II

MRC SEA FOR HYDROPOWER ON THE MEKONG MAINSTREAM

CLIMATE CHANGE BASELINE ASSESSMENT WORKING PAPER

8 March 2010

The MRC SEA of Hydropower on the Mekong mainstream comprises 4 main phases: (i) scoping, (ii) baseline assessment, (iii) opportunities & risks assessment, and (iv) avoidance, enhancement and mitigation assessment.

The Baseline Assessment Report has two volumes:

VOLUME I: Summary Baseline Assessment Report

VOLUME II: Baseline Assessment Working Papers

This working paper is one of eight in Volume II of the baseline assessment report. The two volumes formally conclude the baseline assessment phase of the SEA and documents the outcomes of the baseline consultations and SEA team analysis.

Disclaimer

This document was prepared for the Mekong River Commission Secretariat (MRCS) by a consultant team engaged to facilitate preparation of a Strategic Environment Assessment (SEA) of proposals for mainstream dams in the Lower Mekong Basin.

While the SEA is undertaken in a collaborative process involving the MRC Secretariat, National Mekong Committees of the four countries as well as civil society, private sector and other stakeholders, this document was prepared by the SEA Consultant team to assist the Secretariat as part of the information gathering activity. The views, conclusions, and recommendations contained in the document are not to be taken to represent the views of the MRC. Any and all of the MRC views, conclusions, and recommendations will be set forth solely in the MRC reports.

This document incorporates a record of stakeholder consultations and subsequent analysis. Whether they attended meetings or not all stakeholders have been invited to submit written contributions to the SEA exercise via the MRC website.

For further information on the MRC initiative on Sustainable Hydropower (ISH) and the implementation of the SEA of proposed mainstream developments can be found on the MRC website: http://www.mrcmekong.org/ish/ish.htm and http://www.mrcmekong.org/ish/SEA.htm

The following position on mainstream dams is provided on the MRC website in 2009.

MRC position on the proposed mainstream hydropower dams in the Lower Mekong Basin
More than eleven hydropower dams are currently being studied by private sector developers for the mainstream of the Mekong. The 1995 Mekong Agreement requires that such projects are discussed extensively among all four countries prior to any decision being taken. That discussion, facilitated by MRC, will consider the full range of social, environmental and cross-sector development impacts within the Lower Mekong Basin. So far, none of the prospective developers have reached the stage of notification and prior consultation required under the Mekong Agreement. MRC has already carried out extensive studies on the consequences for fisheries and peoples livelihoods and this information is widely available, see for example report of an expert group meeting on dams and fisheries. MRC is undertaking a Strategic Environmental Assessment (SEA) of the proposed mainstream dams to provide a broader understanding of the opportunities and risks of such development. Dialogue on these planned projects with governments, civil society and the private sector is being facilitated by MRC and all comments received will be considered.

CONTENTS

CLIMATE CHANGE BASELINE ASSESSMENT

Key strategic issues

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

1 OVERVIEW

Climate changes in the Mekong region influence ecosystems, livelihoods and development through changes in regular weather – ie daily, seasonal and annual patterns – and through irregular extreme events. The main influences are temperature, rainfall and runoff, sea level, tidal fluctuations and extreme events such as storms, floods and drought.

Those climatic and hydrological parameters are all changing in the Mekong region with knock on effects on water volume and flow, and on saline intrusion and soil and water quality. Records in LMB countries show that average annual temperatures and rainfall have increased, as have sea levels and the occurrence of storms with impacts on settlements, lives and natural systems, most clearly in coastal and estuarine situations.

Modeling of future climate change at national and regional scale is in its early days – but it is showing the pace and scale of change is gaining momentum with potential effects on existing and future infrastructure and sector development. The nature of that change varies from one LMB catchment to the next although some regional trends are discernable - Rising temperatures would be accompanied by increased rainfall and runoff during the summer monsoon season with more intense tropical storms expanding flooding especially in low-lying coastal areas. The extremes between wet and dry season rainfall would increase with some areas experiencing more extended dry periods. A rise in sea levels of 16 cm by 2030 and up to 45 cm by 2070 is expected (Preston 2006).

While the situation is variable throughout the region, key economic sectors are expected to experience direct impacts, some with reduced productivity including fisheries (especially aquaculture) and agriculture. Hydropower development has a two way relationship with climate change – both as a potential moderator of some changes such as increased extreme flooding, and as an impacted sector affecting design and location of projects and potential hydropower capacity.

This baseline paper synthesizes the available analysis and views on past and future trends in climate change for each LMB country, for the overall region, and then according to the six Mekong mainstream hydro-ecological zones. It explores implications of those trends on areas and development sectors.

The SEA works with a projected baseline to 2030 and beyond for some aspects of climate change – taking in the BDP Definite Future Scenario and the LMB 20 year scenario without LMB mainstream dams. The DFS includes 40 tributary dams constructed since 2000, under construction or committed and 6 China mainstream dams. In the DFS, the total live or active storage of the tributary dams and of the Chinese reservoirs[1] is 21,222 MCM or 4.6% and 22,189 MCM or 4.7% respectively of the annual water volume leaving the Delta – making a total of 9.3%. Under the LMB 20 year "without" scenario, there are 70 tributary dams (30 additional to the DFS with a live storage of 20,185 MCM or 4.2%) and the 6 Chinese dams – with a total active storage making up 13.5% of Mekong water.

Two key considerations when assessing climate change effects are:

1. the global (and national) development scenarios (they vary in terms of impacts on green house gas emissions), and
2. the climate models used in applying the IPCC/national scenarios to the Mekong region

Those considerations are important to keep in mind when interpreting and comparing climate modeling results because:

- Different IPCC/national scenarios result in differing scales of change
- Different models can lead to differing estimates for the range and pace of changes within one scenario

This baseline paper has four main parts – presenting the evidence (i) from the perspective of each of the four LMB countries, (ii) in terms of the overall region, (iii) for each hydro-ecological zone and (iv) according to the main economic sectors affected.

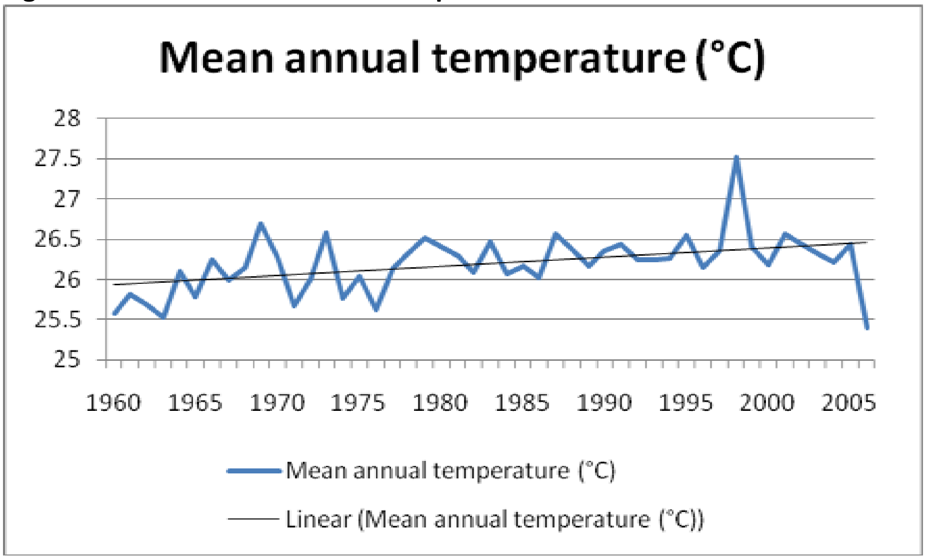
2 CAMBODIA

2.1 PAST TRENDS

From 1960 to 2005, the average temperature in Cambodia has increased by 0.8°C (Figure 1). The rate of increase is most rapid in the drier seasons at a rate of 0.20-0.23°C per decade and slower in the wet seasons at a rate 0.13-0.16°C per decade. The frequency of unusually hot days and nights has increased throughout the year by 12.6% and 17.2% respectively while cold days and nights have decreased (McSweeney et al. 2008). Also the period saw increased variability with greater extremes in maximum and minimum temperatures especially in the past decade.

[1] The Manwan reservoir in Yunnan has been in operation since 1993, but its live storage is minor (250 MCM) therefore it is included with the other Chinese reservoirs

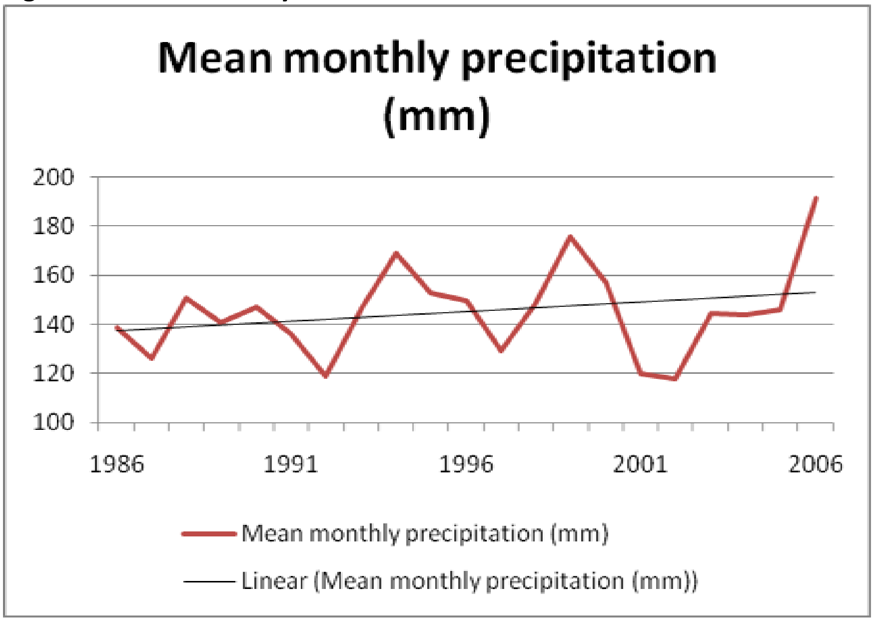
Figure 1: Trend in mean annual temperature 1960 to 2005 - Cambodia



Source: ICEM analysis based on Oxford University School of Geography and Environment data[2]

The experience with rainfall is more complex. Mean monthly rainfall over Cambodia did not show any consistent increase or decrease between 1950 and 1985 but over the past 20 years it has increased by 15mm (Figure 2). Most notable since 1960, the variability from one year to the next has increased as have extremes between maximum and minimum rainfall.

Figure 2: Mean monthly rainfall between 1982 and 2006



Source: ICEM analysis based on Oxford University School of Geography and Environment data

2.2 FUTURE TRENDS

[2] http://country-profiles.geog.ox.ac.uk/index.html?country=Cambodia&d1=Observed&d2=Mean&d3=Timeseries&d4=Absolute

All climate models applied to Cambodia predict increases in temperature and rainfall, but the extent of change forecast and its geographic distribution varies. In Cambodia, it is predicted that by 2025 there will be an increase in mean annual temperature of between 0.3 and 0.6°C and by 2100, an increase between 1.4 and 4.3°C (MRC 2009).

Rainfall would also increase depending on location, time and emission scenario. Under A2, annual rainfall in 2100 would increase between 3 and 35% from the current conditions depending on location. Low land areas would experience greater change than high land areas (MOE, 2001).

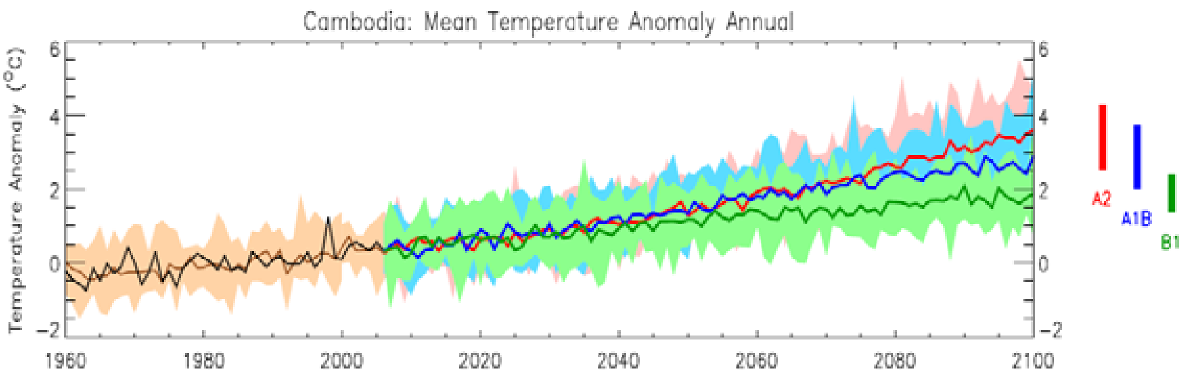
A 2008 study projected future climate conditions for Cambodia under three IPCC emission scenarios - A1B, A2 and B1 - as follows (McSweeney et al 2008):

- The mean annual temperature is projected to increase by 0.7 to 2.7°C by 2060, and 1.4 to 4.3°C by 2090 (Figure 3)
- All scenario projections indicate substantial increases in the frequency of days and nights that are considered hot in the current climate.
- Increases in annual average rainfall, mainly due to wet season rainfalls (up to 31% by the 2090s), and partially offset by projected decreases in dry season rainfalls.
- The proportion of total rainfall that falls in heavy events is projected to increase by an additional 0 to 14%, by the 2090s mainly in the wet season, and partially offset by decreases in the dry.
- Increases in the magnitude of 1 and 5-day rainfalls of up to 54mm and 84mm respectively by the 2090s largely in the wet season.

Rainfall increases and variation in extremes are projected mainly in the central agricultural plains stretching from the southeast to the northwest, where rainfall has historically been below the national average; these areas are already vulnerable to floods and drought (MOE, 2001).

Coastal areas will be vulnerable to sea-level rise projected to be between 0.23 to 0.56m under A2 by the 2090's with consequent increased saline intrusion into surface and ground water.

Figure 3: Cambodia - mean annual temperature – 1960 to 2100 for A2, A1B and B1



Source: McSweeney et al. 2008

3 LAO PDR

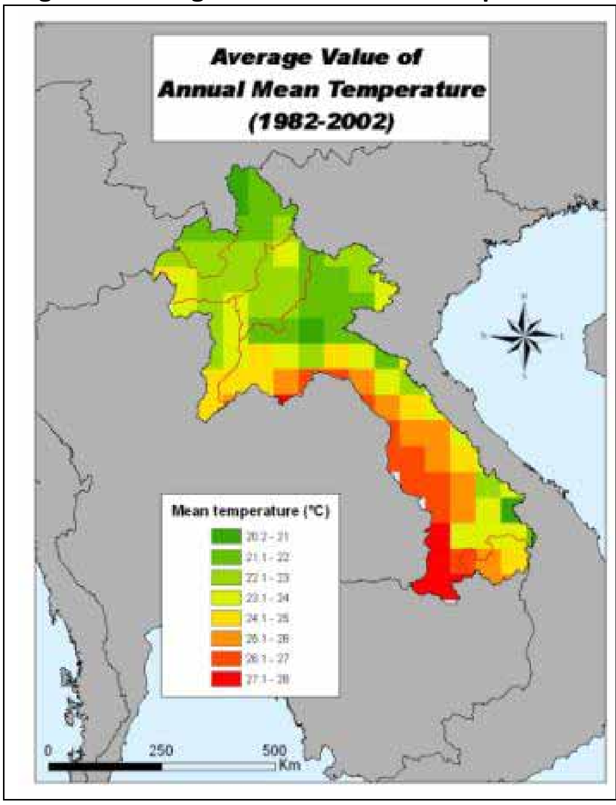
3.1 PAST TRENDS

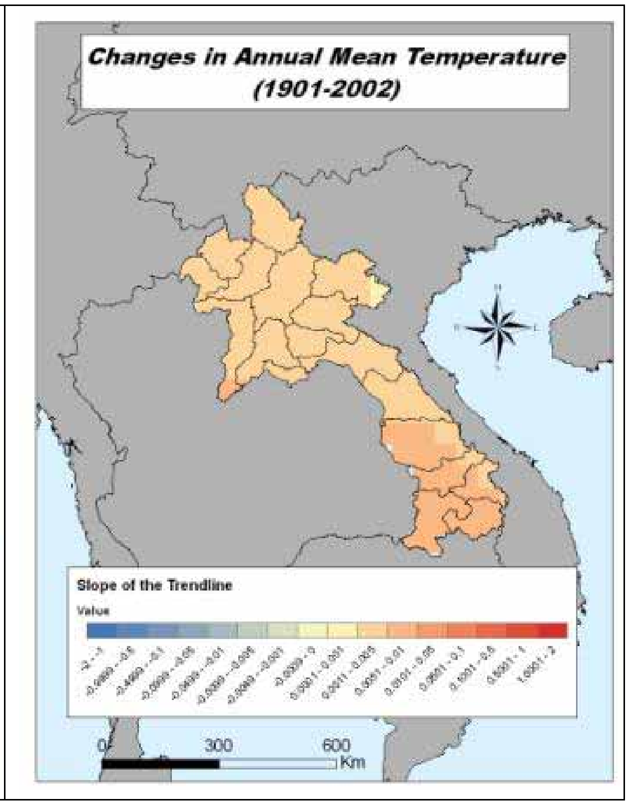
The National Adaptation Program of Action to Climate Change (NAPA) Report for Lao PDR states that the impacts of climate change have already been experienced through an increase in floods and droughts (WREA 2009). WREA found that, from 1995 to 2005 in particular, drought conditions were characterized by higher and irregular increases in temperature.

From 1901 to 2002 there were significant increases in annual mean, minimum and maximum temperatures throughout the country but particularly in the south. Most northern and central areas increased by 0.1 to 0.5°C. In southern parts the increase was 0.5 to 1.0°C (Figure 4 and 5).

There have been significant trends in rainfall (some areas increasing, others decreasing), but not large compared to the inter-annual variations (Salazar et al 2009).

Figure 4: Annual Mean Temp 1982 – 2002
Figure 5: Changes in annual mean temperature – 1901 to 2002





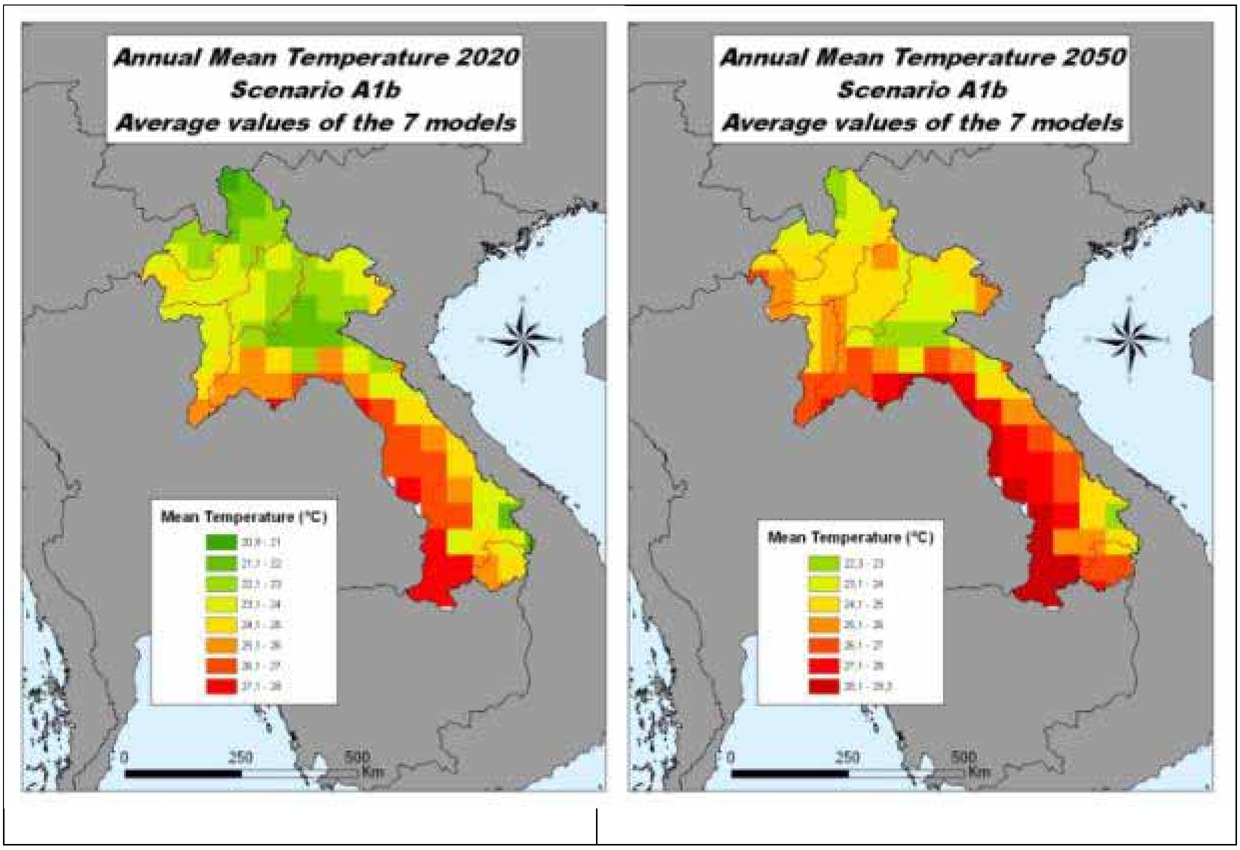
Source: Salazar et al 2009

3.2 FUTURE TRENDS

Based on the A1B scenario, past trends will intensify with continued increases in annual minimum, mean, & maximum temperatures throughout the country, but particularly in the south and west (Salazar et al 2009) (Figure 6 and 7). For example for Sayabouri, observed annual mean temperature between 1982 – 2002 was 23.7 °C; and forecast annual mean temperature for 2020 and 2050 is 24.4 °C and 25.7 °C respectively - a 2°C increase over the next 40 years.

There would be significant and variable changes in rainfall with an increase in the severity, duration and frequency of floods and droughts (MRC 2009).

Figure 6: Lao PDR: Annual mean temperature distribution for 2020 with A1B
Figure 7: Lao PDR: Annual mean temperature distribution for 2050 with A1B



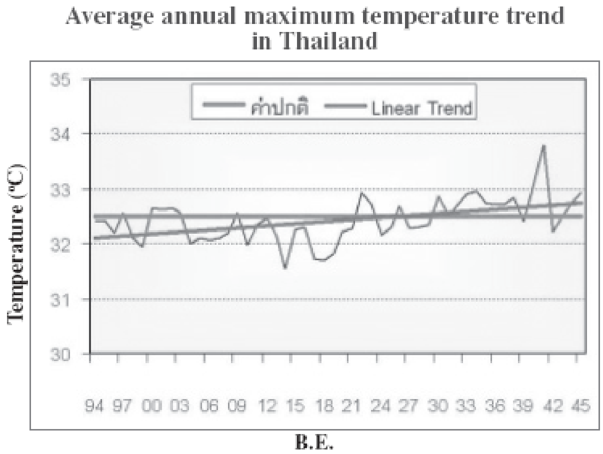
Source: Salazar et al 2009

4 THAILAND

4.1 PAST TRENDS

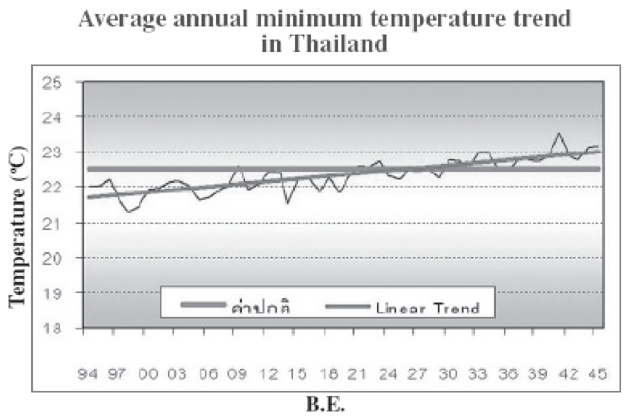
According to the Meteorological Department of Thailand, there has been an increase in maximum (0.8°C) and minimum (1.2°C) temperature and a decrease in rainfall during 1951-2002 (B.E. 2494-2545) (Figures 8 to 10)

Figure 8: Increasing trend in Thailand's average annual maximum temperature during 1951-2002 (2494-2545 B.E.)



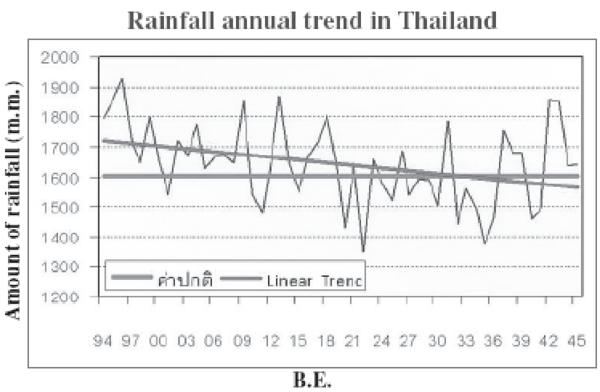
Source: Chamnong Keawchada ,B.E. 2546 in Boonprakrob 2006.

Figure 9: Increasing trend in Thailand's average annual minimum temperature during 1951-2002 (2494-2545 B.E)



Source: Chamnong Keawchada ,B.E. 2546 in Boonprakrob 2006.

Figure 10: A decreasing trend in amount of annual rainfall in Thailand during 1951-2002 (2494-2545B.E).



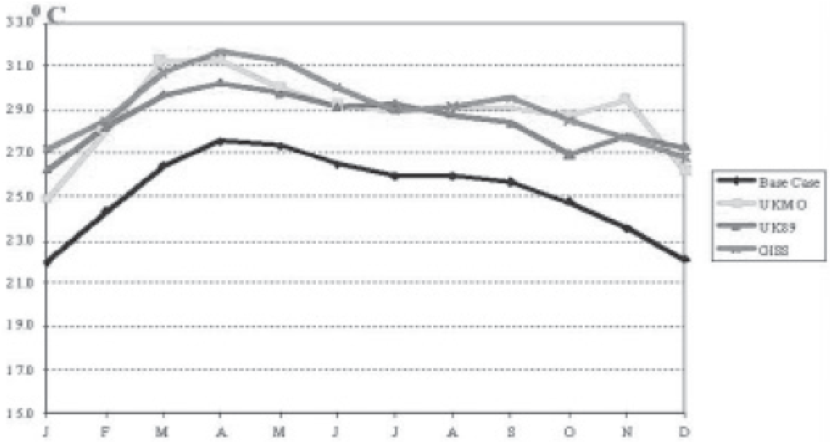
Source: Chamnong Keawchada ,B.E. 2546 in Boonprakrob 2006.

4.2 FUTURE TRENDS

Climate modeling in Thailand for B2 and A2 forecasts an increase in average temperature by 2100 from 21.5-27.5°C to 25-32°C (Figure 11). The temperature increases by 2.5°C in the northeast region and by 3-3.5°C in the central, north, and west regions. The hot period of the year will extend longer and the cold period will be significantly shorter (SEA START RC. 2006).

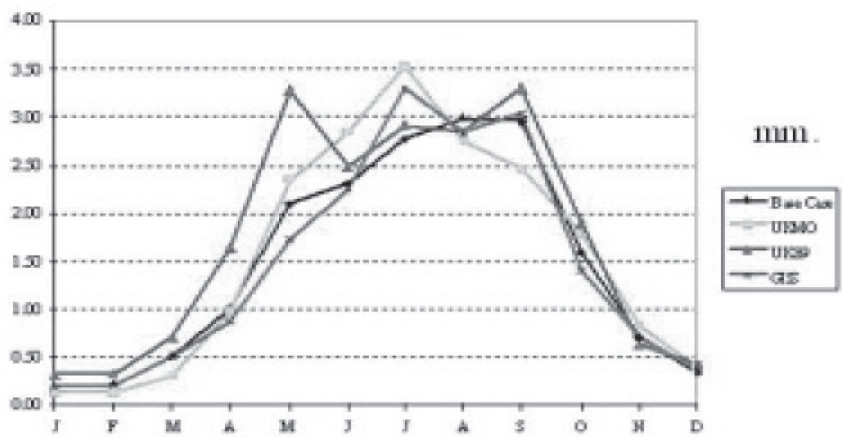
The distribution of rainfall changes across the country. The amount of rainfall in the northeast remains constant while it increases by 40% in the south. The amount of rainfall in other parts of the country increases by 20% (Figures 12 and 13). Overall the length of rainy season would remain the same, but with higher rainfall intensity.

Figure 11: Increase in temperatures by 2100 for A2 (results from 3 GCMs against the baseline)



Source: TEI, 1999

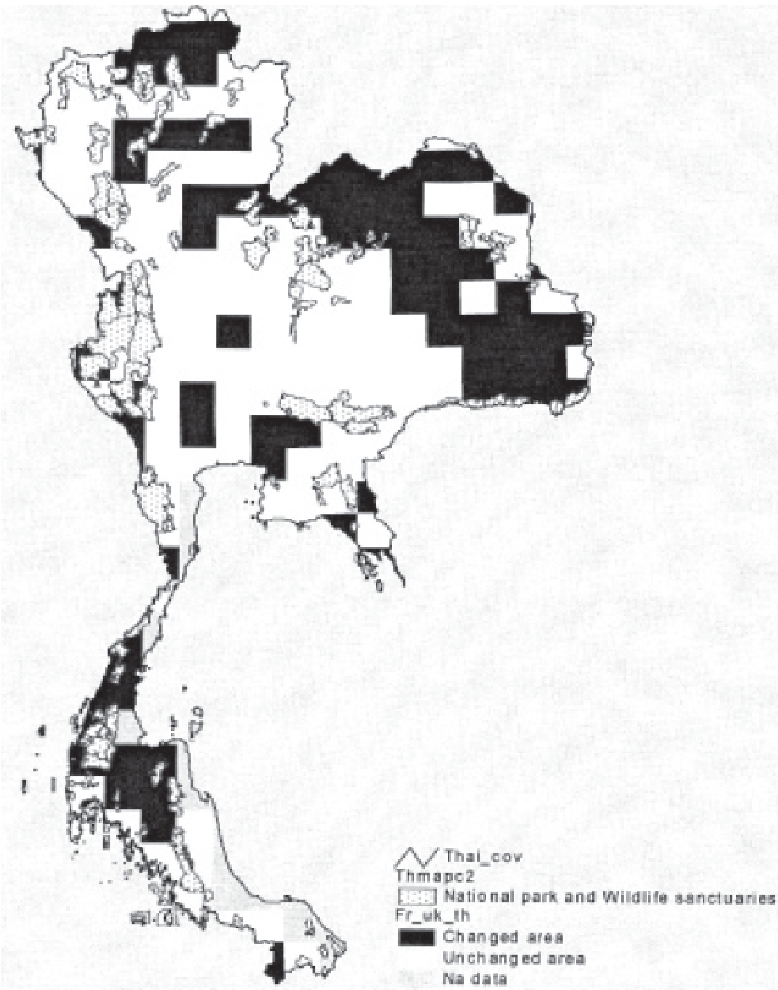
Figure 12: Comparing 2100 annual rainfall patterns with baseline climate using three GCMs: UK 89,UKMO and GISS for A2



Source: TEI, 1999

One Thai research group defined zones in Thailand which would be most susceptible to climate change – many of those hotspots are located within the Mekong River Basin and especially in the south east region already subject to more prolonged droughts (Boonprakrob 2006) (Figure 13). Of the national parks and wildlife sanctuaries distributed all over Thailand, 32 are situated in climate change hotspots

Figure 13: National parks and wildlife sanctuaries in Thailand that are situated in climate change hot spots



Source: Boonprakrob 2006

5 VIETNAM

5.1 PAST TRENDS

In the last 50 years, Vietnam's average temperature increased by 0.5-0.7°C (MONRE 2009). The rate of increase is most rapid in the dry winter seasons at 0.08-0.11°C per decade (Figure 14). This warming has been more rapid in the southern parts of Vietnam than the central and northern regions. The frequency of hot days and hot nights has increased by 7.8% and 13.3% respectively in every season while the frequency of cold days and nights, annually, has decreased significantly (McSweeney 2008).

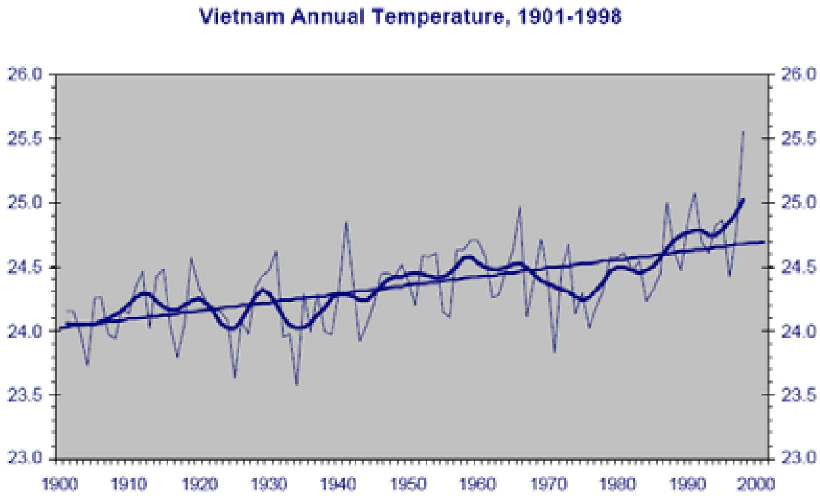
Rainfall has decreased in most localities in the north and increased in most areas of the South during all seasons (Figure 15). In winter rainfall fell by 23% (Table 1). In the Mekong Delta, there have been trends of increasing rainfall and temperature since 1976 in all seasons (Figure 16)

Table 1: Climate change in Vietnam – precipitation trends 1901 to 1998

Vietnam	Period	Trend	Trend %
Annual	1901-1998	-184.59	-9.97
Winter	1901-1998	-63.05	-23.05
Summer	1901-1998	-113.67	-7.21

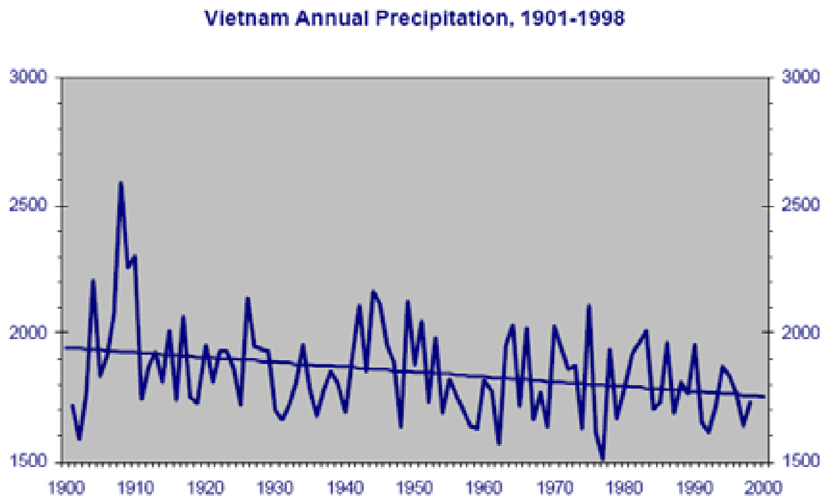
Source: Schaefer, 2002

Figure 14: Vietnam Annual Temperature – 1901 - 1998



Source: Schaefer, 2002

Figure 15: Vietnam annual precipitation – 1901 - 1998



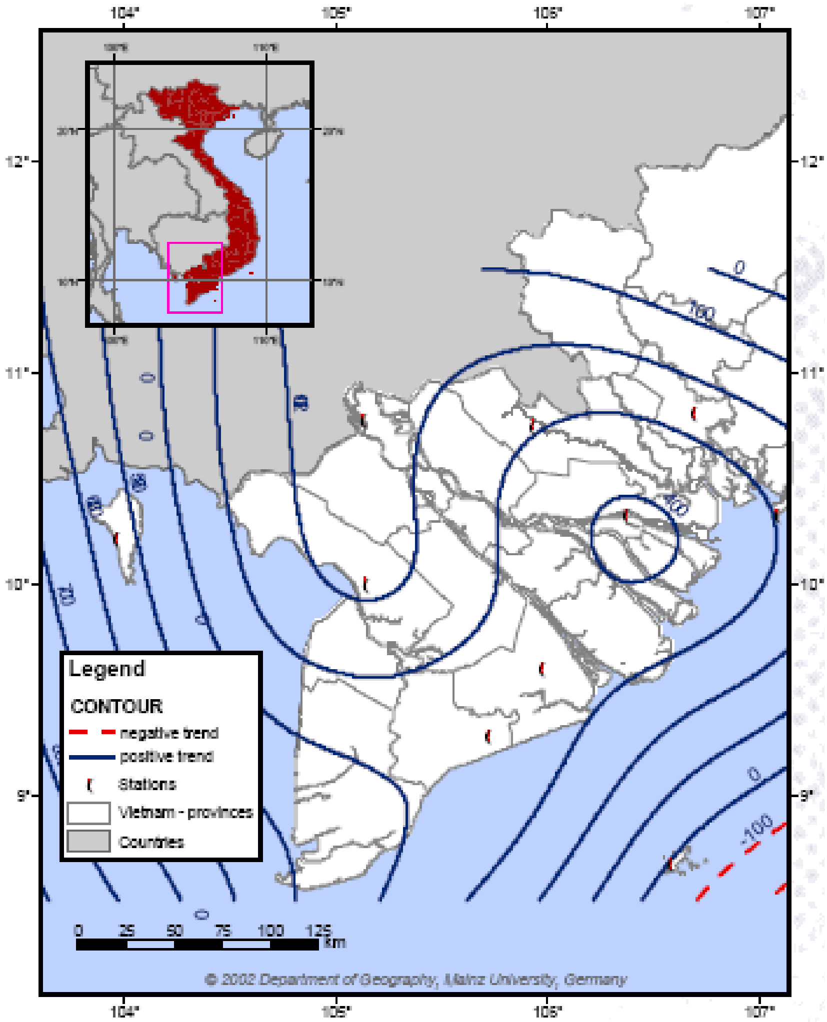
Source: Schaefer, 2002

Contrary to the national average decrease in rainfall, during the past 30 years, the Mekong Delta has experienced substantial increases in rainfall, as high as 177% during winter in Soc Trang on the coast and a 30% annual increase (Table 2 and Figure 16).

Table 2: Observed climate change in the Mekong Delta – rainfall trends 1976-2000

Station	Summer %	Winter %	Annual %
Bac Lleu	8.49	79.51	14.86
Phu Quoc	11.09	67.91	17.96
Rach Gia	3.53	58.40	8.43
Chau Doc	7.78	47.92	13.05
Soc Trang	6.60	175.88	17.79
My Tho	20.32	176.82	30.14
Moc Hoa	10.62	93.95	17.52
Con Dao	-4.75	88.39	-0.18
Vung Tau	19.58	19.09	19.57
Tan Son Hoa	4.11	104.74	13.25

Figure 16: Observed climate change in the Mekong Delta - rainfall

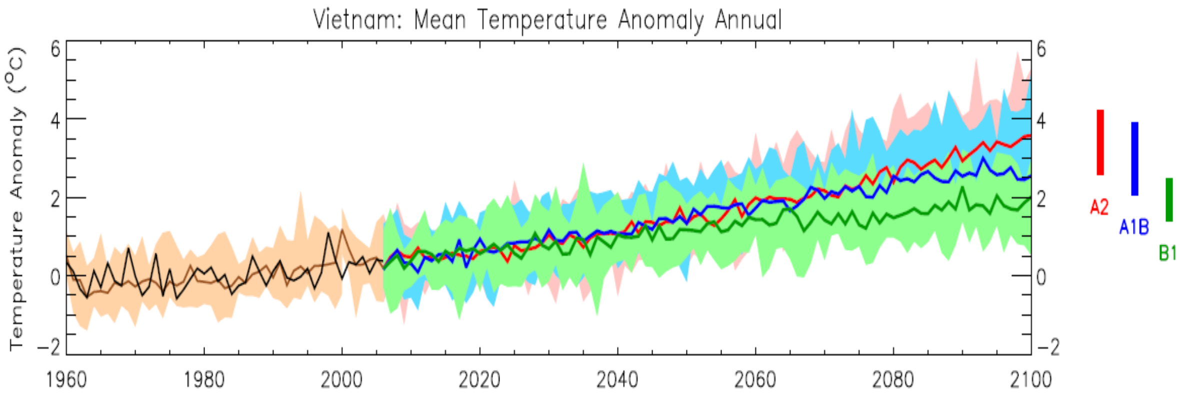


Since 1901, the sea level rose by 20cm and the number of typhoons and tropical depressions has risen to 7 or 8 a year. The impact of storms and floods has intensified in part due to increasing populations and settlements in vulnerable areas. Though preventive measures have been actively taken, losses and damages from disasters are severe and increasing. In the last 10 years alone, natural disasters have cost Vietnam around 800 lives and 1.5% of GDP a year (MONRE 2009).

5.2 FUTURE TRENDS

By 2100, MONRE has forecast that Vietnam's average temperature will increase to between 1.1° C (low emission scenario) and 3.6 ° C (high emission scenario) above the average for the 1980-1999 period (MONRE 2009) (Figure 17). The temperature rise will be greatest in the North, around 2.8 ° C. Overall, winter temperatures will rise more rapidly than summer temperatures. The number of days with temperature higher than 25°C will increase.

Figure 17: Vietnam – mean annual temperature – 1960 to 2100 for A2; A1B and B1



Source: McSweeney et al. 2008

The MONRE forecasts also show greater total rainfall, wetter wet seasons and drier dry seasons, especially in the southern region. Annual rainfall would increase 1.0 to 5.2% in low emission and 1.8 to 10.1% in high emission scenarios. Rainfall begins to intensify over fewer months in the rainy season (an overall increase of 19%), while the dry season will become more prolonged.

More frequent and intensifying storm surges: MONRE projects more typhoons, with higher wind velocity in typhoons and extending over longer periods. The typhoon intensity is forecast to be stronger, especially during El Ninõ years. What was once a one in 30 year storm is likely to become a one in ten year event.

MONRE forecasts the average level of Vietnam's seas to rise 28-33 cm by 2050 and 65-100 cm by 2100 compared to the 1980-1999 period. The MONRE A2 forecasts for the Southern Region of Vietnam including the Mekong Delta are summarized in Table 3.

Table 3: Climate Change Predictions for southern region of Vietnam for A2

Factors	Season	2010	2050	2070
Temperature increase (^{0}C)	n/a	0.3	1.1	1.5
Change in precipitation (%)	Wet	0	0 to 5	0 to 5
	Dry	0	-5 to +5	-5 to +5
Sea level rise (cm)	n/a	9	33	45

6 REGIONAL CLIMATE CHANGE FORECASTS

6.1 REGIONAL CLIMATE CHANGE TRENDS

The trends identified in national climate change modeling are reinforced by a number of assessments on a regional scale – primarily by CSIRO (Eastham et al. 2008), SEASTART (2006) and MRC (Hoanh et al. 2010 and MRC 2009). Projected climate changes for the Mekong basin point to:

- increasing variability
- a wetter wet season
- less rain during the dry season in the south - and
- more frequent extreme weather events (Eastham et al. 2008).

Seasonal water shortages and floods are expected to become worse in some areas of the basin, as may saltwater intrusion into the Mekong Delta due to storm surges and sea level rise (Carew-Reid 2007; Southern Institute for Water Resources Planning 2008).

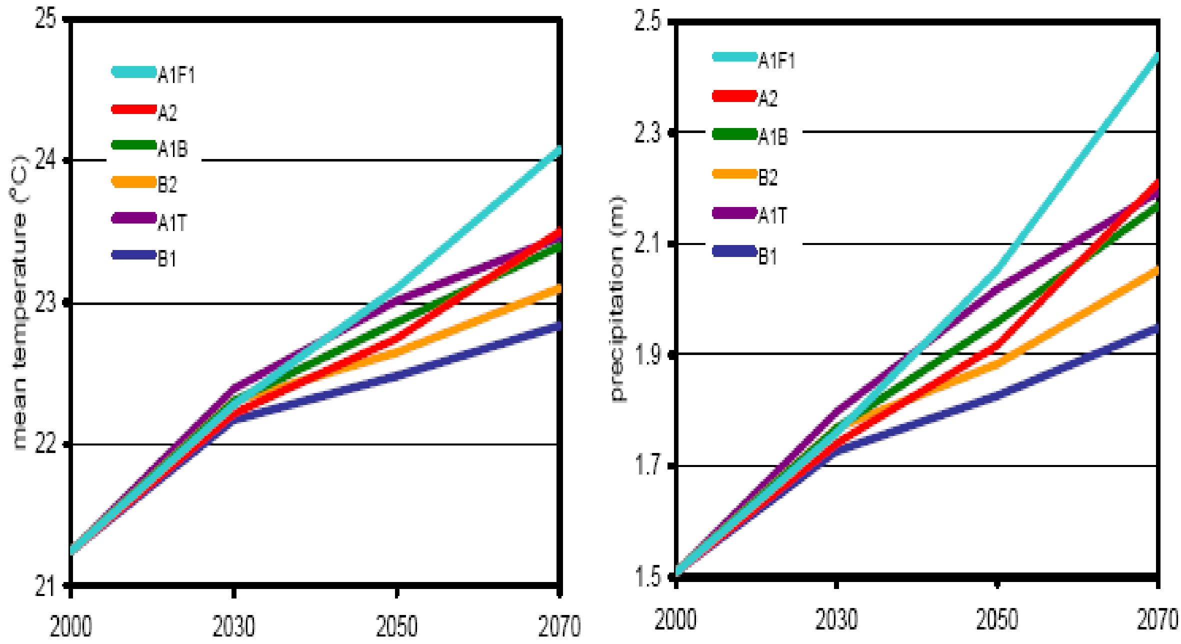
The most extensive modelling trials to date for the basin were conducted by CSIRO (Eastham et al. 2008).[3] That team evaluated 24 models and selected 11 as the most appropriate for the Mekong region. First a range of IPCC emission scenarios were modelled for 2030, 2050 and 2070 to obtain a sense of the range in changes which could be expected under different global development futures (Figure 18). Important findings were that increases in temperature and rainfall are significant under all scenarios. Also, to 2030 all scenarios are relatively closely clustered but then diverge significantly between the extremes of A1F1 and B1. By the time the Mekong mainstream hydropower projects if approved would be handed to the governments around 2070 under the BOT arrangements the differences between scenarios become substantial – close to 1.5°C mean annual temperature and 0.5m mean annual rainfall.

A1B was selected for more detailed analysis for 2030 as a medium change scenario. Taking that scenario and the mean results from 11 models, changes in the basin vary from:

- catchment to catchment
- North to South
- season to season
- year to year

Figure 18: Projected mean annual temperature and mean annual rainfall for the Mekong Basin for different IPCC scenarios at 2030, 2050 and 2070

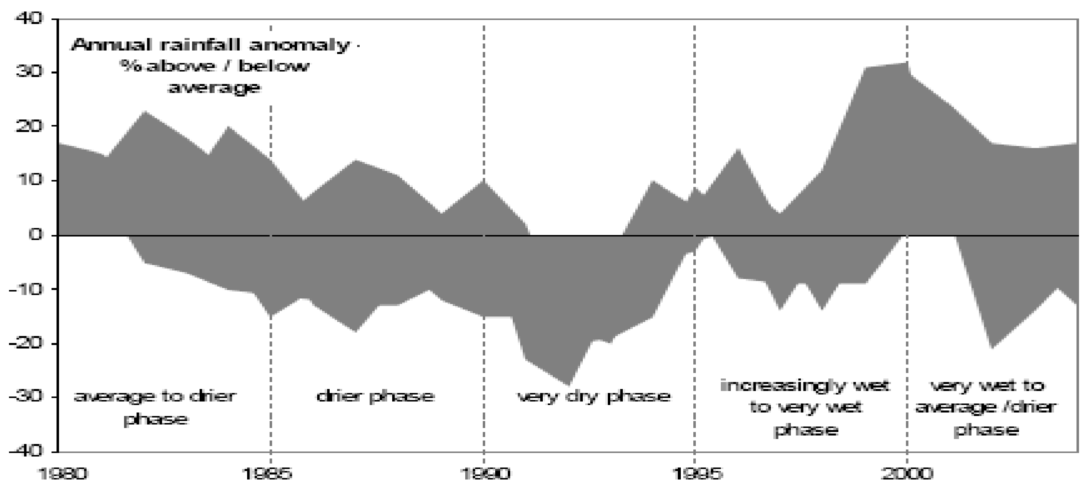
[3] A number of modeling studies have been conducted for the Mekong Basin – results for temperature have been within a similar range – but greater divergence is found for rainfall. Annex 1 provides a summary of the main modeling studies and their results for temperature and rainfall. Divergence is due to use of different models, scenarios, timeframes for observed data, and projections for a period or single year and point to the need for an expert group to arrive at a consensus on the most likely ranges and location specific effects.



Source: Eastham et al. 2008

Those spatial and temporal differences build on past trends which show increased variability in key climate parameters. In most years, the geographic variability of total rainfall over the basin is already high. Also, deviations of annual rainfall from the average have been as high as 30% with severe droughts in 1992 (when the peak and volume of the flood were 40% or more below the average figures) and extreme wet and flooding during 1999 to 2002 (Figure 19). Despite the increase in variability, over the last 50+ years the regional timing and duration of the south-west monsoon appears to have remained the same (MRC 2010). That situation is expected to change.

Figure 19: Deviations of regional rainfall above and below average over the 25 years between 1980 and 2004



Source: MRC 2010

Table 4 provides a summary of the main climate changes projected for 2030 under A1B. Mean basin temperature is forecast to increase by almost 4% with greater increases in northern zones of the basin – rising close to 1.4°C above the historical mean in Yunnan Province (Figure 20).

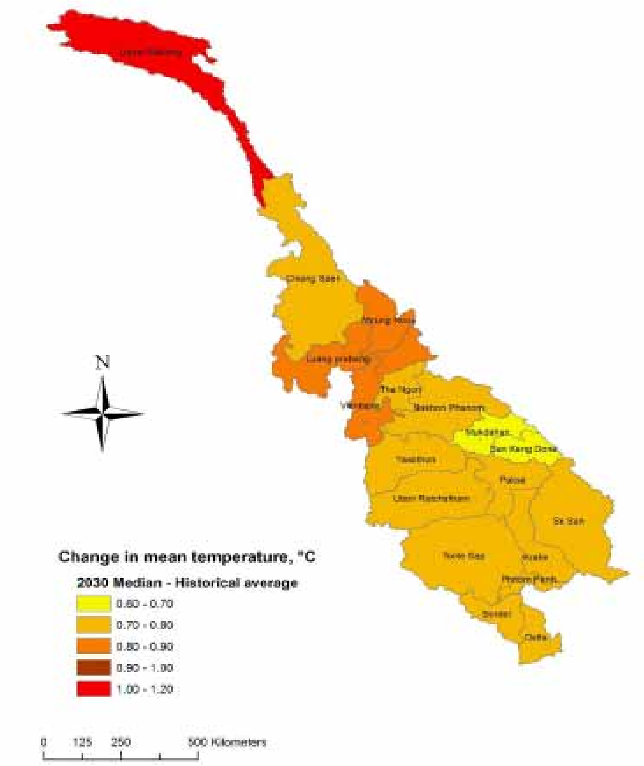
Annual rainfall is projected to increase by 13.5%, mainly due to increases in the wet season (May to Oct). Increases will be especially high in the Upper Mekong Basin and in the central and southern zones (Figure 21).

Dry season rainfall will increase in northern hydro-ecological zones – ie 1 and 2 north of Vientiane (Figure 28 shows the hydro-ecological zones for the mainstream Mekong River) and decrease in southern zones – ie 3 to 6 from Vientiane to the Delta (Figure 22). The overall disparity between wet and dry seasons is set to increase especially in zones 3 to 6.

Table 4: Climate change in the Mekong basin – annual averages (2030 for A1B)

Indicator	Historical record 1951-2000	2030	Increase
Temperature	▪ 21.2°C	▪ 22.0°C	▪ **3.7%** or 0.8°C
Rainfall	▪ 1.509 m	▪ 1.712 m	▪ **13.5%** or 0.2m
Runoff	▪ ~512,000 mcm	▪ ~619,000 mcm	▪ **21%** or ~107,000 mcm
Flow (the mean annual discharge at Kratie)	▪ 13600 m3s-1, (from 1924-2006)	▪ 16592 m3/s	▪ **22%**
Flooding (incidence of extreme wet events at Kratie – zone 5)	▪ Annual probability 5% ▪ Duration 5.1 months	▪ Annual probability 76% ▪ Duration 5.7 months	▪ **71%** increased probability ▪ **12%** increase in duration ▪ Increase of 3,800km^2 area of flooding in delta

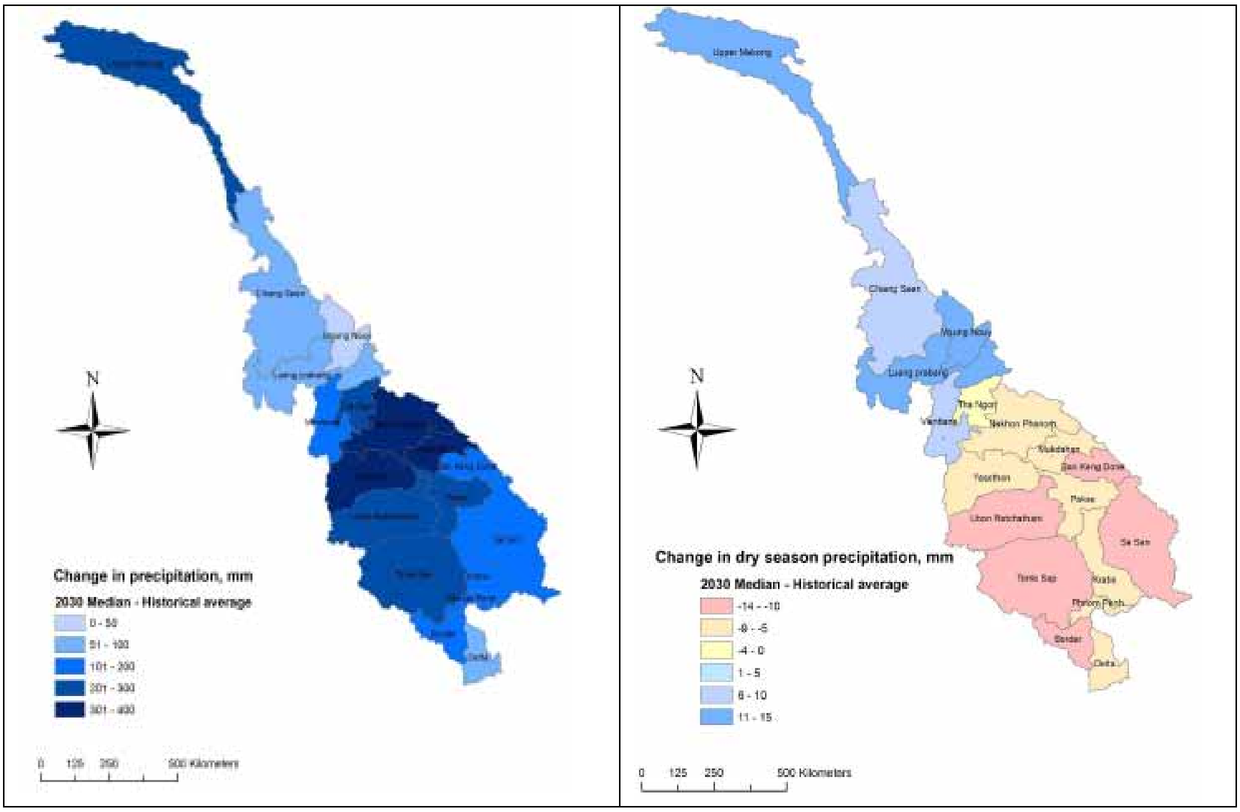
Figure 20: Projected change in mean temperature at 2030 compared with historical (1951-2000) mean temperatures (A1B)



Source: Eastham et al. 2008

Figure 21: Projected change in mean annual precipitation at 2030 compared with historical (1951-2000) mean precipitation

Figure 22: Projected change in precipitation during the dry season (November to April) at 2030 compared with historical (1951-2000) mean precipitation

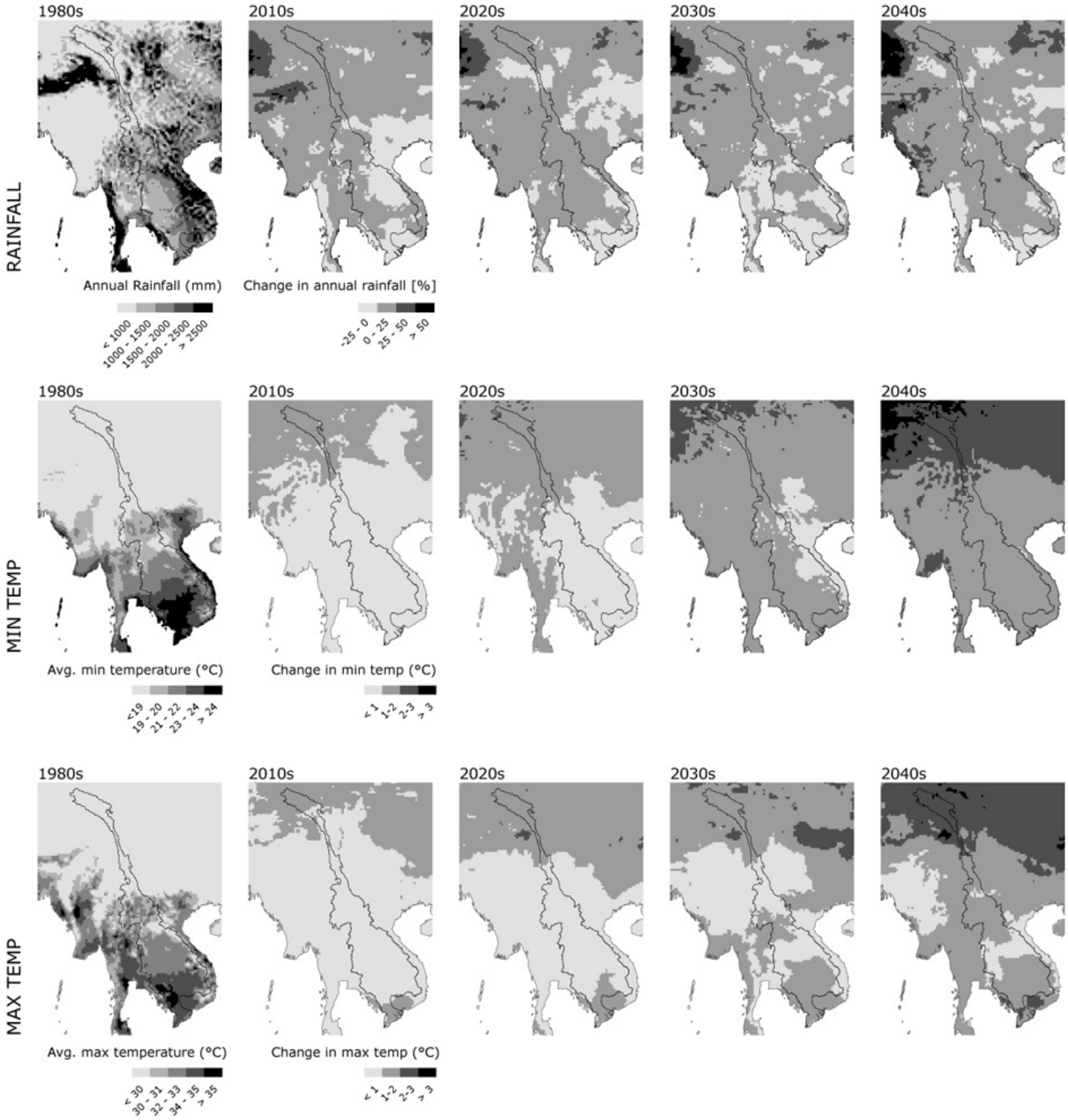


Source: Eastham et al. 2008

Modeling of the A2 and B2 climate scenarios by the Helsinki University of Technology (TKK) and Southeast Asia START Regional Center found similar trends - the region is likely to be warmer throughout, with greatly extended warm periods over the year (Figure 23). By the 2040's, maximum temperatures will increase by 3^{o}C or greater in the north with minimum temperatures falling by 2 to 3 ^{o}C in the same region.

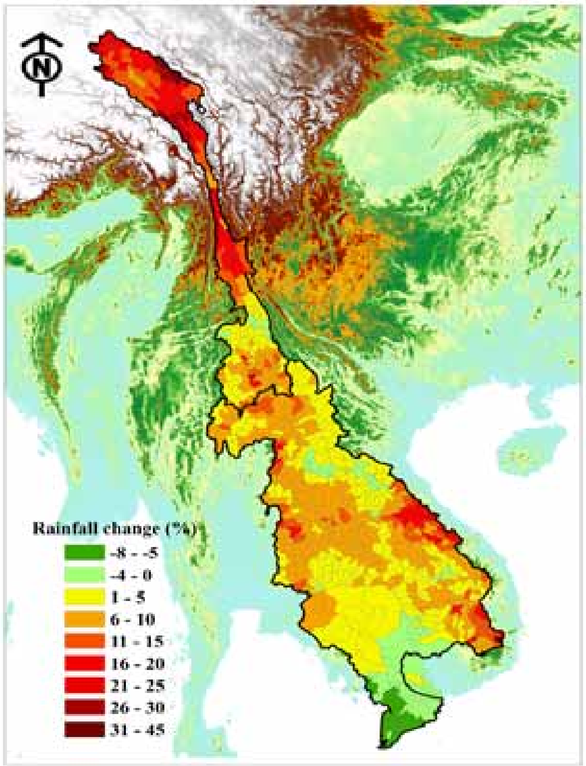
By the 2040's, rainfall is likely to fluctuate in the first half of century, with a steady increase in intensity and quantity except in some southern areas (TKK 2009) (Figure 24). An MRC team had similar results when modeling mean annual precipitation during 2010–2050 for scenario A2 (Figure 25). They found increases in rainfall of 15 to 45% in the Upper Mekong Basin with reductions of 5 to 8% in the south, especially the Mekong Delta.

Figure 23: Changes in rainfall and temperature in the Mekong basin to 2040's for A2



Source: Matti Kummu 2010, TKK 2009

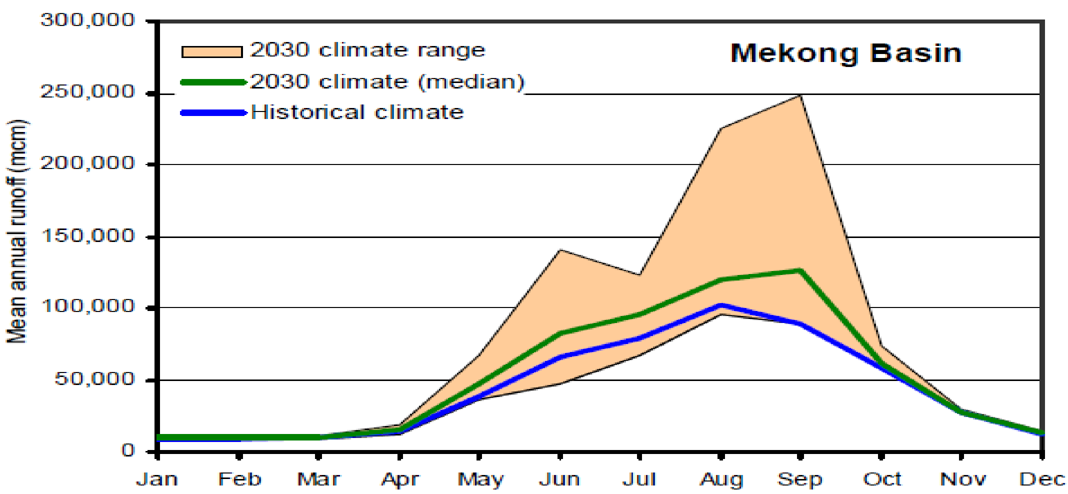
Figure 24: Change in mean annual precipitation (%) during 2010–2050 compared to 1985–2000 for scenario A2



Source: MRC 2010

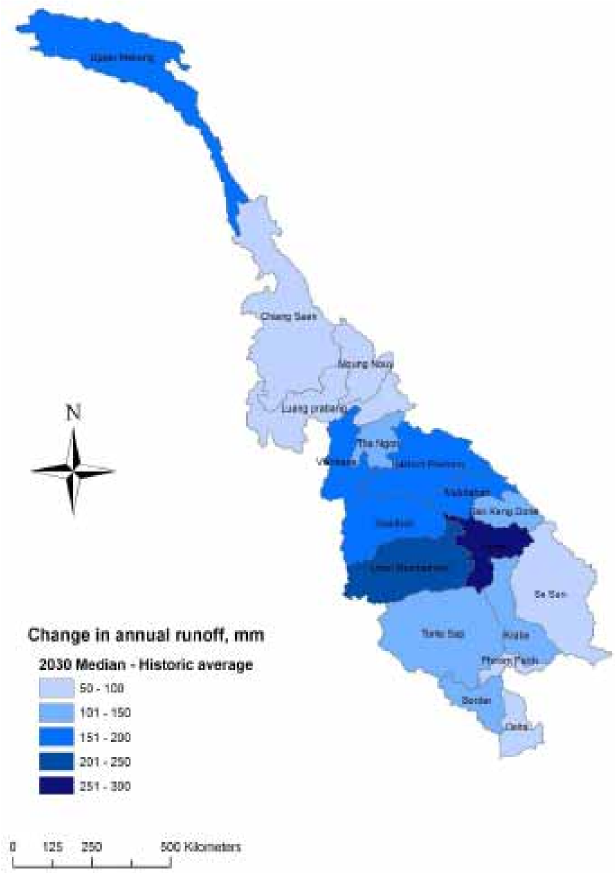
The effects of climate change on the basin's hydrology are projected to be very significant. For the A1B scenario in 2030, total annual runoff from the basin is forecast to increase by 21% mainly during the wet season in the upper areas of the Mekong floodplains (Eastham et al. 2008). Mean annual runoff between July and October for that year are especially high with a pronounced increase towards the end of the wet season with the effects of prolonging the flood (Figure 25). Changes in mean annual runoff are particular high in the southern part of the basin (Figure 26). Annual discharge at Kratie would increase by 22% with increases in all months but mainly the wet season.

Figure 25: Historical (1951-2000) and future (2030) monthly runoff



Source: Eastham et al. 2008

Figure 26: Change in mean annual runoff at 2030 compared with historical (1951-2000) mean annual runoff for catchments of the Mekong Basin



Source: Eastham et al. 2008

Glacial and snow melt: The 2007 China National Report on Climate Change estimates that, over the past 20 years, the glacial area of the Tibetan Plateau has shrunk by approximately 4.5%, and by 7% over the last 40 years[4]. Discharge from glacial and snow melt is expected to increase by some 20% but impact on flow and water availability would be small because, historically, it contributes only 0.1% to annual discharge to the LMB – and that contribution will remain at similar levels in 2030 as a proportion of the total increase in runoff from the UMB (Eastham et al. 2008).

On this issue, recent MRC modelling for A2 draws similar conclusions - the contribution of snowmelt to the annual water yield (or runoff) at the Chinese-Lao border will increase slightly from 5.5% to 8% (higher than the CSIRO estimate). That contribution in the dry season is more significant although the percentage increase in river discharge does not change much and its effects diminish moving down river (MRC 2010).

Flooding: The increases in runoff would result in increases in all parameters relating to flooding under A1B and A2 (Table 5). Flooding would increase throughout the basin – with downstream zones affected

[4] Eriksson, et al., 2009.

most. Wet and dry season water levels are projected to increase. For example at Kratie (zone 5) the annual probability of extreme wet flood events will increase from 5% (historic conditions) to 76%. It would increase to 96% in the wet season. Duration of flooding is forecast to increase in zone 5 and its onset would come earlier – meaning the Tonle Sap maximum and minimum area and water levels would increase annually as would the area of annual average flooding in Delta, anticipated to increase by 3,800km2. The effects of those increases would be greatest on the mainstream Mekong due to cumulative contribution from tributaries.

Table 5: Trends in hydrology in the Mekong Basin due to climate change for A2

Characteristic	Trend in change due to CC	Description of trend
Water level (Feb-Jul)	⇧	Very likely increases
Water level (Aug-Jan)	⇧	Likely increases
Annual cumulative flooded area	⇧	Very likely increases
Annual maximum water level	⇧	Likely increases
Annual maximum flooded area	⇧	Likely increases
Flood start date	⇦	Very likely occurs earlier
Flood end date	⇨	Likely occurs later
Flood peak date		Changes not consistent
Flood duration	⇧	Likely increases

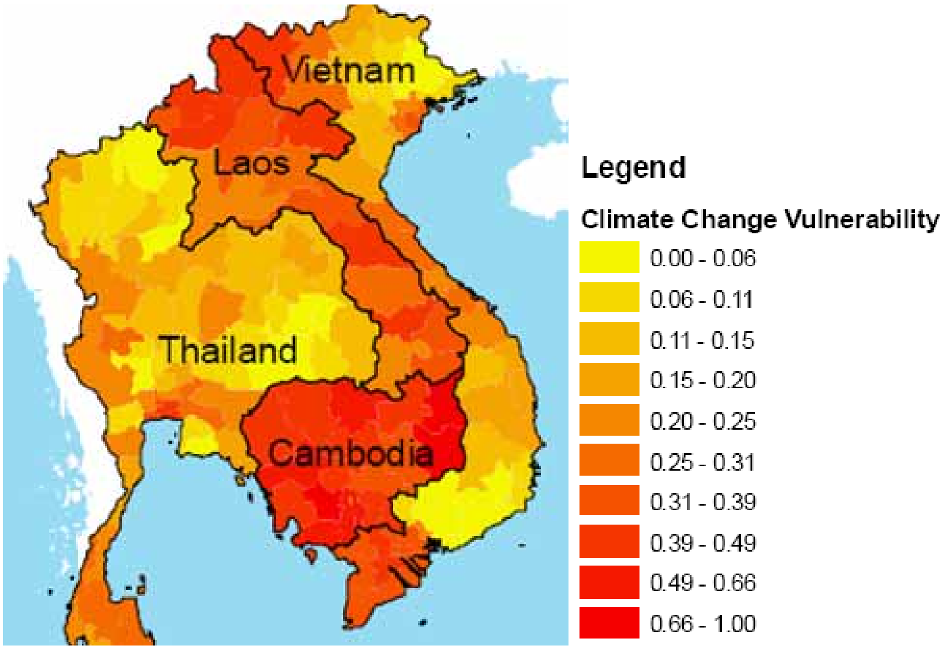
Source: TKK 2009

Drought: Despite rainfall increases, more dry spells are projected with greater extremes between wet and dry seasons in southern and eastern areas. Northern Thailand and the Tonle Sap catchment (zone 5) would still be susceptible to high water stress in the dry season.

Vulnerability: IDRC has mapped climate change vulnerability in SE Asia – which overlays exposure with indicators for sensitivity and capacity to adapt.[5] The greater area of the LMB was shown to be extreme on the vulnerability index (Figure 27), particularly in Laos and Cambodia. Thailand and Vietnam were considered to have a higher capacity to respond to change in their parts of the basin – even though registering extreme on the exposure rating (Yusuf 2009).

Figure 27: Climate change vulnerability in the LMB

[5] The IPCC defines vulnerability as "The degree to which a system is susceptible to, or unable to cope with the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC 2001, p.995).



Source: Yusuf 2009

6.2 GREEN HOUSE GAS EMISSIONS

GHG emissions are a consideration in defining energy options. The total emissions from the four LMB countries is about 1.5 per cent of total world GHG emissions and about 35 per cent of emissions from the ASEAN countries (Table 6, MRC 2010, WRI 2009). Cambodia has the lowest per capita emissions while Thailand has the highest and is close to the world average. From 2000 to 2005, the emissions intensity decreased for all four LMB countries reflected a reduction in emissions relative to economic growth (WRI 2009).

Those World Resources Institute figures do not include emissions from planned irrigation (Figure 31) and hydropower reservoirs (Figure 32) under the BDP Definite Future Scenario. An estimate of GHG emissions from hydropower reservoirs in the region is provided in the power theme chapter.

Carbon dioxide (CO_2) and methane (CH_4) are the relevant gases with reservoirs. CO_2 is generated by the decomposition of organic materials under aerobic conditions and CH_4 is produced by decomposition processes under oxygen-deficient conditions. Depending on the volume and carbon content of the inundated biomass, significant emissions of greenhouse gases can occur. Organic matter originates from the flooded area, the primary production in the reservoir and from the river upstream. The different pathways the gases reach the atmosphere are by diffusing and bubbling in the reservoir itself and in the river downstream. Large quantities of gases can be released when the water is passing the turbine and the spillway. If reservoirs are relatively small or run of river, the highest rates of CO_2 and CH_4 emissions can be in the first 50 km downstream. The total emissions from the hundreds of existing and planned irrigation reservoirs in the LMB could be a significant contribution to total GHG emissions from the basin and to national figures.

The WRI figures do not include emissions from natural sources, which for Cambodia and Vietnam at least are likely to be quite significant given the extent of their wetlands, particularly Tonle Sap, marshes and estuarine swamps and waterways. Emissions of GHG from ecosystems periodically flooded under natural conditions are especially important - the following figures have been recorded for CH4 emissions in mg CH4/m2/day for: marshes - 253, floodplains - 100, swamps - 84, and lakes - 43 (Aselman and Crutzen 1989). A complex interaction could be expected if climate change increases the surface area and depth of Tonle Sap. Most GHG emissions would come from the flooded forest zone where mud flats and marshy land is regularly flooded. If this zone is reduced in size then emissions from the lake would decrease proportionally.

The effects on emissions from agriculture and forestry also need to be considered when land/resource use changes are anticipated. For example, reductions in the area of paddy expected with climate changes in the Delta would have implications for the level of emissions. In 1994, Vietnam's total greenhouse gas emission was 103.8 million tons of CO2 equivalents. Agriculture was the largest emitter (50.5%) followed by the energy sector (24.7%). Rice cultivation contributed 62.4 % of the methane emissions from agriculture. For rice paddy fields in Vietnam emissions have been recorded at 228 mg CH4 /m2/day. Similarly, in Cambodia, the agriculture sector contributes about 18% of total GHG emission in the country, mainly from paddy (MoE, 2002).

Table 6: Greenhouse gas (GHG) emissions absolute, per capita and relative to GDP

Country/region	GHG emissions (tonnes CO_2 eqv.)	GHG emissions/capita (t CO_2 eqv./person)	GHG emission intensity (t CO_2 eqv./million year 2000 international US$)
Cambodia	22.7	1.6	1131.6
Lao PDR	17.4	3.1	1691.1
Thailand	351.3	5.6	788.7
Vietnam	176.9	2.1	993.2
ASEAN	1609.4	2.9	747.0
China	7219.2	5.5	1353.6
Europe	5047.7	10.3	387.4
USA	6963.8	23.5	561.7
Russia	1960	13.7	1151.4
World	37766.8	5.8	672.3

Data representing 2005 excluding contribution from land use change (WRI 2009).

7 CLIMATE CHANGE BY SECTOR AND HYDRO-ECOLOGICAL ZONES

The SEA has adopted six hydro-ecological zones as a framework for analysis and assessment (Figure 28):

Zone 1 – China to Chiang Saen – headwaters and mountain river

Zone 2 – Chiang Saen to Vientiane – upland river in steep narrow valley

Zone 3 – Vientiane to Pakse – the Thai/Lao midstream section and tributaries

Zone 4 – Pakse to Kratie, including wetlands of Siphandone, Khone Falls, Stung Treng and Kratie, including a number of significant tributaries

Zone 5 – Kratie to Phnom Penh and the Tonle Sap - Floodplains and the Great Lake

Zone 6 – Phnom Penh to the sea – Mekong delta, tidal zone

Each broad ecological band reflects distinctive biophysical characteristics of a reach of the Mekong River and the tributary catchments flowing into it, including their topography, geology and terrestrial ecology. A sense of the transition from one zone to the next moving north to south is given in Figure 29 which tracks the river profile from headwaters to mouth and its proportion in each country. Climate changes will differ from zone to zone because of the changing biophysical context and varying influence of latitude, mountains and sea.

This section provides a zone by zone summary of conclusions from climate change studies on the nature of changes and some projected effects (Figure 30).

Figure 28: (i) Main hydro-ecological zones of the Mekong River and (ii) location of BDP sub-areas

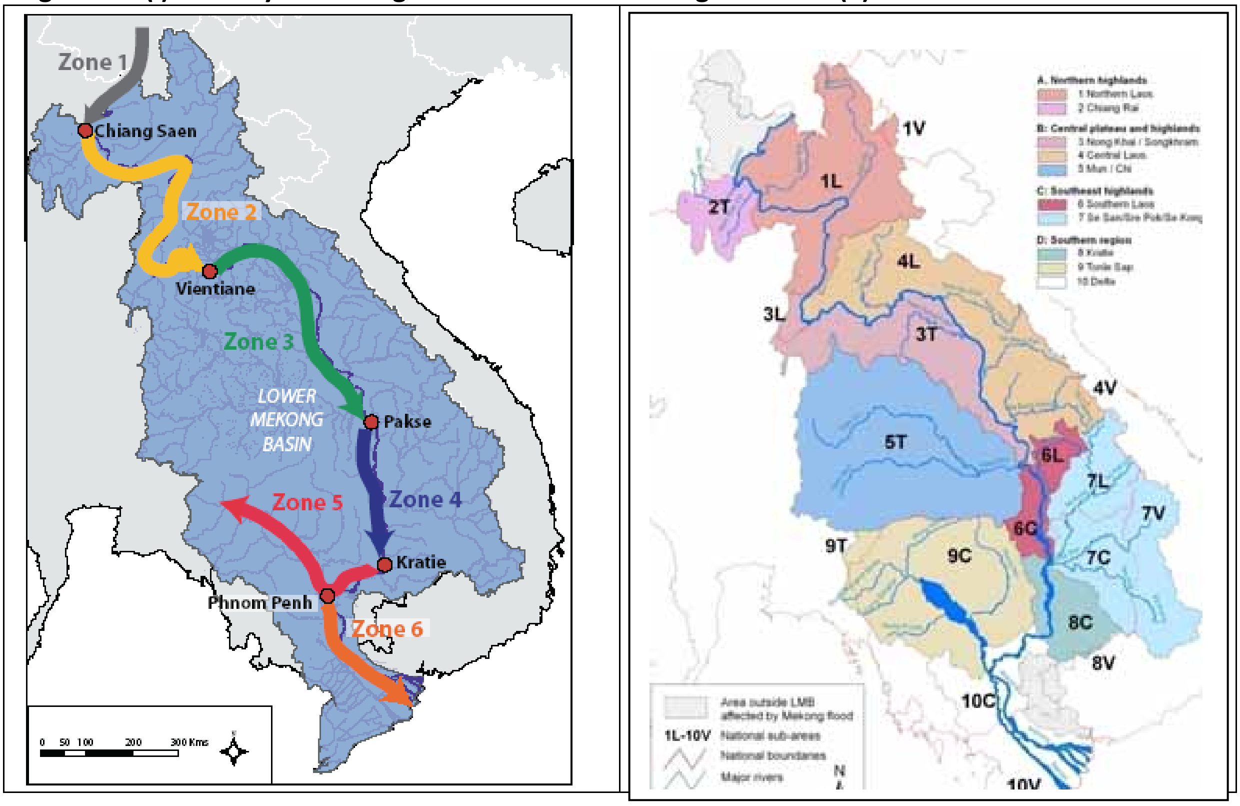
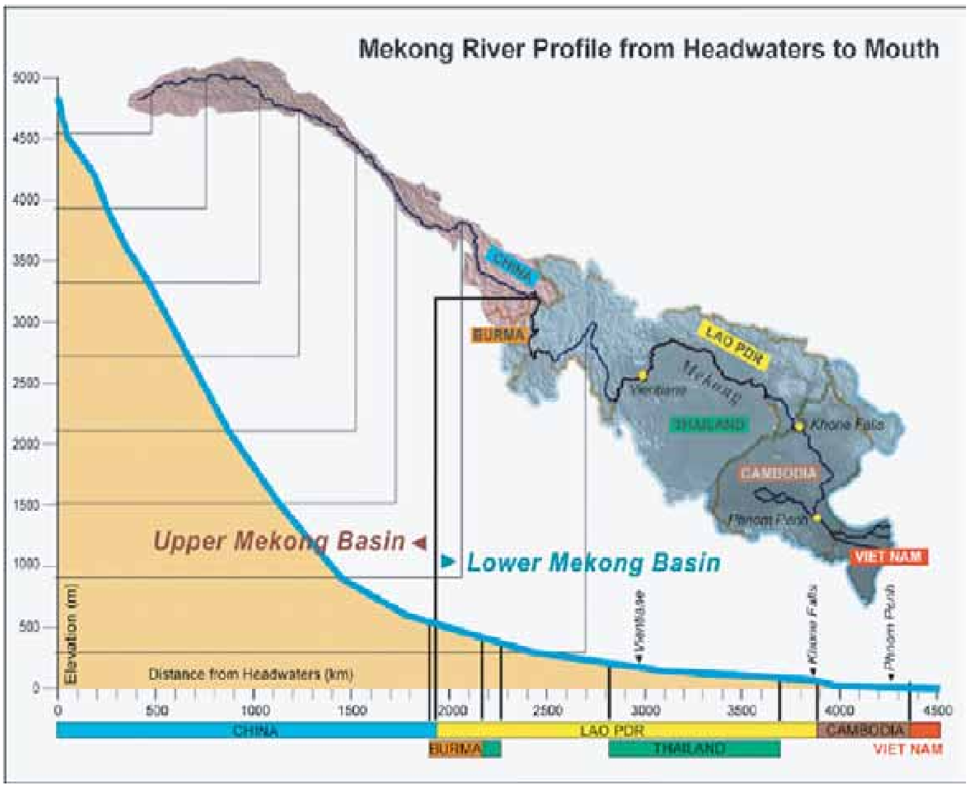


Figure 19: Mekong River Profile from headwaters to mouth



Source: MRC 2010

7.1 ZONE 1 – CHINA TO CHIANG SAEN

Precipitation: Under A2 the 2010-2050 mean annual rainfall in the UMB increases by 10.9% compared to that of 1985 – 2000. The percentage increases in the dry season from November to April is 27.5%, much higher than those in the wet season from May to October: 7.7%. However, dry season precipitation is only about 11 - 13% of the annual total. Under A2 the mean annual precipitation may increase by 44 - 45% in parts of the UMB (Hoang 2010, MRC 2010).

Temperature: For A2 over 2010 to 2050, mean annual average temperature is forecast to increase 0.9°C. Similar changes are expected for the maximum and minimum temperatures. The highest temperature increases will be in the uppermost part of the UMB (Hoang 2010).

Runoff: For A1B in 2030, the highest percentage increase in annual runoff is for the Upper Mekong catchment, where it is likely to increase by 111% - a change of~13,000 mcm.

Agricultural productivity and food availability would decrease (Figure 30).

Figure 30: Summary of predicted regional climate change impacts by hydro-ecological zone (A1B)

LMB Catchment	Agricultural Productivity	Food Availability	Temperature	Annual Precipitation	Dry Season Precipitation	Annual Runoff	Dry Season Runoff	Annual Water Stress	Dry Season Water Stress	Flooding Potential	Max Flows/water level	Flood Duration	Flooded Area	Dry Season Minimum Flows	Saline Intrusion
Zone 1 – China to Chiang Saen – headwaters and mountain river	-	-	+	+	=	+	=			+	+	+		+	
Zone 2 – Chiang Saen to Vientiane – upland river in steep narrow valley	-	-	+	+	+	+	+			+		+	+		
▪ **Moung Nouy: Northern Lao PDR**	-	-	+	+	+	+	+			+					
▪ **Luang Prabang: Northern Thailand and Northern Lao PDR**	-	-	+	+	+	+	+			+					
▪ **Vientiane: Northern Lao PDR and of North-east Thailand**	+	- [1]	+	+	+	+	+			+					
Zone 3 – Vientiane to Pakse – the Thai/Lao midstream section and tributaries	+	- [1,2]	+	+	-	+	+/-	+ [3]	+ [5]	+					
▪ **Tha Ngon: Central Lao PDR**	-	-	+	+	-	+	+			+					
▪ **Nakhon Phanom: Central Lao PDR and North-east Thailand**	+	- [2]	+	+	-	+	-			+					
▪ **Mukdahan: Southern Lao PDR and North-east Thailand**	=	- [2]	+	+	-	+	+			+					
▪ **Ban Keng Done: Central Lao PDR**	+	- [1]	+	+	-	+	-			+					
▪ **Yasothon: Northeast Thailand**	+	- [1]	+	+	-	+	+	+ [3]	+ [5]	+					
▪ **Ubon Ratchathani: Northeast Thailand**	+	+	+	+	-	+	+	+ [4]	+ [5]	+					
Zone 4 – Pakse to Kratie, including wetlands of Siphandone, Khone Falls, Stung Treng and	+	- [1]	+	+	-	+	-	+	+	+	+	+			

LMB Catchment	Agricultural Productivity	Food Availability	Temperature	Annual Precipitation	Dry Season Precipitation	Annual Runoff	Dry Season Runoff	Annual Water Stress	Dry Season Water Stress	Flooding Potential	Max Flows/water level	Flood Duration	Flooded Area	Dry Season Minimum Flows	Saline Intrusion
Kratie, including a number of significant tributaries															
▪ **Pakse: Southern Lao PDR and Northeast Thailand**	+	-[1]	+	+	-	+	-	+	+	+					
▪ **Se San: Southern Lao PDR, NE Cambodia & Central Highlands of Vietnam**	+	-[1]	+	+	-	+	-			+	+	+			
Zone 5 – Kratie to Phnom Penh and the Tonle Sap - Floodplains and the Great Lake	+	-[1]	+	+	-	+	-		+	+	+	+	+	+	
▪ **Kratie: Far southern Lao PDR and Central Cambodia**	+	-[1]	+	+	-	+	-			+	+	+	+	+	
▪ **Tonle Sap: Central Cambodia**	+	-[1]	+	+	-	+	-		+	+	+	+	+	+	
Zone 6 – Phnom Penh to the sea – Mekong delta, tidal zone	-	-	+	+	-	+	-	+[2]	+	+	+	+	+	+	+
▪ **Phnom Penh: South-eastern Cambodia**	-	-[1]	+	+	-	+	+	+[2]	+	+			+		
▪ **Border: Southern Cambodia and South Vietnam**	-	-[2]	+	+	-	+	-	+[2]	+	+	+	+	+	+	+
▪ **Delta: South Vietnam**	-	-[2]	+	+	-	+	-	+[2]	+	+	+	+	+	+	+

1= due to decrease in surplus; 2 = due to population growth ; 3 = moderate level; 4 = medium level; 5 = high level

+	Predicted increase	-	Predicted decrease	=	Status quo		Unstated

Source: ICEM drawing from Eastham et al. 2008, TKK 2009, MRC 2010 and other sources.

Fish diversity would decrease: The effects of climate change on fish in this zone are inextricably linked to development in other sectors, such as hydropower and agriculture. Increased glacial and snow melt would combine with existing and planned dams in Yunnan Province to reduce water temperature – that along with the obstruction of fish migration could reduce fish habitat, populations and species diversity. The resulting decrease in fisheries productivity could be offset to some extent by reservoir fisheries and aquaculture – to a degree yet to be demonstrated.

7.2 ZONE 2 – CHIANG SAEN TO VIENTIANE

In this zone, temperature and annual rainfall is forecast to increase along with annual runoff. Dry season rainfall and runoff would increase. The zone would have an increased potential for flooding.

Agriculture productivity is projected to decrease in the northern catchments of Moung Nouy and Luang Prabang, while increasing in the Vientiane catchment – overall food availability in excess of demand would decrease, placing greater pressure on fisheries and other aquatic resources and riverbank gardens.

This zone will be under increasing natural system stress.

7.3 ZONE 3 – VIENTIANE TO PAKSE

A key feature of this central reach zone is the very high moisture deficits of the Khorat Plateau. In Khon Kaen evaporation exceeds rainfall by almost 700 mm in an average year. Only two summer months have a surplus of any significance, compared to five and six months elsewhere in the Basin. The area is particularly vulnerable to critically low levels of soil moisture during winter, has a high incidence of agricultural drought conditions and the highest regional crop water requirements (MRC 2010). This zone includes extensive investments in irrigation and hydropower projects on tributaries (Figure 31).

With climate change, in the **Tha Ngon and Ban Keng Dong catchments** of central Laos, temperature and annual rainfall are projected to increase as will the potential for flooding. Dry season rainfall would decrease. They differ in dry season runoff – increasing in Tha Ngon and decreasing in Ban Keng Don. Agricultural productivity is the reverse of that trend – decreasing in Tha Ngon and increasing in Ban Keng Don, but food availability in excess of demand decreases in both catchments.

In the **Nakhon Phanom Catchment** of central Lao PDR and North-east Thailand, temperature, rainfall and annual runoff increases as does the potential for flooding – but not in the dry season which sees reduced rainfall and runoff. Agricultural productivity increases but so too does existing food scarcity through population growth.

Annual runoff in **Yasothon Catchment** will increase by 92% as will the potential for increased flooding. Dry season rainfall decreases while dry season runoff increases. Annual water stress (ratio of withdrawals to availability) reduces to medium to high. Dry season water stress decreased but remains high. Agricultural productivity is either unaffected or increases, but existing food scarcity is forecast to increase through population growth. Only in the **Ubon Ratchathani Catchment** does agricultural productivity increase along with food availability in excess of demand – the only catchment in the Mekong Basin to have such a forecast for 2030 under A1B.

Overall increased pressure on aquatic resources and fisheries can be expected in this zone.

7.4 **ZONE 4** – PAKSE TO KRATIE

Zone 2 includes the extensive wetlands of Siphandone, Khone Falls and Stung Treng, and a number of significant tributaries. In Southern Laos and Northeast Thailand (ie the **Pakse Catchment)** temperature and annual precipitation and runoff is expected to increase along with the potential for flooding. Dry season rainfall would decrease but runoff would increase. Agricultural productivity is forecast to increase but food availability in excess of demand decreases.

Similarly, in the **Se San Catchment of** Southern Lao PDR, North-east Cambodia and Central Highlands of Vietnam, temperature and annual precipitation and runoff would all increase as would the potential for flooding. Dry season precipitation and runoff would decrease. The forecast for agriculture is similar throughout this zone – agricultural productivity increases although food availability in excess of demand decreases.

This zone includes significant planned investments in irrigation projects (Figure 31) and the major tributary hydropower developments taking place on the 3 “S” rivers – the Se San, Srepoc and Se Kong (Figure 32). There is a complex interaction between the anticipated increase in runoff in this zone due to climate change and the effects of multiple hydropower and irrigation reservoirs on flow regimes.

Fish migration and biodiversity would reduce in the tributaries within this zone due to reservoir development and increased fishing pressure linked to reduced agricultural food security.

7.5 ZONE 5 – KRATIE TO PHNOM PENH AND THE TONLE SAP

In the **Kratie Catchment** in far southern Lao PDR and Central Cambodia, temperature and annual rainfall are projected to increase along with annual runoff and the frequency of extreme floods - the annual probability of extreme floods would increase from 5% to 76%. Peak flows, flood duration and flooded area would also increase. Dry season rainfall and runoff would decrease although dry season minimum flows are projected to increase.

This zone includes the major basin feature of **Tonle Sap and its catchment** in Central Cambodia. As in other parts of the zone, temperature and annual rainfall is projected to increase, as would annual runoff creating a high probability of increased flooding. Also forecast is a decrease in dry season rainfall and runoff with a subsequent high probability of increased dry season water stress.

Those greater extremes in wet and dry season rainfall and runoff would increase the seasonal fluctuation in Tonle Sap Lake area and levels (Figure 33). Maximum area of the lake during the wet season is projected to increase from 15,000 km^2 by an average of 3,600km^2 – ie to 18,600km^2. The maximum water levels would increase by an average of ~2.3 m each year during the wet season. Flooding would start earlier in the wet season and last longer. Minimum levels would also increase (by 0.1m), meaning that areas of flooded forest would become permanently submerged and possibly die back.

Fish habitat would be reduced and agricultural areas, housing and infrastructure which is establishing closer to the lake might be negatively affected. The higher sediment load from the 21% increase in annual runoff would affect fisheries productivity. Extreme weather events could harm fish production by causing loss of aquaculture stock and destroying fishing and aquaculture infrastructure. Some freshwater species will thrive in a changed climate, while others may die out (Johnston et al. 2009).

Overall in Zone 5 agricultural productivity is projected to increase but overall food availability in excess of demand would decrease, placing greater pressure on fish stocks.

7.6 ZONE 6 – PHNOM PENH TO THE SEA

Zone 6 introduces a wide range of additional climate change effects because of coastal/marine influences. The zone includes the **Phnom Penh Catchment** in South-eastern Cambodia, the **Border Catchment:** Southern Cambodia and South Vietnam and the **Delta Catchment** to the sea. Throughout the zone increased temperature and annual rainfall is forecast. The annual runoff is project to increase – by 65% in the Phnom Penh Catchment – and there is a high probability of increased flooding with expansion in flooded area. Dry season precipitation would decrease throughout, but in the Phnom Penh Catchment at least, dry season runoff would increase while in the more southerly areas of this zone dry season runoff is expected to reduce.

The zone would experience a decrease in agricultural productivity and food scarcity would increase due to population growth. A combination of upstream and seaward climate change influences would have complex effects on agriculture, fisheries and other sectors and livelihoods.

The Delta is particularly susceptible to climate change. The IPCC's Fourth Assessment Report forecast that, by 2050, more than 1 million people in the Delta will be directly affected by the impacts of climate change as a result of coastal erosion and land loss, primarily caused by decreased sediment delivery by rivers due to dams but also as a result of sea level rise. Under sea level rise scenarios of 20 cm and 45 cm permanent inundation would shift inland up to 25 km and 50 km respectively. At the onset of the flood season (August), the average increment in water levels would be 14.1 cm and 32.2 cm respectively. At the peak of the flood season (October), high discharge from upstream attenuates sea water intrusion. With an overall 21% anticipated increase in basin runoff, the combined effects of upstream discharge and sea level rise would lead to greatly expanded flooding – especially when combined with storm surge and extreme tides.

The situation would be aggravated if sediment levels in rivers were reduced and the Delta began to decrease in area. Significant changes to the Delta are already underway. In 2009 the CESBIO biosphere research centre using satellite imagery from 1973 to 2008 found that the eastern coast of the Mekong Delta is being eroded at a rate of 30 to 50 metres a year and along the western coast the shoreline is advancing at a rate of 70 to 100 metres a year (Planet Action 2009).

Figure 31: Existing and planned irrigation projects in the Lower Mekong Basin

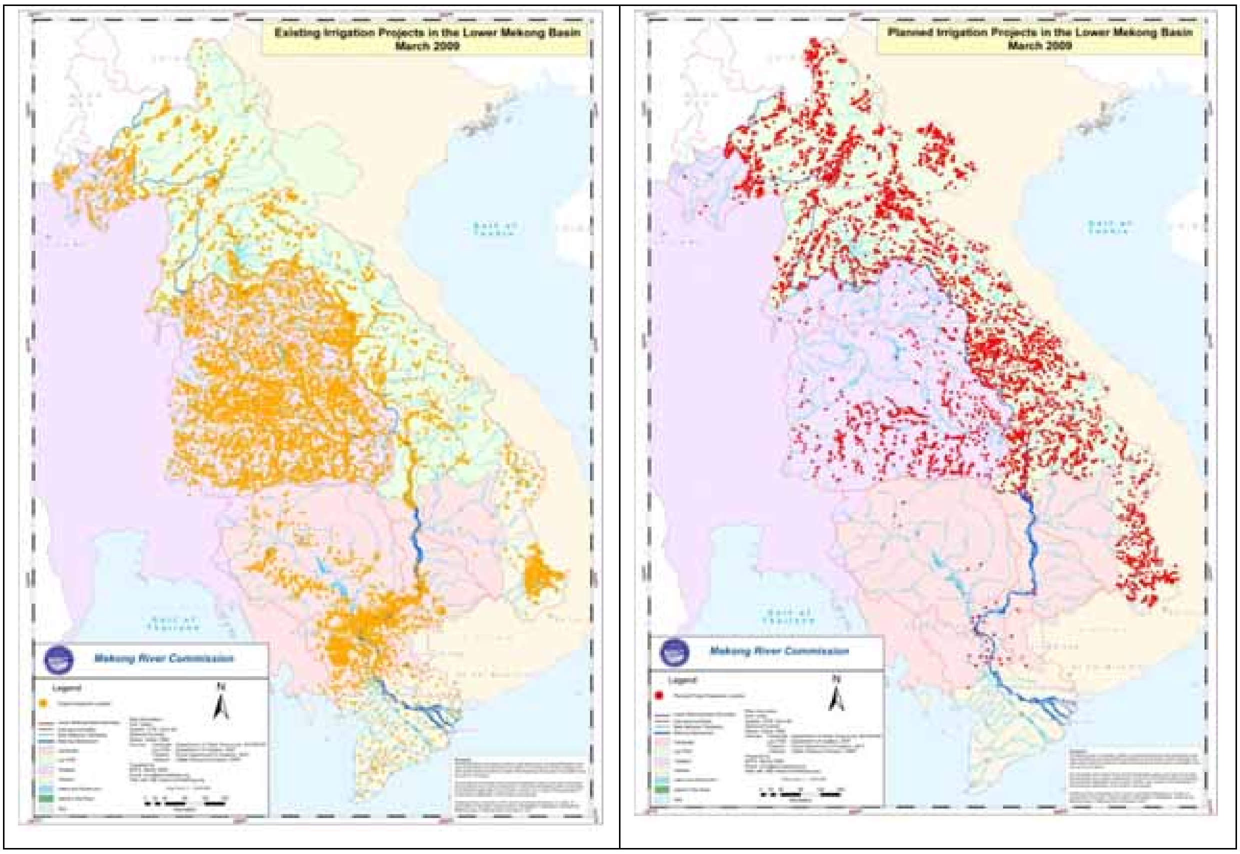


Figure 32: Existing and planned hydropower dams in the Mekong Basin

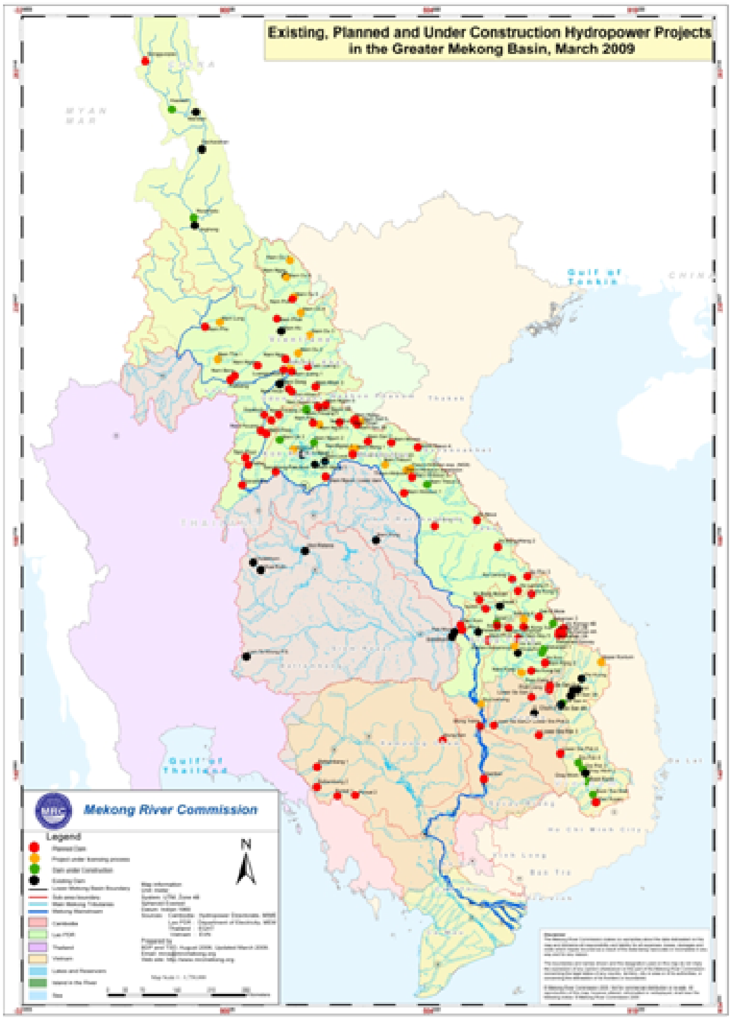
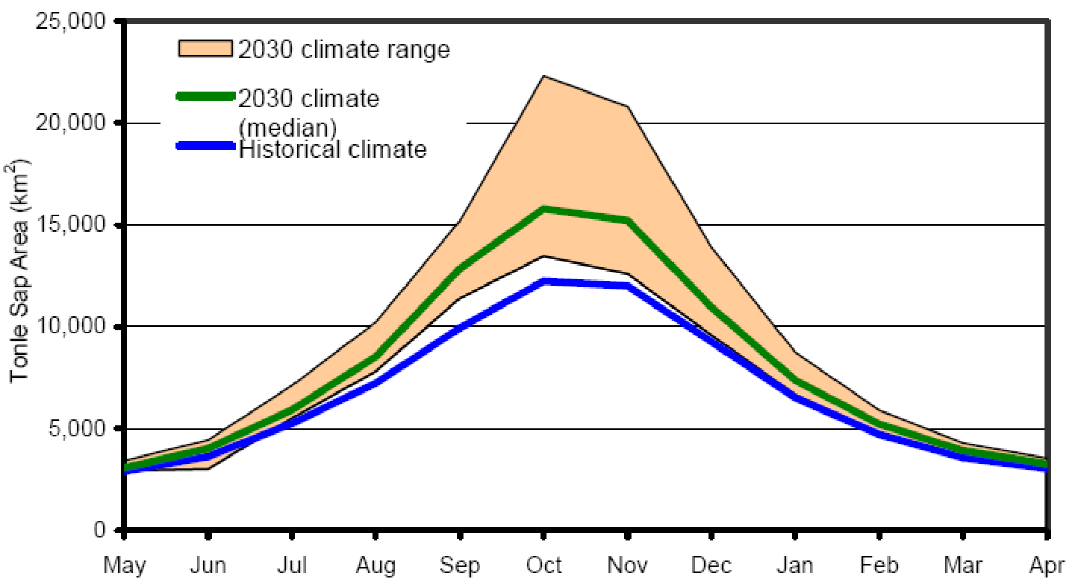


Figure 33: Historical (1951-2000) and future (2030) seasonal fluctuation in area of Tonle Sap Lake



Source: Eastman et al 2008

Agriculture: Significant cultivation areas could be under salt water due to sea level rise, storm surge and tidal influences. SEA START RC (2006) found that rice production in the Delta may be severely impacted, especially summer autumn crop production, where yield may be reduced by over 40%. Food scarcity could increase as supply fails to meet the demands of a growing population. The total area of agricultural activities could be reduced resulting in food scarcity and higher food prices, affecting the whole country given the Delta's importance for national food production (MRC 2009)

Rice production would be affected through excessive flooding in the tidally inundated areas and longer flooding periods in the central part of the Delta due to storm surge, extreme tides and storms. These adverse impacts would affect all three cropping seasons, Mua (main rain-fed crop), Dong Xuan (Winter-Spring) and He Thu (Summer-Autumn) unless preventive measures are taken (Wassmann 2004).

Natural systems: The area of **mangrove forest** in the Delta is expected to decrease due to sea level rise, increased incidence of droughts, and increased erosion and wave action. Many coastal ecosystems such as mangroves and salt marshes would be affected. They are essential to maintaining wild fish stocks, as well as supplying seed to aquaculture. Mangroves and other coastal vegetation buffer the shore from storm surges that can damage fish ponds and other coastal infrastructure and may become more frequent and intense under climate change (WorldFish Centre 2009).

Terrestrial forest ecosystems could also be affected with changes in temperature and drought incidence leading to increasing incidence of forest fire and spreading of plant pests and diseases. Saline intrusion would limit the range in some species and enlarge the potential range in others.

Fresh water systems: Salinity intrusion due to storm surge, extreme tidal flooding and SLR in the delta is expected to reduce the area and quality of habitat for freshwater organisms and affect the vertical distribution structure of ecosystems. A countervailing increase in minimum dry season flows could possibly reduce saline intrusion.

Marine systems: The pH of the South China Sea has been declining due to absorption of carbon dioxide. Warmer sea temperatures and sea acidification could affect numerous organisms and habitats, including coral reef, sea grass and mangroves ecosystems. Productivity of coastal and marine products could decrease by one third with reductions in the abundance of fish species with high commercial value and decrease in size of fish species.

8 CLIMATE CHANGE INFLUENCES ON KEY DEVELOPMENT SECTORS

8.1 FOOD SECURITY AND AGRICULTURE

Figure 30 summarises the projected effects of climate change in terms of trends – increasing, decreasing or remaining the same – for a range of climate parameters and for food security. The most notable forecasts under A1B for 2030 are:

- in the northern zones 1 and 2, and in the Delta zone 6, agricultural productivity is expected to decline (Table 6)
- the number of sub catchments deficit in production would increase (Zones 5 and 6 - Phnom Penh, Border and Delta catchments in the south of the basin)
- food security in all zones is expected to decline due to decrease in food surplus and/or increases in population without proportional increases in production
- there would be an overall increase in agricultural production in the basin of 3.6% but an increase in food demand of 93%, and a fall in food production above demand of 53%

The climate change effects on agricultural productivity vary zone by zone – and by catchments within each zone but some notable trends would be:

- Increase in wet season rainfall would increase productivity of rain fed rice,
- Decrease in dry season rainfall in some areas would lead to a fall in irrigated rice production
- More dry spells could affect crop productivity in some catchments
- Water availability generally will increase for all uses
- Increased floodplain deposition
- possibly water logging of soils due to increased duration of flooding
- In the delta, increased salinity due to sea level rise, storm surge and extreme tides would reduce agricultural productivity
- Soil erosion will increase due to increased runoff
- Increased erosion of river banks and channels

Table 6: Agricultural production and food demand – historical and 2030 with climate change

Indicator	Historical record (million tonnes)	2030 (million tonnes)	Increase
Agricultural productivity in the basin	42.9.	44.5	3.6%.
Paddy or equivalent food demand	17	33	94% due to population growth
Food production above demand	25	11	Fall of 56%

8.2 FISHERIES

Cambodia and Laos are among the most vulnerable national economies in the world to potential climate change impacts on its capture fisheries (Allison et al 2009). This vulnerability is due to the combined effect of predicted climate changes, the relative importance of fisheries to national economies and diets, and limited capacity to adapt to potential impacts and opportunities.

The main climate variables influencing fisheries are changes in air and water temperatures, rainfall, salinity, river flow, nutrient levels, sea and lake levels, glacial/snow melt, storm frequency and intensity and flooding. Fish reproduction, growth and migration patterns are all affected by temperature, rainfall and hydrology. Those variables are projected to change in the Mekong Basin. The known direct effects include changes in the abundance and distribution of species and assemblages and impacts on fishing operations and infrastructure. Indirect effects include:

- changes in aquatic habitat, ecosystem productivity and the distribution and abundance of aquatic competitors and predators; and,
- impacts on other food production sectors that affect people's livelihoods, food security and intensity of dependence on fisheries.

In addition fisheries ecosystems and livelihoods will be affected by climate impacts on other natural resource sectors, and vice versa. Ecosystems that support fisheries, particularly wetlands and riverine habitats, can lie downstream of other human activities (including damming, agriculture and industrial abstraction and effluents) that can reduce their ecological resilience. Influences which reduce fisheries productivity can lead to increased pressure on terrestrial ecosystems and biodiversity. Conversely, reliance on fisheries may increase further as climate change reduces agricultural crop production and/or food security as is forecast for the Mekong basin.

The specific effects of climate change on fish and fisheries in the basin has not been thoroughly studied and might have negative and positive impacts and be influenced by links to other developments and resource uses. At this stage the following conclusions can be drawn:

- Increasing runoff throughout the Mekong Basin would increase sediment and organic loading in rivers, lakes and wetlands, with higher nutrient levels boosting fishery productivity. This effect may be offset by sediment retention behind existing and planned dams upstream.
- Changes in precipitation will affect seasonal flooding patterns that drive inland fish production. While greater wet season flooding may boost production in some inland fisheries, drier dry seasons may threaten stocks of both wild and cultured fish.
- Raised wet season flood level of the Tonle Sap lake by 2.3 meters would extend feeding grounds and encouraging fish production.
- In some locations – eg flooded forest – habitat may be reduced due to increase in lake size (and no room for ecosystem shift because of agricultural encroachment). Seasonal wetland habitats in channels might reduce.
- Cambodian fish catches are increasingly made up of species whose abundance is largely driven by the annual flood pattern. This cycle may be amplified by the higher hydrological variability predicted with climate change, bringing extreme annual fluctuations in fish abundance (Fish Site 2009).
- Small increases (1–2°C) in water temperature may have sub-lethal effects on tropical fish physiology, particularly reproduction.

- Saltwater intrusion caused by rising sea levels may change species distribution and composition threatening freshwater fisheries while creating opportunities for catching and cultivating high-value brackish or marine species.
- The extended flooding and extreme events may affect aquaculture – particularly when located in the coastal areas of the delta.

8.3 HYDROPOWER

Under the BDP Definite Future scenario to 2015, there are 40 existing and planned tributary hydropower dams – a further 30 under the LMB 20 year scenario. Climate change has implications for the hydropower sector because:

- Increased rainfall, runoff and flow throughout basin would increase potential capacity of tributaries for hydropower
- Increase in extreme wet events an important consideration in dam design and operations
- Some catchments will experience very high increases in runoff and water volume – possibly beyond the capacity of existing tributary schemes.
- Dam design and retrofitting would need to take into account changing conditions of rainfall and runoff and of extreme events

Hydro-ecological zones 3 and 4 are the most significant in terms of tributary contribution of flow at Kratie and the number of existing and planned tributary hydropower projects. The projected increase in runoff from climate change will have particular implications for those zones.

Table 7: Contribution of total flow at Kratie (%)

Zone			%	%	%
	RIVER REACH	Lancang	West bank	East bank	Total
1	Lancang	16			16
	Lancang - Chiang Saen (with Myanmar contribution)		4	1	5
2	Chiang Saen - Luang Prabang		3	6	9
	Luang Prabang - Vientiane/Nong Khai		4	1	5
3	Nong Khai - Mukdahan		5	22	27
	Mukdahan - Pakse		6	5	11
4	Pakse - Kratie		3	24	27
	% Total	**16**	**25**	**59**	**100**

9 CONCLUSIONS

The conclusions of the climate change baseline respond to the three key strategic issues identified for this theme:

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

The SEA baseline assessment works with a projected baseline to 2030 – taking in the BDP Definite Future Scenario and the LMB 20 year scenario without LMB mainstream dams. The DFS includes 40 tributary dams constructed since 2000, under construction or committed and 6 China mainstream dams. In the DFS, the total live or active storage of the tributary dams and of the Chinese reservoirs[6] is 21,222 MCM or 4.6% and 22,189 MCM or 4.7% respectively of the annual water volume leaving the Delta – making a total of 9.3%. Under the LMB 20 year "without" scenario, there are 70 tributary dams (30 additional to the DFS with a live storage of 20,185 MCM or 4.2%) and the 6 Chinese dams – with a total active storage making up 13.5% of Mekong water.

9.1 PAST TRENDS AND PROJECTIONS

Already, climate changes in the Mekong region are influencing ecosystems, livelihoods and development through changes in regular weather – ie daily, seasonal and annual patterns – and through irregular extreme events. The main influences (and indicators of change) are temperature, rainfall and runoff, sea level, tidal fluctuations and extreme events such as storms, floods and drought.

Past trends: Over the past 3 to 5 decades, trends of increasing mean annual temperature have been recorded in each LMB country. Most notable is the increase in variability from one year to the next.

The trends in rainfall are less consistent with increasing variability and extremes between wet and dry in Laos and Cambodia, a decrease in Thailand, and decreases in most localities in the north of Vietnam with increases in most areas of the South during all seasons. In winter in Vietnam rainfall fell by 23%.

Seasonal changes are important, with most increases in rainfall occurring during the wet season. All countries have experienced decreasing rainfall during the dry season with aggravated drought and water stress situations in many catchments.

Future climate: Future climate change has been assessed using a range of models, IPCC scenarios and methods during the past decade. The projections vary according to the IPCC scenario modeled and the models used. Projected changes in the basin also vary from catchment to catchment, North to South, season to season and year to year. Yet, distinctive and consistent trends are discernable across all studies – just varying in extent. For all IPCC scenarios, increases in temperature and rainfall are projected, with sharper increases and divergence between scenarios from 2030.

[6] The Manwan reservoir in Yunnan has been in operation since 1993, but its live storage is minor (250 MCM) therefore it is included with the other Chinese reservoirs

Results for A1B – selected by CSIRO as it represents a mid-range scenario in terms of development impacts on GHG emissions – provide a good indication for the overall trends in the region, and for the hydro-ecological zones. They are used as the main basis for summarising trends to 2030 here.

Temperature: Steady increases in mean basin temperature by 0.8°C. Greater increases are expected in northern zones of the basin up to 1.4°C in Yunnan Province.

Rainfall: Annual rainfall to increase by 13.5% (0.2m) mainly due to increases during the wet season (May to Oct). Dry season rainfall will increase in northern zones (1 and 2) and decrease in southern zones (3 to 6 – ie from Vientiane to the Delta). The overall disparity between wet and dry seasons will increase especially in zones 3 to 6.

Runoff: Total annual runoff from the basin is projected to increase by 21% mainly during the wet season with the annual discharge at Kratie increasing by 22% with increases in all months but mainly the wet season. This projection takes into account estimates for water use by future populations in the basin and irrigation.

Flooding: Flooding is projected to increase throughout the basin – with downstream zones affected most. For example at Kratie (zone 5) the annual probability of extreme wet flood events will increase from 5% (ie historic conditions) to 76%. It will increase to 96% in the wet season. The duration of flooding will increase in this zone with an earlier onset. The maximum and minimum area and water levels in Tonle Sap would increase annually. The annual average flooding in Delta would also increase by 3,800km^2 The impacts of this increase in flow and flooding could be expected to be greatest on the mainstream Mekong due to cumulative contribution from tributaries.

Drought and dry seasons flow: Despite rainfall increases, zones 3 to 6 are projected to experience reduced rainfall and runoff during the dry season. Southern Laos, Northeast Thailand, Central and Southeastern Cambodia, including the Tonle Sap catchment and the Delta region are still susceptible to high water stress during the dry season. More dry spells and a greater severity in drought periods are expected. The past trend of increasing variability with greater extremes between wet and dry seasons, especially in southern and eastern areas, it projected to continue.

9.2 MODIFYING EFFECTS OF HYDROPOWER AND IRRIGATION

Some of the projected trends in climate change would be moderated by economic developments in the basin. The planned hydropower dams and irrigation projects, in particular, would interact in various ways to modify the hydrological effects of climate change. Hydropower storage reservoirs can control the release of water and affect daily, seasonal and annual flows. Irrigation extracts water from rivers or reservoirs affecting flow volume. Other water users such as industry and domestic sectors are expected to double over the next 20 years but will remain relatively small consumers.

Runoff: During full operation of all the existing and planned hydropower dams, one might expect them to have a significant effect in seasonal regulation of the 21% increase in total annual flow projected with climate change. During the annual flood, the dams might hold back water, and during the dry they might increase normal flows. In practice over the next 20 years to 2030, the regulatory influence of the planned dams will be determined by their construction schedules – many could take ten years to construct once approved and inevitably, development of projects will be staggered, potentially expanding the influence of the construction phase over several decades. The total storage (ie active and dead) of these reservoirs could be three times the live storage. While dams are being filled, water is being withheld from the Mekong effecting both wet and dry season flows.

The expansion of the irrigated areas in the basin will increase 10.9% annually mainly for dry season irrigation when water runoff and flow is lowest. Until 2030, that development and increasing consumption (35% on 2000 levels) will occur while the hydropower dams are under construction. The combined "withdrawal" of storage water for the reservoirs and for irrigation would have significant effects on wet and dry season flow.

In summary - For the "construction" period from now until 2030, tributary and Chinese hydropower dams could:

(i) Reduce dry season flows and make them more unpredictable – offsetting the benefits of increased flows due to climate change in zones 1 and 2 and compounding reduced dry season flows in the others.
(ii) Reduce wet season flows potentially reducing the increased threat of flooding due to climate change up to a defined capacity – after which more serious flooding might occur because of the need for substantial releases from many dams
(iii) Compound the trend of increasing saline intrusion in the Delta by further reducing dry season flows.

Increased extraction for irrigation could:

(i) Reduce dry season flows and make them more unpredictable – offsetting the benefits of increased flows due to climate change in zones 1 and 2 and compounding reduced dry season flows in the others.
(ii) Compound the trend of increasing saline intrusion in the Delta by further reducing dry season flows.

9.3 SUMMARY OF CLIMATE CHANGE EFFECTS ON DEVELOPMENT SECTORS

The projected 2030 increases in temperature, rainfall and runoff with more extreme climate events will influence the productivity of economic sectors and livelihoods.

Agriculture: Overall agricultural productivity will increase in the basin (around 3.6% by 2030) but food security will decrease, despite the increasing areas under irrigation. Those decreases are due to:

(i) Reduced dry season rainfall and runoff in central and southern zones
(ii) Increasing saline intrusion in the Delta due to storm surge and tidal influences and decreases in dry season rainfall and runoff.

(iii) Increasing populations and reduced production in excess of demand

Fisheries: Overall fish biodiversity and stability in fisheries sector production is expected to decrease in the basin despite some climate change benefits of increasing flooded area and nutrient loading. The decreases are due to the complex interplay between:

(i) Decreased agricultural productivity and food security increasing demand and pressure on fish populations
(ii) Increased riparian populations and fishing pressure
(iii) Dramatically reduced fish migration and aquatic biodiversity in zone 1 and in Mekong tributaries due to dam and infrastructure construction
(iv) Reduction of flooded forest habitat in Central Cambodia due to increased area and depth of Tonle Sap
(v) Reduced fresh water habitat in the Delta due to increased saline intrusion (not adequately offset by increases in dry season releases from upstream reservoirs during hydropower dam operational period – ie following 2030 for most projects)
(vi) Increased disturbance and destruction of fish habitat due to flooding of riverine wetlands, construction of infrastructure and pollution from expanding settlements and industry.
(vii) The benefits to productivity of increased nutrients due to increased runoff and erosion with climate change may be offset by reduced sediment due to China and tributary dams, especially in the central highlands of Vietnam.

Hydropower: Overall the hydropower sector will benefit from climate changes from increased capacity in basin catchments, but there are risks.

(i) Increased rainfall, runoff and flow throughout basin would increase potential capacity of tributaries for hydropower
(ii) Some catchments will experience very high increases in runoff and water volume – possibly beyond the capacity of existing tributary dam schemes – creating risk of failure and need for retrofitting
(iii) Increase in extreme wet events and incidence of flood events brings a risk of catastrophic failure (climate change may turn a 1 in 10,000 year flood risk into a more regular event – eg a 1 in 1000 flood?)
(iv) Dam design and retrofitting would need to take into account changing and more variable conditions of rainfall and runoff and of extreme events

Livelihoods: Aquatic and terrestrial natural systems are under increasing stress in the Mekong basin. While there are benefits, overall climate change will increase that stress by

(i) Increasing the need to make agriculture more productive and extensive and by increasing pressure to exploit aquatic resources.
(ii) Reducing fish habitat, feeding and nursery areas
(iii) Increasing water stress in some catchments and the frequency and intensity of drought periods

The negative natural systems impacts of climate change have knock-on effects on livelihood activities. Other developments, such as hydropower dams, intensify natural system stress and the negative effects of climate change.

Climate changes such as temperature and rainfall increases and increased incidence of flooding will also increase health risks which would reduce labour productivity and increase levels of poverty.

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Annex 1: Comparison between climate change modeling results for the Mekong Basin

Climate change	**Modeling team**								
	Snidvongs et al. (2003)	TKK & START (2008)	Hoanh et al. (2003)	Hoanh et al (2010)	Eastham et al. (2008)	Johnston et al., 2009	McSweeney et al. (2008a & 2008b)	ADB (2009)	Ruosteenoja et al. (2003)
Coverage	Lower Mekong Basin		Mekong Basin				Cambodia, Viet Nam	Thailand, Viet Nam	SE Asia
Scenarios	-	A2	A2, B2	A2, B2	Broad range – focus on A1B	A2, B2	A2, A1B, B1	A1F1, B2	A1F1, A2, B1, B2
Period	From [1×CO_2] to [2×CO_2]	1960-2099	1960-2099	1985-2050	1951-2000 and 2030	1960-2049	1970-2090	1990-2100	1961-2095
Temperature	+ 1 to +3°C (over 100 year period)	Will increase	+0.026 to +0.036°C/y	+0.020 to +0.023°C/y	+0.012 to +0.014°C/y	+0.023 to +0.024°C/y	0.00 to +0.06°C/y	+0.03 to +0.06°C/y	+0.01 to +0.05°C/y
Annual rainfall	Will increase	Will increase	-1.64 to +4.36 mm/y	+ 1.2 (B2) to +2 (A2) mm/y	+0.1 to +9.9 mm/y	No significant change	+0.3 to +0.6 mm/y	*1990-2050:* A1F1: -1.14 to 0.66 mm/y B2: -1.62 to +1.26 mm/y ; *1990-2100:* A1F1: +3.27 to +4.91 mm/y; B2: -1.63 to -2.45 mm/y	Almost always insignificant
Rainy season	Wetter rainy season and 1-month delayed	Wetter rainy season and 1-month delayed		Wetter rainy season: +1.2 (B2) to +1.5 (A2) mm/y	Wetter rainy season (+1.7 to +6.1 mm/y)	Wetter rainy season in North and Gulf of Thailand (From +0.2 to +0.6 mm/y)	Wetter rainy season : +0.8 to +1.5 mm/y (KH); +0.4 to +1.5 mm/y (VN)		Wetter rainy season and 1-month delayed
Dry season	Dry season drier and longer	Dry season drier and longer		Wetter dry season in UMB +0.9 mm/y and insignificant change in LMB	Dry season rainfall to increase north, and to decrease in the south	Drier dry season on both sides of Gulf of Thailand (-2.5 to -2.8 mm/y)	Drier dry season: -0.7 to -0.1 mm/y (KH); -0.3 to -0.1 mm/y (VN)		Dry season drier and longer

Adapted from Hoang MRC 2010