delta (as happened in 2008).

3.5b Continuing Rainfall

Flooding across the Cambodian Lowlands and Cuu Long Delta is sustained by continuing rainfall, especially during the period November-December, when receding flood levels of 30-50 mm/day can be offset by daily rainfalls of this amount.

3.6 Flood Severity

There are several ways of depicting the severity of mainstream floods (and droughts) in the MB. This can be done in terms of the frequency distribution of peak annual flood levels at various gauging stations along the Mekong River[11] , or the frequency distributions of peak annual discharges and annual flood volumes, either independently or jointly. Alternatively, the number of days spent above nominated water levels (stage-duration curves) can be used to depict flood severity. Figure 3.4 shows stage-duration curves for annual mainstream floods over the period 2000-2008 at four locations:

- Vientiane and Kratie on the Mekong River in Lao PDR and Cambodia respectively;
- Prek Kdam on the Tonle Sap River in Cambodia; and
- Tan Chau on the Mekong River in the Cuu Long Delta.

Also shown on these diagrams are the ‘alarm’ and ‘flood’ water stages: *Alarm Stage* alerts authorities of a possible flood and the need to make initial preparations; *Flood Stage* indicates that a flood is occurring and may become more severe. The diagrams indicate that over the period 2000-2008, the Year 2008 Flood was the worst flood at Vientiane (flood levels peaked at about 1 m above flood stage and remained above flood stage for 6 days); the 2000, 2001 and 2002 Floods were all major flood events at Kratie (although none of these floods rose above flood stage); the Year 2000 Flood was the worst event at Prek Kdam (flood levels peaked at 0.34 m above flood stage and remained above Flood Stage for 20 days); the 2000, 2001 and 2002 Floods all exceeded Flood Stage at Tan Chau and remained above Flood Stage for up to 65 days. Conversely, it is easy to see the floods that didn’t cause problems at the various sites (e.g. the Year 2003 and 2007 Floods were minor floods of little significance at all four sites).

[11] See Figure 3.3, which clearly depicts the severity of the Year 2000 Flood at Tan Chau.

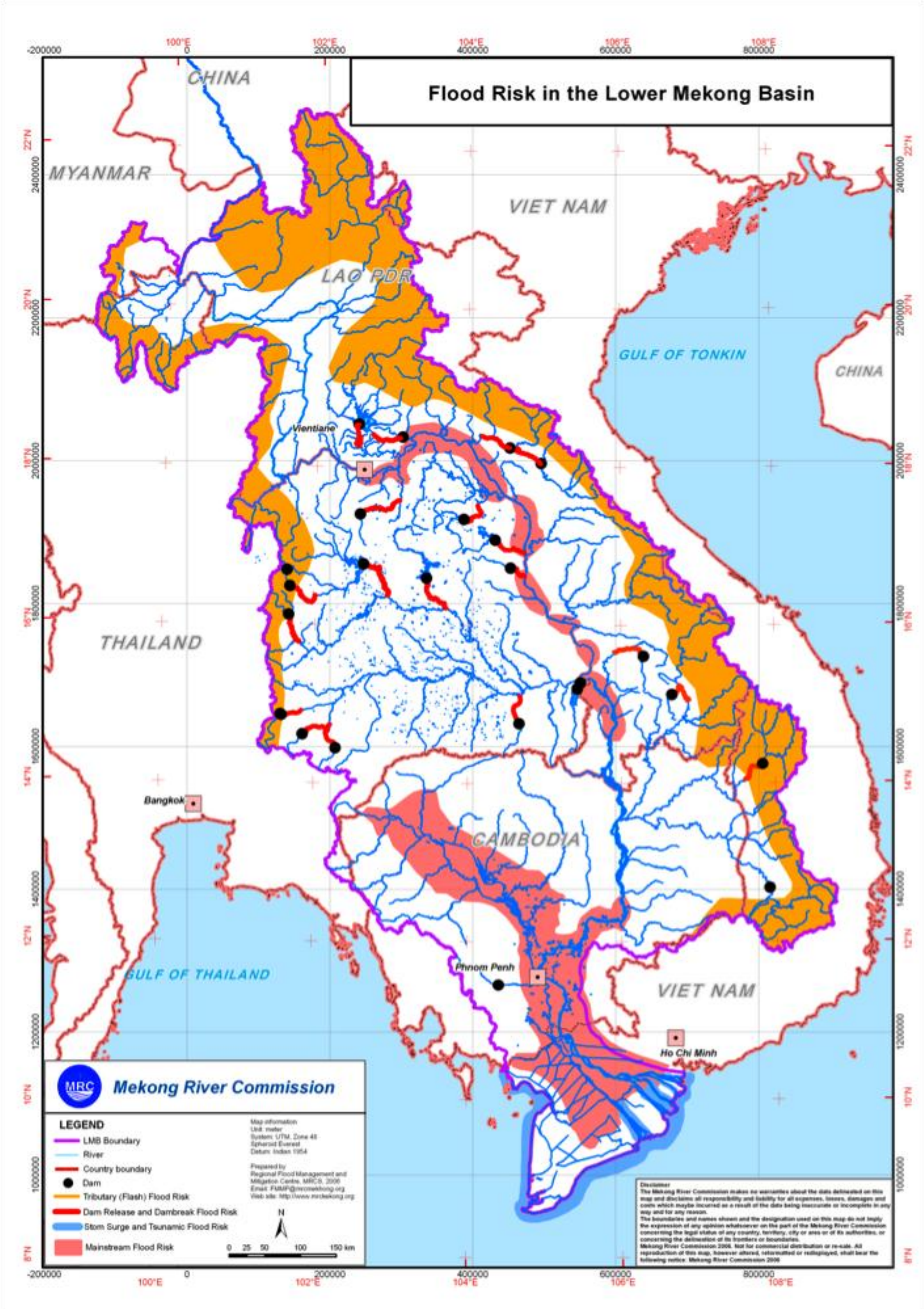


Figure 3.2 Indicative Areas of Flooding, Lower Mekong Basin

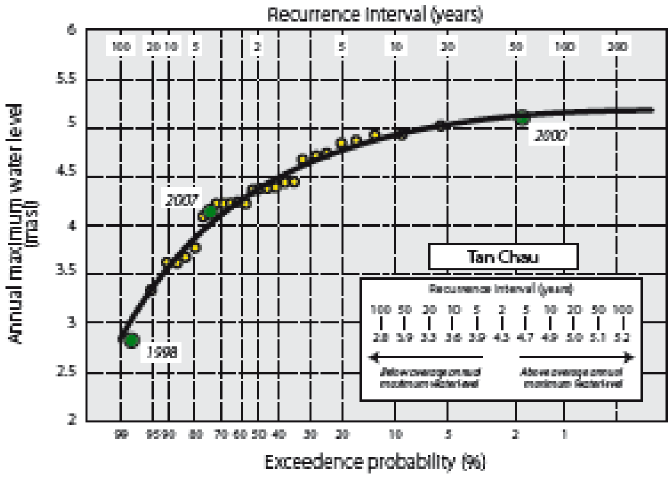


Figure 3.3 Frequency Distribution of Peak Annual Flood levels at Tan Chau[12]

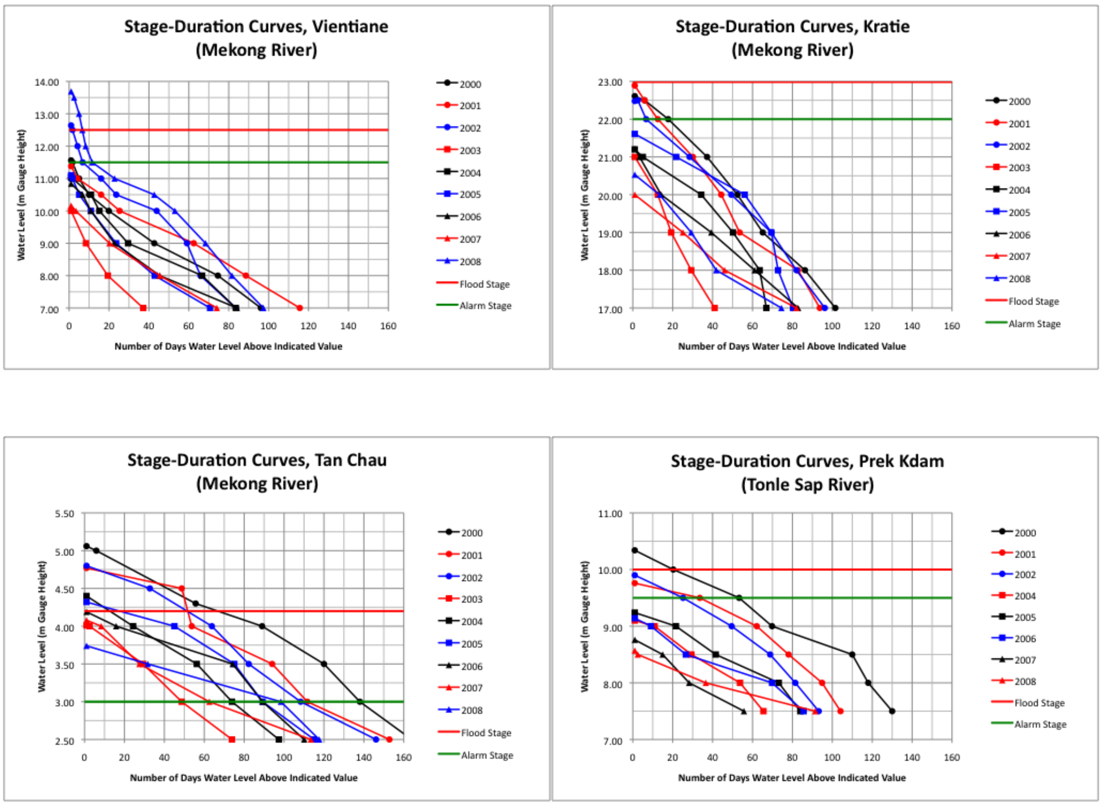


Figure 3.4 Stage-Duration Curves, Lower Mekong Basin

[12] Source: MRC (2008)

Box 1: The Year 2000 Floods

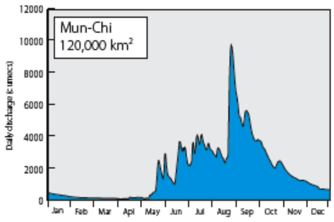
The Floods of 2000 were characterized by extreme flooding of deep and of extended duration across the Cambodian Lowlands and the Cuu Long Delta (347 people killed in Cambodia, 481 killed in Viet Nam), accompanied by widespread and severe flash flooding across the Khorat Plateau of Thailand (25 deaths) and in the Northern and Eastern Highlands of Lao PDR (15 deaths).

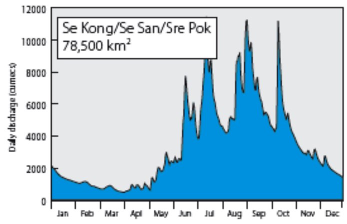
The Floods of 2000 arose from rainfalls associated with the South-west Monsoon, an active low pressure system over the central regions of the LMB, coupled with TD-04W (1 June), TS Kaemi (23 August) and TC Wukong (10 September).

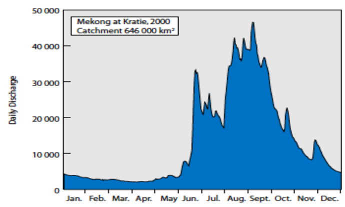
- In June, heavy rain associated with Tropical Depression 04W fell in the Northern Highlands and along the central and Southern provinces of Lao PDR (see below). In July and early August, heavy rains fell over central Lao PDR and the Khorat Plateau.
- Around 23 August, this situation was exacerbated by widespread heavy rains associated with the arrival of TS Kaemi over the central provinces of Lao PDR and the Khorat Plateau, after crossing the central coast of Viet Nam around Da Nang.
- The rainfall and flooding situation was further worsened by the arrival of TC Wukong on 10 September, which delivered heavy rains to the Khorat Plateau, the central and Southern provinces of Lao PDR and the North-eastern provinces of Cambodia. The rains of TC Wukong amplified the mainstream flood wave as it moved into Cambodia and sustained the extended flooding over the Cambodian Lowlands and the Cuu Long Delta.

This rainfall behaviour is evident in the three discharge hydrographs shown below. In the Mun Chi catchments of the Khorat Plateau, TS Kaemi generated the outflow spike into the Mekong in August; the impact of TC Wukong in September is muted in these catchments. The outflow from the '3S' catchments of Southern Lao PDR, North-eastern Cambodia and the Eastern Highlands of Viet Nam is more complex, with major outflow events in June, July, August-September and October. The peaks in June (TD-04W) and July are associated with the earlier rainfall events; outflows associated with TS Kaemi and TC Wukong are seen in August-September; the peak in October was caused by TS-28W, which skirted the Viet Nam coastline (6-13 October). Finally, further downstream at Kratie, the discharge hydrograph has coalesced and subsumed into two major peaks, one in June and the other in August-September, although lesser peaks from TS-28W and TS Rumbia (8 December) are apparent in October and December.

Reference: MRC, 2005a, MRC 2006a, MRC 2007a, MRC 2007c.








Tropical Depression 04W (June)


Tropical Storm Kaemi (August)


Tropical Cyclone Wukong (September)


Tropical Storm 28W (October)


Tropical Storm Rumbia (December)

Box 2: The Year 2006 Floods

The Floods of 2006 were comparatively modest and occurred in different places across the basin (Northern Highlands, Southern area of the Eastern Highlands and the Great Lake). The South-west Monsoon was subdued; the principal driver of 2006 flooding was tropical storms. Mainstream flood volumes were below average, often significantly so, especially in the Lower Reaches and across the Cambodian Lowlands and Cuu Long Delta.

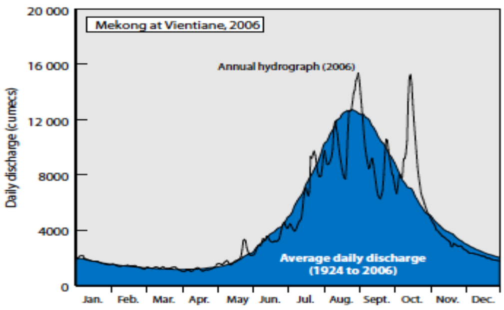
In addition to the South-west Monsoon, three tropical storms spawned in the western Pacific to the east of the Philippines were the principal agents of flooding during 2006.

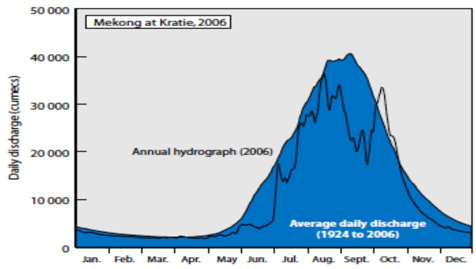
- In the last week of August, TS Prapiroon crossed the south China coast and moved into the lower reaches of the Upper (Lancang) Basin in August, causing flash flooding in Luang Namtha, the northernmost province of Lao PDR, where 132 villages were inundated, and in the Kok and Ing Basins of Chiang Rai province in northern Thailand (3 people killed).
- TS Xangsane crossed the central coast of Viet Nam (Da Nang City) on 1 October, passing over Southern region of Lao PDR and the Khorat Plateau of Thailand, where it degenerated into a widespread tropical depression before moving further westwards across Thailand and offshore into the Andaman Sea. TC Xangsane caused flash flooding in Attepeu province, the Southernmost province of Lao PDR, where 270 villages were inundated and five people were killed, and in the Kong, Chi and Mun Basins of the Khorat Plateau of Thailand (no fatalities), and was responsible for flood levels at Chau Doc and Tan Chau reaching their 2006 peaks (equal to about the average annual peak value). As it traversed the LMB, Xangsane also caused extreme regional flooding in Cambodia around the Great Lake, where 11 people were killed.
- After causing massive destruction in the Philippines, TS Durian veered south-west and travelled along the coast of Southern Viet Nam and the Cuu Long Delta in early December before crossing the Malay peninsular and passing into the Andaman Sea. Durian caused significant damage and loss of life in coastal provinces to the north of the Delta. In the Delta itself, 19 deaths were recorded, but most appear to have been associated with strong winds rather than floods. Storm surge effects associated with TS Durian increased water levels along the coastline and flood levels in the delta reaches of the Mekong and Bassac Rivers.

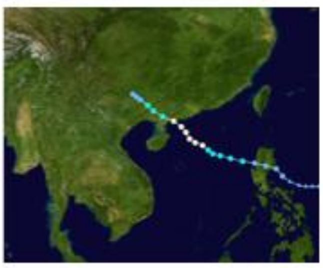
In August and September, spring tides caused (worsened) mainstream flooding in Dong Thap province of the Cuu Long Delta.

The 2006 flood hydrographs of the Mekong River at Vientiane and Kratie are shown below. The flood volume at Vientiane is about average, the volume at Kratie is less than average; the two discharge spikes associated with TSs Prapiroon and Xangsane are readily evident in both hydrographs

Reference MRC, 2007c

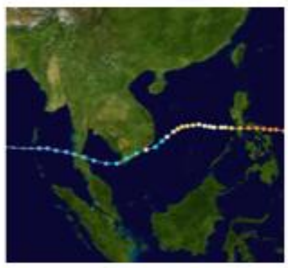






Tropical Storm Prapiroon (Aug)

Tropical Storm Xangsane (Oct)



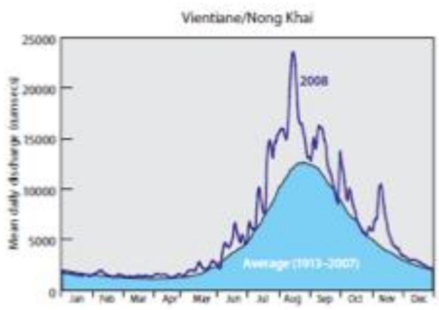
Tropical Storm Durian (Dec)

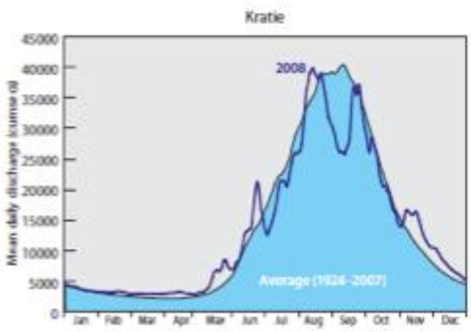
Box 3: The Year 2008 Floods

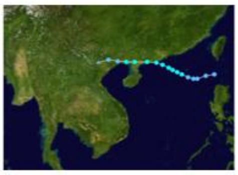
The Floods of 2008 were characterized by high mainstream flood levels (the highest in 30 years) along the Upper and Middle Reaches of the Mekong in Lao PDR and Thailand, some limited flash flooding in the Northern Highlands of Lao PDR and in the Eastern Highlands of Viet Nam and Cambodia, and no mainstream flooding of significance across the Cambodian Lowlands or the Cuu Long Delta.

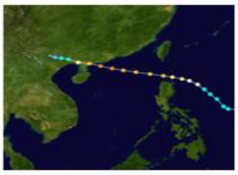
- In June, heavy monsoonal rains caused flash flooding along tributaries draining the central provinces of Bolikhamxay and Khammouane of Lao PDR (see discharge hydrograph at Kratie). In July, flash floods occurred along the Nam Lik and Nam Song rivers of Northern Lao PDR (accompanying landslides caused four deaths).
- In mid-August, TS Kammuri crossed the Leizhou Peninsular, entering Southern China and Northern Viet Nam to deliver heavy widespread rains over the Northern Highlands upstream of Luang Prabang, causing extensive mainstream flooding along the Upper and Middle River Reaches of the Mekong in Lao PDR and Thailand and backwater flooding along the Lower Reaches of tributaries. Peak discharge and annual flood volume were both significantly greater than median values at Luang Prabang and Vientiane. However, by the time the floodwave had travelled downstream to Kratie, it had subsided and peak discharge and annual volume were significantly less than their median values (MRC, 2009c). In Lao PDR, some 664 villages were affected; 3 people were killed. In Thailand, 2,300 villages were affected and 6 people were killed. Vientiane experienced its worst flooding in 30 years and only emergency sandbagging operations prevented greater damage.
- In September, Tropical Storms Hagupit and Mekkhala delivered further heavy rains to the Northern and Eastern Highlands respectively, to be followed in October by Tropical Storm 22W, which delivered heavy rain to the Eastern Highlands and the 3S catchments.
- In Cambodia, mainstream flood damage in 2008 was insignificant; flood levels did not exceed Alarm Stage anywhere along the Mekong or Bassac Rivers. Storms in September caused flash floods in several northern and Northwestern Cambodian provinces, damaging 10,500 ha of mainly rice crop.
- Flooding was also minor in the Cuu long Delta, although flood levels at Tan Chau and Chau Doc were above Alarm Stage, but not Flood Stage, for extended periods. Spring tides in October caused tidal flooding in Can Tho City. In May and August, there were flash floods in the Vietnamese area of the Eastern Highlands (Upper Sre Pok and Se San basins) resulting in five deaths a. In late November, TS Noul moved into the southeastern area of the LMB, causing further flash flooding in these Eastern Highlands catchments (and a further 2 deaths).

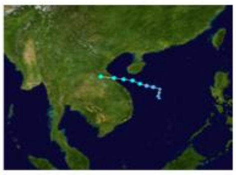
Reference: MRC, 2009c



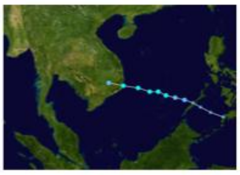



Tropical Storm Kamuri (Aug)


Tropical Storm Hagupit (Sep)


Tropical Storm Mekkhala (Sep)


Tropical Storm 22W (Oct)


Tropical Storm Noul (Nov)

3.7 Flood Risk

Table 3.3 shows a qualitative ranking of the relative risk (impacts) of the different types of floods in the LMB. Mainstream floods across the Cambodian Lowlands and Cuu Long Delta have the highest risk because of their widespread nature, the number of people affected and the long duration of flooding. The risk associated with tributary floods (of all types) is significantly smaller (fewer affected people, more localized). The risks associated with local, man-made and maritime floods are significantly smaller yet again (the likelihood of these floods occurring is very small).

Table 3.3 Relative Flood Risk in Riparian Countries of the Lower Mekong Basin

FLOOD	CAMBODIA	LAO PDR	THAILAND	VIET NAM
Mainstream	Very High	Medium	Medium	Very High
Tributary - Flash	Medium	High	Medium	Medium
Tributary - Combined	Medium	Medium	Medium	No Exposure
Tributary - Landslip	Small	Medium	Medium	Small
Local	Small	Small	Small	Small
Dam Release	Small	Small	Very Small	Small
Dam break	No Dam break Incidents have occurred in the LMB			
Storm Surge		No Exposure		Small
Tsunami		No Exposure		Very Small

3.8 The Cost of Floods

Floods disrupt the life and well-being of affected peoples in the LMB, reducing agricultural production (typically rice), curtailing income, fostering sickness and disease, damaging public infrastructure and private assets, interfering with schooling and generally sustaining poverty. Despite these adverse effects, people continue to live in flood-prone areas because of the fertility of the floodplain and population pressure (the population density of the Cuu Long Delta is some 450 persons/km2). Over time, the flood-prone peoples of the basin have learned (and in more recent years have been assisted by national governments) to ‘live with floods’ (see Section 6.3f).

The peoples of the LMB recognize both ‘good’ and ‘bad’ mainstream floods (there is no good side to flash floods). The Cambodian Lowlands and the Cuu Long Delta are the rice bowls of Cambodia and Viet Nam, producing some 12-14 B tonnes of rice per year. Other mainstream and tributary floodplains of the basin are also important for rice production. A ‘bad’ mainstream flood reduces rice production. Such a flood is characterized by one or more of the following: early onset, high water levels, extended duration or delayed recession, which reduce the yield of the preceding, current and following rice crops. Conversely, the enhanced rice production and other benefits of a ‘good’ (or normal) mainstream flood are considered to outweigh any residual adverse effects. Figure 3.5 shows the impact of the ‘bad’ floods of 2000, 2001 and 2002 on the value of agricultural production in the Cuu long Delta (MRC, 2009c). The floods depress the annual value of agricultural production by perhaps USD 200-300 M per year.

Table 3.4 shows the cost and impact of floods in the four riparian countries of the LMB over the period 2000-2008, as provided by official agencies in the four countries. There is no agreed standard for estimating flood impacts or the cost of flood damage in the four countries. The figures include direct costs to agriculture, public infrastructure and some private assets. The figures do not include indirect damages (the cost of business disruption, etc). As such, the figures of Table 3.4 should be considered indicative. Consistent and better flood damage estimation procedures are required for the LMB. Notwithstanding these shortcomings, the results of Table 3.4 indicate the broad impacts of recent floods in the LMB.

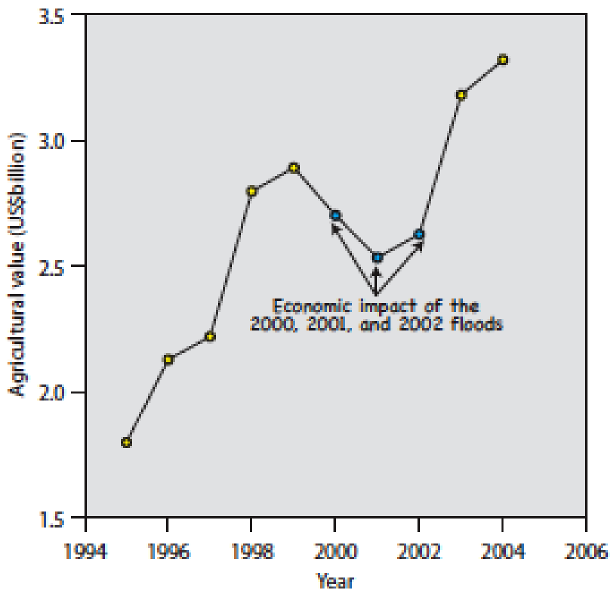


Figure 3.5 Effect of Recent Floods on Agricultural Production, Cuu Long Delta

3.8a Cambodia and Viet Nam

High levels of flood damage in Cambodia and Viet Nam are associated with mainstream flooding across the Cambodian Lowlands and Cuu long Delta. Flash flooding is relatively frequent in the 3S catchments of both countries, but the costs of flash flooding are much less than mainstream flooding. The mainstream flood of 2000 was especially severe ('bad') in Cambodia and the Cuu Long Delta: 800 people were killed, over 13 M were affected, and the total cost was over USD 400 M. Most of the deaths were children (up to 80 percent). The mainstream flood of 2001 was also severe in the Lowlands and Delta. The 2006, 2007 and 2008 mainstream floods were normal ('good') in Cambodia and the Cuu Long Delta, apart from severe regional flooding around the Great Lake in Cambodia caused by TS Xangsane in 2006 (see Box 2).

Table 3.4 also shows details of flooding in the Upper Reaches of the 3S catchments of Viet Nam (Eastern Highlands). The worst year was 2007, when 29 people were killed by severe flash floods in August and November. In early August, TD 06W grazed the central coast of Viet Nam off Binh Dinh province before moving away to the north, bringing heavy rainfalls to the 3S catchments and causing extensive flooding (3-day rainfalls of 300-600 mm were common). In mid-November, the remnants of TC Peipah crossed the South Vietnamese coast at Binh Tuan province before moving over the Southern area of the Eastern Highlands and causing repeat flooding in these catchments.

3.8b Lao PDR

Flood damage in Lao PDR is mainly associated with flash flooding in the Northern Highlands and in the northern and Southern regions of the Eastern Highlands, although backwater and combined flooding occurs in the Lower Reaches of Eastern Highland tributaries. From Table 3.4, it is seen that high flood damage occurred in the years 2001, 2002 and 2008. The Year 2001 Floods were a combination of mainstream and flash floods caused by TS Usagi, which moved into the Northern Highlands in early August. Damages in 2002 appear to be associated more with flash floods in the northernmost and central provinces of Lao PDR. Damages in 2008 were associated both with mainstream floods (damage to the urban area of Vientiane accounted for 45 percent of the total damage) and flash and combined floods along tributaries (see Box 3).

3.8c **Thailand**

Flood damage in Thailand is associated with flash floods in Chiang Rai province (Northern Thailand), mainstream flooding along the Mekong River, backwater flooding along the Lower Reaches of tributaries draining the Khorat Basin, and by poor drainage from the flat, Middle Reaches of Khorat Basin tributaries (see Boxes 1, 2 and 3). Table 3.4 shows two sets of flood impacts for Thailand: one for the country as a whole and the other (partial) for the LMB. Northeast Thailand can account for up to about 25 percent of the cost of flood damage for the whole country, but is more often a much lower proportion. From the data available, the Floods of 2000 and 2001 were severe for the portion of the LMB in Thailand. In 2000, there was widespread flooding over the Khorat Plateau associated with the southwest monsoon, TS Kaemi and TC Wukong (see Box 1). In 2001, the Khorat basin was flooded again, this time in response to TC Usagi. When TWSs move into the northern region of the Northern Highlands, flash flooding typically occurs in Chiang Rai province (as in 2005 and 2006).

3.8d **Average Annual Flood Damage**

The results of Table 3.4 can be used to provide an approximate estimate of average annual flood damage in the four countries. These results are shown in Table 3.5. As noted above, these costs include direct costs to agriculture, infrastructure and buildings, but not indirect costs[13]. Table 3.5 also shows assumed indirect flood damages in the four countries: 25 percent for the Delta, 20 percent for Cambodia and 15 percent each for Northeast Thailand and 10 percent Lao PDR. (These figures are presumed to reflect general differences in the extent and duration of flooding and levels of commercial development in the flood-prone area). The average annual damage for the LMB is thus estimated to be USD 61 M/year. Table 3.5 also shows recent MRC estimates of average annual flood damage (MRC, 2009c). The two sets of estimates are in reasonable agreement except for Thailand, where it appears that the MRC estimates are based on figures for the whole country rather than figures for Northeast Thailand. Both sets of estimates are approximate, and it can be inferred that the average annual damage for the LMB is USD 60-70 M/year and is concentrated in Viet Nam and Cambodia, which between them account for about two-thirds of the total.

3.8e **Health Hazards and Other Costs**

Floods are a threat to life and limb, although the hazard of death is generally small given the number of flood-affected people (see Table 3). Apart from economic costs and the physical danger of floods, outbreaks of water-borne diseases, such as leptospirosis, diarrhoea, gastro-intestinal diseases and conjunctivitis, often associated with stagnant floodwaters and unsafe drinking water, threaten the health of flooded peoples (MRC 2007c). An outbreak of leptospirosis in Thailand in the aftermath of the Year 2000 Flood killed 224 people (AFP, 2000).

The regular annual mainstream flooding of the Cambodian Lowlands and the Cuu Long Delta disrupts the schooling of many children, handicapping their future endeavours and sustaining poverty. In Cambodia, schools across the Cambodian Lowlands can be closed for up to 2 months each year (Helmers et al, 2004).

---

13 The indirect costs of a major flood to the Australian inland town of Nyngan amounted to two-thirds of the direct damage costs (SCARM, 2000). However, this figure reflects the urban nature of Nyngan and is not appropriate for the LMB.

Table 3.4 Annual Flood Impacts, 2000-2008, Lower Mekong Basin

Cambodia

Year	Cost (M USD)	People Killed	People Affected	Damaged Crops (ha)
1996	86.5	169	-	250,200
2000	161.0	347	3.4 M	421,600
2001	36.0	62	0.6 M	164,200
2002	12.5	-	1.5 M	45,000
2003	-	-	-	-
2004	55.0	-	-	247,400
2005	3.8	4	-	55,000
2006	11.8	11	-	14,500
2007[a]	9.0	10	147,200	9,500
2008[a]	5.8	-		18,900

[a] Damage in 2007 and 2008 in Cambodia was almost solely related to flash flooding.

Lao PDR

Year	Cost (M USD)	People Killed	People Affected	Damaged Crops (ha)
1996	10.4	-	-	67,500
2000	30.0	-	-	42,900
2001	56.0	-	-	42,200
2002	61.0	3	249,800	33,700
2003	18.3	-	-	800
2004	4.1	-	-	14,400
2005	18.3	5	480,900	56,000
2006	3.1	5	89,800	6,900
2007	18.0	2	118,100	7,500
2008	56.0[a]	7[b]	95,200	28,500

[a] Vientiane accounted for 45% of the total damage.
[b] Flash floods caused 4 deaths, mainstream floods 3 deaths.

Cuu Long Delta of Viet Nam

Year	Cost (M USD)	People Killed	People Affected	Damaged Crops (ha)
1996	113.0	-	-	-
2000	250.0	453	10 M	2.0 M
2001	99.0	393	1.0 M	-
2002	0.3	71	0.3 M	-
2003	15.0	23	-	-
2004	3.0	38	-	-
2005	3.5	44	-	-
2006	15.0	55	77,700	14,700
2007[a]	1.5	30	67,500	46,400
2008[a]	-	7	-	28,500

[a] Minimal damage in 2007, 2008.

Eastern Highlands of Viet Nam

Year	Cost (M USD)	People Killed	People Affected	Damaged Crops (ha)
1996	-	4	-	-
2000	-	>20	-	
2001	-	-	-	-
2002	3.0	2	-	9,000
2003	0.5	6	-	1,000
2004	-	-	-	-
2005	-	-	-	-
2006	-	0	-	130
2007[a]	50.8	29	-	20,300
2008	1.0	7	-	80

[a] Flood damage in LMB of Viet Nam in 2007 was predominately due to flash flooding in the 3S catchments.

Thailand (Whole Country)

Year	Cost (M USD)	People Killed	People Affected	Damaged Crops (ha)
1996	200	-	-	-
2000	280	-	-	-
2001	105	192	2.85 M	-
2002	375	-	-	-
2003	58	54	1.9 M	255,000
2004	24	32	2.3 M	528,000
2005	170	88	2.9 M	272,000
2006	202	340	5.2 M	897,000
2007	48	62	3.6 M	423,000
2008	72	97	4.5 M	1.21 M

Northeast Thailand (LMB)

Year	Cost (M USD)	People Killed	People Affected	Damaged Crops (ha)
1996				
2000	21.0	25	-	-
2001	23.9	34	660,000	-
2002				
2003				
2004				
2005	2.8	0	305,000	39,500
2006	6.8	-	-	-
2007				
2008				

References: MRC Annual Flood Forums (2002a, 2003a, 2005b, 2006b, 2007d, 2008b, 2009b) and MRC Annual Flood Reports (2006a, 2007c, 2008a, 2009c)

Table 3.5 Estimated Average Annual Flood Damage, Lower Mekong Basin

Country	Direct Damages (USD M)	Indirect damages		Total Damage (USD M)	MRC Estimates
		Percentage	USD M		
Lao DPR	10	10%	1	11	10
Thailand	6	15%	1	7	16
Cambodia	15	20%	3	18	25
Viet Nam	20	25%	5	25	25
Total	51	20%	10	61	76

3.9 The Benefits of Floods

Mainstream floods in the LMB are regular massive events that occur each year; the median annual flood volume at Kratie is some 380 km^3 (MRC, 2005a). In its passage downstream and out into the South China Sea, the annual monsoon-driven ‘flood pulse’ distributes water, sediment, nutrients and living organisms across the wetlands, tributaries and channels of the river’s lakes and floodplains. This regular seasonal flooding supports a complex, rich, diverse and highly productive ecosystem that is of fundamental importance to the sustenance and livelihood of most of the Basin’s inhabitants.

3.9a Fish Catch

Flooding endows the peoples of the LMB with environmental, social and economic benefits unparalleled in any other river basin in the world. The total average annual take of the capture-fishery of the LMB is 1.5 M tonnes/year, with a further 0.5 M tonnes/year taken from reservoirs and other forms of aquaculture (MRC, 2003c). The value of the total fish take has been estimated at some USD 2.6 B/year and the estimated value of other aquatic animals (eg frogs, crabs and molluscs) taken from the LMB is some USD 249 M/year (MRC, 2009c). It is estimated that *at least two-thirds of the LMB’s population* is involved in fishing, often on a part-time or seasonal basis; fish is essential to the diet and livelihood of these people, especially subsistence farmers (MRC, 2003c; Johnston et al, 2003).

This prolific fishery is driven and sustained year-to-year by the annual pulse of mainstream flooding, which triggers fish spawning and migration cycles and revitalizes, enlarges and renders accessible wetland habitats for spawning and fish recruitment. Seven environmental parameters have been identified as influencing the annual fish catch, four of which relate directly to flooding, namely flood level and the duration, timing and regularity of flooding (Sverdrup-Jensen 2002). Figure 3.6 shows the relationship between the annual migratory bag net (*day*) fish take (biomass) from the Great Lake and a Flood Index that measures the annual area-duration of flooding (in km^2days). The greater take during years when the flooding is more widespread and of extended duration (higher Flood Index) reflects the greater opportunity that fish have to breed and feed in such floods (MRC, 2009c).

3.9b Wetlands and Associated Services

Flooding is essential to the health of wetland ecological systems, which are a source of food and raw materials and provide a number of regulating, cultural and ecosystem services to nearby communities. There are some 5.25 M ha of flood-affected wetlands in the LMB that provide total services valued at between USD 0.5 B and USD 2.6 B (MRC, 2009c).

3.9c Water Supply

Water supply is an obvious but often overlooked benefit of flooding; as floodwaters recede, channels, canals and depressions across the floodplain store floodwaters for use in the following dry season, especially for irrigation purposes. Sluice gates that can be closed to exclude saltwater enables many channels of the Lower Cuu Long Delta to be used to store mainstream floodwaters during flood recession. There are many irrigation storages in the Khorat Basin of Thailand, the driest area of the LMB, that are recharged by tributary floods. Many farmers practice flood recession agriculture, planting rice, vegetables and other crops as floodwaters recede. The value of agriculture in the LMB that benefits directly from flooding has been estimated at USD 4.5 B/year and is largely restricted to Cambodia (USD 1.0 B/year, where 32 percent of the rice crop are flood recession rice, and the Cuu long Delta (USD 3.5 B/year). Agricultural flood benefits in Lao PDR and Thailand are considered insignificant compared to the irrigated and rainfed agriculture (see MRC, 2009c).

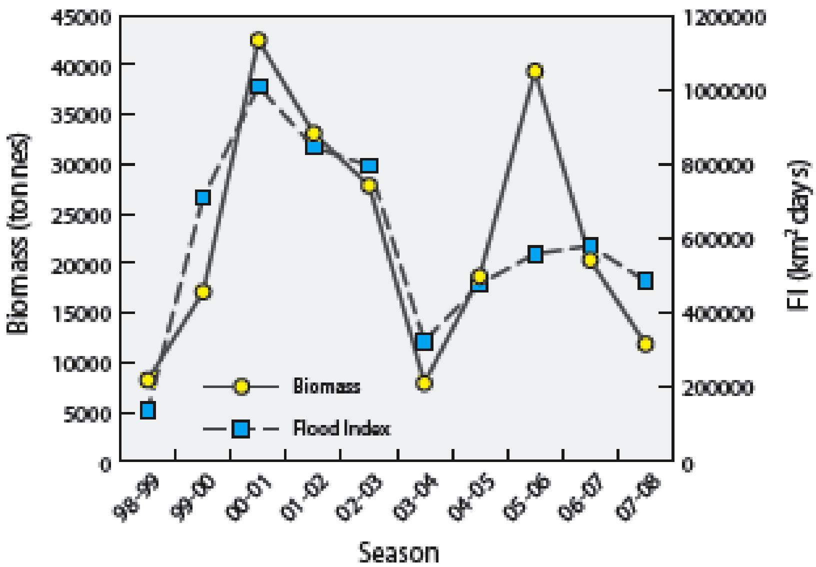


Figure 3.6 Variation of Annual Dai Fishery Take from the Great Lake with Annual Flood Index

3.9d Other Benefits

Flood deposited sediments improve and sustain soil fertility across the floodplains of the LMB. It has been estimated that each year, mainstream flooding delivers 79 M tonnes of nutrient-rich sediments to the Cuu Long Delta, of which some 9-13 M tonnes are deposited on floodplains, the remainder enlarging the Delta (the Ca Mau peninsular of the Cuu Long Delta is growing seawards by 150 m annually) and fertilizing and sustaining coastal fisheries (Fox and Sneddon, 2005; Huang and Tamai, 1999). The economic benefit of seasonal soil rejuvenation must be substantial, given that 25,000 to 45,000 km^2 of the Cambodian Lowlands and the Cuu Long Delta are flooded each year.

Finally, floods serve a number of useful mechanical purposes: they flush stagnant waters and pollutants downstream; recharge groundwater tables; scour and cleanse gravel and rock bed sections of the river; maintain river morphology; and reset vegetation on islands, sandbars and riverbanks (MRC, 2003c).

3.9e **Average Annual Benefit**

Based on the above figures, the annual flood benefited to the LMB lies between USD 7.8 B and USD 10.0 B/year. The benefits are far greater than the annual cost of flooding (including both direct and indirect costs), which has been tentatively estimated at around USD 60-70 M/year in average annual terms and up to USD 800 M for an 'extreme' flood event, as in 2000 (Table 3.5 and MRC, 2009c). Thus, annual flood costs lie between 1 and 10 percent of the annual flood benefit. Even although strongly outweighed by flood benefits, flood costs are very real to flood-affected people and act to perpetuate ongoing poverty. The objective of better flood management is to reduce flood costs and impacts whilst preserving the benefits of flooding to the greatest extent possible. This is discussed in Section 5.2, along with the various factors that affect flood risk and the various measures used to manage flood risk.

4 Droughts in the Lower Mekong Basin

4.1 Types of Drought

Droughts, like floods, can occur anywhere in the LMB. Further, just as there are different types of floods, so there are different types of drought, as described below and shown in Table 4.1 (Helmers et al, 2004).

4.1a **Meteorological Drought**

A *Meteorological Drought* occurs when rainfalls over some prescribed period are significantly less than the long-term average over that period.

4.1b **Hydrological Drought**

A *Hydrological Drought* occurs when a meteorological drought leads to a significant depletion of surface and subsurface water resources, including stream flows, lake and reservoir volumes, and groundwater reserves, over a prescribed period, again compared to long-term average conditions. At its simplest, a hydrological drought in the LMB is less than normal stream flows (i.e. a stream flow deficit) over some prescribed period.

4.1c **Agricultural Drought**

An *Agricultural Drought* occurs when meteorological and hydrological droughts reduce crop yields and livestock and fisheries production. For agriculture, an agricultural drought occurs when the soil moisture is insufficient to meet crop water requirements, leading to reduced yield. (The loss in yield depends on the type of crop, its growth stage and the water holding properties of the soil). In the case of fisheries, agricultural drought occurs when surface water conditions are insufficient to maintain normal fisheries production. Similarly, for livestock: an agricultural drought occurs when the supply of fodder and water are insufficient to maintain normal growth.

Table 4.1 Types of Drought

Category	**Cause**	**Effects**
Meteorological	Less than normal rainfall over some prescribed period.	Short-term droughts of only several weeks duration can reduce the yield of rain-fed rice, and if of sufficient duration, reduce the fodder available for livestock.
Hydrological	Less than normal water availability over some prescribed period.	Droughts of several months duration or longer reduce stream flows and the associated supply of water for irrigation and other purposes, and foster salinity intrusion into the waterways of the Cuu Long Delta.
Agricultural	Impact of meteorological and hydrological droughts on crop, livestock and fishery yields.	The reduced rainfall and irrigation supply associated with meteorological and hydrological droughts (i) reduce soil moisture, curtail crop yield and even kill both annual and perennial crops and (ii) reduce livestock and fishery production.

All droughts are meteorological in the first instance, the deficit in rainfall leading to a deficit in soil moisture and possibly to an agricultural drought in rain-fed areas. If a meteorological drought persists for long enough, it will lead to a deficit in available water resources and possibly to a hydrological drought, which in turn may lead to reduced crop yields in irrigated areas or to decreased livestock and fishery yields.

Rain-fed rice makes up some 90 percent or more of the total rice plantings in the Lao, Thai and Cambodian portions of the LMB (see Section 2.2). Thus, meteorological droughts of even short duration (weeks) and critical timing can be a great consequence to the yield of rain-fed rice and national rice production. In the Cuu Long Delta, widespread and effective water management allows up to three rice crops a year and the proportion of rain-fed rice is smaller (about 50 percent of total rice plantings).

4.2 Drought Occurrence and Severity

4.2a Location

Droughts, like floods, can occur anywhere in the LMB. However, critical soil moisture deficits that reduce plant yields are more likely to be realized in areas of low rainfall. There are two 'dry' areas in the LMB that are highly susceptible to meteorological drought.

1. The Cardamom and Elephant Mountains of Southwest Cambodia create a rain shadow, leading to an area of reduced monsoon rainfall in the southeast of Cambodia.
2. Similarly, the rain shadow cast by the Phang Hoei Range that forms the western limit of the Khorat Plateau in Thailand limits rainfalls across the Plateau itself and across northeast Cambodia.

The average annual rainfall in both these areas is less than 1,250 mm, which is the lowest in the LMB. Both areas are more susceptible to drought than other areas of the LMB. In contrast, the 'wet' areas of the Northern Highlands and Eastern Highlands (see Figure 3.1) have average annual rainfalls of 2,250 mm and higher.

4.2b Drought Severity

The severity of a drought depends upon the following factors:

- Intensity, i.e. water deficit, water use deficit or yield deficit;
- Extent, Timing and Duration; and
- Socio-economic impact.

These four factors need to be considered together in assessing drought severity. For example, a three-week meteorological drought may be of great significance to rain-fed agriculture, especially if it occurs at a critical crop stage, but may have little effect on stream flows or groundwater inflows and be of little consequence to water uses based on these resources. The longer a drought and the greater its extent, the larger the local, regional and national socio-economic impacts

4.2c Annual Meteorological Droughts

Table 4.2 shows the annual frequency of occurrence of *annual meteorological drought* in the four riparian countries of the LMB (Pandey, et al, 2007). These figures have been estimated as the ratio of the number of severe[14] drought years (anywhere in the country) to the total number of years in the period of analysis (1950-2004). The likelihood of a 'drought year' is seen to be highest in Lao PDR and Thailand (two years in five) and declines as one moves down the basin through Cambodia and Viet Nam (one year in three). Note that the figures for Thailand and Viet

[14] A severe drought year is defined as a year in which the annual rainfall is greater than 20 percent of the long-term average rainfall.

Nam are for the *whole country* (see Section 4.2d for seasonal droughts in North-eastern Thailand).

Table 4.2 Annual Drought Frequency, Lower Mekong Basin, 1950-2004

Country	Annual Drought Frequency
Lao PDR	0.42
Thailand	0.45
Cambodia	0.34
Viet Nam	0.30

Source: Pandet et al, 2007.

Figure 4.1 shows percentage deviations of annual rainfall above and below the average annual rainfall (AAR) at three locations in the LMB over the period 1980-2004 (Adamson, 2005):

- *Khon Khaen* is located in the central region of the Khorat Basin (AAR of 1,250 mm);
- *Pakse* is located on the Middle River Reach of the Mekong River some 350 km to the East of Khon Khaen (AAR of 2,000 mm), and
- *Chau Doc* is in the Cuu Long Delta, situated some 390 km to the South of Pakse (AAR of 1,300 mm).

Again defining annual meteorological drought as a year in which the annual rainfall deficit is greater than 20 percent of the AAR, the years of annual meteorological drought can be seen on Figure 4.1 and are listed in Table 4.3.

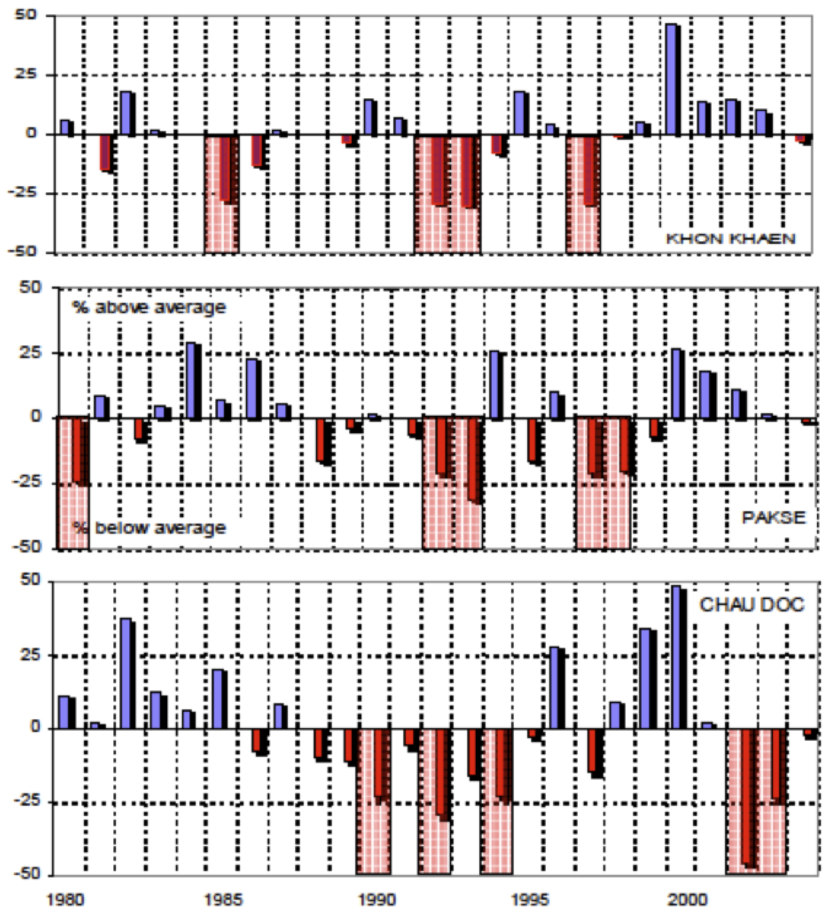


Figure 4.1 Percentage Annual Rainfall Deviations, Khon Kaen, Pakse and Chau Doc, 1980-2004

Table 4.3 Drought Years, Khon Kaen Pakse and Chau Doc, 1980-2004

Station	**AAR (mm)**	**Drought Years (Annual Rainfall Deficit > 20 % AAR)**									
Khon Khaen	1,250		1985		1992	1993		1997			
Pakse	2,000	1980			1992	1993		1997	1998		
Chau Doc	1,300			1990	1992		1994			2002	2003

The results of Figure 4.1 and Table 4.3 illustrate not only the occurrence of annual meteorological droughts, but also the importance of the duration and timing of a drought event. At Khon Khaen and Pakse, it is seen that there is only a minor annual rainfall deficit in 2004, which can be considered to be a 'normal' rainfall year at both stations. However, during the first nine-months of 2004, Khon Khaen experienced slightly above average rainfalls, followed by the *almost complete absence of rainfall* over the last three months (Adamson, 2005). Whilst the annual rainfall deficit for 2004 was close to zero, the deficit over the last quarter of 2004 was close to 100 percent, a fact completely obscured in an annual deficit analysis. Rainfall over this last quarter is essential for late summer plantings of rain-fed rice across the Khorat basin. The complete failure of these rains defined an *extreme seasonal agricultural drought* that resulted in complete and widespread regional crop failure, coupled with associated economic loss and social hardship (see Section 4.2d). Thus, the timing and duration of a drought are equally important in determining socio-economic effects (severity) as the quantum of water deficit. Further, it is readily seen that longer-term analyses (annual) can obscure critical short-term drought behaviour over months or weeks. This is discussed further in Section 4.2d.

4.2d **Seasonal Meteorological Droughts**

The occurrence of drought in Northeast Thailand and its effects on rice production have recently been comprehensively assessed (Pandey, et al, 2007). The study area consisted of 16 provinces, comprising mainly the Khorat Basin. Rice production in this area is predominately rain-fed (only 8 percent of agricultural land in the northeast is irrigated). The findings of the Northeast Thailand Study are reported in some detail as they illustrate a number of important aspects of drought behaviour and assessment.

The Northeast region was divided into three zones based on rainfall and drought risk, the highest rainfall (and lowest drought risk) zone being in the East along the Mekong River and the lowest rainfall (and highest drought risk) zone being in the West in the rain shadow of the Phang Hoei Range. (Zone III is the most drought-prone area of the Northeast – Mongolsawat, 2001). These three zones are shown in Figure 4.2. Three seasonal drought periods were considered: early monsoon (May to August); late monsoon (September to November); and total monsoon (May to November). Table 4.4 shows average seasonal rainfalls across the three risk zones and in the Northeast Region as a whole. A seasonal drought was again defined as occurring when the rainfall deficit was greater than 20 percent of the long-term seasonal rainfall[15]. Figure 4.3 shows the seasonal drought probabilities estimated over the period 1970-2002 for the three Zones and for Northeast Thailand as a whole.

- It is seen that drought is more likely to occur in the 'late' monsoon season (September-October), when rainfalls are more variable and drought interferes with the 'setting' of rice. The 'late season drought probability in Zone III is around 0.25 (a drought year occurs on average once-in-four years). 'Late' season drought probabilities in Zones I and II are around0.20 (i.e. a drought year occurs on average once –in five years).
- 'Early' season drought probabilities are smaller, ranging from 0.06 in Zone II to 0.12 in Zones I and III (i.e., a drought occurs on average once-in-16 to once-in-eight years respectively).

[15] In statistical terms, these 'droughts' correspond to 'severe' or even 'extreme' rainfall deficit events

- The drought probabilities for the entire 'monsoon' period are smaller still, ranging from zero in Zone II to 0.06 in Zone III.
- The drought probability for the total monsoon period over the entire Northeast area is *zero*, i.e. at no time during the period of analysis did the deficit in the annual monsoon rainfall, spatially averaged over the entire northeast area, exceed 20 percent of the long-term value.

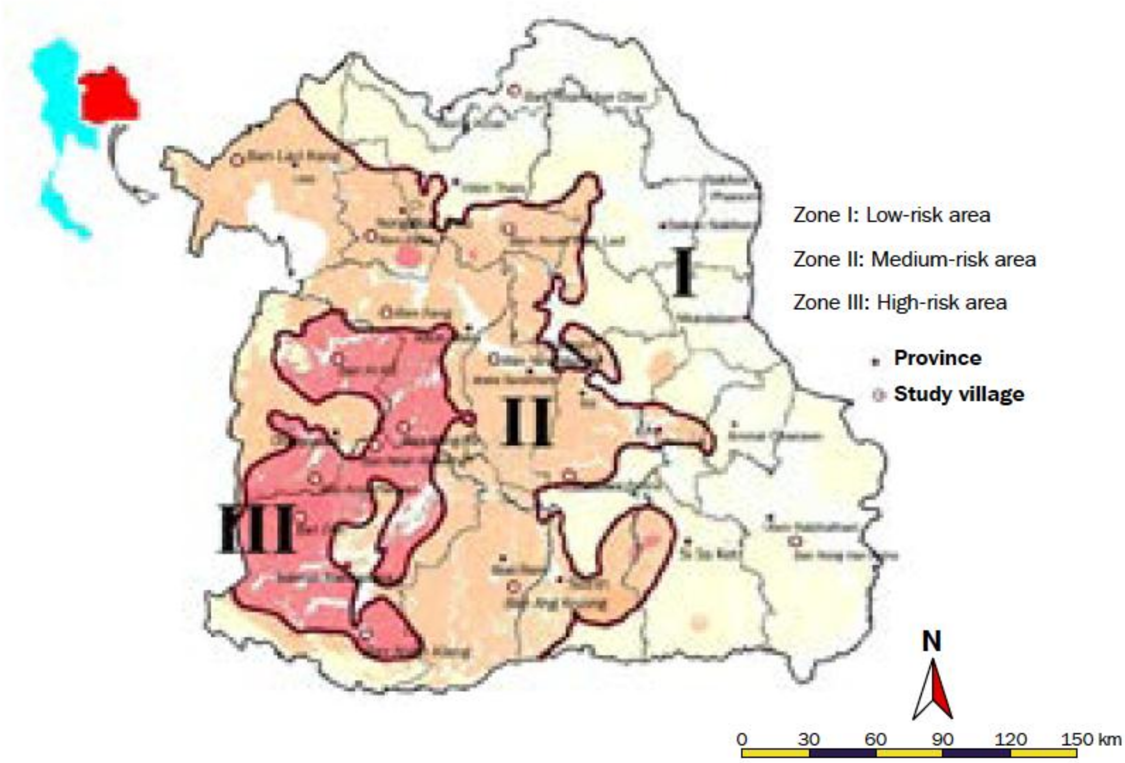


Figure 4.2 Drought Zones of Northeast Thailand (Pandey et al, 2007)

Table 4.4 Average Seasonal Rainfalls, Northeast Thailand, 1970-2002

Region	Drought Risk	Period and Depth of Rainfall (mm)			
		Early (May-Aug)	Late (Sep-Nov)	Monsoon (May-Nov)	Annual (May-Apr)
Zone I	Low	1,120	350	1,470	1,610
Zone II	Medium	760	360	1,120	1,250
Zone II	High	520	370	900	1,040
Northeast	-	880	360	1,240	1,380

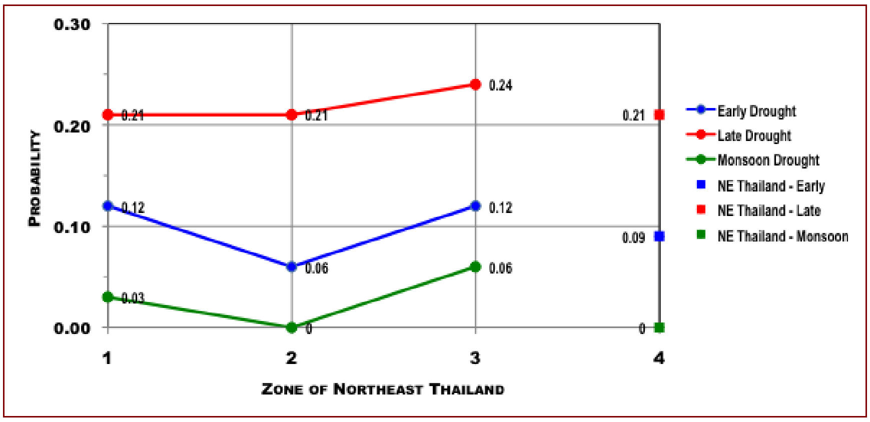


Figure 4.3 Seasonal Zonally-Averaged Meteorological Drought Probabilities, Northeast Thailand, 1970-2002 (Pandey et al, 2007)

Comparing 'early' and 'late' seasonal results of Figure 4.3 to 'monsoon' results (the red, blue and green curves), and the zonal 'monsoon' results (green curve) to the 'monsoon' results for the entire northeast area (the green square), it is noted that *the longer the drought period being analyzed and the greater the area being considered, the less likely a drought is to be registered* because of the temporal and spatial averaging of rainfalls. The Northeast Thailand Study found that meteorological drought in the Northeast Region could be *quite local at times, affecting only one or two provinces*.

Thus, in obtaining reliable results from drought analyses, the length of the drought period and the area under investigation need to be carefully selected.

4.2e **Hydrological Droughts**

Figure 4.4 shows annual stream flow deviations at Vientiane and Kratie over the period 1960-2004 (Adamson, 2005). The period 1986-89 is seen to be an extended four-year hydrological drought at both stations, when annual stream flows were less than average annual values at both stations.

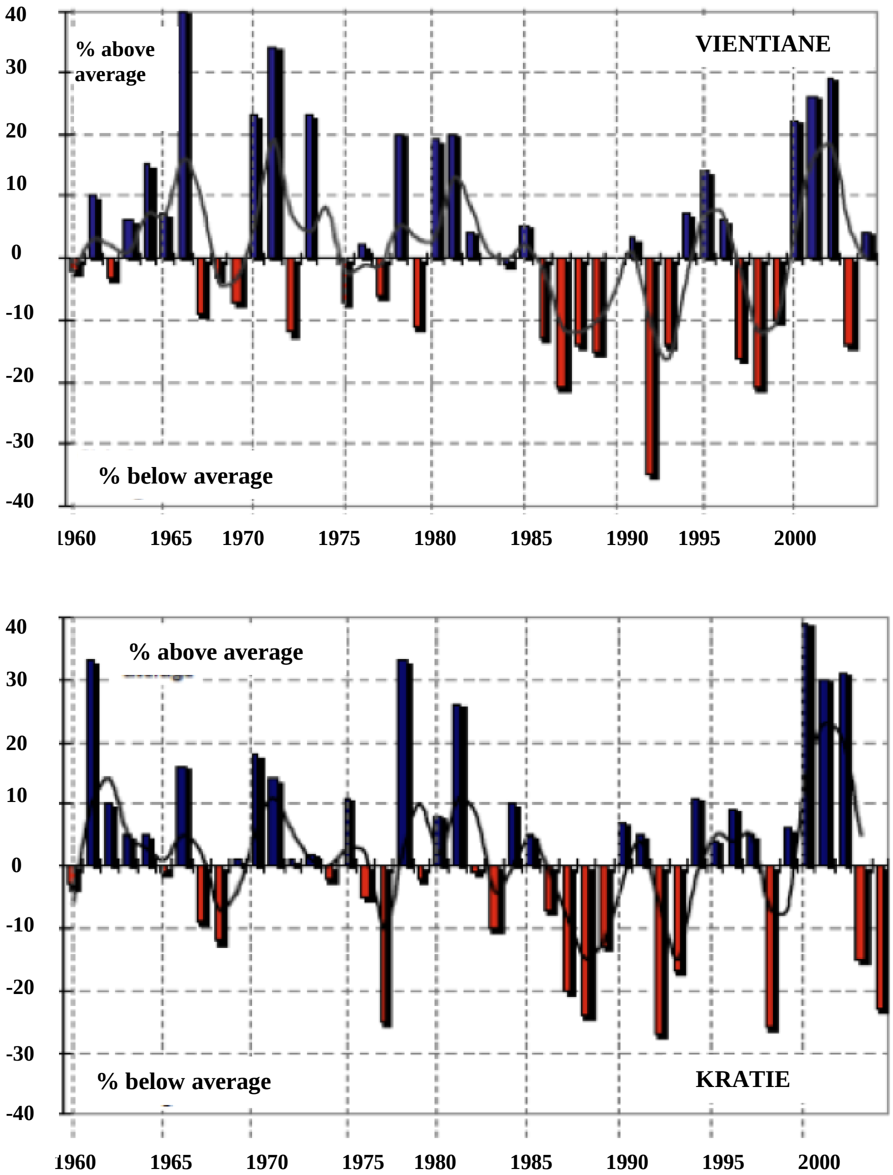


Figure 4.4 Annual Stream flow Deviations at Vientiane and Kratie, 1960-2004

Figure 4.5 shows the 90-day moving average minimum stream flows at Vientiane and Kratie over the period 1960-2005 (Adamson, 2005). (Note these are absolute discharge values and not deviations). Also shown is a shaded area that represents two standard deviations around the average value of the annual 90-day minimum discharge. Any discharge deficit greater than two standard deviations can be considered statistically to be an *extreme deficit.* Whether it heralds a *hydrological drought of extreme severity* depends upon the impact of the deficit on water use and crop, livestock and fish yields.

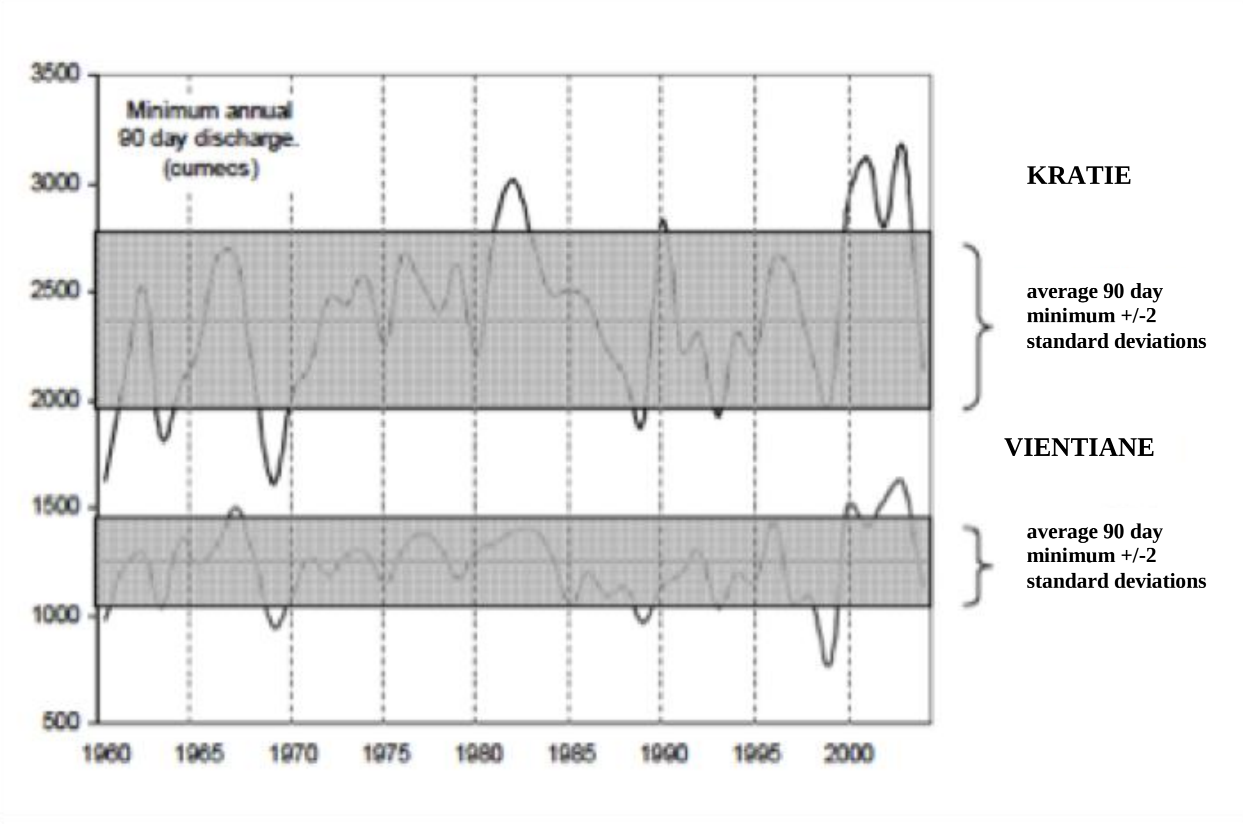


Figure 4.5 90-Day Moving Average Minimum Discharges, Vientiane and Kratie, 1960-2004

It is seen that 1969, 1989, 1993 and 1998 are years of extreme 90-day stream flow deficits at Vientiane and Kratie. It is noted that 1998 was a year of extreme hydrological drought in the Delta (see water levels at Tan Chau in Figure 3.4 and the annual discharge deviation at Kratie in Figure 4.4, but was also a year of 'normal' rainfalls at Chau Doc (see Figure 3.3). Thus, over the 1998 wet season, rain-fed crops in the Delta were fine – on an annual basis - but low discharges during the dry season severely curtailed irrigation supplies into 1999 for autumn and winter crops.

4.3 The Costs of Drought

Like floods, droughts impose a variety of costs on affected peoples. Unlike floods, droughts provide no apparent benefits to human society. The principal costs of drought in the LMB relate to the impact of agricultural drought: i.e. reduced yields or total loss of crops, especially rice (see Section 4.1c), together with reduced fishery and livestock yields. This reflects the largely agricultural nature of human endeavours in the basin, which are often of a subsistence nature.

In Lao PDR, Thailand and Cambodia, rain-fed rice accounts for around 90 percent or more of the total cropped area (see Table 2.5), and is thus susceptible to meteorological drought. Hydrological drought reduces flood recession discharges and dry season flows, and so reduces the availability of irrigation water for recession-rice in all four riparian countries and for winter-rice in the Cuu Long Delta. (Reduced dry season flows in the Lower Reaches of the Mekong and Bassac Rivers enable ocean salinity to penetrate further upstream along the Delta's waterways, so precluding their use as a source of irrigation water).

Readily available definitive information on the costs of drought in the LMB is scarce. Whilst the four riparian countries have procedures for assessing drought costs, little official information is available and the reliability of estimates to hand can be questioned. This limitation in the availability and accuracy of data appears to reflect the complexities of attempting to estimate drought costs and the many stakeholders affected by drought. Better procedures for estimating drought costs are required for the LMB.

Regarding the cost of droughts, information is provided below concerning (i) costs and impacts associated with the 2004-05 Drought, which was severe in all four riparian countries, but less so in Lao PDR, (ii) estimated costs of drought in Northeast Thailand over the period 1970-2004, and (iii) estimated costs of drought in Viet Nam and the Cuu Long Delta over the last nine years.

4.3a **Basin-wide Impacts of the 2004-05 Drought**

The 2004-05 Drought was severe in all four riparian countries. The 2004 wet season finished early, causing widespread failure of the autumn-rice crop, especially in the Cuu Long Delta, where low stream flows allowed ocean salinity to penetrate further upstream than normal, significantly reducing dry-season irrigation supplies (i.e. a *hydrological drought*). Over 104,000 ha of rice were damaged in the Delta. Ben Tre was the worst affected province, where 7,000 ha of rice and 15,000 ha of fruit orchards worth USD 33 M were destroyed. In addition, over 82,000 families were forced to buy water (USD 4.50 per m^3). The total drought damage bill to the Delta was USD 42 M (MARD, 2005). The reduction in mainstream flows in the Delta can be inferred from Figure 4.4, which shows an annual stream flow deficit at Kratie of greater than 20 percent for 2004.

In Cambodia, the 2004-05 Drought was the worst in recent times. 14 out of 24 provinces were affected; rice production fell in all provinces; half-a-million people were reportedly facing food shortages. The situation in Cambodia was exacerbated by the late start to the 2005 wet season (FAO, 2005; WFP, 2009).

The 2004-05 Drought was especially severe in Thailand, where 63 of the nation's 76 provinces were affected. Countrywide, some 9 M people suffered and irrigation use was restricted (and even prohibited) to conserve water for domestic consumption. The estimated cost to the nation was USD 193 M (FAO, 2005). No specific figures were available for the Khorat Basin.

In Lao PDR, the 2004-05 Droughts was less severe than in the other three riparian countries. The 2004 wet-season rice crop was larger than in 2003, so providing a buffer for the dry-season drought. Reduced rainfalls and low stream flows led to a 25 percent reduction in dry-season plantings (FAO, 2005). The Mekong displayed a small annual stream flow excess at Vientiane in 2004 (see Figure 4.4).

4.3b **Agricultural Drought**

Rice Production in Northeast Thailand

As part to their study of the effects of drought in Northeast Thailand, described in Section 4.2d, Pandey et al (2007) also estimated the effects of drought (rainfall deficit) on rice production. Annual rice production data (by province) was combined with the total monsoon drought probability (also by province) to estimate the average annual loss of production due to drought across the northeast region at *78,000 T/pa worth some USD 10 M/pa.*

In the second part of the Study, a detailed survey was undertaken of farmers' response to drought and the effect of drought on household income. Some 300 farming households from 15 villages across the three zones were surveyed. It was found that during drought years, farmers reduced the planted area of rice by 21 percent compared to 'normal' years (these and following figures relate to the Northeast Region as a whole). When coupled with the reduction in yield caused by drought (45 percent), this resulted in a 56 percent loss in rice production in a typical drought year. The average annual household income in a normal year was USD 2,600, of which rice production contributed USD 550. Thus, drought causes a loss of income of some USD 310 per year or 12 percent of the total household income. Whilst a 12 percent reduction in household income may appear to be of small consequence, this estimate is based on average household conditions and income. A different picture emerges if the distribution of household income is taken into account. The average total income of the bottom quartile of farmers surveyed was USD 610 and that of the top quartile was USD 6,160 (differences were associated with crop diversification and a higher proportion of off-farm income). In the bottom quartile, a drought year results in the loss of 31 percent of average household income, compared to a drop of only seven percent in the top quartile, so confirming that the poor are most disadvantaged by drought.

This study provides a detailed socio-economic assessment of the impact of drought on rice production in the Northeast Thailand. It illustrates the complexity of drought behaviour in terms of the area and event duration adopted for analysis (droughts can be quite local as well as widespread; a long event period may miss short-term but significant droughts). The average annual cost of drought in Northeast Thailand was estimated at USD 10 M/year. However, this is likely to be an underestimate, as the defined 'drought event' is based on monsoonal rainfalls over a seven-month period. An analysis based on one, two or three-month drought events, especially at critical crop stages, would be expected to identify a greater number of 'drought years' and hence a higher drought cost[16]. This again demonstrates that the adopted duration and timing of drought analyses is important in assessing the impact of droughts on agriculture.

Fish Yield from the Great Lake of Cambodia

Figure 4.6 shows the annual *dai* fish catch from the Great Lake of Cambodia over the period 1998-99 to 2007-08 (MRC, 2008a). This diagram allows the impact of *hydrological drought* on *dai* fishery yield to be estimated (i.e. the impact of the resulting *agricultural drought*). The average annual *dai* fish take over the above period is some 23,000 tonnes/year. The annual fish take falls to about 10,400 tonnes/year in 1998-99, 2003-04 and 2007-08, which are 'drought' years. This reduction corresponds to about one standard deviation below the average annual value, and the loss in production can be considered statistically to be 'significant' to 'severe'. The reduction in fishery yield in drought years is caused by the associated reduction in available water and fishery habitat. In the three drought years, the Great Lake Flood Index felt from 600,000 km^2days (average conditions) to around 300,000 km^2days. Thus, a 50 percent reduction in the normal Flood Index (caused by *hydrological drought*) resulted in a 55 percent reduction in fish yield (*agricultural drought*).

16 Presumably, 'seasonal' rice production data were not available, hence the use of an annual analysis.

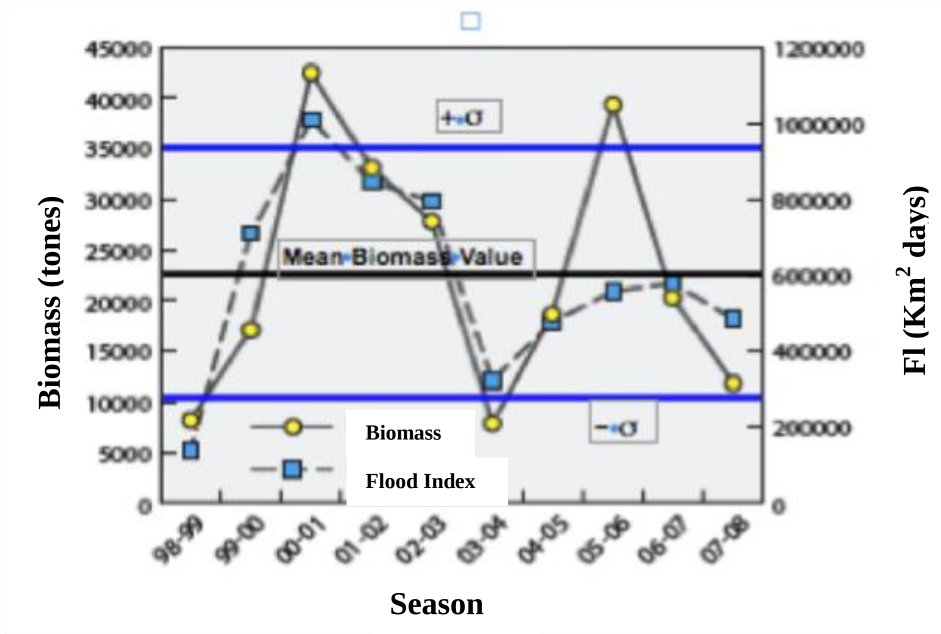


Figure 4.6 Dai Fish Catch from the Great Lake

At a representative value of USD 1.4/kg, the reduction in fish yield of 10,400 tonnes/year in the three 'drought years' amounts to a loss of some USD 14.5 M/year (see MRC, 2009c). The significance of hydrological drought on the yields of other fisheries has not been assessed.

Livestock Costs

Drought adversely affects livestock, leading to shortages of fodder and water, which in turn lead to stressed animals that lose weight and are more prone to disease and possible death. The cost of droughts to animal husbandry has not been estimated.

Social Costs

Droughts also impose a variety of social costs on affected peoples, including loss of income, food and water shortages, increased susceptibility to disease, and additional hardships (Helmers et al., 2004). A shortage of water for latrines and washing purposes, coupled with a decline in the availability, quality and safety of water supplies, often leads to an increase in diarrhoea and other gastro-intestinal diseases during drought periods. During a drought, household members, often women and children, have to spend a considerable time each day collecting water for domestic use and providing water and fodder for livestock. This can and does interfere with children's schooling. All of these social costs help sustain poverty, especially in subsistence households.

4.3c Cost of Droughts in Viet Nam, 1998-2005

The Viet Nam National Mekong Committee provided details of droughts affecting Viet Nam over the period 1998-2005 (VNMC, 2009). These results, which are shown in Table 4.5, illustrate a number of aspects of drought behaviour in Viet Nam and to a lesser extent, the Cuu Long Delta. Eight droughts occurred over this period, three wet-season droughts and five dry-season droughts (wet-season droughts are shaded dark grey). Of the eight droughts, four affected the Cuu Long Delta (shaded light grey). In terms of national impact, the worst drought was the first drought of 1998, which was of five-month duration. Some 173,000 ha of crops were destroyed, comprising two-thirds rice and one-third fruit trees, at a cost to the country of

USD 385 M. Of the four droughts affecting the Cuu Long Delta, three were dry season hydrological droughts, low flows enabling additional salinity intrusion upstream into the Delta's waterways, so reducing the availability of irrigation water for autumn and winter crops.

Table 4.5 Details of Droughts in Viet Nam, 1998 - 2005

Year	Drought Characteristics			Extent of Drought	Drought-Affected (ha)		Lost Crop Area (ha)		Cost (USD)	
	No.	Duration	Period		National	CL Delta	National	CL Delta	National	Delta
1998	1.	5 Months	Dec[a]-Apr	Whole Country	1.023 M	-	173,000	-	385 M	-
	2.	4 Months	May-Aug	Central Areas	87,000	0	2,700	0	-	0
1999	1.	4 Months	Dec[b]-Apr	Red River & CL Deltas	101,500	-	21,500	4,420	-	6 M
2002	1.	3 Months	Feb-Apr	Central & S. Areas	286,000	70,300	67,500	17,800	91.2 M	24 M
	2.	3 Months	May-Aug	Central Areas	-	0	118,000	0	50.0 M	0
2004	1.	3.5 Months	Jan-Apr	Northern Areas	-	0	-	0	-	0
	2.	5 Months	Jul Nov	Central & S. Areas	246,500	-	134,500	-	-	-
2005	1.	6 Months	Nov[c]-Apr	Central & S. Areas	172,000	-	34,500	-	110 M	-

[a] 1997. [b] 1998. [c] 2004

Regarding drought impacts in the Delta, Drought No. 1 of 2002 was a dry season drought that occurred over the period February - April. Some 70,300 ha of the Delta were affected; crops were lost from 17,800 ha (25 percent of the affected area). Crop losses in the Cuu Long Delta accounted for about one-quarter of the national crop loss in 2002, and based on these figures, the cost of 2002 Drought No. 1 in the Delta can be estimated as USD 24 M, or USD 1,350/ha of crop loss. Using this latter figure, the cost of the dry season Delta drought of 1999 is estimated to be USD 6.0 M. The cost of the other two droughts in the Delta cannot be estimated from the figures of Table 4.5.

4.3d Total Cost of Drought in the Lower Mekong Basin

So what can we say about the total cost of droughts in the LMB? First, the existing information is sporadic, incomplete and uncertain. Table 4.6 summarizes the various drought cost estimates presented here. They are 'snapshots' of the cost of the impact of individual droughts (except for the estimate made by Thailand) on specific sectors and underestimate total drought costs. None of the figures represent total cost across all sectors (eg. fisheries). Notwithstanding these shortcomings, the estimated costs are 'significant'. Drought costs for the Cuu Long Delta in 2002 and 2004-05 are significantly greater than flood costs for seven out of nine of the floods that occurred over the period 2000-2008 (see Table 3.5). In terms of drought impact on rice production, the average annual cost to Northeast Thailand has been estimated at USD 10 M/year (and this is expected to be an underestimate). This figure is comparable with the average annual cost of flood damage in Northeast Thailand (see Table 3.5). Given the relatively high frequency of severe drought in the LMB (two years in five in Lao PDR and Northeast Thailand, one year in three in Cambodia and possibly Viet Nam - see Table 4.2), it is expected that the average annual cost of drought will be greater than the average annual cost of flooding, perhaps significantly so.

Table 4.6 Estimates of the Cost of Drought Impacts, Lower Mekong Basin

Country	Year	Estimated Cost (USD M)	Comments	Source
Lao PDR	-	-	No data available	-
NE Thailand	Average Annual	10 per year	Rice production only. Probably an underestimate	IRRI, 2007.
Cambodia	2002-03	22	Principally rice production.	WFP 2009
	2004-05	21	Principally rice production.	WFP, 2009
	1998-99	14.5	Loss in *dai* fishery catch from the Great Lake.	Section 4.3c
	2003-04	14.5	Loss in *dai* fishery catch from the Great Lake.	Section 4.3c
	2007-08	14.5	Loss in *dai* fishery catch from the Great Lake.	Section 4.3c
Cuu Long Delta	1999 (First)	6	Mekong Delta	Table 4.5
	2002 (First)	24	Mekong Delta	Table 4.5
	2004-05	42	Mekong Delta	MARD, 2005

4.3e **Other River Basins**

The behaviour and socio-economic costs of floods in the LMB are similar to those experienced in other great, heavily settled river basins used principally for agricultural purposes, such as the Indus, the Ganges and the Brahmaputra Basins of the Indian Subcontinent. In all four basins, flooding is driven by the Southwest Monsoon, coupled with TWSs. One difference is that flood protection embankments are used much more extensively to reduce flood risk in three basins of the subcontinent than in the LMB (with the possible exception of the Cuu Long Delta). In the Brahmaputra Basin of Assam, over 4,500 km of flood protection embankments have been built along the 640 km reach of the Brahmaputra River and along its tributaries. However, such flood control efforts are not completely successful and flooding caused by the overtopping or failure of ‘flood protection’ embankments is common in the three basins of the subcontinent.

The floodplains of the Yangtze and Yellow Rivers of People’s Republic of China have been developed to a much greater degree than the floodplains of the LMB, and are home to many cities and high-density urban, commercial and industrial developments, as well as agriculture. Because the flooding of these areas would cause a catastrophic loss that would significantly reduce China’s GDP, flood risk along the Yangtze and Yellow Rivers is controlled to a very high degree. The banks of the Middle and Lower Reaches of both rivers are protected by a continuous series of conservatively designed, strongly constructed, and well-maintained and protected flood protection embankments and sacrificial flood basins. The impetus for this work was the Yangtze Flood of 1954. However, in August 1998, the flood embankment of the Yangtze River failed with catastrophic consequences: 3,000 people were killed, 14 M people were rendered homeless and 13.3 M houses were damaged or destroyed. The estimated cost of flood damage was USD 26 B.

5 Management of Flood and Drought Risk in the Lower Mekong Basin

5.1 Preamble

We do not 'manage' or 'control' floods or droughts *per se*, but rather the risks associated with these events. Risk is the downside of chance. We speak of the chance of success, but the risk of failure. In risk management terms, 'risk' refers to the (adverse) impact of an event. It incorporates the likelihood (probability) of an event occurring and the consequences of that event on affected communities, i.e. the socio-economic impact (SEI). There is a human side to risk, namely the socio-economic vulnerability of the affected community. The impact of an adverse event on a highly vulnerable community is worse than on a less vulnerable (or more resilient) community.

5.2 Flood Risk and Flood Risk Management

5.2a **Flood Risk**

Before describing the management of flood risk, a number of basic flood risk concepts are briefly discussed and described:

- We do not 'manage' floods *per se*. Rather, we manage flood risk.
- Flood risk depends upon the *likelihood* (probability) of flooding and the *consequences* of flooding (flood impacts).
- We generally cannot reduce flood risk by reducing the likelihood of a flood occurring, which is defined by the nature and severity of the underlying physical phenomenon (rainfall, storm surge, tsunami, etc). However, we can reduce flood risk by 'managing' the *nature* of flooding through the construction of *flood mitigation measures*, such as flood protection embankments, flood control dams, etc, and by reducing the *impact of flooding*.
- The impact of flooding depends upon the *nature of the flood* itself (peak flood height, duration, rate of water level rise, etc), and *flood mitigation measures* in place, and the *socio-economic vulnerability* of the flood-prone community.
- Community vulnerability depends upon the *population at risk, land-use and infrastructure* in the flood-prone areas, and *community flood resilience*.
- Community resilience can be strengthened through the development of *flood preparedness, response, relief and recovery plans* (PPRR plans).

Thus, we can represent 'flood risk' by the following equation:

$$\text{Flood Risk} = \text{Function}\,(L_f, N_f, Pop_r, LU, CR)$$

Where: L_f is the likelihood of flooding,
N_f is the nature of flooding,
Pop is the population at risk,
LU is land-use, and
CR is the community resilience to flooding.

We cannot reduce the likelihood of flooding, but we can reduce flood risk by moderating the nature of flooding (through structural works such as flood protection embankments, flood control dams, etc), reducing the population at risk (land-use controls), ensuring that land-use across flood-prone land is appropriate to the level and nature of flood risk (i.e. land-use is resilient to flooding), and by increasing community flood resilience (through the formulation of flood prevention, response, relief and recovery plans - PRRR plans).

Flood risk depends upon with the severity of a flood (as measured by its likelihood of occurrence). It also depends on the characteristics of flood behaviour. Deep, fast flowing floodwaters are more hazardous and cause more damage than shallow, slowly moving floodwaters; the greater the area of flooding, the more people affected, and the greater the damage. Flood risk is also highly dependent on land-use; flood-sensitive land-uses increase flood risk. In the LMB, major land-uses adversely affected by flooding include agriculture, animal husbandry and urban settlements (typically villages). In addition, floods cause considerable damage and service disruption to flood-prone infrastructure and buildings (which can be addressed by flood proofing).

The nature of flood risk in the LMB is discussed in detail in Joy, 2007a and 2007b.

5.2b **Integrated Flood Risk Management**

Integrated flood risk management (IFRM) is a ***planning process*** that attempts to better manage flood risks by means of formulating an ***IFRM Plan*** that integrates and coordinates the actions of all parties that affect or are affected by flood risk.

IFRM identifies *three flood risks*, *five primary flood risk management measures* (one structural and four non-structurals) and *four supplementary flood risk management measures.* These nine measures need to be considered together to define an integrated and coordinated strategy to manage flood risk. Summary details of these risks and risk management measures are shown in Table 5.1.

Principal Flood Risk Management Measures

The five principal flood risk management measures are described below. One of these measures is ‘structural in nature (structural works), the other four measures are ‘non-structural’ in nature.

Structural Works The aim of structural works, which include flood protection dikes, flood control reservoirs, sacrificial flood basins, river improvements, etc., is to protect existing and future development from flooding, i.e. to ‘*keep the water away from the people’*. It is generally impossible to provide total protection against flooding, but structural works can reduce the likelihood of flooding and the associated existing and future flood risks. Flood protection embankments are commonly used in the four riparian countries, more so in the Cuu Long Delta than elsewhere. Large multi-purpose dams attenuate major floods, but often only to a small degree (see Section 6.3d)

Land-use Controls. Floodplain zoning is aimed at ‘*keeping people away from the water’*, i.e. attempting to ensure that land-use is appropriate to flood hazard and that flood-sensitive land-uses are shepherded into less hazardous areas of the floodplain. Land-use controls can limit flood risk exposure to community infrastructure, assets and the population at risk and are the most cost-effective means of reducing the growth in future flood risk. However, land-use controls will be of limited effectiveness in the LMB because of unrelenting and increasing population pressures across flood-prone areas of the basin.

Development and Building Controls Along with regional and community flood emergency planning, development and building controls recognize that flooding cannot be eliminated and aim ‘*to minimize flood damage to infrastructure and assets’* by ‘flood proofing’, so reducing residual flood risk by enabling the ready return to use of infrastructure and assets in the aftermath of a flood. Infrastructure damage is a significant component of total flood damage in Cambodia and to a lesser extent elsewhere in the LMB. To date, little consideration appears to have been given to reducing losses by flood proofing, although for some years Viet Nam has had a program of constructing flood-proof houses in the Cuu Long Delta (see Section 6.3f).

Table 5.1 Flood Risks and Flood Risk Management Measures

Item	Name	Details
Flood Risk	1. Controlled Risk	The flood risk that is controlled by existing structural flood protection works (e.g. dams, flood protection embankments) in relation to the 'existing community situation' with regard to fabric of the flood-prone community (land-use, population, infrastructure, socio-economic vulnerability, etc.) and the nature of flooding at this location.
	2. Residual Risk	The flood risk to existing developments over and above the controlled risk. It is generally impossible to completely eliminate flood risk. A residual risk associated with the overwhelming or failure of structural flood protection works generally (always) remains.
	3. Future Risk	The risk exposure of flood-prone communities at some time in the future. Future risk relates to new developments and is generally (inevitably) higher than the current residual risk because of population growth in flood-prone areas, together with increases in the standard of living and the increased vulnerability of communities and 'new' land-uses.
Principal Flood Risk Management Measures	1. Structural Works	Aim at 'keeping the water away from the people'. In the LMB structural works typically consist of flood protection embankments. The various upstream dams proposed for the basin will also have a mitigating effect on flood flows (but not flood duration).
	2. Land-Use Zoning	Aims at 'keeping people away from the water'. Aims to ensure that land-use is appropriate to flood risk and hazard by defining flood hazard zones and regulating land-use within these zones.
	3. Building and Development Controls	Recognizes that flooding will occur (residual risk) and aims to limit the damage caused to buildings and infrastructure by 'flood-proofing'.
	4. Regional Flood Emergency Planning	Recognizes that flooding will occur (residual risk) and aims to limit socio-economic impacts on flood-prone communities by the provision of flood emergency services (preparedness, response, relief and recovery services). Regional flood emergency services are State-based.
	5. Community-Based FRM	Recognizes that flooding will occur (residual risk) and aims to increase the flood resilience of flood-prone communities by developing a CBFRM Plan comprising local preparedness, response, relief and recovery arrangements.
Supplementary Flood Risk Management Measures	1. Land-Use Planning	Land-use planning provides a foundation for land-use zoning. In zoning flood-prone land, land-use factors additional to flood risk also need to be taken into account: the socio-economic needs of the community, together with ESD, NRM and RBM considerations.
	2. Flood Simulation Modelling	Enables the impacts of structural works and floodplain developments on flood risk and flood behaviour to be assessed. Also used for flood forecasting purposes. Flood simulation modelling is an essential tool of modern flood risk management.
	3. Flood Forecasting	Flood forecasting enables flood-warning time to be increased. Simple statistical-based manual methods or complex computer-based methods can be used.
	4. Flood Warning	If flood warning is to be effective, i.e. to significantly reduce flood risk, warnings must be accurate and timely and warning recipients must know how to respond appropriately (response plans).

Regional Flood Emergency Planning The provision of regional flood emergency services, typically by State agencies, is aimed at assisting flood-prone communities better prepare for, respond to, endure, and recover from floods, i.e. reducing residual flood risk. To this end, Regional Preparedness, Response, Relief and Recovery Plans (PRRR Plans) are developed. These activities are aimed at reducing community vulnerability by assisting flood-prone communities to better '*live with floods*'. In recent years, there has been a change of focus in regional flood emergency planning activities from response and relief activities to supporting community-based activities aimed at flood preparedness and vulnerability reduction.

Community Flood Emergency Planning In this case, flood-prone communities are encouraged to accept responsibility for their own community flood risk and to develop Community Flood Preparedness, Response, Relief and Recovery Plans to reduce flood impacts. Again, these activities are aimed, in the most direct sense, at reducing residual flood risk and community vulnerability. Today's community-based flood risk management activities place increasing emphasis on flood preparedness and vulnerability reduction.

To maximize the effectiveness of regional and community-based flood emergency planning initiatives, regional and community-based activities need to be coordinated. In addition to 'PRRR' Plans[17], other important elements of flood emergency planning at both regional and community levels include flood education (i.e. increasing the flood awareness and flood readiness of emergency service providers and affected communities) and financial measures (such as relief payments). Another important community-based initiative is livelihoods improvement, i.e. the identification and uptake of more flood-tolerant livelihoods to reduce the financial impact of flooding.

Supplementary Flood Risk Management Measures

The four supplementary flood risk management measures are described below. All of these measures are 'non-structural' in nature; forecasting and warning are commonly regarded as principal flood risk management measures in their own right, although they are better regarded as part of regional and community-based flood emergency response.

Integrated Land-Use Planning is necessary to define land-use controls for flood-prone areas. Along with flood risk, the integrated land-use planning process needs to embrace other factors affecting land-use, such as the socio-economic needs of the community, together with ecologically sustainable development and natural resource management considerations.

Flood Simulation Modelling via mathematical models provides an understanding of flood behaviour across the area of interest, e.g. the extent, depth and velocity of floodwaters across the floodplain, the rates of rise and fall of floodwaters and duration of flooding, and so enables flood risk and hazard to be assessed quantitatively. Flood simulation models can be quite complex. The MRC has developed hydrologic and hydraulic computer models to simulate flood flows along the mainstream river reaches of Lao PDR and Thailand and across the Cambodian Lowlands and the Cuu Long Delta.

Flood Forecasting allows the future behaviour of an actual flood event to be simulated (predicted) analysed and used for warning purposes. Typically, mathematical models are used to generate flood forecasts. In recent years, MRC's Flood management and Mitigation Programme (FMMP) has developed a mainstream forecasting model for the river reaches and Lower floodplains and a 'Flash Flood Guidance System' to assist in the provision of 'flash flood alerts' along tributaries (See Section 6.1b).

Flood Warning is an essential component of regional and community-based flood emergency response plans. Ideally, flood warnings should be accurate and delivered in a timely fashion to those at risk, who should know how to respond appropriately and reduce their vulnerability.

Interactions between Flood Risk Management Measures

Figure 5.1 shows the five principal FRM measures. Financial measures, flood preparedness, response, relief and recovery plans (PRRR plans) and flood education measures are important elements of flood emergency management and have been shown separately.

---

17 Preparedness, Response, Relief and Recovery

Figure 5.2 shows all nine flood risk management measures and the interactions between them. They are seen to interact in a complex way, indicating a strong need for ‘integration’ of individual FRM activities across all relevant agencies that influence or are affected by flood risk (see Joy 2007a for details). It is also seen that land-use planning in general needs to play a large role in IFRM. Not only does flood risk have to be taken into account in determining appropriate land-use across flood-prone areas, but also community needs, environmentally sustainable development considerations, natural resource management considerations and river basin management considerations.

In effect, Fig 5.2 provides a framework for the integrated management of flood risk (see Section 5.4 for details).

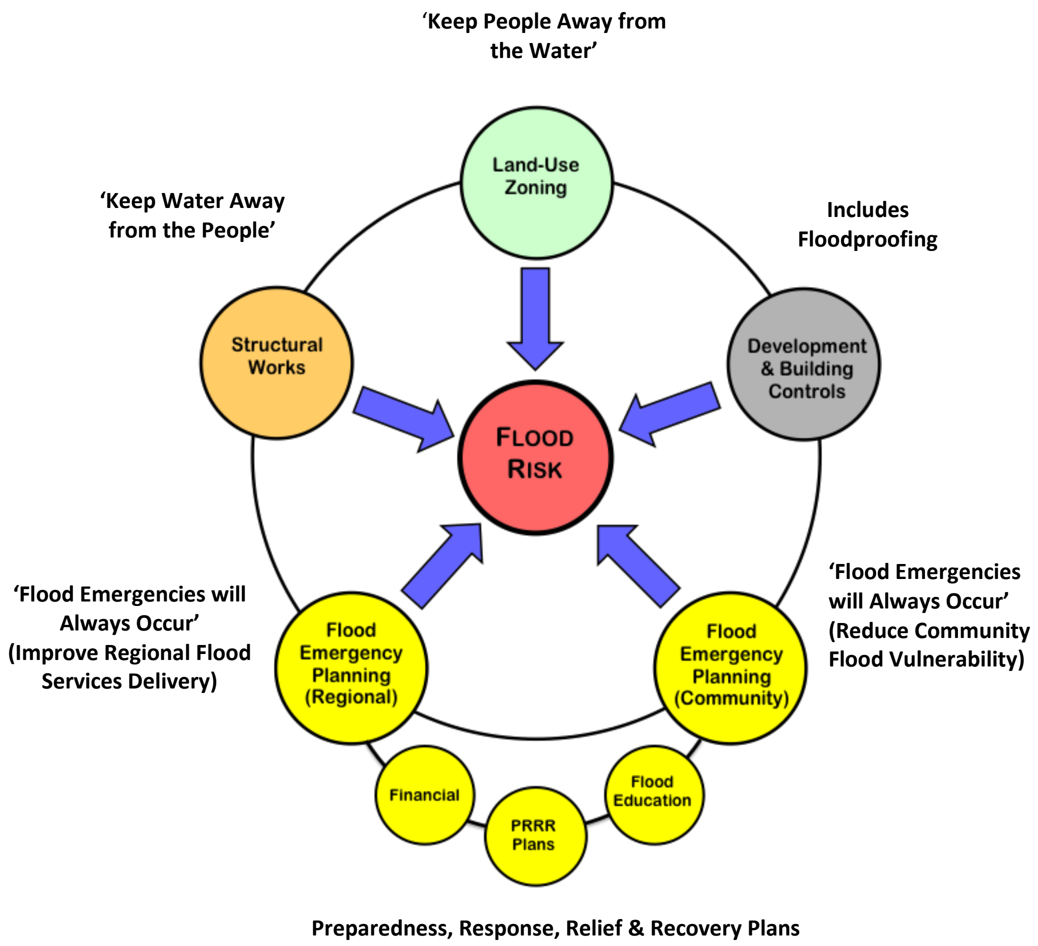


Figure 5.1 Flood Risk Management Measures

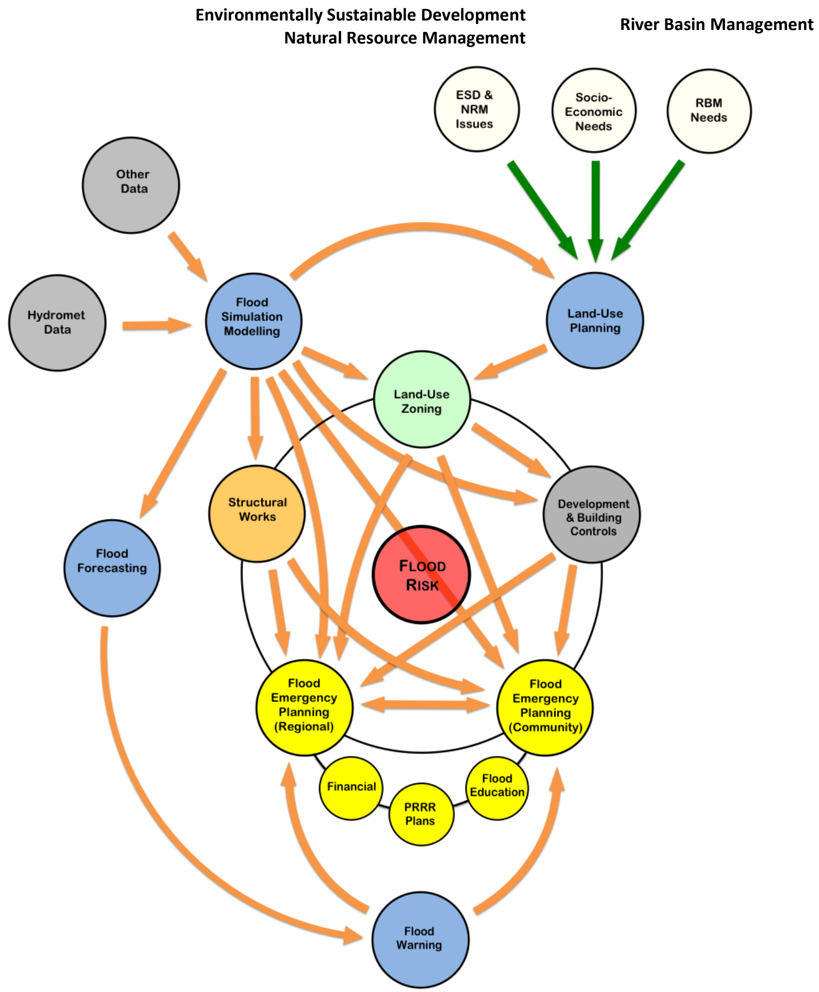


Figure 5.2 Flood Risk Management Framework

Effectiveness of Flood Risk Management Measures

Table 5.2 shows the general effectiveness of the principal measures that can be used to manage the three flood risks.

- *Structural works* define the level of controlled risk for an existing development situation. As additional structural works are built, the level of controlled risk increases and the level of residual risk decreases, i.e. there is less residual risk to manage.
- *Flood emergency planning* (at both the regional and community level) is the principal instrument to manage residual flood risk; the retrofitting of flood-proofing measures to existing buildings and infrastructure at risk can also reduce residual flood damage to these items and reduce the resulting service and socio-economic disruption
- *Land-use Controls* and *Building and Development Controls* (including flood-proofing new developments and infrastructure) are the most cost-effective means of controlling future flood risk.

Table 5.2 Effectiveness of Flood Risk Management Measures in Relation to the Three Flood Risks

Flood Risk Management Measure	Controlled Risk (Existing Development)	Residual Risk (Existing Development)	Future Risk (New Development)
1. Structural Works	✓		
2. Land Use Controls			✓
3. Development and Building Controls		✓ (Retrofit)	✓
4. Flood Emergency Planning (Regional)		✓	
5. Community-Based Flood Risk Management		✓	

5.3 Drought Risk and Drought Risk Management

5.3a Drought Risk

As with flood risk, a number of basic drought risk concepts are briefly discussed and described before describing drought risk management:

- We do not ‘manage’ droughts *per se*. Rather, we manage drought risk.
- Drought risk depends upon the *likelihood* (probability) of a drought occurring and the *consequences* of the drought (drought impacts).
- We cannot reduce drought risk by reducing the likelihood of a drought occurring, which is defined by the nature and severity of the underlying physical phenomenon (rainfall, stream flow and soil moisture deficits)[18]. However, we can reduce the *impact* of drought risk through structural works to provide supplementary water supplies (dams) and by implementing water conservation measures.
- The impact of a drought depends upon the *nature of the drought* itself (time of onset in relation to crop growth stage, duration, etc), the *drought mitigation measures* in place, and the *socio-economic vulnerability* of the drought-prone community.
- Community vulnerability depends upon the *population at risk*, *land-use* in the drought-prone areas, and *community drought resilience*.

[18] Cloud seeding can be used in an attempt to increase rainfall. However its effectiveness is still contentious; it is thought that cloud seeding has never been attempted in the LMB.

- Community resilience can be strengthened through the development of *drought preparedness, response, relief and recovery plans* (PPRR plans).

Thus, the relationship between drought risk and the various factors affecting risk can be written in the same way as flood risk:

Drought Risk = Function (L_d N_d Pop_r, LU, CR)

Where: L_d is the likelihood of drought occurring,
N_d is the nature of the drought,
Pop is the population at risk,
LU is land-use, and
CR is the community resilience to drought.

We cannot reduce the likelihood of drought, but we can reduce drought risk by moderating the nature of drought (through structural works, such as supplementary water supply from dams or groundwater, or by water conservation measures), reducing the population at risk (land-use controls), ensuring that land-use across flood-prone land is appropriate to the level and nature of drought risk (i.e. land-use is resilient to drought), and by increasing the drought resilience of drought-prone communities (through PRRR plans as described above).

Drought risk depends upon with the severity or 'intensity' of a drought (as measured by its likelihood of occurrence of rainfall, stream flow and soil moisture deficits). It also depends on the characteristics of drought behaviour. The time of onset of a drought in relation to crop growth cycle and its duration play major roles in determining the reduction in agricultural yield. Drought risk is also highly dependent on land-use; drought-sensitive land-uses increase drought risk. In the LMB, major land-uses adversely affected by drought include agriculture, animal husbandry, fisheries and urban settlements (typically villages). Unlike floods, droughts do not cause damage and service disruption to infrastructure and buildings.

5.3b **Integrated Drought Risk Management**

Like IFRM, integrated drought risk management (IDRM) is a ***planning process*** that attempts to better manage drought risks by means of formulating an ***IDRM Plan*** that integrates and coordinates the actions of all parties that affect or are affected by drought risk.

IDRM identifies *three drought risks*, *three primary flood risk management measures* (one structural and two non-structurals) and *three supplementary flood risk management measures.* These six measures need to be considered together to define an integrated and coordinated strategy to manage drought risk. Summary details of these risks and risk management measures are shown in Table 5.3.

Principal Drought Risk Management Measures

The three principal drought risk management measures are described below. One of these measures is 'structural in nature (structural works), the other two measures are 'non-structural' in nature.

Structural Works The aim of structural works, which include dams (both large and small) and groundwater wells to provide additional water for use in times of drought, along with water conservation measures to minimize water wastage, is to *supplement and husband the available water*. It is impossible to provide total protection against droughts, but structural works can reduce the impacts associated with existing and future drought risks. It is noted that a large programme of hydropower dam construction is proposed for the LMB. Hydropower releases during the dry season will make more water available for dry season irrigation and reduce the impacts of droughts. It is also noted that in many areas of Cambodia and North-eastern Thailand, farmers construct small dams in the wet season to trap runoff for use in the dry season. (A sophisticated system of colmatage canals was developed across the Cambodian Lowlands for this purpose).

Table 5.3 Drought Risks and Drought Risk Management Measures

Item	Name	Details
Drought Risk	1. Controlled Risk	The drought risk that is controlled by existing structural works (e.g. supplementary water supplies, water conservation measures) in relation to the 'existing community situation' with regard to fabric of the drought-prone community (land-use, population, socio-economic vulnerability, etc.) and the nature of drought at this location.
	2. Residual Risk	The drought risk to existing developments over and above the controlled risk. It is generally impossible to completely eliminate drought risk. A residual drought risk associated with the limited capacity of supplementary water supplies generally (always) remains.
	3. Future Risk	The risk exposure of drought-prone communities at some time in the future. Future risk relates to new developments and is generally (inevitably) higher than the current residual risk because of population growth in drought-prone areas, together with increases in the standard of living and the increased vulnerability of communities and 'new' land-uses.
Principal Drought Risk Management Measures	1. Structural Works	Aim at 'delivering additional water supplies' and reducing water wastage (water conservation measures).
	2. Regional Drought Emergency Planning	Recognizes that droughts will occur (residual risk) and aims to limit socio-economic impacts on drought-prone communities by the provision of drought emergency services (preparedness, response, relief and recovery services). Regional drought emergency services are State-based.
	3. Community-Based DRM	Recognizes that droughts will occur (residual risk) and aims to increase the drought resilience of drought-prone communities by developing a CBDRM Plan comprising local preparedness, response, relief and recovery arrangements.
Supplementary Drought Risk Management Measures	1. Drought Monitoring	Measurement of rainfall, stream flow and soil moisture deficits. Enables the severity and trend in drought development to be tracked.
	2. Drought Forecasting	Drought forecasting, which is based on current drought deficit indicators and likely future rainfalls and stream flows (in the medium-term), enables the likely onset, severity and duration of droughts to be assessed. Simple statistical-based methods or complex computer-based methods involving satellite images can be used.
	3. Drought Warning	If drought warning is to be effective, i.e. to significantly reduce drought risk, warnings must be accurate and timely and warning recipients must know how to respond appropriately (response plans).

Regional Drought Emergency Planning The provision of regional drought emergency services, typically by State agencies, is aimed at assisting flood-prone communities better prepare for, respond to, endure, and recover from droughts, i.e. to reduce residual drought risk. To this end, Regional Preparedness, Response, Relief and Recovery Plans (PRRR Plans) are developed. These activities are aimed at reducing community vulnerability by assisting drought-prone communities to better '*live with droughts'*.

Community Drought Emergency Planning In this case, drought-prone communities are encouraged to accept responsibility for their own community drought risk and to develop Community Drought Preparedness, Response, Relief and Recovery Plans to reduce drought impacts. Again, these activities are aimed, in the most direct sense, at reducing residual drought risk and community vulnerability.

To maximize the effectiveness of regional and community-based drought emergency planning initiatives, regional and community-based activities need to be coordinated. In addition to 'PRRR' Plans, other important elements of drought emergency planning at both regional and community levels include drought education (i.e. increasing the drought awareness and drought readiness of emergency service providers and affected communities) and financial measures (such as relief payments). Another important community-based initiative is livelihoods improvement, i.e. the identification and uptake of more drought-tolerant livelihoods to reduce the financial impact of droughts.

Supplementary Drought Risk management Measures

The three supplementary drought risk management measures are described below. All of these measures are 'non-structural' in nature.

Drought Monitoring The ongoing development of a drought can be monitored in real-time by tracking rainfall and stream flow deficits at nominated gauging locations. Deficits need to be tracked over a variety of durations because the uncertain future nature of rainfall and stream flow behaviour, and need to be updated at regular intervals. Appropriate tracking durations for meteorological droughts could be 15, 20, 30, 45, 60 and 90 days, with rainfall deficits updated weekly. For hydrological droughts, appropriate tracking durations could be 1, 2 and 3 months, with figures updated monthly. Soil moisture can also be monitored (approximately) in real-time from satellites, so allowing soil moisture deficits to be tracked. The National Weather Service of the USA provides such data, both for the USA and globally (see NWS, 2009a and 2009b respectively), as shown in Figure 5.3, and combines a number of drought markers into an overall drought index for the USA (NOAA, 2009 and Adamson, 2005)[19]. Thus, the three markers of droughts can be monitored individually, in a combined form, or supplemented with additional markers to generate a 'drought index' that provides a basis for drought forecasting and drought warning. No formal drought monitoring (in real-time) is currently undertaken in the LMB.

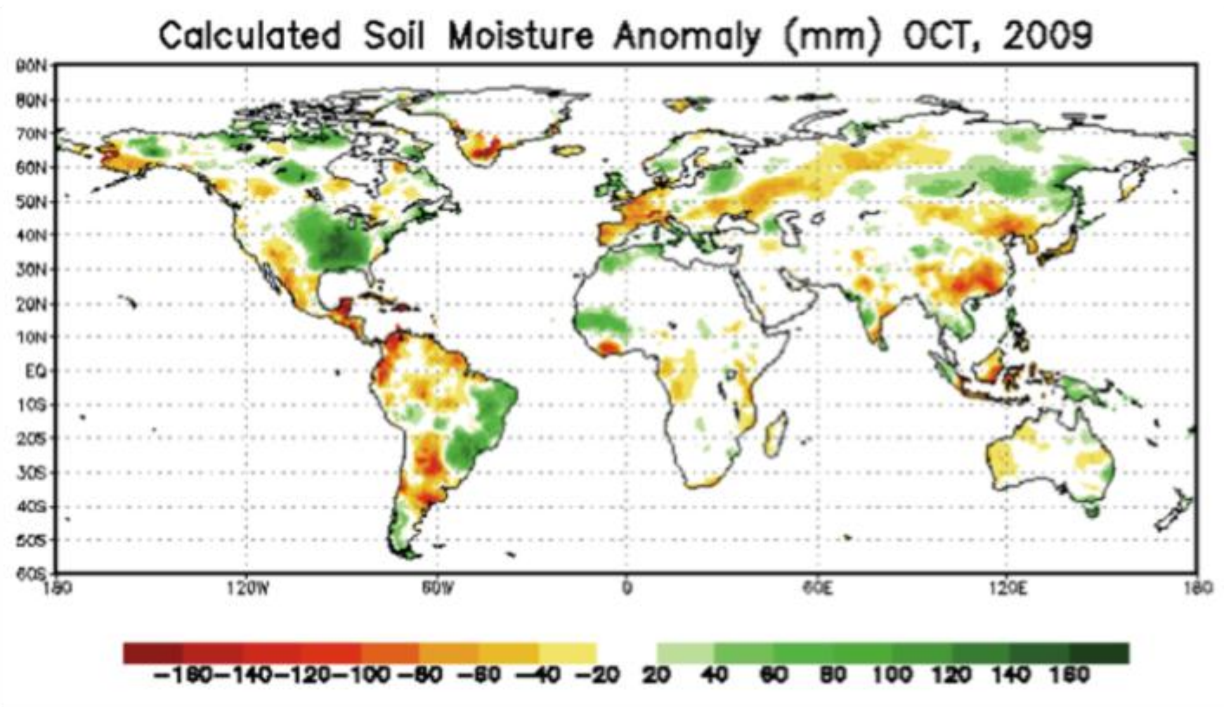


Figure 5.3 Soil Moisture Anomaly, October 2009 (NWS, 2009b)

19 In assessing the likelihood of flash flooding, it is noted that the MRC Flash Flood Guidance System operated by RFMMC provides real-time estimates (updated hourly based on satellite estimates of rainfall) of soil moisture in 6,400 basins across the LMB. Thus, MRC already has the heart of a soil moisture monitoring system for drought management (see van Woersem et al, 2010 for details)

Drought Forecasting Drought monitoring information can be combined with forecast rainfalls to provide drought forecasts. The National Weather Service of the USA provides short and longer-term drought forecasts for the USA (NWS, 2009c). This procedure could be applied to the LMB.

Drought Warning Finally, drought forecasts can be used to formulate drought warnings and prepare regional emergency services and communities for an increase in drought severity and impact. As with floods, it is essential that farmers and others know how to respond effectively to drought warnings, so emphasizing the importance of drought education.

Interactions between Drought Risk Management Measures

Figure 5.4 shows the three drought risk management measures. Financial measures, PRRR plans and drought education measures are important elements of drought emergency management and have been shown separately.

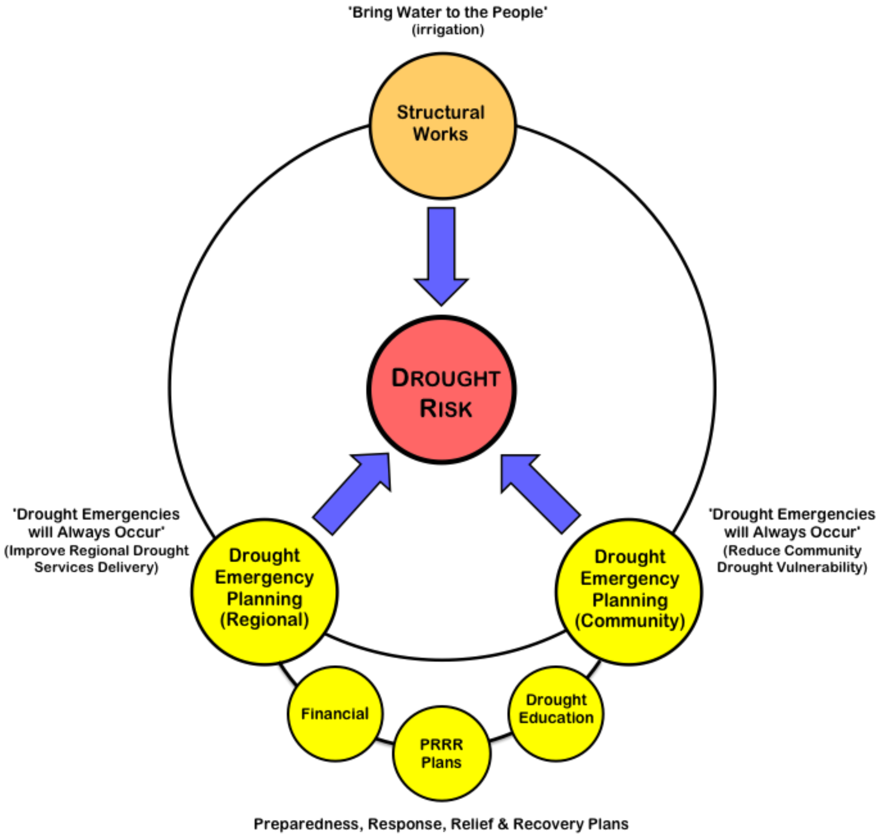


Figure 5.4 Drought Risk Management Measures

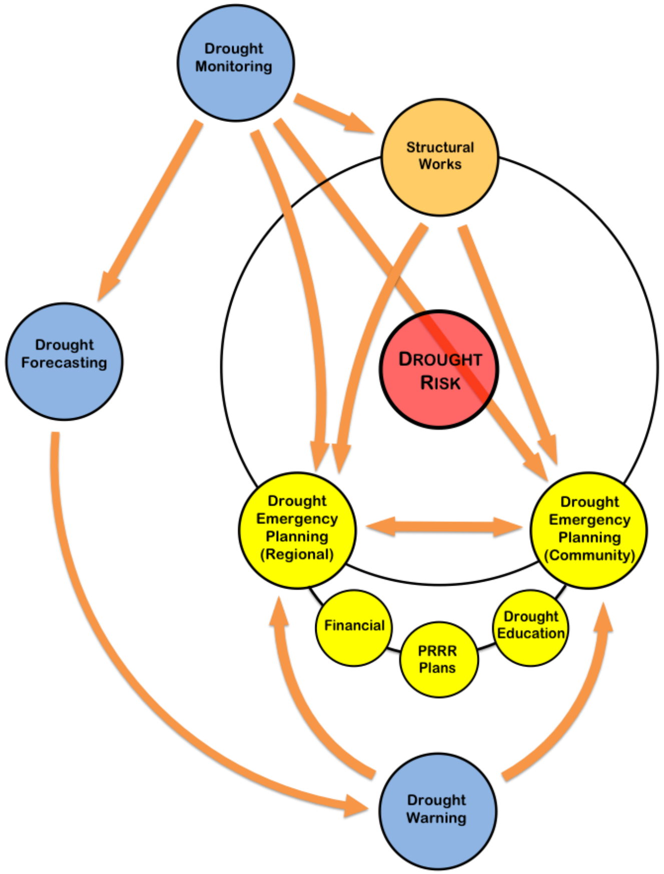


Figure 5.5 Drought Risk Management Framework

Figure 5.5 shows all six drought risk management measures and the interactions between them. They are seen to interact in a complex way, although less so than the flood risk management measures of Figure 5.2, but still indicating a need for 'integration' of individual DRM activities across all relevant agencies that influence or are affected by drought risk. Unlike FRM, land-use planning does not play a significant role in DRM. Droughts are commonly inflicted on the rural poor of the LMB, many being subsistence farmers who at best eke out an income a little above subsistence level. There is very little opportunity for them to change their farming practices or lifestyle.

In a similar manner to floods, Figure 5.5 provides a framework for the integrated management of drought risk (see Section 5.4 for further details). The interconnections in the drought management framework are much sparser than in the flood framework because of fewer options to reduce drought risk.

Effectiveness of Drought Risk Management Measures

Table 5.4 shows the general effectiveness of the principal drought risk measures that can be used to manage the three drought risks.

Table 5.4 Effectiveness of Flood Risk Management Measures in Relation to the Three Flood Risks

Flood Risk Management Measure	Controlled Risk (Existing Development)	Residual Risk (Existing Development)	Future Risk (New Development)
1. Structural Works	✓		
2. Drought Emergency Planning (Regional)		✓	
3. Community-Based drought Risk Management		✓	

Drought-prone communities - and this includes most communities in the LMB - are exposed to *existing, future and residual drought risks* in a similar way to flood-prone communities. However, there are differences between flood and drought risk. Flood causes physical and economic damage to community infrastructure and assets, as well as to day to day community endeavours, such as farming, schooling, commerce, etc. Drought also imposes costs on day to day community activities, but it does not physically damage community infrastructure and assets (apart from public gardens). Whilst a number of structural measures are available to reduce flood risk, the provision of irrigation supplies, whether large scale or small scale, is the only day to day structural measure available to significantly reduce drought risk (there have been no instances of cloud seeding in the LMB).

5.4 Integrated Flood Risk Management

5.4a Importance, Concepts and Principles

IFRM has a central role to play in the better management of flood risk in the LMB. Recently, a follow-on phase of MRC's FMMP (FMMP 2011-2015) has been formulated (see Section 6.1b for details) largely founded on the need to deliver capacity building and demonstration projects in IFRM to national agencies to enable them to implement IFRM in their day to day work.

IFRM embodies the following concepts and principles:

- The need to identify all parties affected by or affecting flood risk - at regional, national, provincial, local and community levels - and the need to integrate FRM actions and efforts by all parties into an agreed and cohesive IFRM plan.

- The need for a clear and transparent allocation of roles and responsibilities across the various parties affected by or affecting flood risk.
- The need for a participatory and consultative planning process at all levels to formulate an effective IFRM Plan.
- Recognition that flood risk is *but one factor* affecting the use of flood-prone land and that other considerations need to be included in the IFRM planning process, e.g. population growth, community aspirations, socio-economic needs, natural resources management considerations, river basin management issues, ecologically sustainable development needs, etc.
- The need to objectively evaluate the cost-effectiveness and cost-benefits of alternative FRM measures to ensure that an IFRM Plan delivers 'value for money'.

Effective monitoring and evaluation of flood risk management outcomes, together with the regular reassessment of IFRM Plans to ensures that objectives are being met, that the plan remains up-to-date, and that new circumstances are addressed as they arise

Whilst IFRM concepts and principles are easy to define, their implementation is often difficult. IFRM considerations cut across the activities, roles and responsibilities of many government departments and agencies. Often cooperation is not forthcoming. One way of fostering cooperation and the integration of flood risk management efforts and activities is through the formation of an 'IFRM Committee' on which all parties that affect or are affected by flood risk are represented. Such a committee can oversee the formulation of an IFRM Plan. Such plans should be prepared for all levels of management. The contents of a local IFRM Plan to manage flood risk at the community level are described below.

5.4b **IFRM Plans**

The most basic output of the IFRM process is an *IFRM Plan* that addresses flood risk in the area of interest (which may be regional, transboundary, national or local in scope). This plan states how residual and future flood risks are to be managed and is based on a number of component studies:

- An assessment of *existing and likely future land-use* in the area of interest, including population growth. This may involve national, transboundary and local land-use considerations across many national sectors, such as agriculture, transport, water resources development, industry, commerce, etc, i.e. the statutory planning process such as it is.
- An evaluation of *existing, future and residual flood risks*. This requires the use of flood simulation models to investigate flood behaviour and flood risk under present day and future circumstances. Important factors affecting future flood risk are population growth, climate change, land-use change and infrastructure development. In the case of the Mekong Basin, one major factor influencing future flood risk will be the *many hydropower dams* proposed for the basin, which will tend to reduce downstream flood levels, but extend the duration of flooding, and may have impacts at the regional, transboundary, national and local levels. Another major factor influencing future flood risk is the impact of *climate change* on flood behaviour.
- An evaluation of the *economic cost-effectiveness* and cost-benefits of the five flood risk management measures and four ancillary measures, together with the associated *social, environmental and natural resource management implications* of these measures. This is followed by a judicious selection of the most appropriate measures to manage flood risk. Included in these studies will be an assessment of the economic, social and environmental vulnerability of flood-prone communities and the impacts thereon of the proposed flood risk management measures.

- Identification of the any changes in existing or new stakeholder roles and responsibilities to effectively implement the IFRM Plan. This step addresses the integration of efforts across flood risk management measures, institutions, communities, districts and provinces.

Essential elements of IFRM planning include the identification and inclusion of all stakeholders and a willingness to undertake the necessary institutional changes.

Steps in the preparation of an IFRM Plan include:

1. *Establish an IFRM committee*. Such a committee should include representatives of all agencies that affect or are affected by flood risk, as well representatives from communities at risk. The purpose of the committee is to provide a consultative vehicle that directs the process of formulating the floodplain management plan. A lead line agency at national, provincial or district level (depending on the level of the plan) should be appointed to chair this committee. The most appropriate Line Agency in the various MCs is not clear and remains the choice of each country. However, it should be an agency with considerable political strength as IFRM cuts across many different agencies and a number of hard-nosed decisions that impinge on the wants of individual agencies are likely to be required.
2. *Collect relevant data*. A number of different data items are required, including details of past flooding behaviour, the socio-economic basis and current flood vulnerability of flood-prone communities included in the study, expected population growth and land-use change over the planning period, current flood risk management practices (at regional, national, provincial and district levels) and any deficiencies therein, survey details of waterway cross-sections and floodplain topography, etc. Much of the socio-economic data will need to be collected by survey. Likely change to future land-use is an important element of a floodplain management plan, as it defines future flood risk. Efforts should be made to obtain information from all agencies that affect land-use or the provision of infrastructure across the floodplain (such agencies should be represented on the IFRM committee).
3. *Conduct a flood study.* The purpose of a flood study is to evaluate the risk and hazard of flooding across the floodplain by providing information on the extent, depths and velocities of floodwaters and their distribution across the floodplain. This will normally require the use of numerical flood simulation models. Such models need to be developed and calibrated against historical flood data for the area of interest. The changing nature of hazard and risk across the floodplain can then be investigated for a range of 'standard' flood events (e.g. the one-in 20 Year ARI event). Such models need to be used to investigate the residual risk and the future risk,
4. *Conduct a floodplain risk management (IFRM) study*. The purpose of the risk management study is to determine the best means of managing the residual and future flood risk in the area of interest. This is where the IFRM risk management diagram of Figure 5.2 comes in. The feasibility, costs, effectiveness and benefits of all five flood risk management measures and four ancillary flood risk management measures need to be carefully assessed and the most appropriate mix of measures selected. Land use planning is an especially important management measure. Note that land-use planning across flood-prone areas has to address community wants and needs, ecologically sustainable development, natural resource management and river basin management considerations. The assessment of land-use issues can be a lengthy process. The land-use planning capacities of the MCs vary from country to country. Capacity building in basic land-use planning concepts is likely to be required. Further, the standard and effectiveness of land-use planning instruments are likely to vary in effectiveness and from country to country. Note that if structural measures are included in the mix of flood risk management measures, the environmental impacts should be evaluated and managed.

5. *Prepare an IFRM plan*. Based on the results of the above studies, a floodplain risk management plan is drafted, which needs to account for a range of factors including changes to flood behaviour and risk associated with future changes to population and land-use, the economic and social consequences of the proposed risk management measures, the ecological and environmental consequences associated with the proposed plan, it being noted that the beneficial effects of flooding should be preserved as much as possible, and local planning needs, restrictions and opportunities.
6. *Implement the Plan*. The successful implementation of a floodplain risk management plan involves the coordinated actions of a number of national, provincial, district and community-based agencies and organizations, together with local inputs from NGOs and possibly high level contributions form RFMMC. This is not an easy process. Floodplain risk management plans need to be evaluated at regular intervals to ensure that they are delivering the desired outcomes and to identify any major changes to the planning assumptions used in the preparation of the plan, e.g. flood behaviour, land-use, etc.

5.4c **IFRM Policies and Strategies**

An *IFRM Policy* is a succinct formal statement of a government's intentions regarding flood risk and its management. The Policy is an output from the IFRM Plan. An *IFRM Strategy* is essentially a formal statement of how a government will implement the Policy and Plan.

5.4d **IWRM, IFRM and IRBM**

Where does *Flood Risk Management* (FRM) fit within IWRM considerations? FRM is a cross-cutting issue that affects and is affected by developments in many other water resource sectors (see Sections 2.3 and 2.4 of the main Report and WWF, 2009b). As such, FRM considerations form an important component of IWRM, as the World Water Forum has noted:

> *'The management of water-related disasters such as floods and droughts, including proper risk management, should not be considered in isolation, and should comprise an essential part of IWRM. Managing the extremes of the hydrological cycle comprises the essence of water resources management, as these events can have severe social and economic consequences on development. Improved management of extremes can produce high rates of return in terms of GDP (Gross Domestic Product), maintaining economic growth and social cohesion.'* (WWF, 2009a)
>
> *'A central goal of IWRM at the river basin level is to achieve water security for all purpose, as well as manage risks while responding to, and mitigating, disasters.'* (WWF, 2009a)

Thus, FRM is an integral part of IWRM and should be embedded in the IWRM process, which comprises the three pillars of:

1. An effective enabling environment;
2. An appropriate institutional framework; and
3. The use of effective management instruments.

In effect, the primary and supplementary measures indicated in Table 5.1 and Figure 5.2 are generic 'management instruments' of IFRM. The IWRM process provides a generic framework for the implementation of IFRM. The following factors facilitate the development and implementation of IWRM (Jonch-Clausen, 2004) and are equally applicable to IFRM:

- A strong political will;
- A clear distribution of roles and responsibilities between stakeholders;
- Highly motivated drivers maintaining commitment throughout the process (‘champions’);
- Exchange of knowledge and experience between agencies, states and countries;
- Setting clear milestones for achievement; and
- Monitoring and evaluation of progress, performance and impact (outcomes).

Integrated River Basin Management (IRBM) is the application of the IWRM process to a river basin.

> *‘The river basin approach seeks to focus on implementing IWRM principles on the basis of better coordination amongst operating and water management entities within a river basin, with a focus on allocating and delivering reliable water-dependent services in an equitable manner.’*, (WWF, 2009a).

The river basin is a natural unit for water management purposes. It defines the hydrological boundaries; considerations of water allocation between ‘users’ and ecosystems often need to be addressed at the basin level. Many river basins lie in different countries or different states, so introducing international and inter-state issues into the management process.

The World Water Forum stresses the need for an appropriate enabling environment and institutional framework to implement IWRM on a river basin scale. (See below). These comments are equally applicable to implementing IFRM on a basin-scale. It is noted that the Mekong River has a long-standing RBO, the MRC, which provides a solid platform for the inclusion of IFRM considerations in the integrated management of the water resources of the Mekong Basin.

> *‘A key aspect of IWRM requires that the national government(s) create an enabling environment, including a legal framework, to facilitate a multi-sectoral coordinated basin-level approach. Thus, there will need to be linkages and coordination amongst the national, regional, local and basin levels. The responsibilities of the different levels of administration and relevant stakeholders and their relationships and roles within river basin management need to be clearly defined.’* (WWF, 2009a)

5.5 Integrated Drought Risk Management

A process similar to IFRM can be applied to the integrated management of drought risk. To date, there is no evidence of such an approach in the LMB, either regionally or nationally. This is something for MRC’s new drought management programme to consider.

6 Flood and Drought Management Initiatives in the Lower Mekong Basin

6.1 Flood Management Initiatives

6.1a Roles and Responsibilities

The management of flood risk in the LMB is the statutory responsibility of the four riparian governments, each of which has different priorities and differing capabilities regarding the provision of flood risk management services. A number of different agencies and programs provide resources and assistance to the flood risk management endeavours of the countries. Many international donors finance flood risk management programmes and projects (e.g. ADB, WB, GWP and ASEAN); numerous NGOs also provide flood preparation, response, relief and recovery assistance along with capacity building, typically at the community level. The Mekong River Commission (MRC) has a basin-wide role in flood management though its Flood Mitigation and Management Programme (FMMP 2004-2011), which is described below. Improved coordination and integration of the various flood risk management initiatives would lift the overall effectiveness of individual efforts to reduce flood risk.

6.1b The Mekong River Commission

The MRC has a limited but important role to play in flood risk management in the LMB. According to Article 1 of the 1995 Mekong Agreement, 'Areas of Cooperation', 'flood control' is listed as one of the activities to be managed for the '*mutual benefits of all riparian and to minimize the harmful effects that might result from natural occurrences and man-made activities*' (MRC, 1995). Thus, 'natural' flood risk and any 'man-made' activities that affect flood risk fall within the MRC's ambit of cooperation. However, MRC's role is limited to (MRC, 2001):

(i) The provision of technical products and services to the four countries;

(ii) Facilitating the resolution of transboundary flood issues; and

(iii) Capacity building and technology transfer.

The MRC *has no mandate to physically manage flood risk* in the LMB; it can only assist the riparian countries to do so.

FMMP 2004-2010 was formulated in response to the widespread devastation caused by the Year 2000 Floods, with the overall objective being '*To prevent, minimize or mitigate people's suffering and economic losses due to floods, whilst preserving the environmental benefits of floods*' (MRC, 2004). The Program was funded by a number of donors and has five components, details of which are shown in Table 6.1. Capacity building is an important and common element of all components. The reactive nature of the Program (in response to the Year 2000 Floods), coupled with the need for donors to fund individual components that met their development goals, meant that the integration of the various components into a comprehensive flood risk management framework (see Section 6.1b) was not as strong as it could have been (see van Woersem and Joy, 2009, for details).

Table 6.1 Details of MRC's Flood Management and Mitigation Programme 2004-2011

Programme Component		**Key Activities**
C1	Establishment of a Regional Flood Management and Mitigation Centre.	Establish regional centre in Phnom Penh. Improve mainstream and tributary flood forecasts, including flood forecasting models, and the collection and handling of hydrometeorological data.
C2	Structural Measures and Flood proofing.	Develop and demonstrate a comprehensive set of best practice guidelines for the design, construction, maintenance and impact assessment of structural flood mitigation measures, and for the flood proofing of infrastructure and buildings.
C3	Enhancing Cooperation in Addressing Transboundary Flood Issues.	Demonstrate the use of flood simulation models to assist in the understanding and resolution of transboundary flood issues.
C4	Flood Emergency Management Strengthening.	Improve flood emergency planning at the community and local government levels. Foster inter-province and inter-country assistance in flood emergencies.
C5	Land Management.	Assess local flood behaviour and incorporate the associated flood hazard into land-use decision making by communities and local government.

To date, the FMM Programme has spent some USD 27 M on the better management of flood risk in the LMB. Key achievements of FMMP 2004-2010 include:

- The establishment of a purpose-built regional flood management and mitigation centre (RFMMC) at Phnom Penh in Cambodia (Component C1). This centre will become the 'Office of the Secretariat, Phnom Penh' (OSP) and can continue serve as a regional focus for future basin-wide flood risk (and possibly drought risk) management initiatives.
- The development of improved mainstream flood forecasting procedures of world-class standard (Component C1).
  - (i) The new mainstream flood forecasting system uses the 'Flood Early Warning System' computer platform to manage hydrometeorological data, flood simulation models and flood forecasts (Delft, 2009).
  - (ii) A hydrologic rainfall-runoff model (URBS) is used to forecast tributary discharges and mainstream flood behaviour along the mainstream river reaches of Lao PDR and Thailand (URBS, 2009).
  - (iii) Currently (early 2011), a multi-channel one-dimensional hydraulic model (ISIS) is being tested for use in forecasting flood discharges, water levels and velocities over the Cambodian Lowlands and Cuu Long Delta (Wallingford, 2009). This model runs from Kratie to the South China Sea and includes the Great Lake and all tributaries draining this portion of the basin.
  - (iv) One-day and 7-day basin-wide forecast rainfalls generated by a climate model on a 40 km x 40 km spatial grid are used to make flood forecasts (NWS, 2009d). Figure 6.1 shows a broad-scale 7-day forecast for the Southeast Asia Region.
  - (v) During the flood season, RFMMC provides 1-day and 5-day water level forecasts at 22 locations along the mainstream of the Mekong and Bassac Rivers, and 1-day and 7-day estimates during the dry season.
  - (vi) A 'Flash Flood Guidance System' that assesses the likelihood of flash flooding in tributaries has been installed at the RFMMC for testing (HRC, 2009) and is now operational. This system (MRCFFG) uses satellite estimates of soil moisture and 6-hour forecast rainfalls (NWS, 2009b; NWS, 2009d) to estimate the likely depth and rate of surface runoff, and hence the likelihood of flash flooding.

- Components C2, C3, C4 and C5 have all delivered a number of successful pilot projects that demonstrate the principles and application of individual flood risk management measures.
- All five components have managed to engage with counterpart agencies in the four countries and have delivered intensive capacity building.

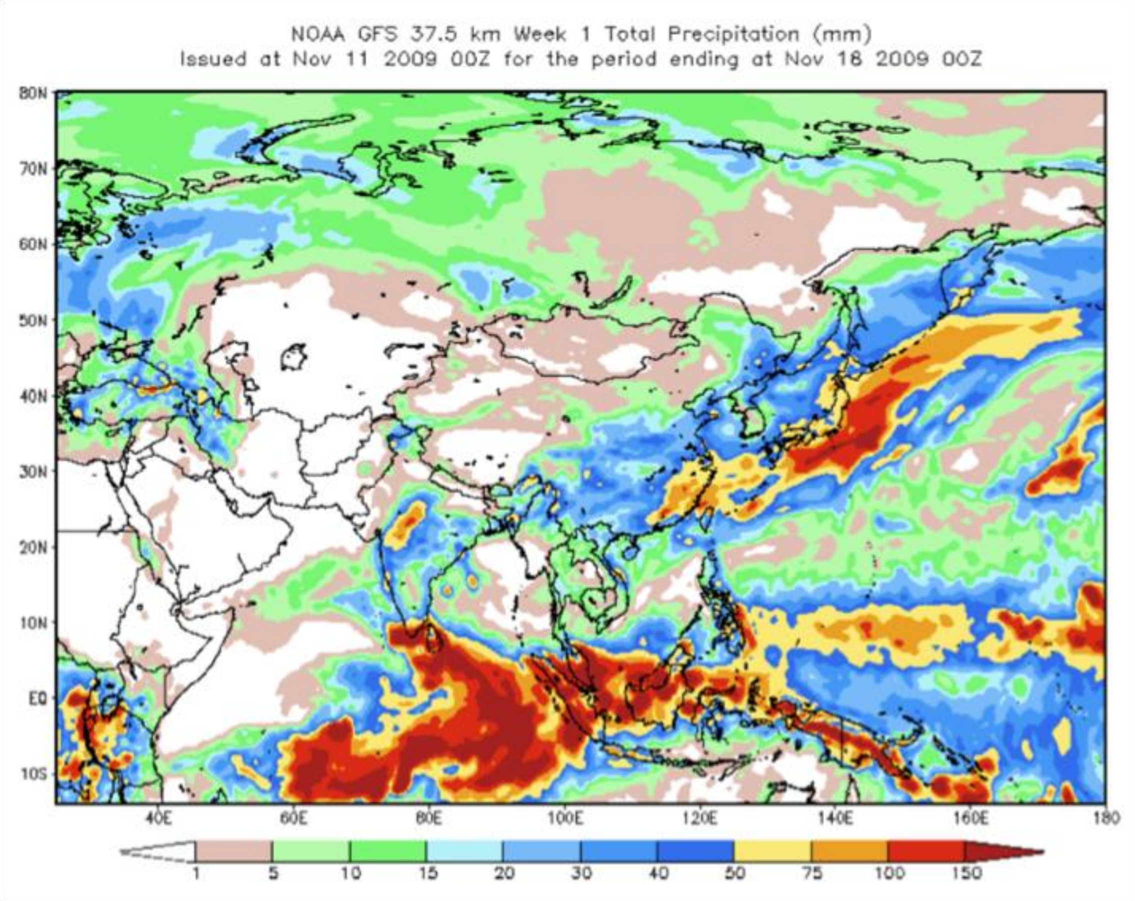


Figure 6.1 7-Day Forecast Rainfalls, Southeast Asia (NWS, 2009d)

All components of FMMP 2004-2011 are now (January 2011) approaching completion. The program itself has recently been reviewed and its extension into a second phase has been recommended (van Woersem and Joy, 2009). The review found that many of the flood risk management 'products' produced and demonstrated by the five components had not been taken up with full effectiveness by the four member countries. To some extent, this reflects the reactive nature of the design of FMMP. A second phase for the FMMP (FMMP 2011-2015) has now been formulated (see van Woersem et al, 2011) comprising:

(i) Consolidation and improvement of key functions at the RFMMC (the provision of flood forecasts and warning information for mainstream and flash floods) and possible expansion of these functions to include tributary forecasting, drought assessment and possibly drought forecasting, and an assessment of the impact of climate change on flood and drought behaviour;

(ii) Continuing to assist member countries resolve transboundary flood risk issues through the provision of technical, socio-economic and administrative tools and analyses;

(iii) Provision of capacity building and training;

(iv) Assisting member countries through the development, dissemination and support of flood risk management products; and

(v) Assisting member countries understand and implement IFRM principles in their land-use and other planning processes.

6.2 Drought Management Initiatives

6.2a Roles and Responsibilities

The management of drought risk in the LMB largely mirrors that of flood risk. Drought risk management is the statutory responsibility of the four riparian countries. Again, each country has different priorities and differing capacities, and is assisted in these endeavours by a host of agencies and programs. Whilst irrigation is one of the water resource uses listed under 'Areas of Cooperation' in the 1995 Mekong Agreement to be included in the '*sustainable development, utilization, management and conservation of the water and related resources of the Mekong River Basin*' (MRC, 1995), MRC again *has no mandate to actively manage drought risk*, and it actions are limited to providing products, assistance and capacity building, as with floods. Many NGOs contribute to the management of drought risk in the four countries, typically at the community level, providing emergency food supplies and seed for next season's crop, i.e. emergency response. However, these days NGOs are increasingly beginning to address the reduction of drought vulnerability at the community level. As with floods, improved coordination and integration of the various drought risk management activities being undertaken by NGOs and government agencies is likely to lift the overall effectiveness of individual efforts.

6.2b Mekong River Commission

One difference between flood and drought risk management in the LMB is that MRC *does not as yet (January 2011) have* an active and ongoing drought (risk) management program (DMP), although a latent program has been defined (Adamson, 2005; MRC, 2007e). Like the FMMP, the DMP was formulated in response to a specific natural disaster, namely the drought of 2004-05, when deficits in wet season regional rainfalls led to widespread drought and the loss of rain-fed crops in Northeast Thailand and Cambodia (meteorological drought), and reduced dry season flows led to the loss of irrigated crops in the Cuu Long Delta because of the greater upstream migration of ocean salinity (hydrological drought). The proposed DMP consists of five components, as described in Table 6.2. The cost of the DMP has been estimated at USD 14 M (MRC, 2007e). The Program has been included in MRC's 2011-15 Strategic Plan and is currently awaiting donor funding, although limited initial activities have started. Average annual drought costs are equal to or greater than flood costs (see Section 4.3d). DMP is a needed initiative of significant potential benefit to drought-affected peoples of the LMB and it should be brought to fruition within MRC. As discussed in the formulation of FMMP 2011-2015, the RFMMC could undertake various activities on behalf of the DMP. This is something that needs to be resolved in the future.

Table 6.2 Proposed Drought Management Programme, Mekong River Commission

Programme Component		Objectives
C1	Drought Forecasting	To provide reliable early warning information on the status and severity of droughts based on improved hydrometeorological monitoring and seasonal forecasts of drought markers.
C2	Drought Impact Assessment	To improve the generation, transfer and uptake of improved and tested drought management and mitigation strategies.
C3	Drought Management Policy	To provide an enabling management and institutional environment for improved cooperation and drought management of the MRC, NMCs, MRCS, partner organizations and civil society.
C4	Drought Preparedness and Mitigation Measures	To close the gap between water supply and demand in drought-prone parts of the LMB through planning and promoting implementation of appropriate structural and non-structural measures.
C5	Programme Management	To effectively manage the DMP.

6.3 Aspects of Flood and Drought Risk Management in the Lower Mekong Basin

This section comprises a miscellany of various aspects of flood and drought management in the LMB that are of importance or interest. They mainly address the impacts of developments in flood-prone areas on flood behaviour and risk (i.e. structural works).

6.3a Flood Risk Planning

Any physical development in flood-prone areas will affect flood behaviour and flood risk, possibly unacceptably. Conversely, these developments will also be exposed to flood risk, possibly to an unacceptable level. Such developments include flood protection embankments (interfere with flood flows and reduce floodplain storage); road and rail infrastructure (road and rail embankments interfere with flood flows); irrigation developments (the spoil embankments from irrigation channel construction interfere with flood flows); urban developments (greater numbers of people exposed to flood risk); and land filling (reduces the available floodplain storage). Generally, any physical development on flood-prone land needs to be scrutinized closely to assess first, the effect of flood risk on the development and second, its effect on flood risk. Fail to do so leads to ever-increasing levels of flood risk and possibly to unintended consequences regarding flood behaviour. Thus, the formulation and implementation of an effective land-use plan for flood-prone areas is an essential component of modern flood risk management. Such plans are best developed in consultation with all private bodies and government agencies responsible for developments that affect or are affected by flood risk. Computer models are used to assess the impacts of developments on flood risk. To date, it appears that none of the four riparian countries has in place an effective land-use plan for flood-prone areas, although FMMP 2004-2011 is delivering a number of initiatives and capacity building in this area, e.g. pilot land-use planning in Northeast Thailand (C2), the evaluation of flood hazard and its incorporation in local development planning (C5), the development of best management guidelines for assessing and minimizing the impact of embankments on flood behaviour and risk (C3), and the development of best practice guidelines to estimate flood damage (C2).

If flood risk planning is to be effective, it is necessary for national riparian governments to formulate and implement such plans on an integrated and cross-sectoral basis. It is only in this way that an effective mix of flood risk management measures can be defined and the flood risk-altering actions of different government and private sector agencies be assessed and coordinated. Similarly for the MRC: flood risk considerations need to be incorporated in and addressed across all the Commission's Programmes (see MRC, 2007a).

6.3b Flood Embankments

The use of flood protection embankments is a common means of managing flood risk around the world. However, the construction of embankments leads to a progressive loss in floodplain storage, the redirection of flood flows, and an increase in flood levels at other locations. The redirection of flood flows can alter the filling and emptying behaviour of wetlands and interfere with fish spawning cycles and habitat. Thus, the impact of proposed flood protection embankments on flood behaviour and the environment need to be assessed carefully. The effects of constructing a 150-km long flood protection embankment to reduce flooding in the Eastern area of the Cambodian Lowlands have been investigated (MRC, 2007b). The proposed embankment ran along the Eastern bank of the Mekong River from Kampong Cham (about midway between Phnom Penh and Kratie) to Neak Luong (to the North of Tan Chau). It terms of its impact on Year 2000 Flood behaviour, it was found that in the protected area, flood levels were reduced by 2 m or more and the duration of flooding was reduced by 2 months. However, these benefits were offset by increased flood levels elsewhere (an increase of 1 m at Kampong Cham and 0.5 m in the Great Lake). Thus, the proposed embankment would make some people better off, others worse off, and cause significant changes to flooding behaviour, especially to the Great Lake, with associated environmental, fishery and social consequences. All these aspects need to be assessed in detail and considered before deciding on whether to construct such a project.

6.3c Waterway Openings

Road and rail transport embankments across flood-prone areas also interfere with the movement of floodwaters. A common problem is inadequately sized waterway openings through the embankment, leading to a significant increase in flood levels (afflux) upstream of the embankment. The effect of increasing bridge openings in Road No.1 to the east of Neak Luong on flooding across the South-eastern Lowlands of Cambodia has been investigated (see Joy, 2007b for discussion). When the length bridge openings was increased from 150 m to 450 m, it was found that upstream flood levels were reduced from about 1 m to 0.5 m and downstream flood levels were increased by 0.2 m. Because of the flat slope of the flood surface to the east of the road embankment, flood levels were reduced up to 30 km away from the bridge openings. Is such a project to reduce flood risk worthwhile? Certainly the adverse impacts are far smaller than for the flood embankment project described above. Before deciding to proceed with such a bridge widening project, an economic cost-benefit study should be made to see whether the expected benefits outweigh the economic, social and environmental costs.

6.3d Dams

What about the effectiveness of upstream dams in mitigating floods? This is often held up as a general panacea for flood risk. However, it is generally found that dam construction has little impact on downstream flood levels, even for minor floods, because the available volume for flood storage in a multi-purpose reservoir is often small compared to the volume of an incoming flood. Table 6.3 shows the average reduction in annual flood levels at various locations along the Mekong River associated with dam construction under four basin-wide dam development scenarios (MRC, 2005c; MRC, 2007b). Table 6.3 also shows the assumed total active storage capacity of dams in the LMB under these four scenarios, which is estimated to increase fourfold to nine-fold over current levels. It is noted that the average annual flood volume passing Kratie each year is some 350 km^3. It is seen that the greatest reduction in flood levels occurs at Luang Prabang, which is immediately downstream of proposed dam developments in the Chinese portion of the basin and the Northern Highlands. As one move downstream along the Mekong, the reduction in flood levels progressively declines as upstream mitigation effects dissipate and additional tributary inflows enter the Mekong. Reductions at Tan Chau are inconsequential, even for the High Development Scenario. The reduction in flood levels is evens less for extreme flood events, such as the year 2000 Flood. The presence of upstream dams has only a minor influence of the extent of flooding across the Cambodian Lowlands and the Cuu Long Delta: over the period 1996-2000, the average reduction in total annual flooded area was 3-5 percent of the baseline case (38,200 km^2). Thus upstream dams, even under high development scenarios, will do little to alleviate flood risk across the Cambodian Lowlands and Cuu Long Delta, the two critical flood risk areas of the basin. The construction of additional dams in the LMB increases the likelihood of dam release flooding and the possibility of dam break flooding, and will also affect the flooding and drainage behaviour of the Great Lake (MRC, 2007b).

Table 6.3 Effect of Dam Development in LMB on Average Annual Flood levels, 1986-2000

Basin Development Scenario	Total Active Storage Capacity (km^3)	Average Reduction in Flood level (m)				
		Luang Prabang	Nakhon Phnom	Pakse	Kratie	Tan Chau
Current Conditions	5.7	-	-	-	-	-
1. Chinese Dams	28.5	1.81	0.24	0.22	0.01	0.11
2. Low Development	22.3	1.16	0.23	0.11	0.17	0.10
3. Irrigation	22.3	1.16	0.23	0.13	0.26	0.12
4. High Development	47.6	1.93	0.41	0.40	0.47	0.17

In 2004, upstream dams in China were blamed for reduced dry season low flows in the Mekong River (Asia Times, 2004). However, the reduction in low flows was due to hydrological drought. The effect of upstream dams in China is to increase dry season flows all the way down to the Cuu Long Delta (see Adamson, undated).

6.3e Land Clearing

Another factor that is often raised as a contributor to increased flood risk is land clearing in upland and highland areas, which is perceived to increase the volume and rate of surface runoff and hence flood severity. Extensive deforestation has occurred in the LMB since the 1960s (see Adamson, 2006). However, an examination of annual wet and dry season flow anomalies at Vientiane and Kratie over the period 1960-2005 did not display any statistical evidence of changes due to land clearing, and claims that ‘land use changes have historically had a detectable influence upon the regime of the Mekong cannot be substantiated by data analysis.’, (Adamson, 2006). This finding is supported by a detailed review of the impacts of land-use on the hydrological cycle (FAO, 2006). A principal conclusion of this study is that watershed scale is a fundamentally important parameter, and it is only for small watersheds ($\leq$ 10 km^2) that land-use is likely to have a significant impact on hydrological behaviour, including peak flows. With increasing catchment size, the impact of land use on the hydrological regime becomes insignificant compared to other natural factors, i.e. for large-catchment floods, the depth and intensity of flood-producing rainfall overwhelms any effects of land-use. However, the better management of land-use is a key factor in managing the risk of landslip ‘floods’.

6.3f Raised Earth Platforms

Finally, an extensive government flood-proofing program in the Cuu Long Delta is described to illustrate this flood risk management measure. This program involves the resettlement of communities most exposed to flood and landslide risks. Flood-proofing is achieved by the protection of new settlements with flood embankments or by constructing new settlements on flood-free raised earth platforms. The new settlements are supplied with water and electric power. Over the period 2001-08, the Government of Viet Nam constructed nearly 100, 000 new flood-proof houses, and the program has been extended to construct another 55,000 f houses (see Viet Nam News, 2008). This effort will largely eliminate the hazard and social impact of flooding in the new settlements, but not the risk to agricultural crops. In the future, drought risk may assume even greater prominence in the Delta.

6.4 Integration of MRC Programmes

FMMP 2011-2015 has strong potential links to the Drought Management Programme (DMP) and the Climate Change Adaptation Initiative (CCAI). It appears to be relatively straight forward for FMMP 2011-2015 to monitor drought behaviour in the LMB (i.e. rainfall, stream flow and possibly soil moisture deficits) and perhaps even produce drought forecasts, as discussed in Section 5.3b. Climate Change in the LMB is discussed in some detail in Section 7. FMMP 2011-2015 has the capacity to provide support services to CCAI in the form of the estimated impacts of changed flooding behaviour caused by climate change, and possibly the estimated impacts of changed drought behaviour caused by climate change.

Thus, close liaison between the programmes and integration of effort and activities will benefit all programmes and the basin as a whole.

7 Climate Change in the Lower Mekong Basin

7.1 Preamble

Discussion of climate change is spiced with passion and fraught with uncertainty, the latter rarely explicitly acknowledged. In fact, there is a tendency to assume that inferred future climate change scenarios are 'certain', which is not the case. Further, this misguided 'certainty' seems to be flowing through into the planning of 'definite' responses to ameliorate climate change without recognizing the inherent uncertainty in climate change predictions (e.g. the recent frenzy to address the 'problem' of coastal properties in Australia deemed susceptible to coastal flooding caused by climate induced sea-level rise - see DCC, 2009). Such ironbound efforts may miss the mark and squander resources if the realised climate change (or sea level rise) is less or greater than expected, or indeed if it does not eventuate.

Two certain facts should anchor climate change discussion: first, the climate of the globe (and the LMB) is changing (it always has and always will[20]); and second, any change in future climate will affect the flood and drought behaviour in the basin. Accepting that climate change is occurring (irrespective of arguments about causes), basic questions include the likely direction and magnitude of the change, its effect on drought and flood behaviour in the LMB, and the consequences to flood and drought-affected peoples. Notwithstanding the prodigious efforts of many scientists around the world, answers to these questions are uncertain now and will remain so into the future (although the degree of uncertainty will hopefully be reduced).

7.2 Projections

7.2a **IPCC 2007**

The Intergovernmental Panel on Climate Change (IPCC) uses a suite of 24 complex numerical models (AOGCMs) to simulate expected future climate change. The basic driver of these models is CO_2 emissions under various assumed development scenarios. Annex A discusses these models, their shortcomings and their projections for the Southeast Asian Region and for the LMB.

In summary, IPCC identify the following climate changes for the *Southeast Asian Region* in 2080-2089 (compared to 1980-1989):

> '… *median warming* for the region is likely to be 2.5^{o}C by the end of the 21st century, with little seasonal variation.' The use of finer gridded sub-models has indicated ' … the potential for significant local variation in warming, particularly the tendency for warming to be significantly stronger over the interior of landmasses …', (IPCC, 2007, Section 11, p. 883).
>
> '*Area-mean precipitation* increases in most MMD[21] model simulations, with a median change of about 7 percent in all seasons, but the projected seasonal changes vary strongly within the region.' 'The pattern is broadly one of wet season rainfall increase and dry season decrease.' '…. regional high-resolution simulations …. have demonstrated the potential for significant local variation in projected precipitation change.' Rainfall variability will be affected by changes in ENSO and its effect on monsoon variability, but this is

[20] Much of the current dissention concerns the impact of changes in CO_2 levels vs the influence of 'natural cycles'.

[21] Multi-Model Datasets: These are the future climate datasets generated by the selected ensemble of numerical models.

> not well understood ….'. 'The northern part of the Southeast Asia Region will be affected by any change in tropical cyclone characteristics[22].' (IPCC, Section11, p. 885-887).

7.2b **CSIRO 2008**

The Commonwealth Scientific and Industrial Research Organization (CSIRO) selected the 11 AOGCM models that 'best' simulated seasonal rainfall and temperature behaviour in the Mekong Basin over the baseline period 1960-1999. Results from these models were used to assess projected climate change in 2030. A monthly water accounting model was then used to simulate the impact of this projected climate change on stream flows, groundwater, and etc in 18 major catchments in the Mekong Basin in 2030. Annex B discusses this work and likely sources of uncertainty.

The general findings of the CSIRO study were as follows (see Annex B for detailed findings):

> 'Our results indicate a likely increase in *basin mean temperature* of 0.79 ^{o}C, with greater increases for the colder catchments in the north of the basin. Annual precipitation is also projected to increase by ~ 0.2 m (13.5%), resulting mainly from an increase in wet season (May to October) precipitation in all catchments. Dry season rainfall is projected to increase in northern catchments, and to decrease in catchments in the south of the basin (including central and Southern Lao PDR, Eastern Thailand, Cambodia and Viet Nam).
>
> Our study suggests that the *melting of glaciers* in the Upper Mekong is likely to increase under 2030 climate projections. However, since the area and volume of glaciers in the basin is small, the impact on flow and water availability in the Lower Mekong basin is likely to be insignificant both during the period of enhanced melting, and after the glaciers have ceased to exist.
>
> Under the projected climate in 2030, *total annual runoff* from the basin is likely to increase by 21%, an increase of ~107,000 mcm. Runoff increases are projected for all catchments, primarily resulting from increased runoff during the wet season. Dry season runoff is projected to remain the same or to increase in 14 catchments of the basin, with small decreases in dry season runoff likely in the 4 remaining catchments. Despite likely increases in water withdrawals for irrigation, domestic and industrial purposes under future (2030) compared with historic climate conditions, the increase in projected runoff across the basin will maintain or improve annual water availability in all catchments. However, catchments in Northeast Thailand will still experience moderate or medium-high levels of water stress and high stress levels in the dry season. The Tonle Sap catchment of Cambodia is also projected to suffer high levels of stress during the dry season.
>
> It is likely that increased *flooding* will affect all parts of the basin under the projected climate for 2030. We may expect the impact to be greatest in downstream catchments on the mainstream of the Mekong River, because of the cumulative impact of runoff increases from catchments upstream. We have quantified the impact at Kratie, where the frequency of 'extreme wet' flood events is likely to increase from an annual probability of 5% under historic conditions to a 76% probability under the future climate.' (CSIRO, 2008, p iv).

[22] IPCC expect tropical cyclone intensity to increase, but the frequency of cyclones land-falling on Vet Nam may fall; tropical cyclone behaviour will also be affected by changes to ENSO, (IPCC, 2007, Section 11, p. 886-887)

7.2c MRC 2010a

As part of a study of the impact of climate change on selected ‘basin development scenarios’, MRC 2010A used results derived from the ECHAM4 Global Climate Model (developed by the Max Planck Institute of Meteorology and one of the 24 AOGCMs of IPCC 4) to assess likely climate change in the Mekong Basin in 2050. The altered climate was used in conjunction with MRC hydrologic and hydraulic models to assess the impact on the flow regime of the basin. Annex C discusses this work and likely sources of uncertainty.

Unfortunately, the impact of climate change is ‘muddied’ by also including the impacts of various basin development scenarios. It would have been far clearer and more digestible if a single report dealing only with likely climate change had been first produced, before moving onto the combine impacts of basin development and climate change. General findings of MRC 2010A *in relation to climate change alone* appear to be as follows for baseline development conditions and the IPCC A2 development scenario (see Annex C for details):

- The impact of projected climate change on *average annual dry season* rainfalls is small in both the upper and especially the Lower Mekong Basin. The impact on *average annual wet season* rainfalls is greater, increasing in the *Upper Basin* from of 765 mm/year (1985-2000) by some 58 mm/year to an average annual value of 823 mm/year (2042-2050), and increasing in the *Lower Basin* from 1,390 mm/year by 56 mm/year to 1,446 mm/year. Thus, the overall change in *average wet season rainfall* across the entire Mekong Basin from 1985-2000 to 2042-2050 is an increase of some 50-60 mm/year, a relatively modest amount. Note that the above results are for *average seasonal rainfalls*. Individual seasons will be greater or smaller (no details in the study).
- The *average annual maximum*, *average annual minimum* and *average annual* temperatures across the Mekong Basin increase between 1.3 and 1.8 ^{o}C, with increases being greater in the Upper Basin.
- *Average annual high flow season* discharge is projected to increase by 10-15 percent along the entire length of the Mekong mainstream from Chiang Saen to Tan Chau. *Average annual low flow season* discharge is projected to increase by some 30-35 percent along the Upper Reaches down to Pakse, and then by some 20 percent to Tan Chau. *Average annual discharge* typically increases by 10-15 percent along the river length. The reason the increase in discharge is greater in the low flow season is that the existing dams of the Baseline Scenario become fuller at the end of the wet season due to increases in wet season flows, thereby enabling greater dry season flow releases.
- Over the *baseline period 1985-2000*, the mean annual number of *flood days* was 85-105 along the Mekong River, with values typically around 85-95 days. Over the period *2042-2050*, the mean annual number of flood days increases to around 90-105 days, with typical increases in the number of flood days of 15-20 percent in the Upper Reaches down to Nong Khai, with the increase falling to around 5 percent over reaches downstream from Nong Khai.
- MRC 2010A also report on the difference in *flooding behaviour* between the Year 2000 Flood Event and a hypothetical flood event in 2048. The comparison is somewhat meaningless: the Year 2000 Event had a peak daily discharge at Kratie of 54, 900 m^3/s; the hypothetical flood event of 2048 (presumably one thrown up in the simulation of daily discharges by IQQM) under projected climate change conditions in 2048 had a peak daily discharge at Kratie of 95,300 m^3/s (or some 73 percent greater). It would have been more illuminating to investigate the impact of projected climate change on the hydro-meteorological conditions of the Year 2000 Flood and then investigate the impact of the climate-adjusted Year 2000 Flood on flooding behaviour.
- *Salinity intrusion* in the Cuu Long Delta will be curtailed under projected climate change because of the generally greater stream flows in the low flow season.

7.3 Reliability of Projections

How reliable are the two above sets of projections for future climate in the LMB? Sources and likely magnitudes of error (such as can be determined from the published results) are discussed in Annexes A and B.

7.3a **IPCC Projections**

Uncertainties in IPCC future climate estimate arise from three sources: historical data; reporting (distorted by gross spatial and temporal averaging); and modelling uncertainties (see Annex A for details).

In summary, the AOGCMs used by IPCC to investigate future climate change have a number of shortcomings that make inferred future climate change, especially precipitation, uncertain. First, there are unacknowledged uncertainties in the baseline data sets used to define historical climate change and to assess the ability of models to simulate present day behaviour. Second, there are shortcomings in the ability of the models to simulate the present day behaviour of the Southwest Monsoon, TWSs, ENSO and clouds, to say nothing of ocean and solar cycles, all major drivers of the climate and precipitation of the LMB. The models themselves are biased 'wet' for the LMB and there are major differences between the results of individual models. Because of these uncertainties, it is not clear that the results from any one model or even the median result from an assembly of models is appropriate to the LMB.

7.3b **CSIRO Projections**

Uncertainties from a number of sources creep into the CSIRO projections of the future climate change in the Mekong Basin in 2030 and follow-up analyses of the impact of this climate change. These uncertainties include:

- Uncertainties (unacknowledged and unevaluated) in the observed baseline dataset;
- Uncertainties (unacknowledged and unevaluated) in downscaling AOGCM results from the model grid (200 km x 200km) to the analytical grid adopted for the basin (50 km x 50 km);
- Failure of the 24 IPCC AOGCMs to simulate adequately present day (historical) behaviour on a *monthly* basis over the period 1960-1999 (in terms of PCCs and RMS errors), with CSIRO being forced to use a *seasonal* assessment to identify the 11 best models[23];
- Uncertainties (unacknowledged and unevaluated) inherent in the pattern downscaling used to determine behaviour in 2030; and
- Uncertainties (unacknowledged and unevaluated) involved in using monthly precipitation data that fail PCC and RMS tests in a monthly water accounting model (no details of calibration adequacy) to assess the impacts of projected climate change on stream flows, groundwater, etc in 2030.

More general conclusions regarding the CSIRO Study include (i) demonstration of a 'wet' bias in Mekong Basin precipitation estimates from the AOGCMs over the baseline period (which in itself automatically leads to higher stream flows in 2030), (ii) a failure to correct the models (or results) for this bias, before going on to use results derived from these models to assess impacts in 2030, and (iii) the inconsistency of constructing 'responses' to projected climate change before a definitive assessment of the likely nature and magnitude of these changes has been undertaken.

---

23 Given that the 24 models individually fail the simulate monthly climate to a satisfactory degree of accuracy, it is by no means self-evident that the median values of the simulated values is reliable, especially if monthly values are to be used in further analyses. In other words, make sure the foundations are adequate before building houses.

7.3c MRC Projections

The approach adopted by MRC 2010a to evaluate the effects of possible future climate change on rainfalls, stream flows, flooding and salinity intrusion in the Mekong Delta are the most thorough of the three efforts reported here. Rainfalls (and presumably temperatures) were downscaled from an adopted IPPC AOGM to a 22 km x 22 km grid using the PRECIS system. The unadjusted PRECIS rainfalls were then calibrated against observed rainfalls over the baseline period 1985-2000, the 'adjustments' then being applied to the projection period 2010-2050. The unadjusted rainfalls were found to be 'too wet' and substantial adjustments were required. In average annual terms, the projected increases in rainfall were relatively modest and less than those of the other two studies. MRC 2010a then used its rainfall-runoff, stream flow routing and hydraulic models (SWAT, IQQM and ISIS respectively) to assess likely changes to runoff volumes, average annual discharge and daily discharges. Again, the unadjusted PRECIS rainfalls required substantial 'adjustment' to reconcile simulated SWAT runoff based on observed rainfalls over the baseline period to simulated SWAT runoff based on PRECIS rainfalls over the baseline period. Similarly, 'boundary condition' discharges into the IQQM model were adjusted to achieve better agreement between simulate results based on observed discharges and simulated results based on SWAT discharges.

It is noted that the models employed in MRC 2010a to investigate likely effects of climate change on stream flow behaviour are better and proven compared to the models used in CSIRO 2008. Further, the projected changes to rainfalls and stream flows are considerably less in MRC 2010a compared to CSIRO 2008.

According to MRC 2010a, the impact of climate change on flooding is not that great: The average annual number of 'flood-days' in the period 2042-2050 in creases by some 15-20 percent upstream of Nong Khai, falling to only 5 percent downstream of Nong Khai. The influence of climate change on major historical floods (such as the Year 200 Event) was not investigated.

7.4 Response to Uncertainties in Climate Change Projections

Regarding future climate change and its impacts, society is faced with making present day decisions to deal with uncertain future situations and outcomes. This indicates the need for well thought out, robust and flexible contingency plans that are regularly updated in the light of future research findings and are capable of being adapted to future climate outcomes, as Nature progressively realizes them for us. Such a contingency plan should assess and address the likely range of expected outcomes, and not be solely anchored to a single assumed 'certain' outcome. These considerations need to be included in any 'adaptation plans' to address the impact of inferred changes in future flooding and drought behaviour in the LMB.

7.5 MRC's Climate Change Adaptation Initiative

An obvious response to climate change is 'adaptation'; this is what mankind has done over the millennia. And this is a response that is equally valid irrespective of the cause of climate change. The important thing is to assess likely climate change as reliably as possible and then consider adaptation strategies.

Climate change adaptation is the principal plank of MRC's efforts to ameliorate the impact of climate change on the peoples of the LMB. Building on the work of CSIRO 2008, MRC undertook an assessment of national and regional climate change 'wants and needs' in the LMB, including a 'gap analysis (MRC 2009). This study had a four-fold objective:

- To inform a wide audience of the current state of knowledge of climate change issues in the LMB countries and across the region;

- To provide up to date information on regional and national adaptation activities and policy and institutional responses in relation to climate change;
- To present the results of a climate change 'gap analysis' identifying information deficiencies and shortcomings in planned activities and policy and institutional responses;
- To present a series of recommendations for future climate change related to actions of the LMB.

This study provided the basis for MRC's climate change adaptation initiative and was followed by a further study of the likely impacts of climate change on affected peoples in the LMB (MRC 2010b). This study was based on the projected climate changes of IPCC 2007 and CSIRO 2008 and sought to answer three strategic questions:

- What changes are foreseen in climate and hydrological variability and extremes?
- What implications will those changes have for natural and social systems of the basin?
- What implications will those changes have for development sectors in the basin including hydropower (for example in terms of energy generation, operations, CHG emissions and carbon financing)?

Finally, a programme document was developed to describe MRC's Climate Change Initiative (MRC 2011). This Programme is based on a vulnerability assessment of the peoples of the LMB to climate change, followed by adaptation planning and implementation. The Programme will compile, develop and refine tools to support adaptation planning. A number of local demonstration projects will be undertaken to demonstrate the application of these tools. Regarding this approach, it is noted that the findings remain valid irrespective of the causes of any climate change.

It is suggested that rather than slavishly adopt the climate changes of IPCC 2007 and CSIRO 2008, both of which are wanting, often considerably so, MRC would be better advised to undertake an independent analysis of the likely impacts of climate change on the hydrometeorological regime of the LMB. This can be done in two ways: (i) via the AOGM projections, suitably assessed, modified for uncertainties and errors, focussed on the LMB and calibrated to a baseline period (as in MRC 2010a), or (ii) by adopting a statistical approach and adjusting downwards the severities of existing flood and drought events by some considered degree. Both approaches incorporate uncertainties; the most robust analysis probably includes both of these approaches.

7.6 Conclusions

And finally what of future climate change impacts in the basin? The nature of future climate change remains uncertain, despite intense international assessment. This uncertainty is seldom acknowledged. Climate is changing and will continue to change, irrespective of any anthropomorphic effects. Humankind will have to adapt, as it always has.

First and foremost, it is noted that there is no evidence to date of climate change impacts on the hydrometeorological record of the Mekong Basin (Adamson, 2006). An analysis of low flow hydrology at Vientiane and Kratie over the period 1925-2005 showed the existence of longer-term (about 14 years) quasi-oscillations in annual 90-day low flow values, but no significant evidence of climate change. However, it was noted that future changes in the low-flow regime can be anticipated if glaciers on the Tibetan Plateau continue to melt. There is no indication that the onset and end of the south-west monsoon has changed over the period 1952-2005 or that monsoonal conditions have intensified. Finally, there is no significant evidence of changes to the rainfall regime over the period 1923-2005, but again there is evidence of a longer-term quasi-periodicity.

Before accepting future climate predictions for the LMB, uncertainties in these estimates need to be acknowledged and quantified, including uncertainties in the present day baseline data set for the basin. When this is done, the ability of individual models to reproduce this behaviour should be investigated. Only then can we have some confidence (or otherwise) in the ability of the models to predict future climate behaviour. The available IPCC data sets and modelling allow these assessments to be made.

A responsible and prudent approach would be to acknowledge and evaluate these uncertainties, assess the range of likely future climate outcomes and then develop strategies and policies that encompass and are robust, flexible and adaptable the actual future climate outcomes, as they are realized. Climate change may have significant impacts on the socio-economic well-being of the peoples of the LMB. As a first step in developing such strategies and policies, IPCC climate change modelling results specific to the LMB need to be reviewed to determine the ability of models to reproduce baseline present day climate, differences between models, and a range of likely future climate outcomes to be used for planning purposes.

8 References

Adamson, P., 2005. 'Lower Mekong Basin Drought Study: Analysis, Forecasting, Planning and Management'. Revised Version, September 2005. Mekong River Commission.

Adamson, P., 2006. 'An evaluation of Land use and Climate Change on the Recent Historical Regime of the Mekong'. Mekong River Commission, December , 2006

Adamson, P., Undated. 'An Assessment of the Statistical Nature of the IBFM Flow Seasons Vulnerability to Regional Water Resource Development'. Draft Final Report prepared for the Integrated Basin Flow Management Investigation, Mekong River Commission (undated).

Adamson, P.T., T. Burnhill and I. Conlan, 2010 'The Nature of the Mekong - A Physical and Hydrological Perspective'. MRC Technical Report Series. In Preparation.

AFP, 2000. '2 Million Homeless in Mekong Flooding'. Agence France Press, 23 September, 2000.

Archibald, D., 2008. 'Solar Cycle 24'. (Success Print, Bayswater WA: 2008)

Asia Times, 2004. See the following website: http://www.atimes.com/atimes/Southeast_Asia/FD01Ae02.html

Beckman, M., Le Van An and Le Quang Bao, 2002 'Living with Floods: Coping and Adaptation Strategies of Households and Local Institutions in Viet Nam'. Stockholm Environmental Institute, SEI/RESPI Report No. 5, 2002.

Bell, R.W. and Seng, V. 2004 'Rainfed lowland rice growing soils of Cambodia, Lao PDR and Northeast Thailand'. *Water in Agriculture.* ACIAR Proceedings No. 116e, pp161-173.

Bestari, N.G., Shrestha, S. and Mongcopa, C.J. 2006 'Lao PDR: An Evaluation Synthesis on Rice'. Report prepared by Operations Department, Asian Development Bank, September 2006.

Carter, R. M., 2010. *'Climate: The Counter Consensus'*. (Stacey International, London UK: 2010).

Chana, J.C.L. and Xu, M., 2008. Inter-annual and inter-decadal variations of land falling tropical cyclones in East Asia. Part I: time series analysis'. Int. J. Climatol. **29**: 1285–1293 (2009)

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

DCC, 2009. 'Climate Change Risks to Australia's Coasts: A First Pass National Assessment'. Australian Government, Department of Climate Change, November 2009.

Delft, 2009. See the following website for an overview of FEWS computer platform: http://www.wldelft.nl/soft/fews/pdf/fews-english.pdf

DIPNR, 2005. 'Floodplain Management Manual: The Management of Flood-Liable Land'. Department of Infrastructure, Planning and Natural Resources, New South Wales. April 2005.

Eschenbach, W., 2009. 'The Thermostat Hypothesis'. Willis Eschenback, 14 June 2009. http://wattsupwiththat.com/2009/06/14/the-thermostat-hypothesis/

FAO, 2005.	'Southeast Asia: Drought and Onset of the 2005 Rainy Season'. Press Release by the Food and Agricultural Organization of the United nations, 29 April 2005 Update. See following website: http://www.fao.org/Giews/english/shortnews/asiamekong050429.htm
FAO, 2006	'The New Generation of Watershed management Programmes and Projects'. FAO Forestry Paper No. 150. Food and Agricultural Organization of the United Nations, Rome, 2006.
Fox C. and C. Sneddon, 2005.	'Flood Pulses. International Watercourse Law and Common Pool Resources'. Research paper No. 2005/20, United Nations University, World Institute for Development Economics Research, April 2005.
Helmers, K. and S. Jegellos, 2004.	'Linkages between flood and drought disasters & Cambodian rural livelihoods and food security'. Report prepared for International Federation of Red Cross and Red Crescent Societies and the Cambodian Red Cross Society, Phnom Penh, September 2004.
HRC. 2009.	'Mekong River Commission, Flash Flood Guidance System (MRCFFG), User's Guide'. Draft Report Prepared for the Mekong River Commission by Hydrologic Research Center, October 2009.
Huang, G. and N. Tamai, 1999.	'Application of Mike 11 to Lower Mekong River'. Paper presented at the Third DHI Software Conference, 1999. Helsingor, Denmark, 7-11 June, 1999.
Id, J., 2010	'CRU 3b – Urban Warm Bias in GHCN'. Jeff Id, 5 January 2010. http://noconsensus.wordpress.com/2010/01/05/cru-3b-urban-warm-bias-in-ghcn/
IPCC, 2001.	*Climate Change 2001: The Scientific Basis.* (Cambridge University Press, Cambridge: 2001).
IPCC. 2007.	*Climate Change 2007: The Physical Science Basis.* (Cambridge University Press, Cambridge: 2007)
IRRI, 2003b	'Rice almanac 3rd Edition'. 'Table 30. Distribution of rice crop area (000 ha), by environment, 2004-2006'. See: http://beta.irri.org/solutions/index.php?option=com_content&task=view&id=250
IRRI. 2003a.	'IRRI World Rice Statistics (WRS)'. Social Sciences Database, International Rice Research Institute, Los Banos, Philippines. See: http://beta.irri.org/index.php/Social-Sciences-Division/SSD-Database/
IRRI. 2003c.	'Rice almanac 3rd Edition'. 'Viet Nam', pp 102-105.
IRRI. 2003d.	'Rice almanac 3rd Edition'. 'Cambodia', pp 140-141.
IRRI. 2010e.	'Rice almanac 3rd Edition'. 'Thailand', pp 106-109.
IRRI. 2010f.	'Rice almanac 3rd Edition'. Appendix Table 4. Rice crop calendar by country. Asia: pp 1-2. See: http://www.irri.org/science/ricestat/data/may2008/WRS2008-AppendixTable04.pdf
Johnston, R., P. Rowcroft, K.G. Hortle and C. McCallister, 2003.	'Integrating Environmental Values into Resource Allocation - MRC's Approach to the LMB'. Paper presented at Workshop on Integrating Environmental Impacts into Water Allocation Models of the Mekong Basin, University of Economics, Ho Chi Minh City, 15 December 2003.
Maclean, J.L. et al. 2002.	'Rice almanac' 3rd Edition'. Eds. Maclean, J.L., Dawe, D.C., Hardy, B. and Hettel, G.P. (Wallingford, Oxon: CABI Publishing, 2002).

MARD, 2005. ‘Mekong Delta suffers drought damages of US$42 million’. Press Release by the Ministry of Agriculture and Rural Development, Viet Nam, 18 May 2005. See the following website: http://xttmnew.agroviet.gov.vn/TestE/load/tn-spec-nodate-etailTP.asp?tn=tn&id=24631

McKitrick, R., 2010. ‘A Critical Review of Global Surface Temperature Data Products’. July 26, 20101. http://rossmckitrick.weebly.com/uploads/4/8/0/8/4808045/surfacetempreview.pdf (Preliminary Report to be published the Global Warming Policy Foundation).

Mosher, S., 2010. ‘Calculating Global Temperature’. Stephen Mosher, 13 July 2010. http://wattsupwiththat.com/2010/07/13/calculating-global-temperature/

MRC, 1995. Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin, 5 April 1995’. Mekong River Commission, April 1995.

MRC, 2001. ‘MRC Strategy on Flood Management and Mitigation’. Mekong River Commission, November 2001.

MRC, 2002a. ‘Flood Preparedness’. Proc. First Annual Mekong Flood Forum, 23-24 April 2002, Phnom Penh, Cambodia. Mekong River Commission (Undated).

MRC, 2003a. ‘Information Flow, Networking and Partnership’. Proc. Second Annual Mekong Flood Forum, 28-29 October 2003, Phnom Penh, Cambodia. Mekong River Commission (Undated).

MRC, 2003b. ‘State of the Basin Report 2003’. Mekong River Commission. June 2003

MRC, 2003c. ‘State of the Basin Report 2003’. Chapter 7, ‘Fisheries’, pp 101-143. Mekong River Commission, June 2003.

MRC, 2003d. ‘State of the Basin Report 2003’. Chapter 13, ‘Floods in the Lower Basin’, pp 269-281. Mekong River Commission, June 2003.

MRC, 2003e. ‘State of the Basin Report 2003’. Chapter 8, ‘Agriculture’, pp 155-158. Mekong River Commission, June 2003.

MRC, 2004a. Flood Management Programme, Document. Mekong River Commission, November, 2004.

MRC, 2004b. ‘Impact Analysis Tools’. Basin Development Plan Report prepared by Halcrow Group Limited for Mekong River Commission, March 2004.

MRC, 2005a. ‘Overview of the Hydrology of the Mekong Basin’. Mekong River Commission. November 2005.

MRC, 2005b. ‘Flood Management and Mitigation in the Mekong Basin’. Proc. Third Annual Mekong Flood Forum, 7-8 April 2005, Vientiane, Lao PDR. Mekong River Commission (Undated).

MRC, 2005c ‘Modelled Impacts of Scoping Development Scenarios in the Lower Mekong Basin, Report prepared by Richard Beecham and Hugh Cross for the Mekong River Commission, May 2005.

MRC, 2006a. ‘Annual Flood Report 2005’. Mekong River Commission, Flood Management and Mitigation Programme, July 2006.

MRC, 2006b. ‘Improving Flood Forecasting and Warning System for Flood Management and Mitigation in Lower Mekong Basin’. Proc. Fourth Annual Mekong Flood Forum, 18-19 May 2006, Siem Reap, Cambodia. Mekong River Commission, June 2006.

MRC, 2007a. ‘Best practice IFRM Guidelines for the Basin Development Program. Volume 1: Framework for Development of the Guidelines’. Mekong River Commission, Flood Management and Mitigation Programme, March 2007.

MRC, 2007b. ‘Best practice IFRM Guidelines for the Basin Development Program. Volume 2: Background Information’. Mekong River Commission, Flood Management and Mitigation Programme, March 2007.

MRC, 2007c. ‘Annual Mekong Flood Report 2006’. Mekong River Commission, Flood Management and Mitigation Programme, March 2007.

MRC, 2007d. ‘Improving Inputs Towards Medium Term Flood Forecasting and Warning in the Mekong River Basin’. Proc. Fifth Annual Mekong Flood Forum, 17-18 May 2007, Ho Chi Minh City, Viet Nam. Mekong River Commission (Undated).

MRC, 2007e. ‘Drought Management Programme Document’. Draft document prepared for the Water Utilization Programme, Mekong River Commission, 23 March 2007.

MRC, 2008a. ‘Annual Mekong Flood Report 2007’. Mekong River Commission, Flood Management and Mitigation Programme, May 2008.

MRC, 2008b. ‘Integrated Approaches and Applicable Systems for Medium Term Flood Forecasting and Early Warning in the Mekong River Basin’. Proc. Sixth Annual Mekong Flood Forum, 27-28 May 2008, Phnom Penh, Cambodia. Mekong River Commission (Undated).

MRC, 2009a. ‘Adaptation to climate change in the countries of the Lower Mekong basin: regional synthesis report’. Mekong River Commission. MRC Technical Paper No. 24, September 2009.

MRC, 2009b. ‘Integrated Flood Risk Management in the Mekong River Basin’. Proc. Seventh Annual Mekong Flood Forum, 13-14 May 2008, Bangkok, Thailand. Mekong River Commission (Undated).

MRC, 2009c. ‘Annual Mekong Flood Report 2008’. Mekong River Commission, Flood Management and Mitigation Programme, September 2009.

MRC, 2009d. ‘Adaptation to climate change in the countries of the Lower Mekong Basin: regional synthesis report’. MRC Technical Paper No. 24, September 2009.

MRC, 2010a ‘Impacts of climate change and development on Mekong flow regimes, First assessment – 2009’. MRC Technical Paper No. 29. Mekong River Commission, June 2010.

MRC, 2010b ‘Climate Change Baseline Assessment Working Paper’. ICEM, 8 March 2010. MRC SEA for Hydropower on the Mekong Mainstream (International Centre for Environmental Management).

MRC, 2011 ‘Climate Change and Adaptation Initiative, Operational Documents for 2011-2015’. MRC January 2011.

Naklang, K. 2005. ‘Managing soil fertility for sustainable rice production in northeast Thailand’. Pp 357-359. *Rice is life: perspectives for the 21st Century: Proc. Of the World Rice Research Conference, Tsukuba, Japan*. 4-7 November, 2004.

NOAA, 2009. See the following website for the US Drought Monitor: http://drought.unl.edu/dm/monitor.html

NWS, 2009a. See the following website for soil moisture levels and deficits in the USA: http://www.cpc.ncep.noaa.gov/products/Soilmst_Monitoring/US/Soilmst/Soilmst.shtml

NWS, 2009b. See the following website for soil moisture levels and deficits on a global basis: http://www.cpc.ncep.noaa.gov/cgi-bin/gl_Soil-Moisture-Monthly.sh

NWS, 2009d. See the following website for 3,7 and 14-day rainfall forecasts: http://www.cpc.noaa.gov/products/fews/global/asia/

Orssengo, G., 2010	'A primer for disproving IPCC's theory of man made global warming using observed temperature data'. Girma Orssengo, 2August 2010. http://wattsupwiththat.com/2010/08/01/a-primer-for-disproving-ipcc's-theory-of-man-made-global-warming-using-observed-temperature-data/
Paltridge, G. W., 2009.	*'The Climate Caper'*. (Connor Court, Ballan VIC: 2009).
Pandey, S., Bhandari, H. and Hardy, B. 2007.	'Economic Costs of Drought and Farmer's Coping Mechanisms'. ed.S. Pandey, H. Bhandari and B. Hardy. Los Banos (Philippines): International Rice Research Institute, 2007.
Plimer, I., 2009.	*'Heaven + earth, Global Warming: The Missing Science'.* (Connor Court Publishing, Victoria: 2009)
SCARM, 2000	'Floodplain Management in Australia: Best Practice principles and Guidelines'. CSIRO Publishing (Collingwood, Victoria), 2000: pp 101.
Spencer, R., 2009	'New Study in Science Magazine: Proof of Positive Cloud Feedback?' Roy Spencer, 26 July 2009. http://www.drroyspencer.com/2009/07/new-study-in-science-magazine-proof-of-positive-cloud-feedback/
Spencer, R., 2010a.	'The Global Average Urban Heat Island Effect in 2000 Estimated from Station Temperatures and Population Density Data'. Roy Spencer, 3 March 2010. http://www.drroyspencer.com/2010/03/the-global-average-urban-heat-island-effect-in-2000-estimated-from-station-temperatures-and-population-density-data/
Spencer, Roy, 2010b.	'Direct Evidence that Most U.S. Warming Since 1973 Could Be Spurious'. Roy Spencer, 16 March 2010. . http://wattsupwiththat.com/2010/03/16/spencer-direct-evidence-that-most-u-s-warming-since-1973-could-be-spurious/
Stewart, K., 2010.	'The Australian Temperature Record- Part 8: The Big Picture'. Ken Stewart, 27 July 2010. http://kenskingdom.wordpress.com/
Sverdrup-Jensen, S., 2002.	'Fisheries in the Lower Mekong Basin,, Status and Perspectives'. MRC Technical Paper No. 6. Mekong River Commission, 2002.
Taylor, P. 2009.	*'CHILL: A reassessment of global warming theory'*. (Clairview, East Sussex UK: 2009).
UN. 2010.	'Prevention Web'. Website operated by the United Nations to deliver the International Strategy for Disaster Reduction. See the following website: http://www.preventionweb.net/
URBS, 2009.	See the following website for an overview of the URBS Model: http://www.urbs.com.au/
Viet Nam News, 2008.	See the following website: http://english.vietnamnet.vn/social/2008/06/789212/
VNMC, 2009.	Pers. Comm. Viet Nam National Mekong Committee, October 2009.
Wallingford, 2009.	See the following website for an overview of the ISIS Model: http://www.wallingfordsoftware.com/products/isis/tech.asp
WFP, 2009.	'Poverty and Vulnerabilities in Cambodia'. Powerpoint Presentation by Jean-Pierre de Margerie at 'National Forum on Food Security and Nutrition', Cambodia, 6 July, 2009.
Whilhite, D.A. 2000.	'Drought as a natural hazard: concepts and definitions'. In Whilhite, D.A., editor. 'Drought: a global assessment'. London (UK): Routledge Publishers. pp 3-18.

Woersem, B.L.M. and C.S. Joy, 2009.	'Flood management and Mitigation Programme, Mekong River Commission, Phnom Penh, Cambodia: Report of the 2009 Review Mission'. Report prepared for the Mekong River Commission, May 2009.
Woersem, B.L.M., C.S. Joy and N.N. Thuy. 2011.	'Mekong River Commission, Flood Management and Mitigation Programme under the Regional Flood management and Mitigation Centre: Programme Document 2011-2015'. 2 Vols. Report prepared for the Mekong River Commission, March 2011.
Kirby, M., M. Mainuddin and J. Eastham, 2008.	'Challenge Program basin water use accounts: 2. Model concepts and description'. Report for the Challenge Program on Water and Food.
Yoshino, M. 2001.	'Rice Production and Climate Change in Monsoon Asia: Problem in the 21st Century'. Human Ecology Special Issue No. 10: 113-119 (2001).

APPENDIX A IPCC CLIMATE CHANGE PROJECTIONS FOR THE MEKONG BASIN

A1 BACKGROUND

What has the IPCC to say regarding future climate change in the LMB? In a direct sense, It is not a lot. It is necessary to burrow down into the details of the Fourth IPCC Report (IPCC, 2007) to tease out projected climate change effects in the LMB.

For reporting purposes, IPCC divides Asia into six regions (IPCC, 2007: Section 11.4, p. 79). Most of the LMB (93 percent) lies in IPCC's *Southeast Asia Region*, which is defined by the latitude-longitude coordinates 10S-95E and 20N-115E. This is a large area encompassing some 7.3 M km^2, or nearly 5 percent of the total land area of earth (see Figure A1). The Southeast Asia Region includes all of Cambodia, nearly all of Thailand, most of Viet Nam (two-thirds), most of Lao PDR (four-fifths), as well as the Indonesian islands of Sumatra, Java and most of Kalimantan, all of Singapore and peninsular Malaysia, and perhaps one-third of Burma. In addition, the Southeast Asia Region contains significant areas of the Andaman Sea, the Indian Ocean and the South China Sea, and some 565,000 km^2 of the LMB, which amounts to 93 percent of the LMB and 71 percent of the entire Mekong Basin[24]. The area of LMB included in the Southeast Asia Region amounts to about 8 percent of the total area of the Region.

---

24 All of the Chinese and Myanmar portions of the basin, together with about 40,000 km^2 of northern Lao PDR are excluded from the Southeast Asia Region.

Figure A 1 the Southeast Asia Region Adopted for Reporting Purposes, IPCC

The IPCC used 23 ‘atmosphere-ocean general circulation models’ (AOGCMs) to simulate the worldwide climate change associated with various global development scenarios. Twenty one of these models were used to simulate climate in the Southeast Asia Region. Typically, these models divide the global surface into a spatial grid some 300-400 km square and simulate the average climate behaviour in each grid square on a monthly, daily, or even shorter time-scale. The Southeast Asia Region would be defined by 45-80 of these grid squares. The results of this intensive modelling exercise are known as ‘multi-model data sets’ (MMDs) and have been used by many researchers worldwide to assess the nature and likely impact of simulated future climate change (IPCC, 2007: Section TS.5, p.66).

To assess the ability of the models to reproduce ‘present day’ climate behaviour, simulated results over the 20-year *baseline period* 1980-1999 for the Southeast Asia Region were averaged and compared to the average of observed results over this period. Note that the averaging was with respect to both area (the Southeast Asia Region) and time (the 20 years of the baseline period). Thus, the various climate measures (temperature, precipitation) were reduced to a *single number* for comparison purposes. The observed baseline temperature and precipitation data sets used for this comparison were the (worldwide) HadCRUT2v data set (Jones, et. al., 2001) and the CMAP data set (update of Xie and Arkin, 1997) (See IPCC, 2007: Section 11S, Table S11.1, p. SM11.3). The ‘calibrated’ models were then were used to simulate conditions over the next 100 years. Average results (again the average was over area and time) over the 20-year period 2080-2099 were compared to average results from the baseline period to assess ‘climate change’.

A2 TEMPERATURE AND PRECIPITATION IN THE SOUTH-EAST ASIA REGION

A2.1 BASELINE RESULTS (1980-1999)

How well do the models reproduce present day climate in the Southeast Asia Region? Table A1 shows temperature and rainfall biases over the baseline period for the Southeast Asia Region. Some 21 models were used to derive these results, which have been reported by IPCC as single average values for the entire region over the 20-year period 1980-1999. The 50% value shown in Table B1.1 is the median (or middle) result from the 21 models. The following aspects of the baseline simulation are noted:

- The simulation of ***present day season and annual regional temperatures*** is *generally biased low*. The *average seasonal* and *average annual* temperature bias in one-half of the models was *0.5°C to 1.8°C low* (the 50% Column).
- Regarding ***present day regional precipitation***, the median result for *average annual precipitation* is *unbiased*, i.e. as many models over-estimate as under-estimate average annual precipitation. However, estimates of *average seasonal precipitation* are *biased*, i.e. the simulated distribution of precipitation throughout the year differs from the observed distribution. Seasonal precipitation estimates from one quarter of the models are *biased low* by about 10 percent (the 25% Column), and results from a further one quarter of the models are *biased high* by about 20 percent (the 75% Column). Overall, the models tend to be skewed ‘wet’[25] and generate higher precipitation estimates than observed.

[25] Compare the bias in the maximum and minimum values and in the 25% and 75% values – the models are ‘wetter’ rather than ‘drier’.

Table A 1 Biases in Present Day (1980-1999) Surface Air Temperature and Precipitation in the MMD Simulations for Southeast Asia Region

Period	Temperature Bias (° C)					Precipitation Bias (% Rainfall)				
	Min.	25%	50%	75%	Max.	Min.	25%	50%	75%	Max.
DJF	-3.6	-2.6	-1.8	-1.2	0.4	-37	-10	-2	26	49
MAM	-2.6	-1.6	-0.5	-0.1	1.1	-32	-9	11	25	59
JJA	-2.5	-1.8	-0.7	-0.4	1.0	-28	-10	4	16	46
SON	-3.0	-1.9	-1.2	-0.8	1.0	-37	-12	-4	18	51
Annual	-2.8	-1.9	-1.0	-0.5	0.8	-28	-13	0	23	43

Source: IPCC, 2007a: Table S11.1, p. SM11.3

A2.2 FUTURE RESULTS (2080-2099) FOR A1B GLOBAL DEVELOPMENT SCENARIO

Table A2 shows the simulated changes in temperature, precipitation (averaged with respect to area and time) and the number of extreme seasons in the Southeast Asia Region over the 20-year period 2080-2099. These results have been derived for the A1B Global Development Scenario (balanced mix of fossil and non-fossil energy sources). The following aspects of the future simulations are noted:

- The median results from the 21 models show a consistent *increase in regional seasonal and average annual temperatures* of about 2.5°C.
- The median results from the 21 models indicate a *consistent increase in regional seasonal and average annual precipitation* of 6-7 percent.
- *Extreme*[26] *warm periods* (seasonal and annual) will increase in frequency from 5 percent in 1980-99 to 100 percent in 2080-99. *Seasonal extreme wet periods* will increase in frequency from 5 percent in 1980-99 to around 25 percent in 2080-99, whereas *annual extreme wet periods* will increase in frequency to 44 percent. The increase in the frequency of *extreme dry periods* is statistically insignificant.

Table A 2 Projected Temperature and Precipitation Changes in the Southeast Asia Region under A1B Scenario, 2080-2099 Compared to 1980-99

Period	Temperature Response (° C)					Precipitation Response (% Rainfall)					Extreme Seasons[a] (%)		
	Min.	25%	50%	75%	Max.	Min.	25%	50%	75%	Max.	Warm	Wet	Dry
DJF	1.6	2.1	2.5	2.9	3.6	-4	3	6	10	12	99	23	2
MAM	1.5	2.2	2.7	3.1	3.9	-4	2	7	9	17	100	27	1
JJA	1.5	2.2	2.4	2.9	3.8	-3	3	7	9	17	100	24	2
SON	1.6	2.2	2.4	2.9	3.6	-2	2	6	10	21	99	26	3
Annual	1.5	2.2	2.5	3.0	3.7	-2	3	7	8	15	100	44	1

Source: IPCC, 2007: Table 11.1, p. 855. [a] See Footnote.

In summary, the IPCC identify the following climate changes for the *Southeast Asia Region* in 2080-99:

> '… median warming for the region is likely to be 2.5°C by the end of the 21st century, with little seasonal variation.' (See Table A2). The use of finer gridded sub-models has indicated ' … the potential for significant local

[26] Extreme climate values were defined on the basis of the distribution of climate values over the baseline period, the 5 percent exceedance value being adopted as the measure of 'extreme' climate.

variation in warming, particularly the tendency for warming to be significantly stronger over the interior of landmasses …'. (IPCC, 2007, Section 11, p. 883).

'Area-mean precipitation increases in most MMD model simulations, with a median change of about 7 percent in all seasons (Table A2), but the projected seasonal changes vary strongly within the region.' 'The pattern is broadly one of wet season rainfall increase and dry season decrease.' '…. regional high-resolution simulations …. have demonstrated the potential for significant local variation in projected precipitation change.' Rainfall variability will be affected by changes in ENSO and its effect on monsoon variability, but this is not well understood ….'. 'The northern part of the Southeast Asia Region will be affected by any change in tropical cyclone characteristics[27]', (IPCC, Section11, p. 885-887).

A3 TEMPERATURE AND PRECIPITATION IN THE LOWER MEKONG BASIN

Having discussed projected climate changes in the Southeast Asia Region, what about the LMB?

A3.1 BASELINE RESULTS (1980-1999)

IPCC (2007) presents globally mapped results on a grid square basis (with sides of 300-400 km), which allows the range in model estimates of average annual precipitation in the LMB over the baseline period 1980-99 to be 'inferred'[28], as shown in Table A3 (IPCC, 2007: Figure S8.9b, p. SM8-46).

- The baseline observed figure for the LMB is 600-900 mm/year in the Upper Basin and 1200-1500 mm/year in the Middle and Lower Basin.
- The mean value of the error in estimates from the 21 models used in this exercise is +300 to +600 mm/year in the Upper Basin, and from -300 to +300 m/year in the Lower Basin.
- The RMS error of the 21 models is extreme in the Upper Basin (1200 to 1350 mm/year?) and lies in the range 300 to 450 mm/year in the middle and Lower Basin.

The magnitude and sign of these errors – and recall they are for average annual precipitation over the period 1980-1999 – fail to give confidence in simulated results and indicate that in the Upper Basin, the models are generally biased 'wet'.

Table A 3 Simulated Baseline Results, 1980-1999, LMB

Area	Average annual Rainfall (mm)		
	Observed	Mean Error	RMS Error
Upper Basin	600-900	+300 to +600	1200 to 1350
Middle Basin	1200-1500	-300 to +300	300 to 450
Lower Basin	1200-1500	-300 to +300	300 to 450

Source: IPCC, 2007: Section 8, Supplementary, Figure S8.9b, p SM8-46.

27 IPCC expect tropical cyclone intensity to increase, but the frequency of cyclones land-falling on Vet Nam may fall; tropical cyclone behaviour will also be affected by changes to ENSO, (IPCC, 2007, Section 11, p. 886-887).

28 The scale of the maps and the muted gradations of colour mean that interpretation of the results is at best uncertain. It is noted, however, that the output data sets on a grid square basis will provide a better indication of the ability of the models to simulate baseline temperature and precipitation.

A3.2 FUTURE RESULTS (2080-2099) FOR A1B GLOBAL DEVELOPMENT SCENARIO

IPCC (2007) also presents globally mapped results on a grid square basis across the Southeast Asia Region showing the number of models that predict increases in the average annual value of precipitation and the difference between precipitation and evaporation (P-E) over the two 20-year periods 1980-99 to 2080-99 (IPCC, 2007: Section 11S, Figure S11.1, p. SM11.9).

These diagrams can be used to assess approximately the range of simulated climate change results in the LMB, which can be approximately divided into four sub-areas, as shown in Table A4. Again, there are seen to be considerable differences between results from individual models.

- In the Southern area of the LMB Cuu Long Delta and Cambodia), half the models predict an increase in precipitation and (P-E) and the other half predict a decrease.
- In the more northern areas of the basin, a majority of models (about two-thirds or more) indicate an increase in these two climate parameters.

Table A 4 No. of Models[a] Predicting Increases in 2080-99 in Precipitation and (Precipitation - Evaporation) in the LMB under Scenario A1B

Sub-Area of LMB	**Increase in Precipitation**		**Increase in (P-E)**	
	No. Models	**Percentage**	**No. Models**	**Percentage**
Upper Basin (China)	16-17	78%	16-17	78%
N. Lao PDR	14-16	71%	14-16	71%
NE.Thailand/S. Lao PDR	17-18	83%	14-16	71%
Cuu Long Delta/Cambodia	8-13	50%	8-13	50%

[a] 21 Models were used in this exercise. Source: IPCC, 2007: Figure S11.1, p. SM11.9

Thus, it can be inferred that the basin is expected to become 'wetter' and that any increase in evaporation is more than offset by increased precipitation. IPCC present no direct information concerning the increases in precipitation and the change in evaporation on a grid square basis. However, these data are archived away in the various data sets generated from the models and can be used to tease out more details of likely climate change on a grid square basis throughout the Mekong Basin (see Section A4).

A4 UNCERTAINTIES IN IPCC CLIMATE ESTIMATES

There are three principal sources of uncertainty in the IPCC estimates presented above: reporting, data and modelling uncertainties.

1. There are numerous difficulties in developing representative historical *data sets* for temperature to be used for model calibration and verification (see, for example, Plimer 2009, Chapter 7; McKitrick, 2010). A culling of climate stations across the from 1970 onwards reduced the number of climate stations included in the Global Historical Climate Network (GHCN), which forms the backbone of globally averaged temperatures estimates, from over 6,000 to about 1,700 (McKitrick, 2010). It has been argued that many climate stations used in developing historical temperature data sets have been biased high over the last 30-40 years by culling[29], urban heat island and land-use change effects (e.g., Spencer 2010a, 2010b; Id, 2010; McKitrick, 2010), or have been distorted by 'adjustments' made to the temperature record (e.g. Stewart, 2010; McKitrick, 2010). The IPCC Report (AR4) glosses over uncertainties in the

[29] The culling of monitoring stations has resulted in the residual stations of the GHCN being biased towards airport locations, lower latitudes and lower elevations, all of which may tend to bias temperature measurements higher (see McKitrick, 2010).

baseline data sets used to ‘define’ global warming and to assess present day model performance. According to McKitrick (2010):

> ‘The overall conclusion of this report is that there are serious quality problems in the surface temperature data sets that call into question whether the global temperature history, especially over land, can be considered both *continuous* and *precise*. Users should be aware of these limitations, especially in policy-sensitive applications.’

2. *Reporting uncertainties* reflect the gross spatial and temporal averaging inherent in reporting a single value of temperature or precipitation for the Southeast Asia Region for a 20-year period. These results tell us nothing about the adequacy of models to reproduce present day climate variations in the LMB, let alone the climate 100-years in the future. However, as noted above, more specific results for the LMB are expected to be available in the archived outputs from the models.
3. *Modelling uncertainties* are of two types and include those associated with the relatively coarse horizontal resolution of models and those associated with the simplistic representation or even omission of complex physical climate drivers in the models, such as the LMB.
    a. The median horizontal resolution of the 23 AOGCMs used to derive the MMDs is 300 km (60 percent of the models had a resolution of 300 or 400 km). The area of the Mekong Basin is some 795,000 km^2, which is represented by about 9 whole grid squares of horizontal dimensions 300 km square. Not only is this a coarse spatial basis for simulating the climate of the basin, but a number of Mekong Basin grid squares will (presumably) include a mix of topographic elements (e.g. the Tibetan Plateau with possibly the Himalayas and Lower areas) and mixed land-ocean elements (parts of the South China and the Andaman Seas will be included in grids over or close to the Mekong Basin). Mixed topography and mixed land-ocean grid squares present difficulties (and generate uncertainties) in estimating representative climate parameters (data uncertainties) and climate driver process parameters. (See Section 7.3 for a description of how results for the LMB can be derived on a finer spatial basis).
    b. The precipitation regime of the LMB is driven by the Southwest Monsoon and by westward tracking TWSs that landfall on the Viet Nam coast and travel into the basin (see MRC, 2007b, Section 2). How well do IPCC’s AOGCMs represent and simulate the behaviour of these two major synoptic processes, drivers of drought and flood in the LMB? An additional factor affecting climate in the LMB is the El Nino-Southern Oscillation (ENSO), which influences the behaviour of monsoons (IPCC, 2007: Section 11.4.1, p. 879), and rainfall in the LMB and the behaviour of TWSs (Adamson et al, 2010). In the LMB, severe droughts tend to occur in El Nino years, but the relationship between floods and La Nina years is far less consistent. There is evidence that ENSO also influences the number and landfall location of TWSs, with TCs being more frequent and tracking further south in La Nina years (see Adamson et al, 2010). The IPCC findings regarding the ability of models to simulate monsoon behaviour contain the following statements: ‘just 6 of the 18 AOGCMs considered realistically simulated climatological monsoon precipitation for the 20th century’, and ‘Among these models, only four exhibited a robust ENSO-monsoon contemporaneous teleconnection.’ and ‘In short, most AOGCMs do not simulate the spatial or intra-seasonal variation of monsoon precipitation accurately.’ (IPCC, 2007: Section 8.4.10, p. 626). There are difficulties in simulating TC behaviour in GCMs because of the coarse spatial grids of most models and the dependence of TC behaviour on surface sea temperatures (SSTs). Better results are obtained with finer spatial grids and using observed (rather than simulated) SSTs to drive the GCMs. The frequency of TC generation is under-predicted in the Western

Pacific. (See IPCC, 2007: Section 8.5.3, p. 628; and Section 8.3.1.3, p. 613). Progress has been made in the better prediction of ENSO behaviour, but ‘serious systematic errors in both the simulated mean climate and the natural variability exist’ and ‘Most, but not all, AOGCMs produce ENSO variability that occurs on time scales considerably faster than observed.’ (See IPCC, 2007: Section 8.4.7, p. 623).

c. Ocean cycles and solar cycles are major climatic drivers that are not fully included in most AOGCMs (see Taylor 2009, Carter 2010, and Archibald 2009). Clouds and their effects on temperature are also not well represented in AOGCMs; the effects of clouds are included via empirical parameters, but there is uncertainty whether the net radiation feedback from clouds is positive (and increases temperature) or negative (and reduces temperature). (See Taylor, 2009; Eschenbach 2009).

Thus, there are a number of shortcomings in the ability of the IPCC models to reproduce the major synoptic and climate drivers affecting precipitation in the LMB, and this will be reflected as uncertainties in precipitation estimates for the basin, both over baseline periods and in projected future climate. In fact, the IPCC models are not particularly good at simulating precipitation behaviour, even on a global-annually averaged scale. Figure A2 shows the normalized root mean square[30] (RMS) error in the estimates of present day climate (1980-1999) by the various AOGCM models (IPCC, 2007: Figure 8.11, p. 619). The models are seen to be best able to reproduce surface air temperature, followed by MSL pressure, and finally precipitation. IPCC also presents globally mapped results, which allows the range in model estimates of average annual precipitation over the LMB in 1980-99 to be approximately assessed (IPCC, 2007: Figure S8.9b, p. SM8-46). The baseline observed figure for the LMB is 1200-1500 mm/year; the mean value of the error in estimates from the 21 models used in this exercise is +0 to +300 mm/year, indicating the models are biased ‘wet’, and the RMS error of the 21 models is 450-600 mm/year. The size of these errors serves to highlight wide ranging differences between estimates of future average annual precipitation made with AOGCM models and brings into question the ability of the models to simulate meaningful precipitation behaviour in the LMB.

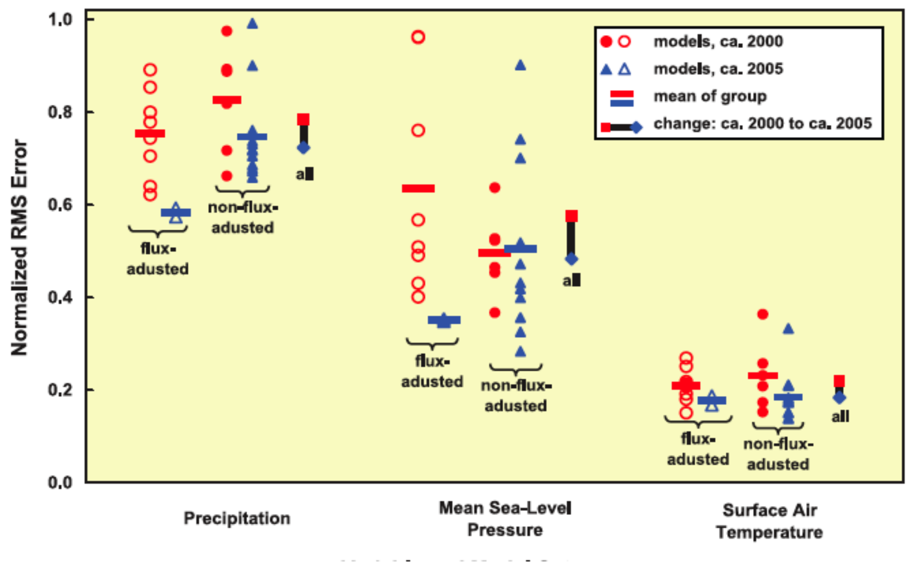


Figure A 2 Ability of IPCC Models to Reproduce Present Day Global Climate over the Period 1980-1999 (Source IPCC, 2007: Figure S8.9b)

[30] The normalized RMS error is equal to the RMS error divided by the average value. The normalized RMS error in average annual precipitation estimates from the flux adjusted AOGCMs (ca. 2005) of Figure 7.1 is about 0.58

A5 CONCLUSIONS

To sum up, the AOGCMs used by IPCC to investigate future climate change have a number of shortcomings that make inferred future climate change, especially precipitation, uncertain. First, there are unacknowledged uncertainties in the baseline data sets used to define historical climate change and to assess the ability of models to simulate present day behaviour. Second, there are shortcomings in the ability of the models to simulate the present day behaviour of the Southwest Monsoon, TWSs, ENSO and clouds, all major drivers of the climate and precipitation of the LMB. The models themselves are biased 'wet' for the LMB and there are major differences between the results of individual models. Because of these uncertainties, it is not clear that the results from any one model or even the median result from an assembly of models is appropriate to the LMB.

Before accepting future climate predictions for the LMB, uncertainties in these estimates need to be acknowledged and quantified, including uncertainties in the present day baseline data set for the basin. When this is done, the ability of individual models to reproduce this behaviour should be investigated. Only then can we have some confidence (or otherwise) in the ability of the models to predict future climate behaviour. The available IPCC data sets and modelling allow these assessments to be made.

APPENDIX B CSIRO ASSESSMENT OF CLIMATE CHANGE IMPACTS IN LMB

B1 BACKGROUND

A recent report prepared by the Commonwealth Scientific and Industrial Research Organization of Australia (CSIRO, 2008) used the climate change predictions of the recent IPCC Study (AR4) to investigate likely climate changes in the Mekong Basin by 2030 and their affect on:

(i) Surface and groundwater availability;

(ii) Flooding and saline intrusion in the Cuu Long Delta; and

(iii) Agricultural productivity.

Climate change and impacts were assessed on a catchment basis over the 18 major catchments of the Mekong Basin. A monthly water account model (Kirby et al, 2008) was used to assess the effects of the projected climate in 2030 on stream flow, groundwater, etc.

B2 FINDINGS

The following findings are quoted from the 'Extended Summary' of the CSIRO Study.

B2.1 TEMPERATURE AND EVAPORATION

'Climate projections indicate an increase in mean temperatures across the basin of 0.79 ^{o}C. The uncertainty around this estimate is relatively small, and ranges from 0.68 to 0.81oC. Projected temperature increases tend to be greater towards the northern parts of the basin with the greatest increase in temperature projected for the coldest catchment of the basin (Upper Mekong). The uncertainty in future temperature projections is low for all months and for all catchments of the basin. Consistent with the trend in projected temperature, potential evaporation is projected to increase by 2030 in all months and all catchments. The increase in annual potential evaporation averaged across the basin is ~ 0.03 m, a change of 2%, and uncertainty around this estimate is low.'

B2.2 PRECIPITATION

'There is greater uncertainty around future (2030) precipitation projections. The most likely projected response in annual precipitation averaged across the basin is an increase of ~ 0.2 m (13.5%), but the projections from different GCMs indicate increases ranging from ~0.03 to ~0.36 m. The projected increase in precipitation varies considerably for different catchments of the basin, with increases ranging from < 0.05 m to > 0.3 m for different catchments.'

'Projected increases in annual precipitation result chiefly from an increase in wet season (May to October) precipitation for all catchments of the basin. The projected response in dry season rainfall varies across catchments, with dry season rainfall increasing by up to 0.013 m in northern catchments. For catchments in the south of the basin (including central and Southern Lao PDR, Eastern Thailand, Cambodia and Viet Nam) dry season rainfall is projected to decrease by amounts less than 0.13 m. Thus the disparity between wet and dry season precipitation will be accentuated for all catchments, but particularly for catchments in the south where both decreases in dry season and increases in wet season precipitation are greatest.'

B2.3 SURFACE RUNOFF

‘Under historical climate conditions, there is strong seasonality in runoff from the basin as a whole, with the greatest runoff observed in the wet months from May to October when precipitation is greatest (Figure 1). Under the projected climate in 2030, total annual runoff from the basin is likely to increase by 21%, an increase of ~107,000 mcm (Figure 1). There is uncertainty around this estimate associated with climate projections from different GCMs, ranging from a decrease of ~41,000 mcm (8%) to an increase of ~460,000 mcm (90%). The median runoff projections for 2030 suggest that total basin runoff will increase in all months of the year, with the largest projected increases occurring in the months of May to September. Thus the seasonality of rainfall conditions is likely to be enhanced under the most likely climate projections.’

‘The response in runoff to projected climate change varies across the catchments of the basin. Under the most likely projections, annual runoff will increase in all catchments, with most of this increase resulting from increased runoff during the wet season. Projected increases in annual runoff range from 0.055 m in the Delta catchment to 0.251 at Pakse. Under the most likely future climate, dry season runoff is projected to remain the same or to increase by up to 0.04 m in 14 catchments of the basin. In contrast, small decreases in dry season runoff (up to 0.006 m) are projected for the Ban Keng Done, Se San, Border and Delta catchments.’

B2.4 FLOODING

‘Under the most likely future (2030) climate, annual discharge at Kratie will increase by 22%. Discharge is projected to increase in all months, with larger increases in the wet season. Minimum monthly flow each year is likely to increase by an average of 580 mcm under the most likely (median) projection. Since low flows at Kratie influence intrusion of salt water into the Delta, increases in minimum monthly flow may have a positive impact on reducing saline intrusion into the delta. The impact on saline intrusion needs to be assessed using a hydraulic model which also considers the impact of climate change on sea level rise. Assessing the potential impact is important, since the productivity of both agriculture and aquaculture in the highly productive and populous delta area depend on salinity levels, their areal extent and their duration.’

‘Annual flood volumes are likely to increase at Kratie, with greater peak flows and longer duration of flooding compared with historic conditions. The frequency of ‘extreme wet’ flood events is likely to increase from an annual probability of 5% under historic conditions to a 76% probability under the future climate. Using a relationship between modelled annual flood volume at Kratie and the area of flooding downstream of Kratie determined from satellite images, we estimated the area affected by flooding each year from modelled flood volumes for the historic and future climate. Using this method of estimation, the indicative area of flooding in the delta is likely to increase by an annual average of ~3800 km^2. The analysis did not include an assessment of any impact of climate change on sea level rise, which may also contribute to increasing the flooded area.’

‘Given the projected increase in runoff for all catchments of the basin, it is likely that other parts of the basin will also be adversely affected to varying degrees by increased flooding under the projected climate for 2030. We may expect the impact may be greatest on the mainstream of the Mekong River, particularly in downstream catchments, because of the cumulative impact of the projected increase in runoff from catchments upstream. It is recommended that the impact of climate change on the frequency of flood events of different magnitude are investigated for other flood prone areas of the basin, so that the impact of greater rainfall and runoff can be better quantified across the basin.'

B3 METHODOLOGY

The CRU_TS_2.1 dataset of the Climate Research Unit of the University of East Anglia was used to develop baseline climate conditions in each of the 18 major catchments of the Mekong Basin. This worldwide dataset comprises *average monthly values* ('gridded values') of climate variables on a 0.5^o x 0.5^o spatial grid (about 50 km x 50 km) over the period 1901-2002, and was constructed by interpolating observed values at monitoring sites included in the analysis. Monthly average catchment values were determined for each of the 18 catchments of the CSIRO Study by spatially averaging gridded values. In effect, a monthly time series of 'recorded' climates values was developed for the 18 catchments for the period 1901-2002.

Simulated results from the 24 AOGCMs of IPCC AR4 for the periods 1901-2001 and 2001-2100 were available from the Programme for Climate Model Diagnosis. (The procedure used to downscale model results from the relatively coarse spatial grids of the AOGCMs – typically 200 km x 200km - to the finer analytical grid of the Mekong Basin - 50 km x 50 km - is not mentioned). Gridded model results across the basin were spatially averaged to yield average catchment values, which were then weighted according to catchment areas to determine 'average basin values'.

A 'baseline period' 1960-1999 was selected for checking the ability of the simulated temperature and precipitation results to reproduce the 'observed' values. For each model, a pattern correlation coefficient (PCC) and the RMS error between simulated and observed values were determined and used to assess the 'goodness of fit' between observed and simulated results. The estimated pattern correlation coefficient included both spatial pattern correlation (catchments across the basin), as well as temporal pattern correlation (monthly values over the period 1960-1999). However, no details are presented regarding the determination of the PCC. (A PCC of 1 represents a perfect match). Catchment PCC and RMS error values were then weighted according to catchment area to yield basin-wide values. These results were then used to select the 11 models that best reproduced climate in the Mekong Basin. Critical values for inclusion the LMB model ensemble were a PCC $\geq$ 0.8 and a RMS error $\leq$ 2 ^{o}C for temperature and $\leq$ 2 mm/day for precipitation. On this basis, the 11 models that best represented average *seasonal* temperatures and precipitation over the period 1960-1999 were selected.

Median monthly values of the future climate projected in 2030 from this ensemble of the '11 best models' were then used to assess the impact on stream flows, groundwater, etc via a monthly water balance model.

B4 COMMENTS

B4.1 SIMULATED BASELINE TEMPERATURE AND PRECIPITATION, 1960-1999

B4.1a Monthly Behaviour

Regarding the simulation of *monthly climate behaviour* over the baseline period (1960-1999), *all 24 models were found to be deficient*, with a low PCC for precipitation and high RMS errors in some months for both precipitation and temperature (see CSIRO, 2008: Figures 11.1 to 11.4). In other words, ***none of the models*** met the 'acceptance' criteria with respect to simulated monthly values.

B4.1b Seasonal Behaviour

Next the ability of the 24 models to reproduce *wet season* (May to October) and *dry season* (November to April) behaviour was investigated. These results are shown in Figure B1:

(i) The 24 models do best simulating wet season temperatures (all meet the accuracy requirements);

(ii) Some 2-5 models fail accuracy requirements for dry season temperatures (RMS error > 2^{o} C);

(iii) Some 8-10 models fail to meet accuracy requirements for wet season precipitation (RMS error > 2^{o} C and/or PCC < 0.8); and

(iv) None of the models meet the accuracy requirements for dry season rainfalls (PCC < 0.8)

These results were used to select the 'best' 11 models, which were then used for the analysis of future climate change in the Mekong Basin. Table B1 shows the visually-estimated average RMS error in wet season (1.8 mm/day) and dry season (0.8 mm/day) rainfalls for the 'better models' under baseline conditions. If these errors are normally distributed, this would mean that about one-third of the simulated wet season values of the baseline period differed from recorded values by 330 mm or more, and that one-third of the dry season estimates differed by 145 mm or more. These figures correspond to RMS errors of 26% of the average wet seasonal rainfall and 57% of the average dry season rainfall and are not inconsequential (see Table B1).

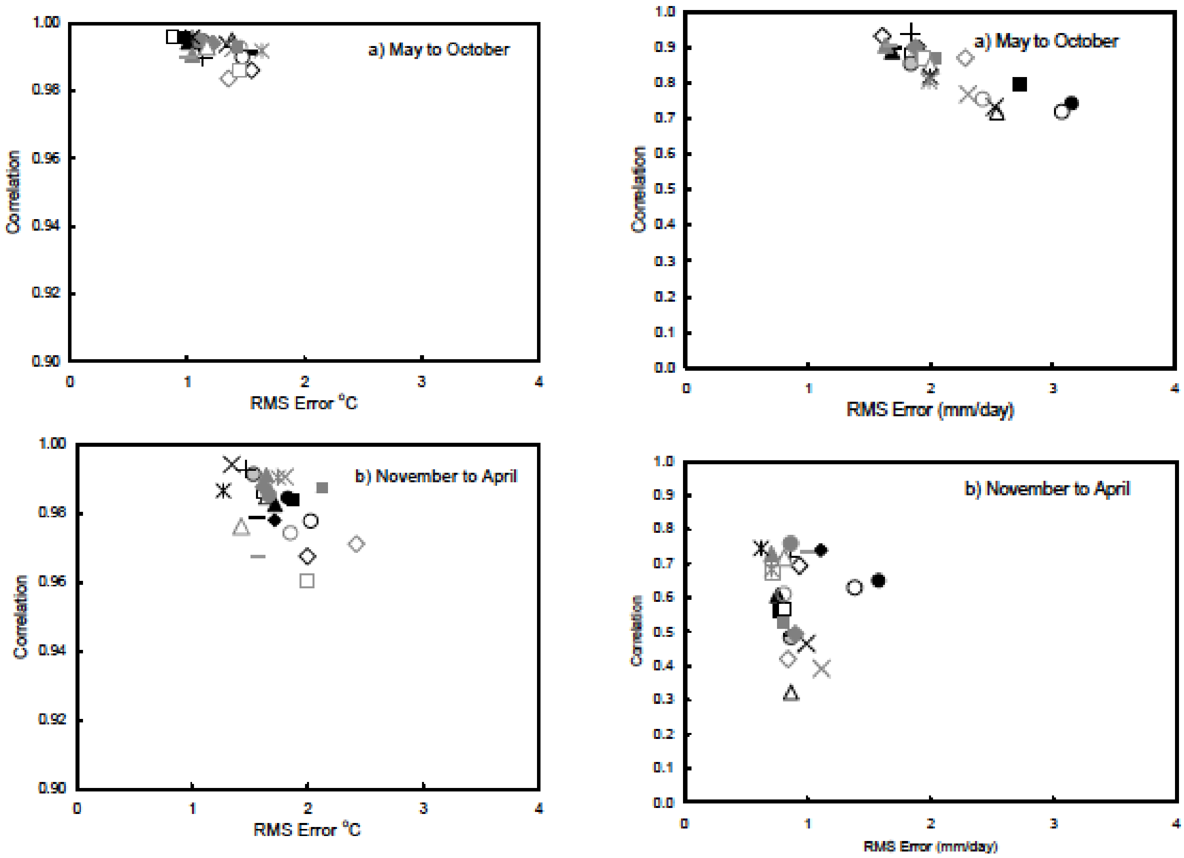


Figure B 1 Basin-Wide Pattern Correlation Coefficients and RMS Errors for Wet and Dry Season Temperature and Precipitation Estimates for Baseline Period, Mekong Basin, 24 AOGCMS of IPCC AR4

(Source CSIRO, 2008: Figs 11.5 and 11.6)

Table B 1 Average RMS Errors in Simulated Wet and Dry Season Precipitation over the Baseline Period

Season	Average RMS Error (mm/day)	Absolute RMS Error (mm)	Average Seasonal Precipitation (mm)	Average Seasonal RMS Error (%)
Wet (May-Oct)	1.8	330	1,253	26%
Dry (Nov-Apr)	0.8	145	253	57%

CSIRO neither comments on nor presents any information regarding bias in the selected models or bias in the median result obtained from the models (errors are quoted as RMS values which give no indication of bias). Based on the discussion of AOGCMs in Appendix A, it is expected that the models are biased 'wet' (this is supported by the range of model estimates of precipitation and runoff, as discussed below).

B4.2 SIMULATED MONTHLY TEMPERATURE AND PRECIPITATION, 2030

'Pattern downscaling' was used to determine likely monthly average temperature and precipitation in the Mekong Basin in 2030 under global development scenario A1B. Pattern downscaling is a process of scaling historical climate patterns to reflect projected increases in global temperatures. Whilst simple mechanically, pattern downscaling, like all downscaling processes has its shortcomings (see IPCC, 2007: Section 11.10, p. 918). CSIRO (2008) gives no indication of the accuracy of the adopted downscaling approach used in the Mekong Basin, apart from the general remark that pattern downscaling constrains future climate patterns to follow historical precedents (in this case over the period 1960-1999) and thus does not incorporate the effect of any change in the behaviour of extreme events. IPCC estimated a global increase in temperature of 0.9 ^{o}C by 2030, and this was used to determine the change in average monthly temperature and precipitation at each gridded data point across the basin. In presenting the results of this exercise, CSIRO shows the median estimate of the 11 'best' models and the range of model estimates. Figures 3.3 to 3.5 (CSIRO, 2008) show the inferred increase in average monthly temperature in each of the 18 catchments of the Mekong Basin. The 11 models are seen to provide consistent estimates of temperature increase. A different outcome is apparent in Figures 3.10 to 3.12 (CSIRO, 2008), which show the inferred change in average monthly precipitation for the 18 catchments. For most catchments, the range of estimated average monthly rainfall in 2030 *includes* the observed baseline value.

Figure B2 illustrates this effect for the projected basin-wide precipitation in 2030. Noting that CSIRO is working with the 11 models 'best' representing the Mekong Basin, and that results are presented in terms of average monthly values for the *entire basin*, this is not an outcome that inspires confidence in the simulation ability of the IPCC AOGCMs. In Figure B2, it is seen that for August and September, range of model estimates above than the median value tends to be greater than the range of estimates below the median value. This indicates that the models as a whole are biased 'wet' in these months.

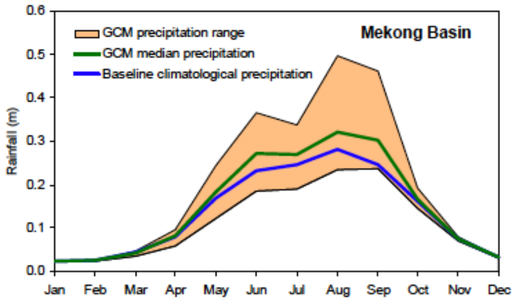


Figure B 2 Projected Average Monthly Rainfall in 2030 compared to Baseline Conditions 1951-2000, Mekong Basin

(Source CSIRO, 2008: Figure 3.6, p. 24)

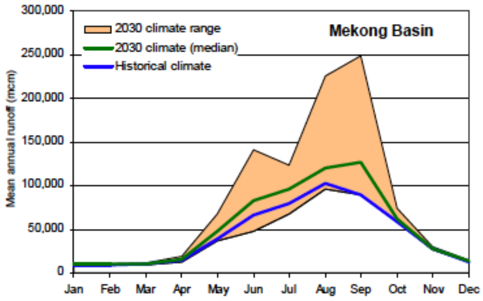


Figure B 3 Projected Average Monthly Runoff in 2030 compared to Historical Conditions, Mekong Basin

(Source CSIRO, 2008: Figure 4.1, p. 35)

B4.3 Simulated Stream flows

Pattern-downscaled monthly estimates of climate parameters were used in conjunction with a monthly water accounting model (Kirby et al, 2008) to estimate the effect of climate change in 2030[31] on surface water and groundwater behaviour in each of the 18 catchments of the basin.

The use of another model introduces another set of uncertainties. The water accounting model was calibrated against a 'historical' baseline dataset. No details are available of this dataset, *including the calibration period, let alone the adequacy of the calibration* (the Report refers to a dataset that is not found at the nominated website).

The inferred changes in average monthly runoff in 2030 are given for the 18 catchments (see CSIRO, 2008: Figures 4.4 to 4.6, pp. 39-41). As with 2030 precipitation estimates, the spread of 2030 runoff projections includes the historical baseline runoff values for many catchments, i.e. some models forecast runoff in 2030 that is less than that over the historical baseline period. Figure B3 shows the estimates of average monthly runoff from the entire basin. The range of model results again encompasses baseline conditions for much of the year, and the ability of the models to generate representative monthly time series of present day and future runoff can be questioned.

B5 Conclusions

Uncertainties from a number of sources creep into the CSIRO projections of the future climate change in the Mekong Basin in 2030 and follow-up analyses of the impact of this climate change. These uncertainties include:

- Uncertainties (unacknowledged and unevaluated) in the observed baseline dataset;
- Uncertainties (unacknowledged and unevaluated) in downscaling AOGCM results from the model grid (200 km x 200km) to the analytical grid adopted for the basin (50 km x 50 km);
- Failure of the 24 IPCC AOGCMs to simulate adequately present day (historical) behaviour on a *monthly* basis over the period 1960-1999 (in terms of PCCs and RMS

[31] The CSIRO Report presents little information on the water accounting model, its calibration, or the manner in which it was used to simulate behaviour in 2030. Presumably, the 'calibrated' model was run from starting point (2000?) through to 2030?

errors), with CSIRO being forced to use a *seasonal* assessment to identify the 11 best models[32];

- Uncertainties (unacknowledged and unevaluated) inherent in the pattern downscaling used to determine behaviour in 2030; and
- Uncertainties (unacknowledged and unevaluated) involved in using monthly precipitation data that fail PCC and RMS tests in a monthly water accounting model (no details of calibration adequacy) to assess the impacts of projected climate change on stream flows, groundwater, etc in 2030.

More general conclusions regarding the CSIRO Study include (i) demonstration of a 'wet' bias in Mekong Basin precipitation estimates from the AOGCMs over the baseline period (which in itself automatically leads to higher stream flows in 2030), (ii) a failure to correct the models (or results) for this bias, before going on to use results derived from these models to assess impacts in 2030, and (iii) the inconsistency of constructing 'responses' to projected climate change before a definitive assessment of the likely nature and magnitude of these changes has been undertaken.

32 Given that the 24 models individually fail the simulate monthly climate to a satisfactory degree of accuracy, it is by no means self-evident that the median values of the simulated values is reliable, especially if monthly values are to be used in further analyses. In other words, make sure the foundations are adequate before building houses.

APPENDIX C MRC ASSESSMENT OF CLIMATE CHANGE IMPACTS IN THE LMB

C1 BACKGROUND

The MRC has recently made an assessment of the impact of climate change on precipitation, temperature and stream flow, along with flood and salinity intrusion behaviour, in the Mekong Basin (MRC 2010a) in 2050 under ‘current conditions’ (development conditions in the basin in the Year 2000) and under various ‘Basin Development Plan’ (BDP) Scenarios involving the construction of dams for hydropower, irrigation and flood control purposes.

A Regional Climate Model (RCM) was used to ’downscale’ climate change projections from an AOGCM to *daily values* on a spatial grid of size 0.2^o x 0.2^o (*22 km x 22km*) across the Mekong Basin. The SWAT hydrological model, the IQQM basin simulation model and the ISIS hydraulic model developed for MRC’s ‘Decision Support Framework’ (DSF) were used to assess the impact of changed climatic (and development) conditions on stream flows, flood behaviour, etc in 2050.

The following discussion only considers the impact of climate change *for the baseline development scenario,* which can be summarized as shown in Table C1.

Table C 1 Baseline Development Scenario

Country	Domestic and Industrial Demand (MCM)	Irrigation (1000 ha)	Dams (Nos.)
Lao PDR	116	324	5
Thailand	935	1,422	12
Cambodia	126	1,340	0
Viet Nam	443	4,295	1
Total	1,620	7,381	18

C2 FINDINGS

C2.1 PRECIPITATION CHANGES

Figures C1 and C2 shows the projected changes in wet season, dry season and annual precipitation over the Mekong Basin during the periods 1985-2000 (baseline period) and 2010-2050. Note that study results are presented as annual averages over three sub-periods: 2010-2025; 2026-2041 and 2046-2050, and have been plotted at the mid points of these periods.

The impact of projected climate change on *dry season* rainfalls is seen to be small in both the Upper and especially the Lower Mekong Basin. The impact on *wet season* rainfalls is greater, increasing in the *Upper Basin* by some 58 mm/year from an average of 765 mm/year (1985-2000) to an average 823 mm/year (2042-2050), and increasing in the *Lower Basin* by 56 mm/year from an average of 1,390 mm/year to 1,446 mm/year. Thus, the overall change in *average wet season rainfall* across the entire Mekong Basin from 1985-2000 to 2042-2050 is an increase of some 50-60 mm/year, a relatively modest amount. Note that the above results are for *average seasonal rainfalls*. Individual seasons will be greater or smaller (no details in the study).

C2.2 TEMPERATURE CHANGES

Table C2 shows the projected changes in mean annual temperatures over the period 1985-2000 to 2042-2050. The mean annual maximum, mean annual minimum and mean annual temperatures are seen to be increased between 1.3 and 1.8 ^{o}C, with increases being greater in the Upper Basin.

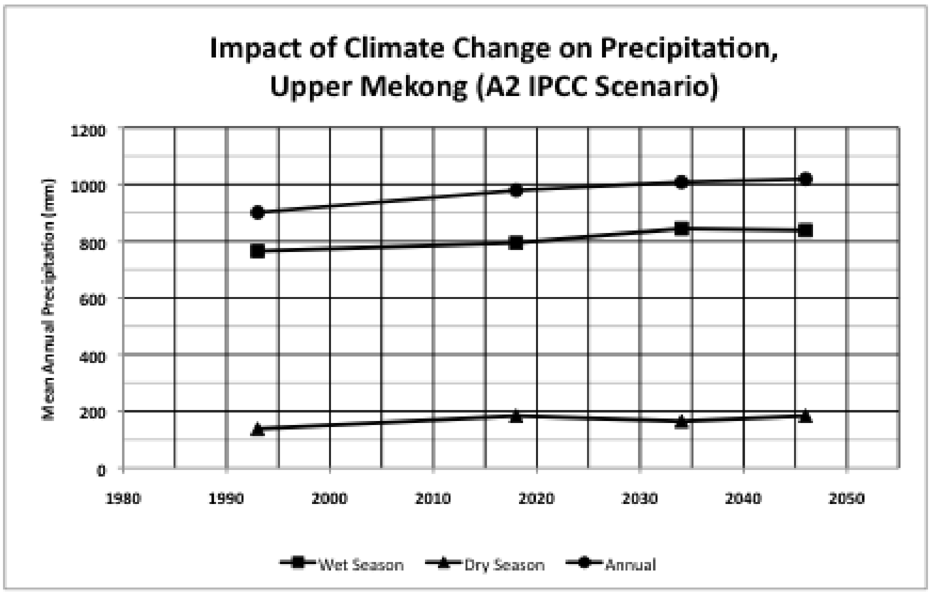


Figure C 1 *Impact of Projected Climate Change on Precipitation, Upper Mekong Basin (IPCC A2 Scenario). Source: Table 4.1, Page 31, MRC 2010a.*

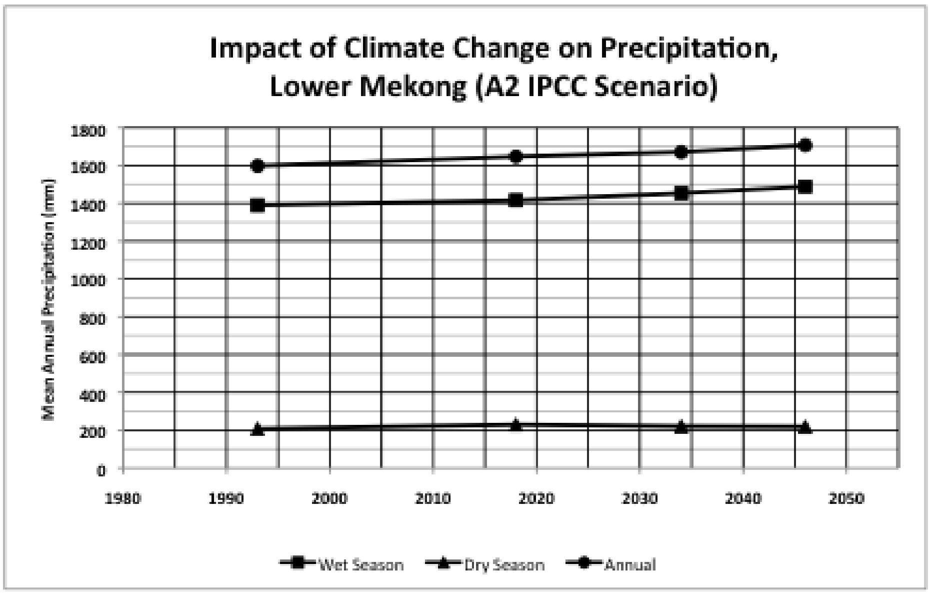


Figure C 2 *Impact of Projected Climate Change on Precipitation, Lower Mekong Basin (IPCC A2 Scenario). Source: Table 4.1, Page 31, MRC 2010a.*

Table C 2 Impact of Projected Climate Change on Mean Annual Temperatures, Mekong Basin(Baseline Development Conditions, IPCC A2 Scenario).

Parameter	Upper Basin (^{0}C)			Lower Basin (^{0}C)			Whole Basin (^{0}C)		
	1985-00	2042-50	Change	1985-00	2042-50	Change	1985-00	2042-50	Change
Mean Annual Max.	18.3	20.0	1.7	30.7	32.0	1.3	28.1	29.5	1.4
Mean Annual Min.	5.4	7.2	1.8	21.5	22.8	1.3	18.1	19.5	1.4
Mean Annual	11.9	13.6	1.8	26.2	27.5	1.3	23.3	24.7	1.4

Source: Hoanh et al 2010, Table 4.2. Page 34, MRC 2010a.

C2.3 STREAM FLOW CHANGES

Table C3 shows the projected changes in mean seasonal and annual stream flows at key locations along the Mekong River over the period 1985-2000 to 2042-2050. *Mean annual high flow season* discharge increases by 10-15 percent along the entire length of the Mekong mainstream from Chiang Saen to Tan Chau. *Mean annual low flow season* discharge increases by some 30-35 percent along the Upper Reaches down to Pakse and then by some 20 percent to Tan Chau. *Mean annual discharge* typically increases by 10-15 percent along the river length.

Table C 3 Impact of Projected Climate Change on Mean Seasonal and Annual Stream flows, Mekong Basin (Baseline Development Conditions, IPCC A2 Scenario).

Location	Mean High Flow Season Discharge (m^3/s)			Mean Low Flow Season Discharge (m^3/s)			Mean Annual Discharge (m^3/s)		
	1985-00	2042-50	Change	1985-00	2042-50	Change	1985-00	2042-50	Change
1. Chiang Saen	4,127	4,498	371 (9.0%)	1,157	1,519	362 (31.3%)	2,642	3008	366 (13.9%)
2. Luang Prabang	6,008	6,400	392 (6.5%)	1,499	2,001	502 (33.5%)	3,754	4,200	446 (11.9%)
3. Chiang Khan	6,636	7,344	708 (10.7%)	1,613	2,170	557 (34.5%)	4,125	4,757	632 (15.3%)
4. Vientiane	6,837	7,653	816 (11.9%)	1,640	2,212	572 (34.9%)	4,239	4,932	693 (16.3%)
5. Nong Khai	6,947	7,802	855 (12.3%)	1,668	2,252	584 (35.0%)	4,308	5,027	719 (16.7%)
6. Nakhon Phanom	11,601	12,962	1,361 (11.7%)	2,172	2,855	683 (31.5%)	6,887	7,909	1,022 (14.8%)
7. Mukdahan	12,522	14,137	1,615 (12.9%)	2,220	2,925	705 (31.8%)	7,371	8,531	1,160 (15.7%)
8. Khong Chiam	14,444	16,457	2,013 (13.9%)	2,386	3,139	753 (31.6%)	8,415	9,798	1,383 (16.4%)
9. Pakse	15,827	18,736	2,909 (18.4%)	2,506	3,430	924 (36.9%)	9,167	11,083	1,916 (20.9%)
10. Stung Treng	20,827	24,286	3,459 (16.6%)	3,515	4,271	702 (20.0%)	12,171	14,328	2,157 (17.7%)
11. Kratie	21,549	25,046	3,497 (16.2%)	3,622	4,446	824 (22.8%)	12,585	14,746	2,161 (17.2%)
12. Kampong Cham	20,935	24,009	3,074 (14.7%)	3,650	4,447	797 (21.8%)	12,292	14,228	1,936 (15.8%)
13. Phnom Penh	20,217	22,175	1,958 (9.7%)	3,718	4,514	800 (21.5%)	11,967	13,345	1,378 (11.5%)
14. Tan Chau	14,435	15,618	1,183 (8.2%)	5,052	5,696	644 (12.8%)	9,743	10,657	914 (9.4%)

Source: Hoanh et al 2010, Tbales 6.1, 6.2 and 6.3 Pages 48-49, MRC 2010a

C2.4 FLOODING CHANGES

The impact of projected climate change on flooding behaviour was investigated in terms of changes to the number of 'flood days', i.e. days with discharges greater than mean annual high flow season discharge. These results are shown in Table C4. Over the *baseline period 1985-*

2000, the mean annual number of flood days was 85-105 along the Mekong River, with values typically around 85-95 days. Over the period *2042-2050*, the mean annual number of flood days increases to around 90-105 days, with typical increases in the number of flood days of 15-20 percent in the Upper Reaches down to Nong Khai, with the increase falling to around 5 percent over reaches downstream from Nong Khai.

The results of Table C5 compare the extent of flooding for *two different flood events*, namely the Year 2000 Event (peak daily discharge at Kratie 54, 900 m^3/s) and a large flood event under projected climate change conditions in 2048 (peak daily discharge at Kratie of 95,300 m^3/s, or some 73 percent greater). It is difficult to interpret flooding behaviour without the hydrographs of both events. It is seen that the extent of flooding (i.e. flood depths greater than 0.0 m) increases by some 8.8 percent for the 2048 event, but the extent of flooding at greater depths increases by much larger amounts, both in absolute terms and proportionally (typically by 30-60 percent for depths over 1.5m). The greater extent of high flood depths presumably reflects deeper flooding along riverside floodplains downstream of Kratie, the relatively small increase in overall flooding presumably reflects the mitigating effect of the Great Lake on flood behaviour in the Cambodian/Cuu Long Deltas. These are different floods. It perhaps would have been more illuminating to investigate the impact of projected climate change on the hydro-meteorological conditions of the Year 2000 Flood and then investigate the impact of the climate-adjusted Year 2000 Flood on flooding behaviour.

Table C 4 Impact of Projected Climate Change on Mean Annual 'Flood Days', Mekong Basin (Baseline Development Conditions, IPCC A2 Scenario).

Location	Mean High Flow Season Discharge Q_{hf} (m^3/s)	Mean Annual Number of Flood Days ($\geq Q_{hf}$)		
		1985-2000	2042-2050	Change
1. Chiang Saen	4,127	97	106	9 (9.3 %)
2. Luang Prabang	6,008	89	102	13 (14.6 %)
3. Chiang Khan	6,636	89	105	16 (18.0 %)
4. Vientiane	6,837	89	105	16 (18.0 %)
5. Nong Khai	6,947	89	106	17 (19.1 %)
6. Nakhon Phanom	11,601	87	94	7 (8.1 %)
7. Mukdahan	12,522	86	93	7 (8.1 %)
8. Khong Chiam	14,444	86	91	5 (5.8 %)
9. Pakse	15,827	86	92	6 (7.0 %)
10. Stung Treng	20,827	88	93	5 (5.7 %)
11. Kratie	21,549	88	93	5 (5.7 %)
12. Kampong Cham	20,935	91	95	4 (4.4 %)
13. Phnom Penh	20,217	93	98	5 (5.4 %)
14. Tan Chau	14,435	105	118	13 (12.4 %)

Source: Hoanh et al 2010, Table 6.14. Page 64, MRC 2010a.

Table C 5 Impact of Projected Climate Change on Year 2000 Flood Event. (Baseline Development Conditions, IPCC A2 Scenario).

Peak Daily Discharge at Kratie (m^3/s)	**2000**	**2048**	**Change**
	54,922	**95,293**	**40,371 (73.5 %)**
Flood Depth Above GL (m)	**Extent of Flooding (km^2)**		
	2000	**2048**	**Change**
> 0.0	44,654	48,579	3,925 (8.8 %)
> 0.5	41,317	46,915	5,598 (13.6 %)
> 1.0	36,393	43,917	7,524 (20.7 %)
> 1.5	30,923	40,563	9,641 (31.2 %)
> 2.0	26,347	36,459	10,112 (38.4 %)
> 2.5	21,971	32,783	10,812 (49.2 %)
> 3.0	17,977	29,006	11,028 (61.4 %)
> 3.5	15,198	25,501	10,302 (67.8 %)
> 4.0	13,570	21,422	7,852 (57.9 %)

Source: Hoanh et al 2010, Table 6.15, page 66, MRC 2010A

C2.5 SALINITY INTRUSION CHANGES

The generally greater stream flows in the low flow season (see Table C2) indicate that salinity intrusion will be curtailed under projected climate change. This is indicated in Table 6.17 of MRC 2010a, but a number of apparent inconsistencies in the Table confuse the message.

C3 METHODOLOGY

C3.1 PROJECTED CLIMATE CHANGE

Chinvanno et al (undated) used the PRECIS[33] Regional Climate Model to downscale to Thailand and mainland Southeast Asia climate change projections made with the ECHAM4 global climate model of the Max Planck Institute of Germany[34]. The spatial resolution of ECHAM4 is 2.8^o x 2.8^o (i.e. about 300 km x 300 km); the solution time step is 24 minutes. Under this ‘model downscaling’ process, climate projections from ECHAM4 are used as boundary conditions to ‘drive the RCM (see Jones, et al 2003). It is unknown whether daily or monthly results from ECHAM4 were used to ‘drive’ the PRECIS RCM, which can be run on a personal computer. The PRECIS results comprised *daily data* on precipitation, maximum and minimum temperatures, solar radiation and wind speed for the periods 1960-2004 and 2010-2050 under IPCC climate change scenarios (‘storylines’) A2 and B2[35]. Details of the downscaling process used in Chivanno et al (undated), any checks that were applied, its success and uncertainties are unknown because, apart from the Abstract, the report is written in Thai.

---

33 The PRECIS model (*P*roviding *R*egional *C*limates for *I*mpact *S*tudies) was developed by the Hadley Research Centre of the UK (Jones et al, 2003).

34 This model forms one of the 24 models of the model ensemble used by IPCC4 to predict future climate change.

35 The A2 Development Scenario largely involves ‘life as usual’ with an ever-increasing population and current regionally oriented and spatially fragmented patterns of economic growth. The B2 Development Scenario is tilted towards economic and environmental sustainability via local endeavours coupled with a slower population increase.

In the study of Chivanno et al (undated), the Mekong Basin was divided into 2,225 grid cells 22 km x 22km. MRC 2010A used the grid cell data sets generated by Cinvanno et al (undated) for the Mekong Basin to assess *mean annual climate change* over three periods:

- 2010-2025 (16 years) A2 and B2
- 2026-2041 (15 years)
- 2042-2050 (9 years)

The period 1985-2000 was used a baseline period.

C3.2 VERIFICATION OF DATA AND MODELS

C3.2a PRECIS Climate Data

Two baseline 'scenarios' were defined to verify the PRECIS hydro-meteorological data and modelling results used by MRC 2010a:

(i) Scenario S1, the daily time series of *observed data* for grid cells and sub-basins; and

(ii) Scenario S2, the daily time series of *downscaled PRECIS data* for grid cells and sub-basins.

The grid cell climate data were processed in three steps to ensure that any bias in the PRECIS climate simulations was removed:

(i) The PRECIS-simulated grid cell data were aggregated together into sub-basin data;

(ii) The PRECIS-simulated sub-basin (S2) data over the baseline period 1985-2000 were compared to the observed sub-basin (S1) data and adjusted for any bias; and

(iii) The bias adjustments were applied to the projected data 2010-2050.

Details of the magnitude of the required adjustments to the PRECIS data are lacking.

C3.2b SWAT Model Water Yields

The eight SWAT models upstream of Kratie were 'calibrated' to ensure that the SWAT-simulated ***total water volume*** over the baseline period 1985-2000 (based on S2 PRECIS-simulated data as input) were consistent with observed total water volume. The PRECIS data were adjusted to bring the simulated and observed yields into agreement. The 18 SWAT models around the Great Lake were similarly calibrated.

Table C5 shows the calibration results for the eight SWAT models upstream of Kratie. The following aspects of Table C5 are noted:

- Using Observed rainfalls, the SWAT Model acceptably simulates the observed runoff over the baseline period (generally within 1 percent).
- Using Unadjusted PRECIS rainfalls, the SWAT model overestimates observed runoff over the baseline period, often by 7 to 8 percent (5 SWAT Models), by 20 percent (one SWAT Model) and by greater than 50 percent (two SWAT Models). In other words, the unadjusted PRECIS rainfall data are 'too wet'.
- Using the Adjusted (calibrated?) PRECIS rainfall data, a much better fit results between SWAT simulated and observed Volume Ratios.

In general, the unadjusted PRECIS rainfall data were too 'wet' (substantially in some cases) for SWAT models upstream of the Great Lake, especially at Chiang Saen, Yasathon and Rasi Salai (see Table C5). It is apparent that substantial adjustments must have been required to make the PRECIS data realize the observed yields.

Table C 6 Calibration Results for SWAT Models Upstream of Kratie, Baseline Period 1985-2000

SWAT Model		**Volume Ratio[a] (%)**		
Model Code	**Evaluation Point**	**Observed Rainfalls**	**Unadjusted PRECIS Rainfalls**	**Adjusted PRECIS Rainfalls**
UMB1	Chiang Saen	101.8	120.2	98.8
LMB1	Chiang Saen	102.2	105.2	101.9
LMB2	Luang Prabang	100.2	107.4	99.4
LMB3	Vientiane	101.0	108.8	100.8
LMB4	Mukdahan	104.5	107.1	104.1
LMB5	Pakse	99.6	107.9	99.5
LMB6	Kratie	100.5	107.1	100.6
LMB7	Yasathon	100.3	150.7	99.9
LMB8	Rasi Salai	99.9	160.6	98.1

Source: Table 5.1, MRC 2010A.
[a] Volume Ratio equals Total SWAT Simulated Volume over Baseline Period divided by Total Observed Volume over Baseline Period

Again, the 18 SWAT models around the Great Lake (see Table 5.2, MRC 2010A) were generally found to be too 'wet' when using unadjusted PRECIS rainfalls, often substantially so. In 14 of the 18 models, the volume ratio was greater then 100 percent; 10 of the 18 SWAT models produced volume ratios of greater than 110 percent; five SWAT models had volume ratios of greater than 150 percent; and in two models, the volume ratio was greater than 200 percent. Again, somewhat Herculean adjustments were necessary to the unadjusted PRECIS rainfalls to bring simulated and observed total runoff volumes over the baseline period into agreement.

C3.2c IQQM Model River Discharges

The IQQM model was used to simulate *daily discharges* at key locations along the Mekong mainstream from Chiang Saen to Kratie and at key points along Mekong tributaries. The model was run with observed (S1) data and adjusted PRECIS (S2) data sets for the baseline period 1985-2000. In the IQQM simulation based on observed S1 data, the discharge inputs at Chiang Saen were taken to be the previous SWAT simulated discharges for the UMB (Upper Mekong Basin) model. The input discharges at Chiang Saen were then adjusted to bring the IQQM simulated discharges based on the adjusted PRECIS S2 data into agreement with the IQQM simulated discharges based on observed S1 data.

Again, the degree of adjustment is not apparent in the results of MRC 2010A, but the IQQM simulated discharges with the adjusted input data agree well with the IQQM-simulated discharges based on observed values. The 'coefficient of efficiency' (CE) was used to compare results obtained with observed S1 data and the adjusted PRECIS S2 data at key locations; in all case the CE values were 0.99 or 1.00[36]. Similarly, the ratio of volumes simulated under S1 and the adjusted PRECIS S2 data were compared at key locations; in general the agreement was within several percent. No further adjustments were made to the adjusted PRECIS data.

[36] The coefficient of efficiency is a measure of the predictive power of hydrological models. A value of 1.00 indicates perfect prediction; a value of zero indicates that the mean value of the observed data is as good a prediction as the predicted value; a value of less than zero indicates that the mean value of the observed data is a better predictor than the model. *In passing, it is noted that 13 of the SWAT models of The Great Lake had CE values of less than zero.*

C3.2d ISIS Model Flood Extent and Salinity Intrusion

In this case, the verification of the ISIS model was made for a single major flood year, 2000 (as opposed to the entire baseline period 1985-2000). Again, the model was run with the observed data (Scenario S1) and with the adjusted PRECIS data (Scenario S2). The agreement between both sets of results was good in terms of areas flooding above nominated depths across the Cambodian/Cuu Long Deltas (differences within 2 percent) and areas affected by salinity above nominated salinity levels (differences generally within 2 percent). No further adjustments were made to the adjusted PRECIS data.

C4 COMMENTS

This study is interesting for several reasons:

1. Although details of the model downscaling from EHGCM4 project climate results to PRECIS results are not given, the downscaled results were 'tuned' to the observed values of the baseline period (1985-2000), i.e. an attempt has been made to ensure that the modelled results reflect the observed results. We can designate this adjustment as *A1*, which is used to bring the observed and downscaled hydro-meteorological results into agreement over the baseline period.
2. The three DSF models, SWAT, IQQM and ISIS have been 'verified' (and tuned in the case of SWAT and IQQM) against observed results over the baseline period 1985-2000.
   - With SWAT hydrological models, substantial adjustments to the PRECIS downscaled rainfall data were necessary to bring simulated water yields based on observed data into agreement with the simulated water yields based on PRECIS data. We can designate this adjustment *A2*, which is used to ensure that SWAT simulated water yields based on observed rainfall data are in agreement with yields based on PRECIS rainfall data.
   - The IQQM model was run with SWAT inputs and (presumably) the A1 adjusted PRECIS data (this is not clear from the Report). A further adjustment, *A3*, was necessary to the upstream inflows at Chiang Saen to ensure that simulated river discharges based on PRECIS data were in agreement with simulated river discharges based on observed data.
   - The ISIS model did not require any further adjustment to the PRECIS data to yield a good agreement to flood and salinity results in the Cambodian/Cuu Long Deltas during the 2000 flood event.
3. Thus, three separate (apparently) adjustments of the downscaled PRECIS rainfall data were necessary achieve agreement with (i) observed rainfalls, (ii) observed runoff volumes, and (iii) observed daily discharge data over the baseline period. Whilst the adopted approach is correct in principle, the lack of detail concerning the basic accuracy of raw downscaled data and the nature and magnitude of corrections to these raw data, coupled with the magnitude of subsequent corrections to modelling results, is less than satisfactory.
4. As in many studies of 'climate change', there is an undignified haste to assess the impacts of projected climate change on 'development scenarios' rather than trying to obtain as reliable estimates as possible of the underlying climate change and unequivocally determine the errors and uncertainties in the projected climate change estimates. In this way it would be possible to assess the effects of climate change under 'best estimate', 'low estimate' and 'high estimate' conditions.

Mekong River Commission
www.mrcmekong.org

Office of the Secretariat in Phnom Penh (OSP)
576 National Road, #2, Chak Angre Krom,
P.O. Box 623, Phnom Penh, Cambodia
Tel: (855-23) 425 353.
Fax: (855-23) 425 363

Office of the Secretariat in Vientiane (OSV)
Office of the Chief Executive Officer
184 Fa Ngoum Road,
P.O. Box 6101, Vientiane, Lao PDR
Tel: (856-21) 263 263.
Fax: (856-21) 263 264

March 2012